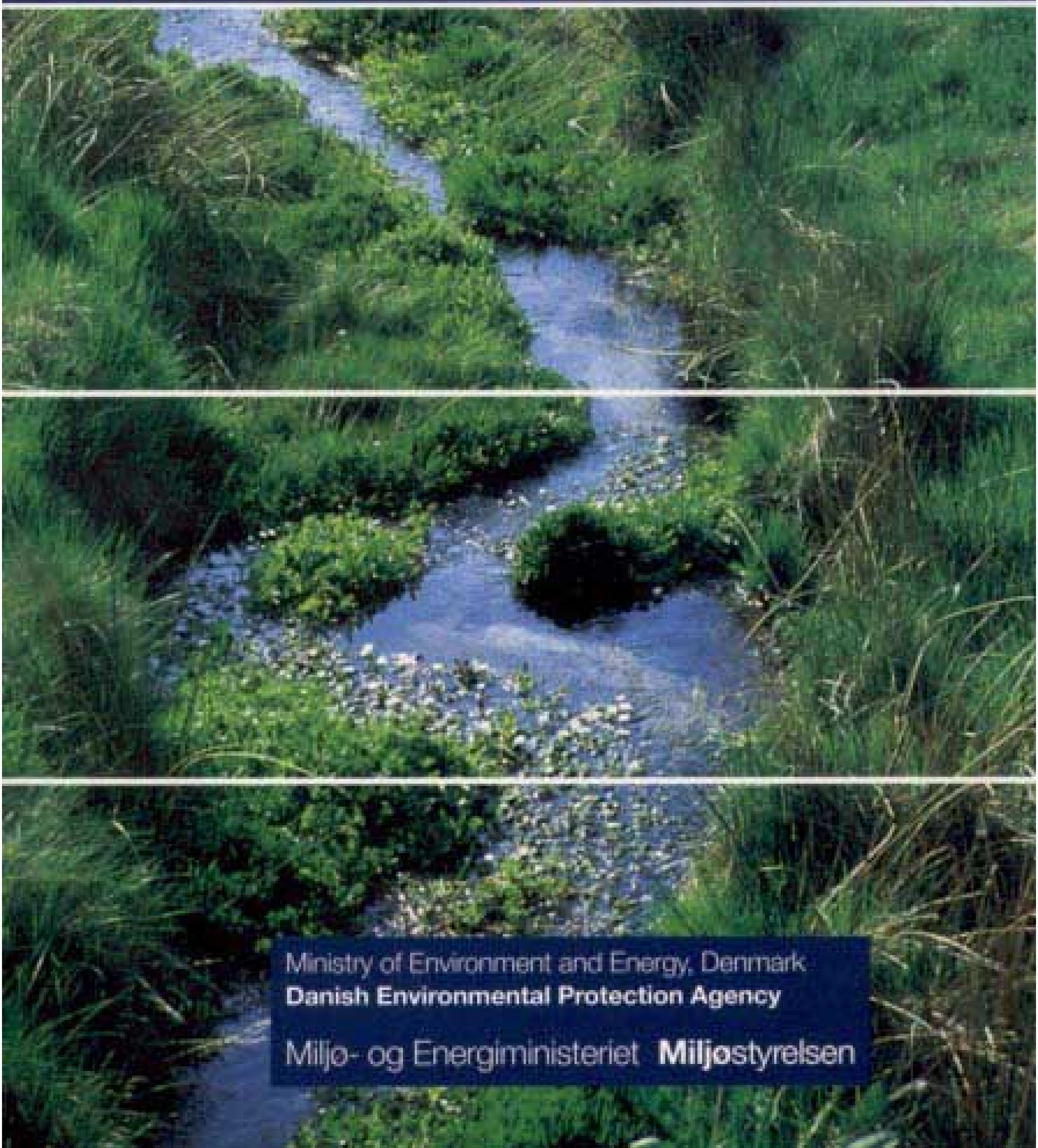
Danish Watercourses

- Ten Years with the New Watercourse Act

Miljønyt nr. 11 1995



Ministry of Environment and Energy, Denmark
Danish Environmental Protection Agency

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- Ten Years with the New Watercourse Act

Collected Examples of Maintenance and Restoration

Bent Lauge Madsen

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Foreword

The new Danish Watercourse Act has been in force for over 10 years. It provides us with possibilities to restore good environmental conditions to our many watercourses. Endeavours to restore them are being undertaken stepwise. The first very important step was to ensure good water quality.

That alone does not give good watercourses, though. By far the majority are, or have been, marked by the only purpose they had under the "old" Watercourse Acts, namely to drain water away rapidly and effectively. They became channels that each year were purged of plants and anything else that hindered the water from draining away. This treatment was detrimental to those plants, fish and invertebrates that had survived pollution of the watercourses.

When the new Watercourse Act was passed in 1982, it became possible to manage the watercourses in such a way that they could once again become the framework for a rich and varied flora and fauna.

In this book, the Danish Environmental Protection Agency has collected a number of examples of how county and municipal authorities throughout the country have made use of the possibilities provided by the new Watercourse Act to benefit the watercourses and the creatures that inhabit them. Examples are provided of how one can clear aquatic plants in such a way as to enable the water to drain away, while at the same time providing a pleasant habitat for the fish. There are also examples of how one can remeander watercourses, as well as examples showing that sea trout can once again find their way upstream to the small watercourses where earlier generations once spawned.

The book rounds off with a preliminary progress report summarizing how far we have come in the 10 years since the new Watercourse Act entered into force. The results are optimistic: It transpires that the Counties and Municipalities are well on the road to managing their watercourses in a manner that benefits nature well.

Introduction

Watercourses are one of the attractive features of the landscape. They have created the valleys and they are the framework for a rich and varied nature, both in the watercourses themselves and in the surroundings.

The first Danes lived near the watercourses. Even though our watercourses are small in relation to those in other countries, we have nevertheless benefited from them down through the centuries. This has left its mark, however. We changed the watercourses. They were dammed up so that the water could drive mills, thereby preventing the migration of salmonid fish up to their spawning grounds.

We have exploited the watercourses for agricultural purposes, agriculture having been the most important business until only a few decades ago. Drainage was a precondition for being able to cultivate the fields. Many of the artificial watercourses, i.e. the ditches, originated as open drainage ditches. In step with increasing cultivation of low-lying areas near watercourses, it became necessary to channelize and deepen the watercourses. This was followed up by hard-handed weed clearance and dredging. All this was to ensure that the water could drain away rapidly and effectively.

The watercourses also provided an easy solution to the problem of sewage disposal. It is hardly a coincidence that the majority of dairies were built alongside watercourses: They could easily dispose of their sewage, and the amount produced was not usually more than the self-purification processes in the watercourses could cope with. Pollution also took place that detrimentally affected the watercourses, however. The sewage from abattoirs and large potato flour factories was more than watercourses such as the river Karup Å and Voer Å stream could cope with. Moreover, when sewerage systems were built in the urban communities, sewage discharge became so great that the pollution had an obvious negative impact on the watercourses.

Long before the Environmental Protection Act entered into force, endeavours were under way to combat the visible pollution of watercourses. Sewage treatment plants were constructed and the pollution of watercourses with silage seepage water, etc, was prohibited. With the introduction of the Environmental Protection Act in 1974, endeavours to combat watercourse pollution were intensified. The Act also contains a planning system that in the case of the watercourses, was im-


Undgå ENSILAGESAFT i vandløbene

Ensilagesaften bør ikke mere forurene vandløbene

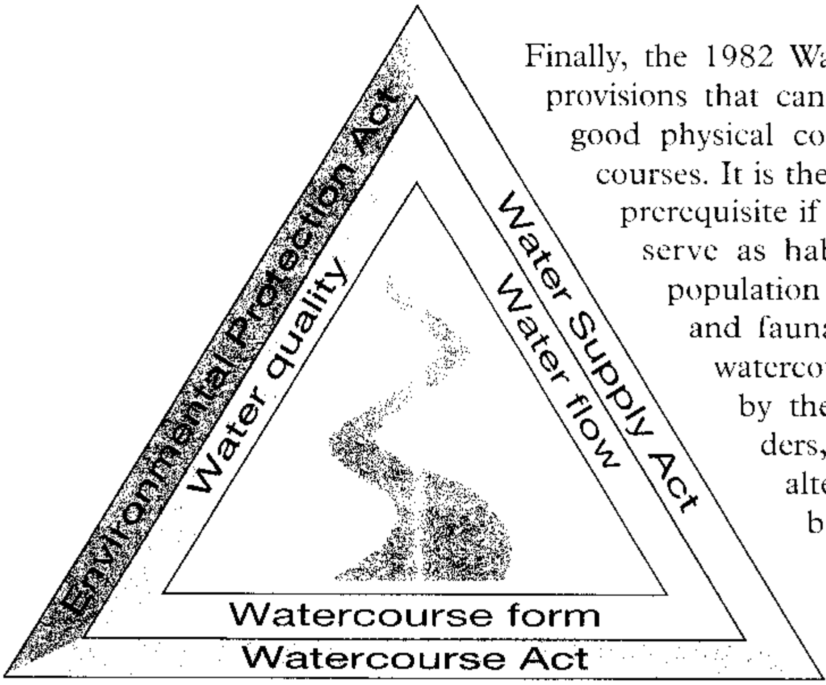
Det er velkendt, at ensilagesaft ved udledning i vandløb, grave og søer kan ødelægge fiskebestanden og andet dyreliv, og hyppigt vil også plantevæksten ændre karakter, så et frisk og rent vandløb i løbet af få år kan forvandles til en grumset, kloakagtig rende. I mange tilfælde kan det påvises, at også byspildevand eller affald fra industrier m. v. giver farlige forureninger og derfor kræver stor opmærksomhed. Men det må indrømmes, at ensilagesaften

Early pamphlet encouraging farmers not to pollute watercourses.

plemented in the form of specific quality objectives, a system that has been, and still is, of the greatest significance for the endeavours to safeguard the watercourse environment. The quality objectives have made it possible to differentiate between different watercourses such that the endeavours can be prioritized where they are of greatest benefit.

In the 1970s it became clear that it was not possible to obtain good watercourses through sewage treatment alone. Good water quality is not enough. The quality of the watercourse as a whole has to be good: There has to be clean water and sufficient water, and the watercourses have to have a form that renders them a suitable habitat for plants and animals.

This holistic approach to watercourse quality is reiterated in the legislation concerning watercourses. The provisions on clean water are found in the Environmental Protection Act: It is stated in all simplicity that man and animals shall have clean surroundings in which to live.
The provisions concerning abstraction of water are found in the 1978 Water Supply Act. Abstraction of water is to be undertaken in a way that takes into consideration the negative impact that abstraction could have on the watercourse fauna.



Finally, the 1982 Watercourse Act contains provisions that can safeguard and restore good physical conditions in the watercourses. It is these conditions that are a prerequisite if the watercourses are to serve as habitats for a good fish population and for a natural flora and fauna. This third aspect of watercourse quality is afforded by the meanders, weed borders, stone beds, the regular alternation between gravel bed and mud bed, between deep and shallow parts, etc., that one finds in natural watercourses.

The idea behind the new Watercourse Act is expressed in its objects clause: This states that watercourse maintenance must be undertaken in a manner that takes into consideration the environmental conditions that should pertain in the watercourse in order that the watercourse quality objective can be met.

There are provisions stating that there may be bushes, trees and other vegetation along the banks. The line of reasoning behind incorporating these provisions in the Watercourse Act was that the resultant shade would curtail weed growth in the watercourses. However, there are also a number of other advantages for the watercourse environment. For example, the shade keeps the water cool and oxygenated on warm summer days.

The Watercourse Act also contains provisions that allow actual restoration to be undertaken. Today one would probably call it re-establishment. The Act enables financial support to be given to such projects.

The provisions of the new Watercourse Act did not change the treatment of our watercourses from one day to the next, not even from one year to the next. This is a process that is taking place stepwise. The Act stipulates several deadlines, among others that new Provisional Orders should be drawn up for each watercourse by the end of 1993. That deadline was prolonged until mid 1996, though. Nevertheless, the new Provisional Orders have not been a precondition for introducing gentle watercourse maintenance, this also being possible on the basis of the old Provisional Orders. However, the new Provisional Orders will enable gentle maintenance to be continued and possibly improved.

Through meetings, courses, publications, the media and other activities, the new provisions have percolated down through the many parties involved in the treatment of our watercourses: From politicians and technical staff to the river keepers and the landowners. In many places a new attitude has developed of how our watercourses should be managed.

In this book a number of examples have been collected that illustrate how the county and municipal authorities have tackled the task. No real guidance has been given. However, some general principles have sprouted from a sometimes hesitant beginning. Creativity has had free play, and there is now a good foundation for a rich variation in watercourse maintenance and restoration.

The task of compiling this book was initiated in 1989 as a collaborative project between the Danish Environmental Protection Agency (Danish EPA) and the National Environmental Research Institute (NERI). The work has been followed by a steering group comprised of Lars Rudfeld (Danish EPA), T. Moth Iversen (NERI), P. Markmann (Danish EPA), M. Bjørn Nielsen (Association of County Councils in Denmark) and Willy Risbjerg (National Association of Local Authorities in Denmark). Ulrich Kern-Hansen (NERI) began the task and compiled data on among other things how the Municipalities undertook maintenance (see p 167). Bent Lauge Madsen took over the task in 1992. He has collected, selected, analyzed and collated the examples presented in the book, as well as arranged and authored the book. P. Markmann has made valuable contributions to Chapter 2, Lars Svendsen (NERI) has provided valuable help with Chapter 1, and Lars Rudfeld has provided a large number of specific improvements to all sections of the book. David I Barry has prepared this English translation.

The most important contributors to the book, however, are the staff members in the Counties and Municipalities, who have provided the material for the book with both goodwill and enthusiasm, and the river keepers, who have undertaken the work in the watercourses.

Bent Lauge Madsen is responsible for the contents of the book and the viewpoints expressed are not necessarily identical with those of the Danish EPA.

Four fundamental terms

This book concerns physical conditions in our watercourses. It therefore starts by explaining which authorities and persons undertake the work, and what is understood by physical conditions and gentle maintenance.

The watercourse authorities

Danish watercourses are divided in three groups: County watercourses, municipal watercourses and private watercourses. The County is the watercourse authority in the case of county watercourses, while the Municipality is the watercourse authority in the case of both municipal and private watercourses. The authority's task is to ensure compliance with the provisions of the Watercourse Act, for example with respect to maintenance.

There is more than just watercourse maintenance and physical conditions to keep an eye on, however. The County has supervisory responsibility for the pollutional state of the watercourses. This is evaluated by investigating which macroinvertebrates inhabit them. The County also investigates the fish population of the watercourses. Together with the macroinvertebrate investigations, these investigations reveal much about the condition of the watercourses and about where endavours should still be concentrated to combat pollution, etc. As a rule it is the Municipality's task to keep an eye on the properties and enterprises that cause the pollution. However, it is the County which has to keep an eye on the larger enterprises and the municipal sewage treatment plants.

Much of the content of this book is derived from the thorough reports that the watercourse authorities compile each year about conditions in their watercourses.

The river keeper

The river keeper, in Danish called the "Åmand", is a very important person with respect to the work that this book reviews, the river keeper being the person who works with the physical condition of the watercourses in practice.

The new Watercourse Act has provided the river keeper with new possibilities for undertaking his responsibilities. Formerly the watercourse and its banks had to be cleared of plants (weeds) by specific deadlines such that the water could flow freely. This was a rule dating from the time when the agricultural sector still needed the low-lying fields adjoining the watercourses. Now the river keeper works towards other goals: He has still to ensure that the water can drain away easily, but the physical environmental conditions in the watercourse must not be harmed. Thus the river keeper has to maintain the watercourses partly in accordance with the natural conditions, and partly in accordance with the environmental plans - i.e. quality objectives - stipulated for the individual watercourses.

During recent years many persons have had to adapt themselves to new ways of working. However, there are hardly very many persons who have had to adapt as much as the river keepers. Previously the river keeper had to leave watercourses in a state as orderly as a golf course. Now a well maintained watercourse is rather one that looks dishevelled. The river keeper

has not only to accept that change himself, he has also the task of explaining to watercourse users, especially farmers, why they are now to be maintained in that way. That part of the work is far from unimportant since the river keeper is that part of the watercourse authority that the majority of users see and converse with.

Good physical conditions

The book repeatedly refers to "good physical conditions" in the watercourses. What is meant by that?

By physical conditions is meant the form that the watercourses have. It is their course through the landscape, whether that be meandering or straight. It is also the form of their cross-sectional profile, with the stones, weed borders, tree roots, gravel and whatever else one can SEE in a watercourse.

The physical conditions can be uniform, as for example in a channelized watercourse with slow flow over a sand bed, with a uniform blanket of weed. The physical conditions can also be manifold and varied, as for example in a meandering watercourse, where there are many different depths and currents, and where there are different types of bed as well as hollows and weed borders.

When physical conditions are uniform there is usually a poor selection of habitats for plants and animals. In contrast, there is a rich selection of habitats for plants and animals in watercourses where physical conditions are varied.

Thus in this book, good physical conditions means a watercourse form that provides a large selection of habitats for plants and animals.

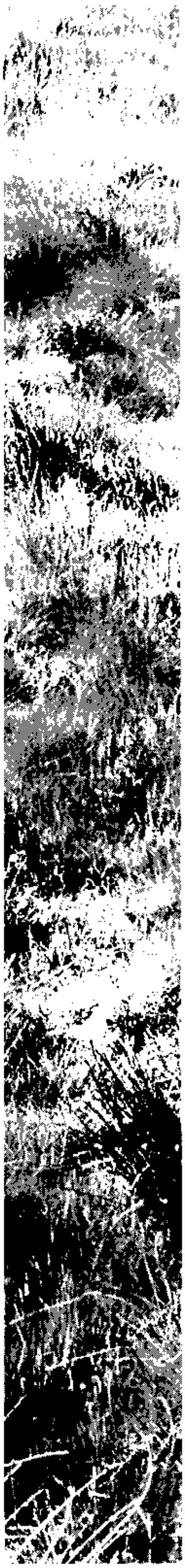
Gentle maintenance

Gentle maintenance of watercourses is one of the main topics of this book. What is meant by gentle maintenance?

Watercourses are maintained in order to ensure that the water can flow freely through them. This is done by dredging up the sand and mud and clearing away the plants - the weed. The regulations for this "traditional" maintenance were previously very simple. One had to clear away all the weed by a specified deadline, and when the watercourse was to be cleaned out it was often natural to also remove the gravel and stones by dredging. The watercourses were "well-groomed and tidy", characterized by order. The physical conditions become uniform, the good habitats are gone and the flora and fauna becomes uniform and impoverished.

When one wants to have a rich flora and fauna in a watercourse one has therefore to maintain the watercourse in a different, more gentle manner, in order not to destroy the varied physical conditions. One must not clear away all the weed or dredge the gravel and stones, and one has to preserve and promote the forms that the watercourse creates itself. One has to work **with** the watercourse, and **not against** the natural forces at play in it.

Thus in this book, gentle watercourse maintenance means treatment that works with and not against the watercourse's own forces, and which creates a good physical framework for a rich and diverse flora and fauna under the natural conditions pertaining in the landscape.



1 Watercourses

Exploitation of our watercourses has often transformed them into less satisfactory habitats. Fish have been prevented from travelling up the watercourses to spawn and watercourses that were once meandering have been turned into uniform channels that have been maintained in a hard-handed manner.

However, the new Watercourse Act of 1982 has provided us with the possibility to rectify the damage. Often it is enough just to change maintenance practice, especially weed clearance, such that the forces at work in the watercourses are once again allowed to help determine their form.

The task of administering our watercourses is relatively straightforward. Firstly, the water quality objectives for each watercourse serve as guidelines for what we hope to achieve; they serve as guiding beacons for the work; secondly, the frequent investigations of watercourse quality undertaken by the county authorities identify the areas that should be accorded priority; and thirdly, the practical task of ensuring the environmental quality of the watercourses is administered by the county and municipal authorities, that is, close to the watercourses and those who use them.

Current efforts to ensure good watercourse quality are to some extent made possible by the knowledge and experience accumulated since the new Watercourse Act entered into force.

The basis for this work is the knowledge we have of the laws of nature that govern in our watercourses - both in those that we have changed and those in which natural conditions still pertain.

The present chapter illustrates some of the things that it is useful to know when one has to reestablish good environmental conditions in our watercourses.

Exploitation of our watercourses

Watercourse legislation is nothing new. It is important to have legislation that ensures just and fair exploitation of the watercourses. In the ancient laws, among others the Jutlandic Law, there were special provisions as to how the water should be shared between mills. There were also rules on the form of salmon and eel traps. They had to be open at intervals to allow the fish to pass to upstream watercourses. There were very strict rules as to how the water should be shared for meadow watering and how the watercourses should drain water away. Until 1982, the many versions of the Watercourse Act primarily aimed at ensuring the drainage of surface water from the agricultural land.

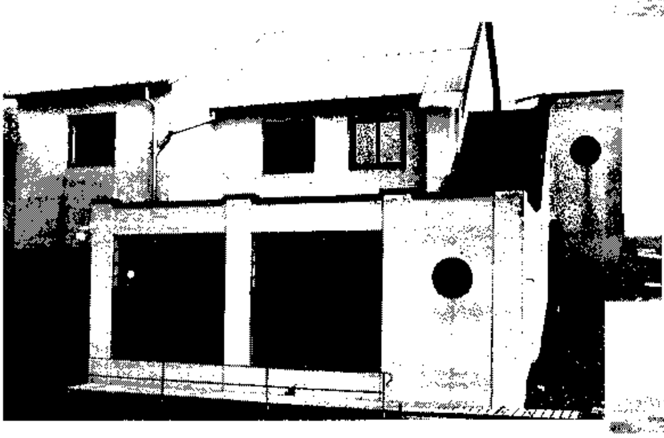


Figure 1.1-1.4

- *Remains of Dalgas dam in the river Skjernå.*
- *A bridge at Bundsbæk mill.*
- *Electricity generating station on the river Skjernå.*
- *Fish farming - a livelihood based on watercourses.*

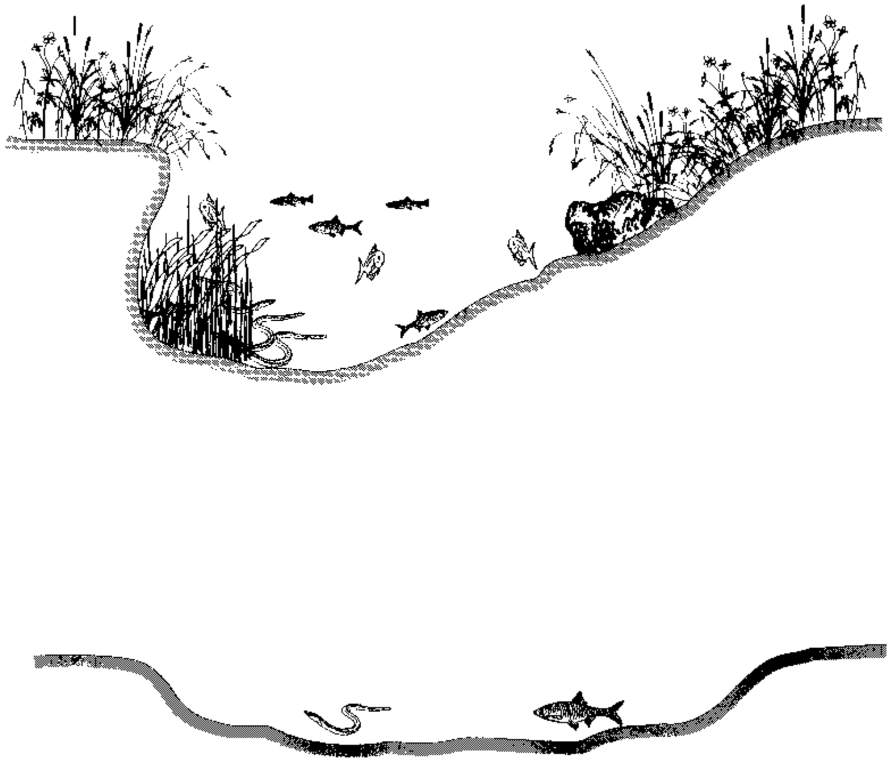


Figure 1.5 *A clean watercourse with a varying morphology can provide good habitats for a variety of species. These disappear when the watercourse becomes uniform.*

Over the centuries, man has left his mark on the watercourses in many ways. Some of them are interesting cultural relics that are worth preserving. These include ancient fords paved with stepping stones, the remains of bridge piles dating back several thousand years, water mills, and the remains of meadow watering facilities. While they can be worth preserving, such hindrances prevent fish from passing. For example, salmon have not been able to travel to the upper reaches of the river Gudenå since mill dams were established many hundreds of years ago. Conflicts can therefore arise between angling and cultural interests; while some people would like to preserve a mill dam because it has historical value, others would like to see it removed because it prevents the passage of fish that they would like to catch further upstream in the watercourse.

The watercourses have undoubtedly been subjected to the greatest change in the present century. The watercourses were regulated in step with widespread drainage of fields, and have since been maintained in an efficient and hard-handed manner. Straightened watercourses drain water away more quickly since they have a greater gradient. At the same time though, the watercourses were transformed into uniform channels with few if any habitats for fish. Since they in addition became polluted by agriculture, industry, towns and fish farms, it is hardly surprising that many of the watercourses became poor habitats for the animals and plants for whom conditions were previously so good. The rich nature in the watercourses became impoverished.

The natural watercourse

The water that flows through a watercourse has ample energy to shape its path. The current erodes material free from the bed and sides of the watercourse and then transports it away before it can be deposited on the bed. The flowing water determines the width, the depth and the path of the watercourse itself.

Freely flowing water will usually follow a twisting and turning path. When the current is allowed to shape the watercourse itself, the result will usually be the winding form illustrated in Figure 1.6. Such a watercourse is said to have meander bends. The outer side of the bends is eroded by the current, and at intervals a meander is sheared off forming a horseshoe-shaped lake. Watercourses can also follow paths other than the meandering type, however (Figure 1.7).

Figure 1.6 *Spørring Å stream.*

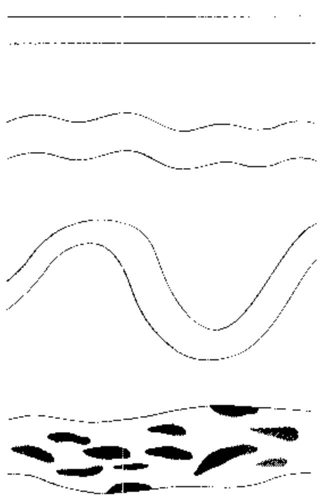


Figure 1.7 *Natural watercourses can follow a straight, a twisting and turning or a braided path.*

If a watercourse cuts through a meander, the segment of land that buds off thereafter belongs to the landowner on whose side of the watercourse the segment comes to lie. Hence it is said that "Rivers move boundaries".

Meanders

Meandering watercourses can look quite different, much depending on the soil and landscape. Nevertheless, they have so much in common that it is more the similarities that catch one's attention than the differences. The bed of meandering watercourses varies between sand, mud, stones and gravel.

In some places the current erodes material away from the sides, while in other places sand and mud sediment out. In some reaches the water depth is the same across the width of the watercourse, while in other reaches it varies (Figure 1.8). However, all this is not random - one finds the same pattern in watercourse after watercourse. It would seem to follow laws of nature that are not always easy to understand. Nevertheless, they are laws that have to be followed if one wants to undertake work on watercourses.

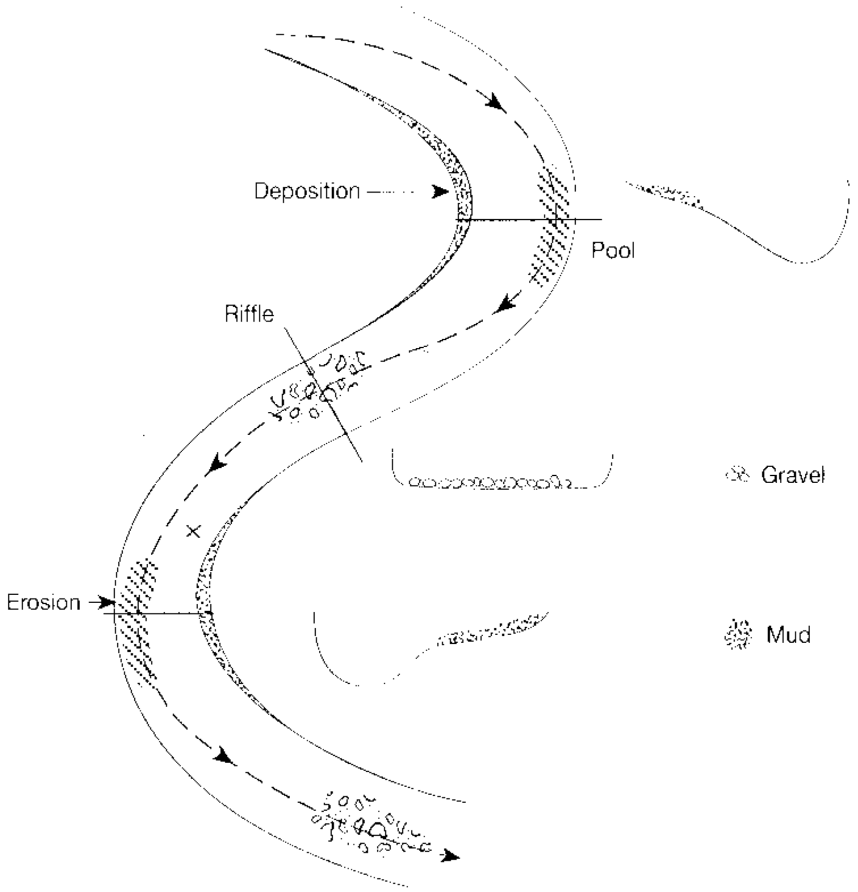


Figure 1.8 *Current, bed and depth conditions follow regular patterns in the watercourse's meanders.*

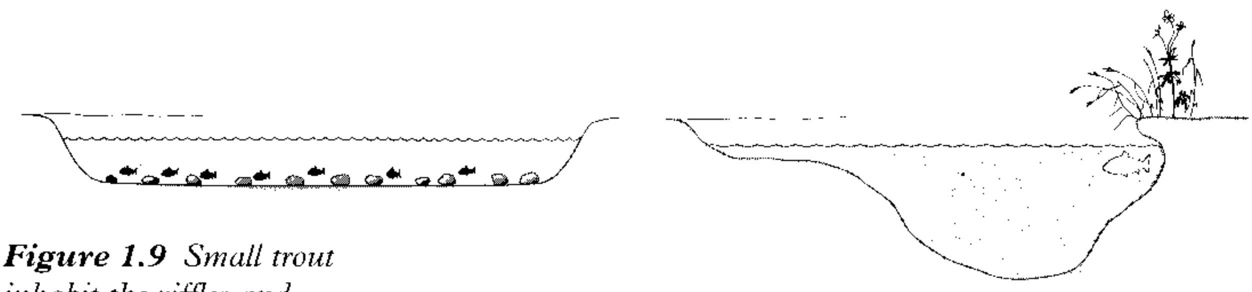


Figure 1.9 *Small trout inhabit the riffles and large trout the pools.*

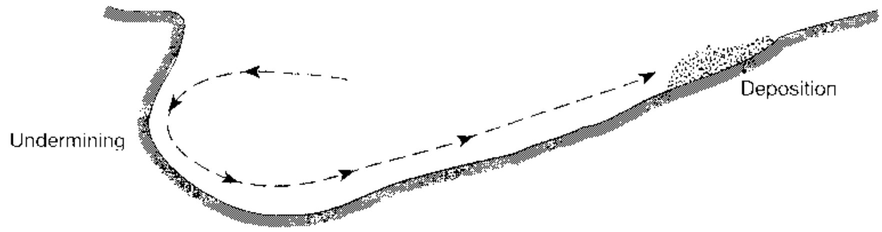


Figure 1.10 *In the meander bends the current runs crosswise.*

Muddy pools are formed on the outer side of the bends, while the material removed is deposited again on the inner side. Between the bends there is a shallow area termed a riffle. In the bend itself, the current whirls in a "corkscrew" pattern (Figure 1.10). It is this current that undermines the bank, thereby forming an overhang.

The considerable variation in current, bed and depth found within the individual meander bends provides good living conditions for many different animals and plants.

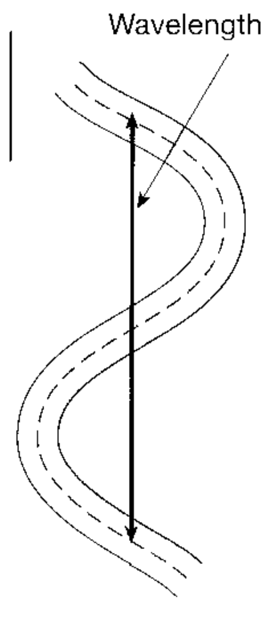


Figure 1.11 *The wavelength of a full meander is approx. 10-14 times the width of the watercourse.*

Meander wavelength

There are several reasons why one might want to restore a regulated watercourse to the natural meandering form. Some people consider a meandering watercourse to be more attractive than a straight one, and a meandering watercourse provides a superior habitat for plants and animals. There is a further good reason for re-establishing a meandering watercourse, however; the water is led away in a manner that preserves the sides and bed of the watercourse more than when the water runs along a straight channel. With straightened watercourses, considerable quantities of sand and mud can be eroded from the bed and sides. This material is transported down the watercourse, often as migratory sand that can destroy trout spawning grounds and bury the stones that are the habitat of many invertebrates. Such problems are partially overcome when meanders are reestablished, as is illustrated in the following sections.

Measurements of meandering watercourses show that there is a rather regular pattern to the shape of the meanders. The broader the watercourse, the longer the meanders. The wavelength of one full meander is approx. 10-14 times the width of the watercourse (Figure 1.11). The width in question is the width when discharge is high and the watercourse is full to the brink. The watercourse has most energy when full and it is such situations that help determine the watercourse's path, depth and width. Nevertheless, daily wear when discharge is low also helps to shape the watercourse.

When one wants to remeander a regulated watercourse, it is important to understand the laws of nature that govern natural watercourses. This applies whether one intends to cut a current channel through the weeds or excavate a new, meandering watercourse.

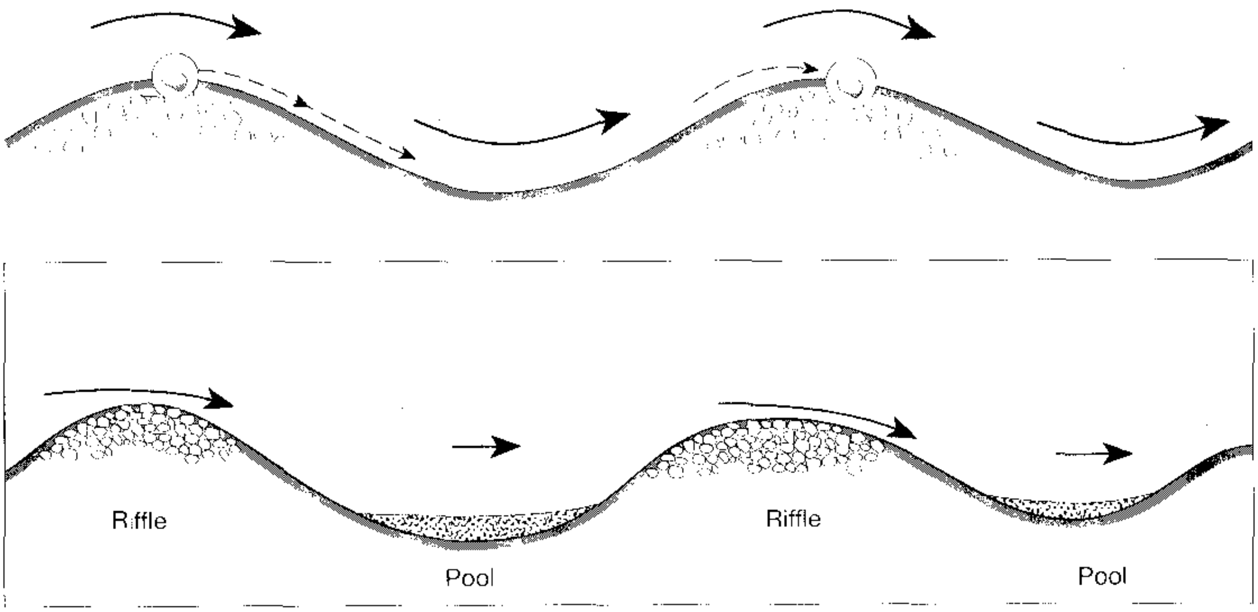


Figure 1.12 *When discharge is high, the current can sometimes move a stone from one riffle to the next. The likelihood of being moved decreases the greater the density of stones and gravel particles.*

Riffles and pools

In the meandering watercourse the shallow riffles and deep pools lie in a regular pattern. The distance between the riffles and between the pools follows the same pattern as the meanders. The distance between two neighbouring riffles is approx. half the wavelength of one full meander, i.e. approx. 5-7 times the width of the watercourse. Riffles and pools can also occur in straight watercourses (Figure 1.26).

Conditions for life differ considerably on the riffles and down in the pools. Riffles have a bed of gravel and stone, and the current is normally stronger than elsewhere. They are inhabited by invertebrates that require a good supply of oxygen, and which are able to tolerate the current. Down in the pools the bed is usually muddy. They are inhabited by invertebrates able to survive under conditions of low oxygen content. It is also in the pools that the largest trout are able to find good hiding places, while the small trout often have to inhabit the riffles (Figures 1.9 and 3.7).

The riffles and pools lie in the watercourse like "waves": one can consider them as bends that go up and down, but which otherwise follow roughly the same pattern as the meanders.

It is difficult for the current to move a stone that lies among other stones, for example in a riffle. They stabilize each other and weaken the current. If a strong current tears a stone loose, it will be washed through the pool and will probably end among other stones in the next riffle. This is sometimes compared with traffic jams (1).

Riffles and pools are most likely formed by the same high discharges that form the meanders (see p 23). It would seem that riffles and pools rapidly form in regulated watercourses if there is considerable variation in discharge (figure 1.12).

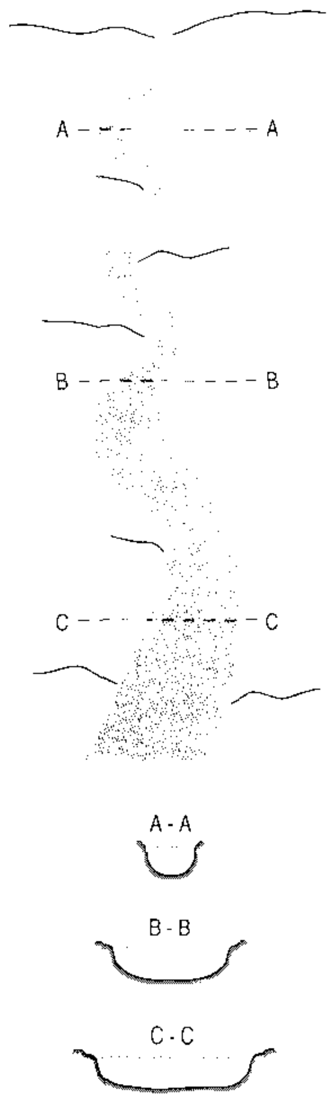


Figure 1.13 *The profile of a watercourse changes between its source and mouth.*

Watercourses reflect the landscape

The natural watercourse follows its own course through the landscape. It is determined by the gradient of the terrain, the type of soil and to a considerable extent by the discharge. The shape of the cross section or profile of watercourses is also determined by the soil type, discharge and distance from its source.

During their passage through the landscape, watercourses become deeper and wider. The further the distance from the source, the greater the amount of water they have to lead away, and the greater the profile has to be to accommodate it.

The smaller, uppermost watercourses are deep relative to their width, while those furthest downstream are shallow relative to their width. If the gradient is equal in the uppermost and lowermost reaches, the rate of flow will be highest in the lowermost reaches, where resistance is lowest (Figure 1.13).

The soil type also helps determine the shape of the watercourse profile. If the soil contains much clay (moraine), the watercourses will be small and deep. This is the form of many watercourses in the rolling eastern part of Jutland and on the island part of Denmark. If the soil contains much sand (glacial melt water plains), the watercourses will be broad and shallow. This is the usual form of watercourses in western Jutland. Regional differences in precipitation also play a role.

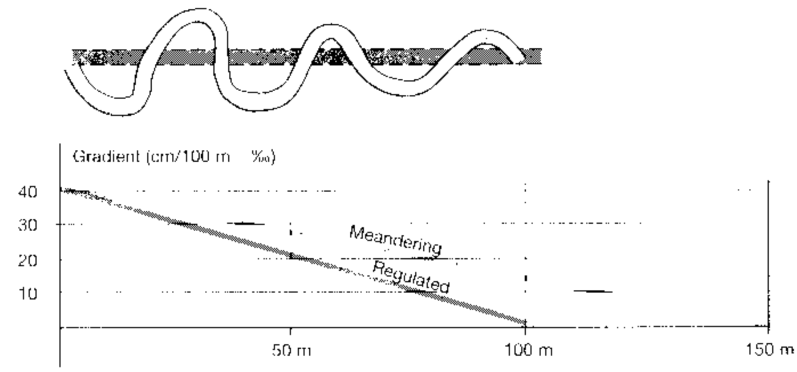


Figure 1.14 *When a meandering watercourse is regulated, its gradient increases.*

The modified watercourse

When the swings and bends of a watercourse are cut away, many of the good habitats for plants, invertebrates and fish disappear. The great variation in physical conditions that characterizes meandering watercourses is superseded by uniform conditions. The meandering watercourses have an intricate pattern of strong and weak currents and there is a large selection of different habitats. There are habitats for invertebrates with completely different requirements as to hiding places, current and oxygen content. In regulated watercourses there is often only a migrating sand bed with few if any hiding places for fish and invertebrates. At best, only a limited number of different animals can live there.

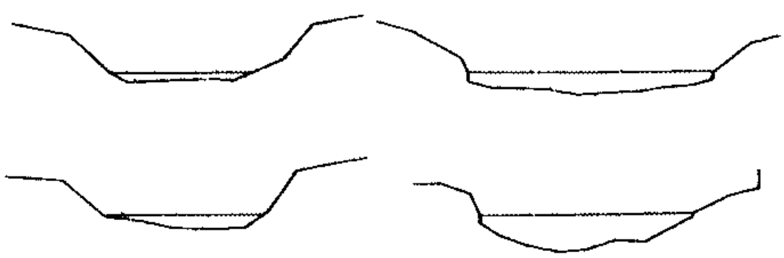


Figure 1.15 *Regulated watercourses can be widened by the current. The broken line shows the original regulated profile. Adapted from (2).*

The difference in habitats is only one of the differences between the two types of watercourse, however. In regulated watercourses the current works differently than in meandering watercourses. When a watercourse is straightened out, the gradient increases and the current becomes stronger (Figure 1.14). The latter affects every metre of the watercourse with more energy than it would in a meandering watercourse.

The current has energy and can undertake work. It can run a water mill or drive a boat downstream. However, it can also use the energy to erode the bed and sides and to transport away the sand and earth that has been eroded free. Although this occurs in both natural and regulated watercourses, the current has more energy in the latter. It can erode and transport more material than is the case in meandering watercourses. Regulated watercourses therefore easily become wider and deeper than the stipulated dimensions (figure 1.15).

The current erodes away at the bed and the sides. If there are no weed borders that can protect against the current, the latter can work unhindered. It can undermine the banks and, if there are no solid roots to reinforce them, eventually provoke their collapse (Figure 1.16). The watercourse will then become wider and wider, with a considerable amount of migratory sand.

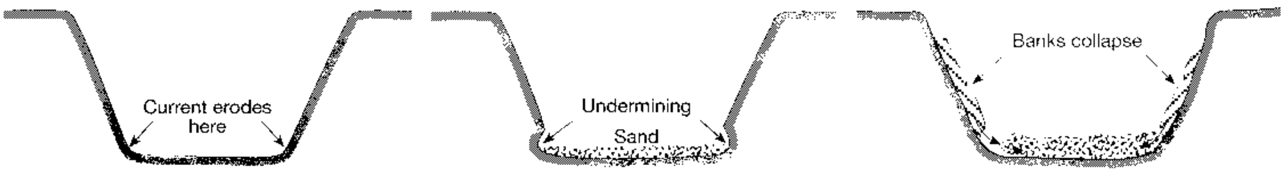


Figure 1.16 *The current can undermine unprotected banks and provoke their collapse.*

The current shares its energy between scraping material free and transporting it downstream. Clay particles are transported suspended in the water, while the sand usually rolls along the bed. Both forms of transport drain the current of energy, however, and it therefore has less and less energy the more it has to transport and the longer the material has to be transported. Moreover, the energy it has to erode away at the bed and sides also decreases. Thus the current usually removes most material in the uppermost reaches of regulated watercourses, whereas the material is deposited in the lowermost reaches.

In the uppermost reaches of regulated watercourses the current has so much energy that it can work its way up through the unregulated reaches. In such transitional reaches it is sometimes necessary to reinforce the bed with stones. One can reduce the impact of the current on the regulated reach by constructing weirs at regular intervals. A considerable part of the energy bound up in the current will be dissipated when the water plummets over the fall. As it usually lands on a concrete base, the energy cannot be used to erode away at the bed. A disadvantage of weirs, however, is that they can hinder the upstream passage of fish (see Chapter 4).

Watercourses in equilibrium

The current in meandering watercourses also has energy with which it erodes, just as in regulated watercourses. Some of the material that the current erodes free is deposited close to its point of origin, often in the same meander bend.

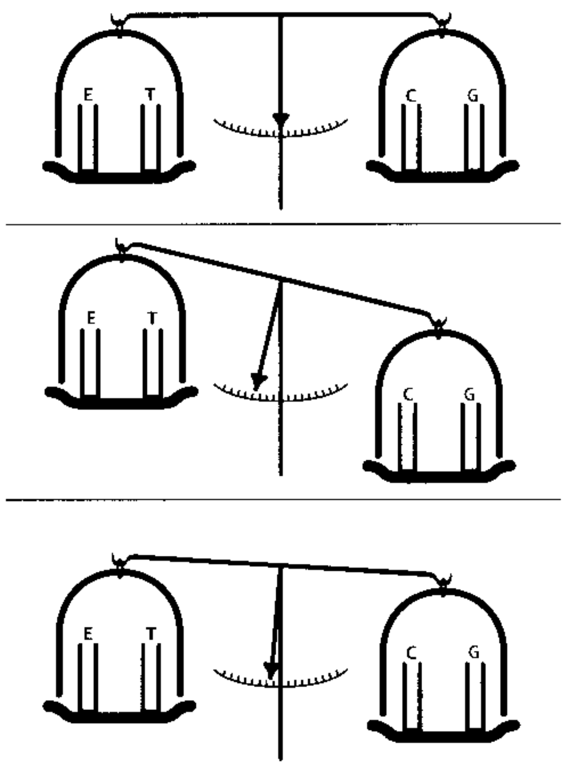


Figure 1.17 *Erosion (E) and transport (T) of material are determined by the gradient (G) and the current (C).*

Gradient and current are both increased by watercourse regulation.

Erosion and transport of material increase, and a new equilibrium is approached.

With a natural watercourse, there is an equilibrium between its gradient and the amount of material eroded and deposited. The watercourse "strives" towards an equilibrium whereby as little energy as possible is expended on eroding the bed and sides. This equilibrium can be brought out of balance when the watercourse is regulated, for example deepened or straightened. The watercourse can also be brought out of balance if discharge increases, for example if storm water overflows from urban areas feed into it. When it rains, considerable amounts of water can be led into the watercourse. The energy thereby imparted on the current enables it to erode more and to transport sand and clay through the watercourse. This is exactly why storm water discharges often lead to considerable problems with migratory sand.

The path to good watercourse quality

When one wants to undertake a piece of work, whether it be to build a house, cross an ocean or re-establish a well-functioning watercourse, it is important to have a goal to steer towards - a guiding beacon.

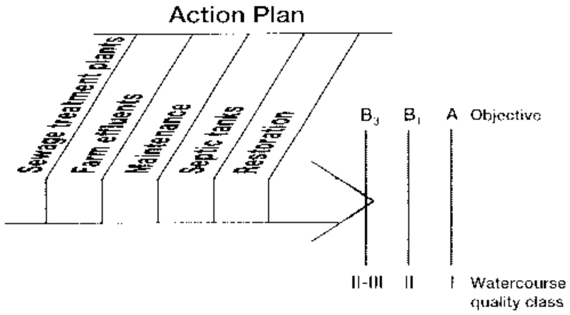


Figure 1.18 *Steps on the path to good watercourse quality.*

The environmental effort to improve watercourses is guided by goals for their use. A system of objectives have been established that act as "beacons" to guide the work with watercourses. They set the course. However, the path leading to the goal has many steps, i.e. subsidiary goals. The first step in the effort to improve watercourses was to ensure the treatment of sewage effluent. The second step was to come to grips with agricultural discharges of liquid manure and seepage water from silage heaps. Such subsidiary goals will soon have been achieved in many watercourses (Table 1.1).

Table 1.1 *Problems in watercourses in three of the municipalities in Vejle County in 1993. Adapted from (3).*

Cause of problem	No. of stations	%
Waste water from treatment plants	27	10%
Waste water from scattered dwellings	65	25%
Waste water from fish farms	10	4%
Agricultural discharge	9	3%
Poor physical diversity due to channelization	101	38%
Hard-handed maintenance	35	13%
Unsatisfactory discharge	17	7%
Total	264	100%

As can be seen from Table 1.1, some of the subsidiary goals have not yet been reached despite the Environmental Protection Act having been in force for 20 years and the new Watercourse Act for 10 years. A stop still needs to be put to the numerous small discharges from sources such as septic tanks, etc., as well as to incidents of poisoning associated with the use of pesticides, and physical conditions in the watercourses need to be improved. Thus the Watercourse Act and appropriate maintenance are essential if the physical quality of watercourses is to be good.

Watercourse quality objectives

Watercourse environmental quality objectives are set forth in each county's Regional Plan. In setting the objectives, consideration is given to the state of the natural conditions, what impact man has had, what the intention is with the watercourse, and what can realistically be achieved.

It would for example be unrealistic to set an objective for a slowly flowing channel on land reclaimed from the sea that would demand an environmental quality only found in a rapidly flowing watercourse in a hilly area. However, it would not be unrealistic to aim to clean up a very polluted watercourse within a certain period, or to improve the physical condition of a watercourse that is severely damaged by maintenance. As with any other type of planning, however, it is necessary to weigh the costs against the benefits.

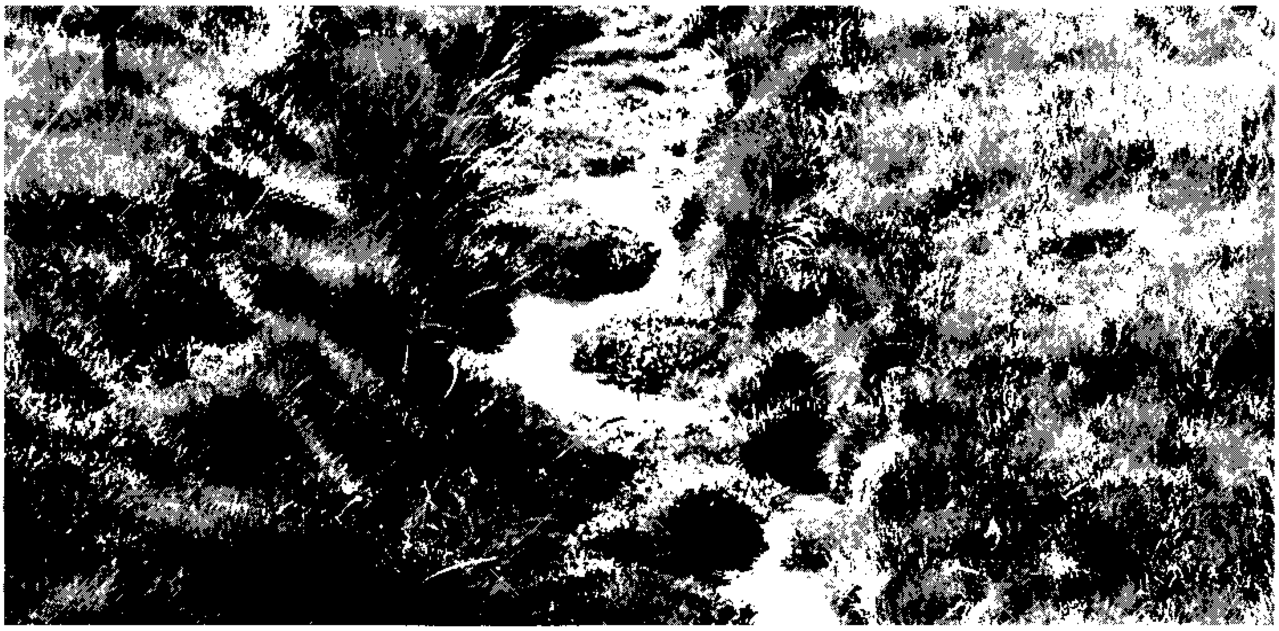
The County Councils can choose between a variety of environmental quality objectives (Table 1.2 and Box 1.1) or they can formulate their own objectives. In principle there are three groups of watercourse quality objectives: stringent objectives, basic objectives and eased objectives. Within each group there can be sub-groups. For example, the basic objectives group includes watercourses that have to be so clean that they can serve as trout spawning and nursery waters (B1), as well as watercourses that only have to be suitable for fish such as roach, eel and bream (B3).

Examples of watercourses with eased quality objectives could be watercourses dug for drainage purposes or those which dry out in the summer. The reason for the latter could be groundwater abstraction in the vicinity or that the watercourse dries out of natural causes. It is worth noting that even those watercourses which do dry out can have such a rich invertebrate fauna that it is worth setting them a stringent quality objective.

In this book, the stringent and basic quality objectives are considered high watercourse quality objectives. Objective F, i.e. ochreous watercourses, is often included as well because with gentle maintenance, such watercourses can often satisfy a higher objective.

Table 1.2 *Examples of watercourse quality objectives. The minimum water quality class (pollution class) that the watercourses have to meet is shown to the right.*

	Objective	Description	Class (minimum)
Stringent objectives	**A** Areas of special scientific interest	Watercourses where it is wanted to protect unique components of nature	II
Basic objectives	**B1** Salmonid spawning and nursery waters	Watercourses that should be able to serve as spawning and nursery areas for trout and other salmonids	II
	B2 Salmonid waters	Watercourses that should be able to serve as nursery and living areas for trout and other salmonids	II
	B3 Cyprinid waters	Watercourses that should be able to serve as nursery and living areas for eel, perch, pike and cyprinids	II
	B4 Watercourses with a varied flora and fauna but of little value to fish		II
Eased objectives	**C** Watercourses to be used for drainage purposes		II - III
	D Watercourses affected by waste water		II - III
	E Watercourses affected by water abstraction		II - III
	F Watercourses affected by ochre		



A Areas of special scientific interest
This objective is usually applied in the case of watercourses in which high priority is given to the following interests:
- Scientific research.
- Preservation of watercourses that are completely or virtually unaffected by anthropogenic activities.
- Preservation of special plant and animal species or communities.
- Preservation of geological, hydrogeological, historical or scenic treasures.

B1 Salmonid spawning and nursery waters, where salmonids already spawn and where fry grow and develop.
Watercourses where physical conditions can be created that render them suitable as spawning and nursery waters for salmonids.
Watercourses whose basic condition renders possible the growth and development of trout fry (but not spawning).

B2 Salmonid waters (nursery and living areas for trout), where there is already a salmonid stock, especially trout.
Watercourses where physical conditions can be created that render them suitable as living and nursery waters for salmonids.

B3 Cyprinid waters, where there is already a stock of eel and possibly pike, perch and roach, as well as other cyprinids.
Watercourses where it is possible to create conditions suitable for a stock of the abovementioned fish.
Transit waters for salmonids, i.e. watercourses connected to lakes and watercourses with higher quality objectives (B1 and B2).

B4 Watercourses with valuable biological characteristics, but where conditions do not allow the presence of a fish stock.

C Watercourses solely used for drainage purposes, and which lack a fish stock or special biological conditions that the County Council wishes to protect.

D Watercourses where authorized waste water discharges cause the quality to be worse than that expected from the natural conditions.

E Watercourses where the effects of water abstraction, either directly from the watercourse or through groundwater abstraction in the catchment, render it impossible to maintain a fish water objective.

F Watercourses that are so markedly affected by ochre discharge that a fish water objective cannot be achieved.

The objectives shall be achieved on the basis of the following guidelines:

A Areas of special scientific interest
The watercourses shall be kept in a natural condition and shall be kept free of influences that can deteriorate their special characteristics.

B1, B2 Salmonid spawning and nursery waters and salmonid waters. Watercourses and lakes shall be ensured the objectives stipulated in the plan.
Obstructions that hinder the passage of fish are not allowed.
The watercourses are to be maintained in an environmentally friendly manner.
A lower water quality than that given in the objective can be accepted in short reaches downstream of waste water and fish farm outfalls.
Water abstraction and technical measures must not hinder compliance with the objective set for a watercourse.

B3 Cyprinid waters.
Watercourses and lakes shall be ensured the objectives stipulated in the plan.
Obstructions that hinder the passage of fish are not allowed.
A lower water quality than that given in the objective can be accepted in short reaches downstream of waste water and fish farm outfalls.
Water abstraction and technical measures must not hinder compliance with the objective set for a watercourse

B4 Watercourses and lakes shall be ensured the objectives stipulated in the plan.
The watercourses are to be maintained in an environmentally friendly manner.
A lower water quality than that given in the objective can be accepted in short reaches downstream of waste water and fish farm outfalls.
Water abstraction and technical measures must not hinder compliance with the objective set for a watercourse.

Plans for the watercourse quality

An objective common to all watercourses is that they must not be polluted. They have to live up to a certain standard of purity and environmental quality. In addition, they usually have to live up to other criteria, for example physical conditions. In the case of watercourses in the basic quality objectives category, it can often be important that the current follows a more or less meandering course; in contrast, such a criterion would be meaningless in the case of a channel designated for drainage.

The more healthy and the more varying the environmental state of a watercourse, the greater the number of invertebrate species that can inhabit it, i.e. there is a diverse fauna. If the environmental state is poor and monotonous, only few species can live there. The fauna is then said to be uniform. Nevertheless, the few species present can sometimes occur in large numbers, as for example is the case with pollution by household sewage.

The environmental state of a watercourse can be evaluated from the invertebrates present. Organic matter pollution of watercourses has been evaluated in this way for many years. Pollution with organic matter causes oxygen deficit and can give rise to black deposits of mud, bacterial films and enormous colonies of microorganisms which blanket the bed with readily visible growths commonly referred to as "sewage fungus". This type of pollution changes the conditions for animal life.

Clean watercourses in which physical conditions are good are usually inhabited by numerous different macroinvertebrates, the so-called "clean water invertebrates". These are mainly large and readily visible invertebrates such as young aquatic

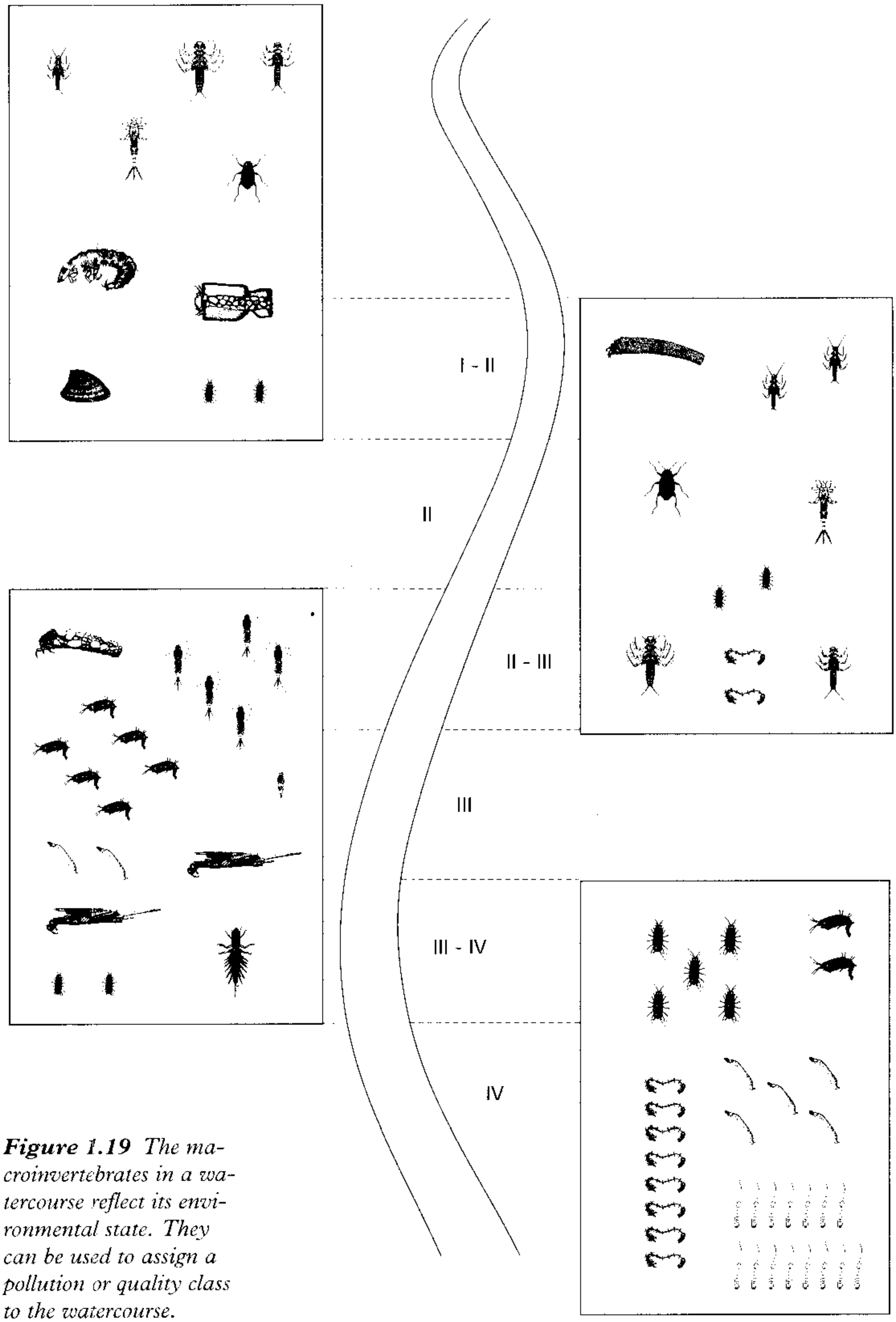


***Figure 1.19** The macroinvertebrates in a watercourse reflect its environmental state. They can be used to assign a pollution or quality class to the watercourse.*

stages of certain insects. Such watercourses are assigned to "pollution class" I. The most polluted watercourses are home to only few species of macroinvertebrates, although they can be present in large numbers. The species that inhabit them are able to tolerate the pollution. Such watercourses are assigned to pollution class IV. Within this range watercourses are assigned to pollution class II or III depending on which macroinvertebrates are present. As a rule there are also intermediate classes, e.g., pollution class II-III.

The physical state of a watercourse also considerably influences which macroinvertebrates inhabit it. Thus even a watercourse with completely clean water can have a fauna resembling in composition that of a polluted watercourse if the current is weak and the bed muddy. As a rule, however, such watercourses lack some of the other characteristics of polluted watercourses, e.g. "sewage fungus", although the fauna is characteristically uniform. On the other hand, a watercourse that is somewhat polluted can have a rich and diverse fauna if the current is strong and the bed stony.

Factors other than pollution with organic matter are now taken into account when evaluating watercourses. Physical state also influences the evaluation of watercourses based on the presence of macroinvertebrates or the lack of species expected to be present.

One can use these classes to follow the trend in watercourse environmental quality in order to determine whether measures such as sewage treatment and gentle maintenance are having the desired effect.

The classes I to IV and intermediate classes such as II-III are still employed, as is the term pollution class, even though the evaluation covers more than just pollution. It is open to question whether the term should really be used. It would perhaps be more appropriate to refer to watercourse quality classes, or simply watercourse classes.

For a number of years now, work has been going on in Denmark to improve methods for evaluating watercourse environmental quality. The use of macroinvertebrates has been adhered to because they serve as good environmental "indicators". One of these methods is the Danish Fauna Index. Instead of the term "pollution class", the quality of the watercourse is expressed in terms of "fauna class" (I to IV).

The trout population is also a good measure of a watercourse's quality, and also its physical state.

The main topic of this book is the physical state of watercourses, and hence watercourse maintenance. For this reason the terms "pollution class" and "pollutional state" will not be used when referring to watercourse quality since the latter is so dependent on physical conditions. Instead only the term "class" will be used, the meaning being "water course quality class".

According to the overall plans for Danish watercourses, no watercourse should be in a class worse than fauna class II-III. Watercourses of this class would typically be those for which eased quality objectives have been designated, but could also be some of the B3 watercourses if they have a weak current and a peat bed. The watercourses with the highest quality objectives must be in class II or better.

Length of the watercourses

The watercourses are divided into three groups according to who is responsible for their maintenance: County watercourses, municipal watercourses and private watercourses. The former two groups are public watercourses.

The Danish Environmental Protection Agency has prepared an analysis of the length of watercourses in the three groups. This is based on information submitted by 14 of the 15 Danish counties (Bornholm was not included) and 165 of the 275 municipalities.

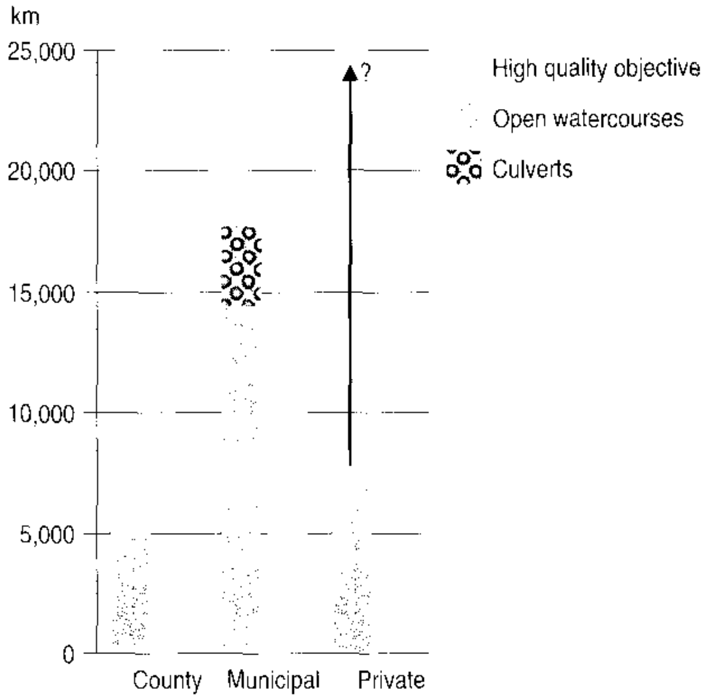
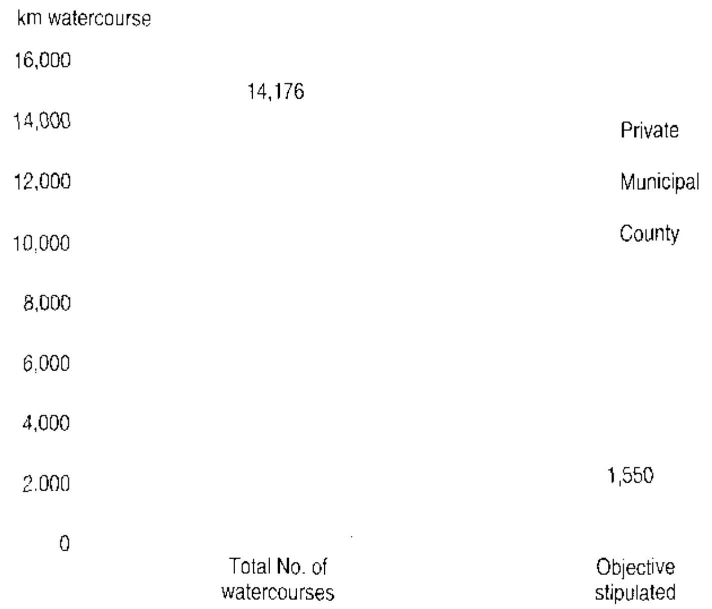


Figure 1.20 *Length of watercourses in Denmark. Adapted from (4).*

From the information submitted, the total length of watercourses can be estimated for the country as a whole: There are approx. 5,000 km of county watercourse and approx. 17,500 km of municipal watercourse. Of this, approx. 3,000 km is culverted, nearly all of which is municipal. This gives a total of approx. 20,000 km of open, public watercourse whose maintenance is the responsibility of the county or municipal authorities. The information submitted also included the number of km watercourse with each quality objective.

Figure 1.20 summarizes the length of public watercourses registered as having high quality objectives (i.e. A + B, including F): The total is approx. 15,000 km. Almost all the county watercourses have a high quality objective - 92% of approx. 5,000 km - as do approx. 3/4 of the open municipal watercourses - just under 11,000 km in all. Of the latter, approx. 1,000 km are designated as ochreous watercourses - objective F. The watercourses with high quality objectives include just over 600 km of culverted watercourse, most of which is municipal.

The submitted information does not provide a realistic estimate of the total length of private watercourse. According to this, there are approx. 4,000 km of private watercourse with a high quality objective, including approx. 100 km of ochreous watercourse. Closer examination would undoubtedly show that there are more private watercourses with characteristics that warrant a higher quality objective.



	Total No. of watercourses	Objective stipulated
Private	10,000	68
Municipal	3,486	792
County	690	690

***Figure 1.21** Length of watercourse in Sønderjylland County. Adapted from (5).*

According to the information submitted, the total length of private watercourse in Denmark is just over 7,000 km. That the total length of private watercourse is undoubtedly greater is indicated by Figure 1.21, which illustrates a survey undertaken in Sønderjylland County. The estimated length of private watercourse in Nordjylland County is of the same magnitude as in Sønderjylland County, approx. 8,500 km. Many of these watercourses are undoubtedly artificial ditches, especially in the flat areas that characterize these two counties.

Former maintenance practice

Under the previous Watercourse Act one had to ensure that the watercourse had the form stipulated in the Provisional Order governing the watercourse. When the watercourse began to change its form towards that of a natural watercourse, action had to be taken. The watercourse had to be regulated such that it corresponded to the stipulated form. This was called watercourse maintenance.

Maintenance followed simple rules: "The watercourse shall be maintained appropriately such that the water drains away effectively". The physical impact that deepening and straightening left on the watercourses was perpetuated by this maintenance. No matter how much the watercourse itself attempted to make good the damage caused by maintenance, the watercourse was once again "put in its place" when the regular maintenance was undertaken at the stipulated time.

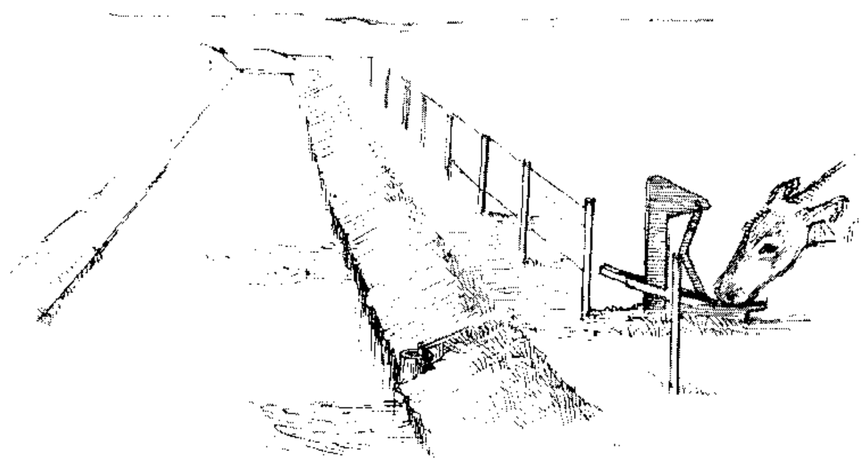


Figure 1.22 *Sketch from a guideline on watercourse maintenance from 1976. Adapted from (6).*

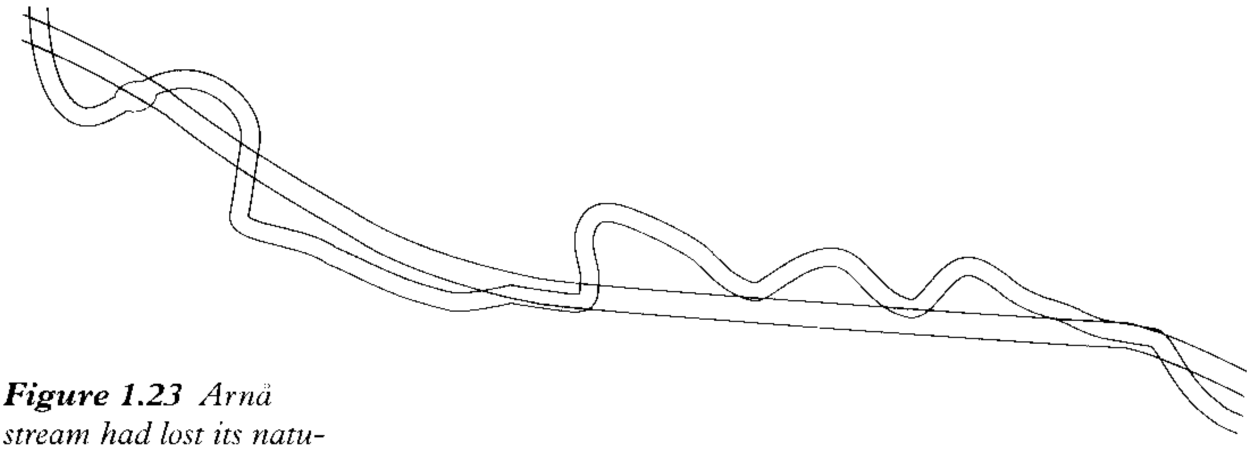


Figure 1.23 *Arnå stream had lost its natural form even before it was regulated. Adapted from (7).*

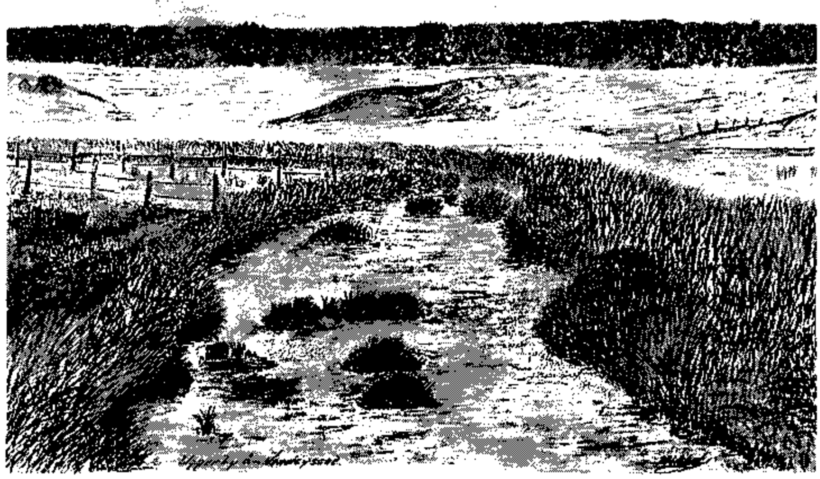
Former maintenance practices worked against rather than with the watercourse. Even those watercourses that were not straightened and deepened were severely affected by maintenance. The small bends gradually became cut off such that the watercourses came to look more and more like regulated watercourses (Figure 1.23).

The old Provisional Orders stipulated how wide and deep each watercourse should be. If one surveys the watercourses, however, it generally transpires that they have become wider and deeper than stipulated in the Provisional Orders that govern them (Figure 1.15). Either they were dug deeper and wider when maintenance was undertaken, or the watercourse itself eroded the sides and bed when the weed had been removed.

New thinking on watercourse maintenance

In 1980 the Danish Environmental Protection Agency Freshwater Laboratory issued a small publication containing ideas how watercourses could be maintained in a manner that would ensure good watercourse quality (8). The publication informed of the importance that gentle weed clearance could have for watercourse quality. Gentle weed clearance involves such practices as conserving hiding places for invertebrates and fish. In addition, these weed beds will enhance the self-cleansing properties of the watercourse because the weed is coated with a film of bacteria and other microscopic organisms that live off organic matter dissolved in the water. The publication included proposals for new methods of maintaining watercourses.

Vandløbskvalitet
og vedligeholdelse,
mål og midler



Miljøstyrelsens Ferskvandslaboratorium

Figure 1.24 *1980 publication on new methods of watercourse maintenance.*

The basic concept is that there must be a correlation between the watercourse objective and the means employed to maintain the watercourse. If the designated objective is that trout should be able to inhabit the watercourse, it is not enough that the water is clean. There also have to be good habitats for the trout. It is therefore necessary that weed clearance be undertaken in a gentle way too (Box 1.2).

Efforts were soon begun in the various counties to evaluate whether the new ideas were of any practical value. An example is a 1980 memorandum from Sønderjylland County suggesting a number of changes to the maintenance practice in the county watercourses (9). The suggestions largely follow the recommendations in the publication from the Danish Environmental Protection Agency's Freshwater Laboratory. The memorandum concluded with a section on the consequences of the changes in maintenance practice: "It can be expected that in step with the implementation of the new maintenance practice, there will be significant changes in the appearance of the watercourses. They will generally appear more "natural" and the need for fascines will probably be reduced. It is possible that the weed and vegetation will be able to stabilize the sides and bed of the watercourses such that the migratory sand problem will in a number of cases be reduced".

It is also acknowledged that the implementation of such a sweeping transition to a new watercourse maintenance practice should be undertaken carefully and stepwise. For example, it is necessary to display considerable flexibility when planning the work so that one can rapidly redress problems such as a too high water level in particularly vulnerable places.

The memorandum includes a number of guidelines as to how maintenance practice should be changed. For example, bank vegetation should not be cut unless a specific instruction to the contrary has been issued by the county technical department. The watercourses must not be dug with mechanical diggers unless careful investigation has confirmed that it is necessary to remove sand that is hindering effective drainage. With regard to weed borders along the sides of the watercourses, the memorandum states that since these do not usually affect drainage, they should be allowed to stand. For each watercourse reach, the county authorities have drawn up proposals as to how the maintenance should be undertaken. The proposals are in accordance with the objective designated for the watercourse. For example, clearance of watercourses designated as spawning and nursery waters for salmonids is, in so far as drainage capacity is ensured, to be undertaken gently using manpower and scythes.

Box 1.2 *1980 proposal for new watercourse maintenance practice.*

Proposal for new watercourse maintenance practice.

There should be a good correlation between the county's objective for a watercourse and the manner in which it is maintained. The objective for many of our watercourses is that they should be a good habitat for fish. However, there are several types of fish waters:

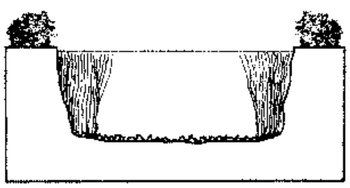
Fish waters

Salmonid spawning and nursery waters:	In these waters, trout or other salmonids should be able to spawn and the fry should be able to grow and develop.
Other salmonid waters:	In these waters, trout and other salmonids should be able to thrive.
Transit waters and other fish waters:	In these waters eel and trout should be able to pass, and eel, pike, perch and cyprinids should be able to thrive.

Maintenance of watercourses with these objectives should be undertaken gently. Otherwise the watercourse quality would be so poor that compliance with the objective would be precluded.

It is important that weeds are not cleared away completely. Part of the weed should remain, e.g in the form of borders along the sides of the watercourse:

Gentle weed clearance



In each individual case it should be evaluated how much weed can be left in place without the water level becoming too high.

Consideration should also be given to the fact that the amount of weed can vary considerably from year to year. Weed clearance must therefore be undertaken as needed, both with respect to its timing and extent.

The memorandum only deals with the county watercourses. However, it concluded by saying that once sufficient experience had been gained, the municipalities could be involved so that the municipal watercourses could also be maintained in accordance with the new principles.

It began with the Voer Å stream system

Nordjylland County authorities were quick to begin experimenting with how the physical condition of watercourses could be improved in practice. They began with Voer Å stream and its tributaries Spånbæk brook and Tøsbæk brook.

Voer Å and several of its tributaries had clearly suffered from regulation and hard-handed maintenance. It was therefore an obvious choice to try to restore them so as to improve their physical condition. Regulation had left both Voer Å and the tributaries lying deep below ground level. There was consequently little danger of flooding adjacent fields if the water level should rise more than expected during the experiments.

After a pilot study in 1978, the Land Tribunal gave permission for an experimental project in part of the Voer Å stream system (Figure 1.25).

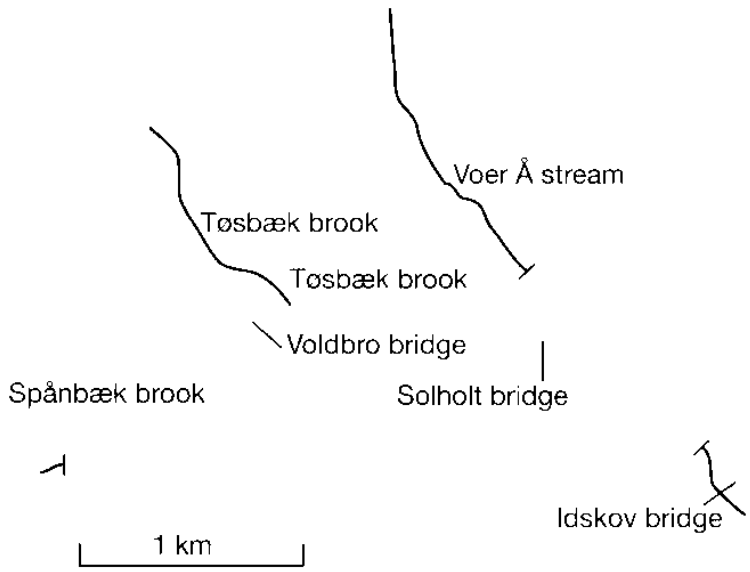


Figure 1.25 *The first experiments were conducted in parts of the Voer Å stream system. The experimental reaches are shown in blue.*

The project was undertaken as a watercourse regulation matter under the provisions of the previous Watercourse Act. While the aim of regulating watercourses had previously been to change their dimensions so as to improve their drainage capabilities, the aim in this case was to change the dimensions in order to provide a better habitat for fish.

Starting in 1980, Nordjylland County authorities undertook a number of physical changes to the watercourses (10, 11). For example, gravel banks were laid at intervals corresponding to the distance between riffles in pristine watercourses. The distance between the tops of the gravel banks was 5-7 times the width of the watercourse. This rapidly led to other changes in the watercourse: The current eroded pools between the gravel banks. Before long the bed resembled that of more natural watercourses.

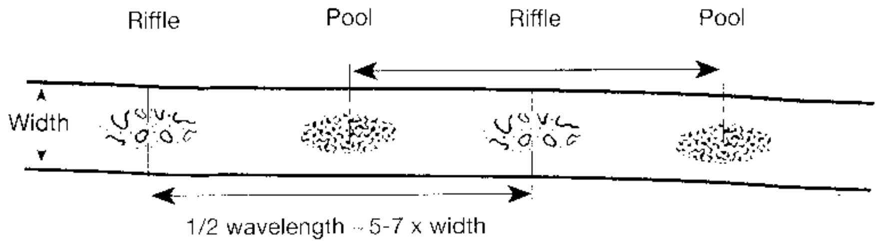


Figure 1.26 *The current can also form riffles and pools in straight watercourses.*

Artificial hiding places for fish were also constructed. Some of them were just a plank held in place by two iron poles (Figure 1.27). Another fish hiding place consisted of PVC pipes with "individual" holes for trout.

Stone banks were also constructed that jutted out from the banks like small peninsulas. They are called current concentrators because they increase the current. In some cases both the bank and the outer side of the current concentrator were stabilized with fascines. In Tøsbæk brook, they were constructed in the form of long stone banks laid alternately on one bank then the other.

Neither the gravel banks nor the current concentrators had any negative effect on discharge. The narrowing of the watercourse was rapidly counterbalanced by the greater depth created by the current.

The experiment provided some experience on how to improve conditions in watercourses. However, it also provided some experience of how not to do so. For example, it is not unimportant how the current concentrators are constructed. Some of those that were established in Voer Å stream were short, had a flat upper side and jutted very sharply into the profile of the watercourse. They had a vertical side facing the water. The Danish Environmental Protection Agency Freshwater Laboratory investigated what effect these current concentrators had (12). The variation in current and bed conditions near the current concentrators was as expected; however, the effect was concentrated near the current concentrator, and resulted in the erosion of a deep hole that reduced the energy of the current. The watercourse between the current concentrators did not benefit from the current. There was not sufficient interaction between two current concentrators, one lying immediately downstream of the other. In addition, unwanted deposits occurred around the current concentrators when the water level rose or fell to around the upper edge of the current concentrators; because the upper surface of the current concentrators was flat, the cross section of the watercourse changed abruptly, thereby causing an abrupt change in sedimentation conditions.

The conclusion reached was that the current concentrators should be longer, like some of those constructed in Tøsbæk brook. This would ensure that the current was imparted enough energy to affect the whole section between two neighbouring current concentrators. Further conclusions were that the current concentrators must not protrude too far into the watercourse, and that the upper surface should be rounded and inclining, the aim being to avoid sudden changes in the watercourse profile when the water level rises or falls.

The studies nevertheless confirmed that despite their deficiencies, current concentrators, in combination with appropriate establishment of gravel banks and gentle weed clearance, were responsible for the more varied physical conditions in the watercourse. Even though the pool in front of the current concentrator was very local, it provided a hiding place for a trout.

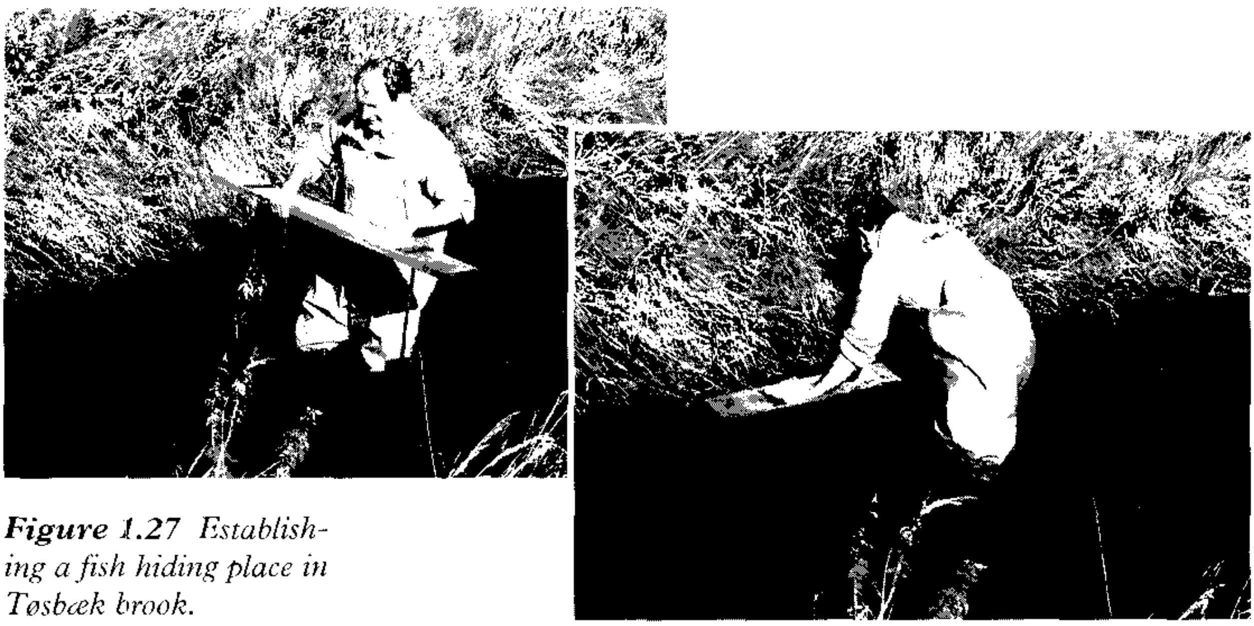


Figure 1.27 *Establishing a fish hiding place in Tøsbæk brook.*

Gentle weed clearance in Voer Å stream

The studies at Voer Å stream also included gentle weed clearance. Weed borders were left on alternate banks along the length of the watercourse such that the water followed a winding path, even though the channel in which it ran was straight (Figure 1.28).

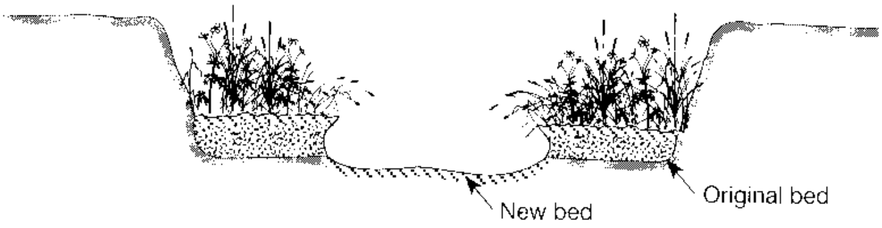


Figure 1.28 *Weed borders in Tøsbæk brook eventually merged with the banks. Adapted from (11).*

When deciding where to position the weed borders, the rule of thumb provided by meandering watercourses was employed: one meander cycle is approx. 10-14 times the width of the watercourse (see p 23). The weed was cleared more frequently than stipulated in the Provisional Order, the aim being to ensure sufficient discharge capacity. After some time, the weed borders silted up and merged with the banks. Bank vegetation grew out and formed a dense root net that stabilized the mud and sand. The watercourse attained a meandering course and became narrower and deeper (Figure 1.28). Its capacity to drain water away did not diminish, however, partly because the current channel had become deeper, and partly because weed clearance was undertaken more frequently.

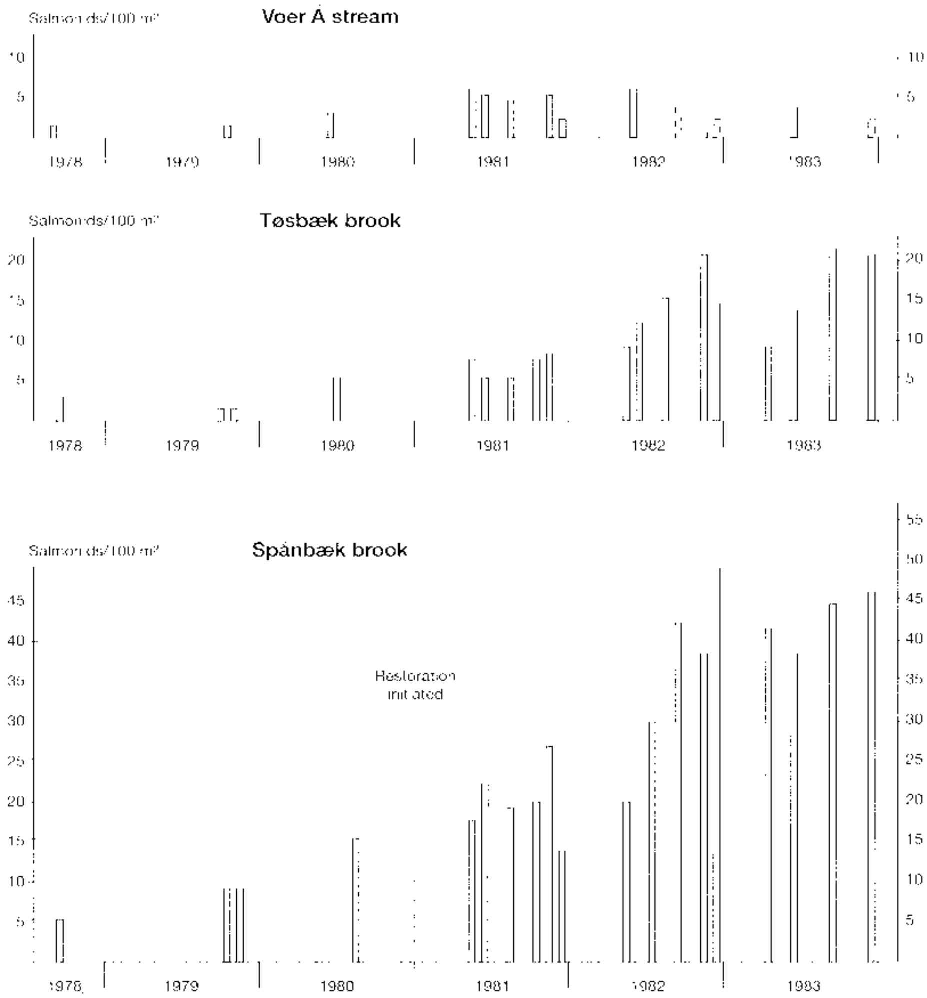


Figure 1.29 *The number of trout in Spånbæk brook and Tøsbæk brook increased. Adapted from (11).*

The gentle weed clearance practice initiated in the initial phase of the experiment in 1981-82 was twice as expensive as the usual maintenance practice. The extra costs can be considered as "construction" costs. After the initial phase, gentle weed clearance was no more expensive than the hard-handed practice.

The efforts paid off

The number of trout increased in those places where gentle weed clearance was undertaken, gravel banks were established, fish hiding places set up and current concentrators constructed (Figure 1.29). The improvement was most marked in Spånbæk brook and Tøsbæk brook, where both restoration and gentle weed clearance were undertaken, and less marked in Voer Å stream. In Tøsbæk brook, the number of trout doubled from 1981 to 1982 near the weed borders, current concentrators and gravel banks. Moreover, there was a further increase in 1983. The trout populations of both Tøsbæk and Spånbæk brooks have now reached a size normal for good quality watercourses of their dimensions (see p 97).

Table 1.3 Increase in trout population associated with various restoration measures.

Stream name	Current concentrators	Weed borders
Spånbæk	4 - 7 x	3 - 5 x
Tøsbæk	7 - 8 x	4 - 5 x

In both Tøsbæk and Spånbæk brooks the trout population increased more near the current concentrators than near the places where gentle weed clearance was undertaken (Table 1.3). Nevertheless, it is gentle weed clearance that is largely responsible for the increased trout population, simply because there are many more weed banks than current concentrators. Gentle weed clearance is also a far cheaper means of improving conditions than actual restoration measures. For example, in 1981 a weed border of the same length as a current concentrator of stone cost approx. DKK 63 to establish in extra weed clearance costs, while the stone "border" cost approx. DKK 7,100.

A new Watercourse Act in 1982

The new Watercourse Act entered into force in 1982. The provisions concerning maintenance contain nothing decidedly new (Box 1.3). There are strict rules on how much the maintenance of watercourses may be changed. Moreover, maintenance shall be undertaken in such a way that drainage capacity is not lessened in comparison with "earlier" methods. What is decidedly new, however, is the objects clause (Box 1.4). In simple terms, this states that the quality objectives must be taken into account when watercourses are to be maintained. The new Watercourse Act also includes a section on restoration measures that watercourse authorities could use in public watercourses so affected by regulation and maintenance that their physical condition does not live up to their designated objectives. The Act gives a detailed description of what was understood by the term restoration at the time the Act entered into force (Box 1.5).

The restoration measures included are those that had proved satisfactory in the USA (Figure 1.30).

At present, however, there is considerable difference between restoration measures employed in the USA and in Denmark. While in Denmark the intention is to create habitats for trout in watercourses in which the population is less than normal, in the USA, restoration is often undertaken in natural watercourses in order to ensure a fish population greater than normal.

Box 1.3 *Some of the maintenance provisions of the new Watercourse Act.*

PART 7

Maintenance of watercourses

Common provisions for public and private watercourses

27.—(1) Watercourses shall be maintained in such a way that the individual watercourse's shape or water discharge capacity does not change.

(2) Waterweed growth in watercourses may be limited by mechanical methods such as weed cutting, unearthing, etc., or by biological methods such as establishing shady vegetation on the banks of the watercourse.

(3) Cut waterweeds shall be gathered unless the material is not detrimental to the watercourse or to the aquatic area that the watercourse discharges into.

(4) Sludge, waterweeds and other material that collects at weirs, dams or other hindrances must not be allowed to proceed onwards to the detriment of the watercourse or the aquatic area that the watercourse discharges into. The watercourse authorities can lay down more specific provisions concerning this.

Box 1.4 *Objects clause: The key to satisfactory watercourse quality.*

PART 1

Objective, etc.

1.—(1) The aim of this Act is to ensure that watercourses can be exploited for the drainage of water, especially surface runoff, waste water and drain water.

(2) The stipulation and implementation of measures in conformity with the Act shall be conducted with deference to stipulations concerning watercourse environmental quality laid down in other legislation.

Box 1.5 *Completely new: Provisions on watercourse restoration measures.*

PART 8

Restoration of watercourses

37.—(1) In the case of public watercourses whose condition does not fulfil the regional water quality targets, the watercourse authorities are empowered to improve conditions by means of the following measures:

(a) the establishment of artificial overhanging banks,

(b) the placement of large rocks,

(c) the placement of logs and the like on the watercourse bed,

(d) the establishment of current convergers and

(e) the establishment of spawning banks.

(2) The watercourse authorities defray the expenses of restoration.

(3) The Environmental Protection Agency can subsidise large restoration projects.

(4) Anyone sustaining a loss as a result of a restoration project has the right to compensation.

(5) The Minister for the Environment lays down more specific regulations concerning restoration projects, including regulations concerning the cooperation between water authorities and between watercourse authorities and other authorities, as well as on the involvement of the public.

Logs positioned on the bed and artificial overhanging banks are useful means of increasing the number of hiding places for trout. However, it is open to discussion whether they improve the aesthetic appearance of the watercourse.

Danish experience with restoration will be examined more closely in Chapters 3-5.

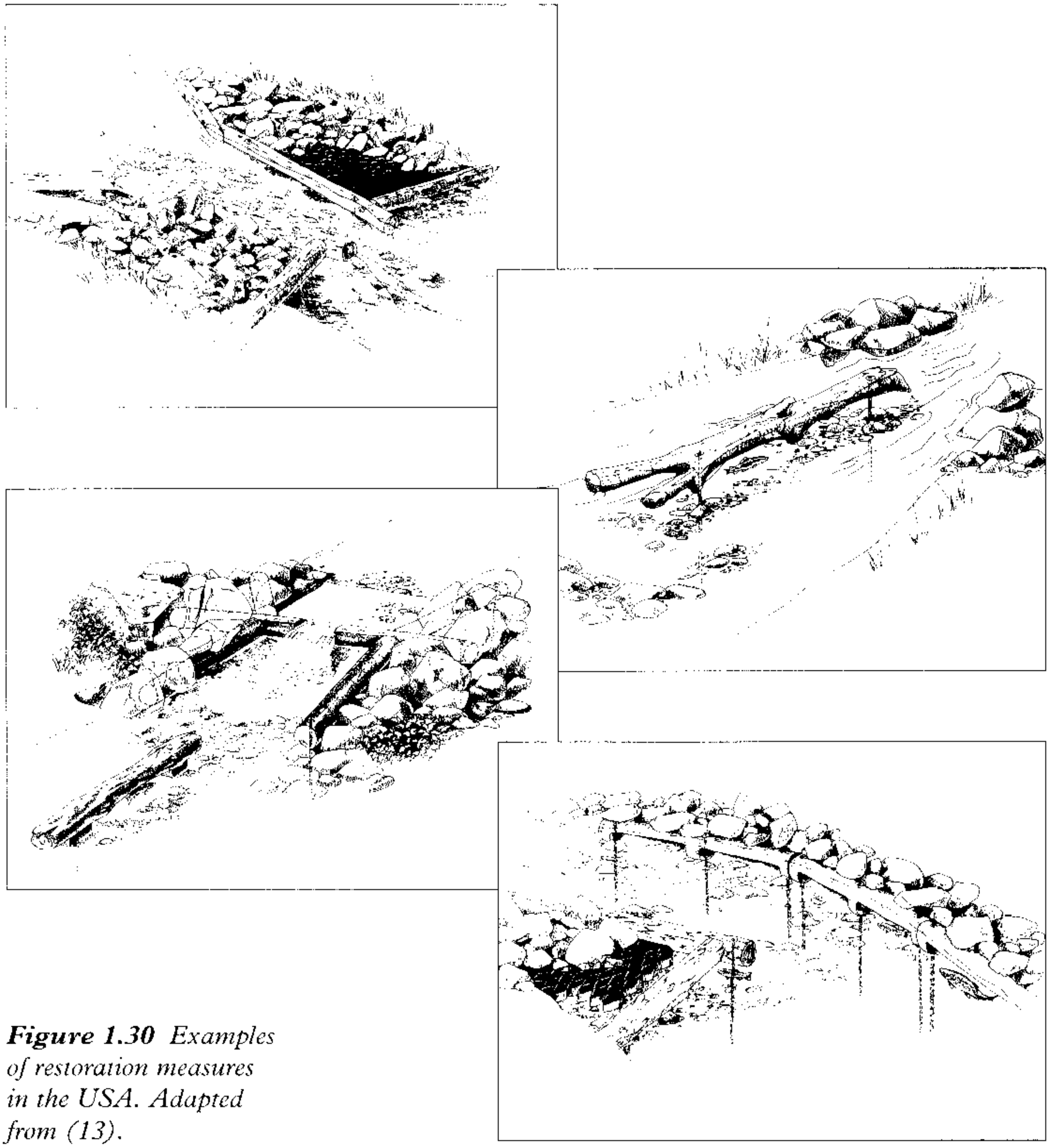


Figure 1.30 *Examples of restoration measures in the USA. Adapted from (13).*

Present maintenance practice

The drainage capacity of watercourses still has to be ensured by maintenance. However, good environmental conditions have also to be ensured for fish, invertebrates and plants. Thus watercourses now have to look quite different from those illustrated in the old guidelines. The river keeper now has to ensure both that the watercourses can efficiently drain away water, and at the same time ensure that their environmental condition is good.

The river keeper has been assigned new tasks. Whereas formerly all weed had to be cleared, including on the banks, some of it has now to be left in place. Watercourse maintenance is in the process of being replaced by watercourse care.

The uniform and "proper" condition of watercourses that resulted from earlier maintenance practice is in conflict with the forces of nature at work in the watercourses. The current does not run in a straight line, but twists and turns. The bed of a natural watercourse is not even and uniform. It continuously alternates between deep and shallow areas, and it is comprised of a changing pattern of sand, mud, gravel and stone.

The river keeper now has to work with the watercourse's own forces. He has to help it to find its own form. Formerly he had to work against the forces that tried to release the watercourse from the straightjacket placed on it by the Provisional Order. With the new possibilities, however, conditions that resemble those in natural watercourses can be recreated with relatively little effort. The result can be a healthy watercourse that is self-purifying and provides a good habitat for fish, invertebrates and plants.

It is often possible to undertake this work within the provisions of the old Provisional Orders. Since many of the watercourses are actually wider than they should be, it is possible to both narrow the watercourses and lay out stone and gravel banks without coming into conflict with their stipulated dimensions. Previously one had to comply with the stipulations on the profile's dimensions if the watercourse was too narrow and the bed too high. Compliance was achieved by widening and deepening the watercourse until it corresponded to the dimensions stipulated in the Provisional Order governing the watercourse, and often until it exceeded them. Now, the stipulated dimensions have also to be taken seriously if the watercourse is too wide and too deep, i.e. the maintenance work has to be restricted to within the limits stipulated in the Provisional Order.

Gentle maintenance practice transforms the watercourses. Table 2.2 shows that the trout population increased in the watercourses of Vejen Municipality following the introduction of gentle maintenance practice.

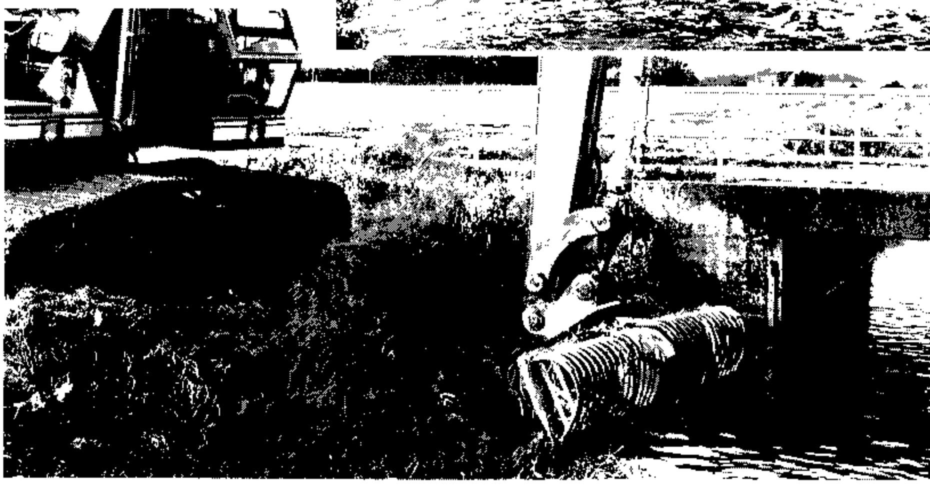
The good results attained by Nordjylland County with gentle maintenance practice in the Voer Å stream system have also had an impact on other of the county's watercourses where weed clearance practice comprises clearing current channels. In Simested Å stream there were 2-3 trout per 100 m^2 when hard-handed maintenance was undertaken. Following the introduction of gentle weed clearance, up to 22 trout per 100 m^2 can be found. In Skibsted-Lyngby Å stream the effect was similar, the number of trout increasing from 2-3 per 100 m^2 under hard-handed maintenance to 19-33 per m^2 after the introduction of gentle weed clearance. The majority of these trout are probably derived from stocking operations. However, a precondition for the survival of stocked trout is the presence of good hiding places. No matter whether the trout are derived from stocking or are natural inhabitants of the watercourse, gentle weed clearance is a decisive determinant of how many fish there is room for.

Chapter 6 presents further examples illustrating that the environmental condition of watercourses is starting to improve. Among other means, this can be measured from the number of trout now present in the watercourses, trout being a good indicator of whether environmental conditions are satisfactory.

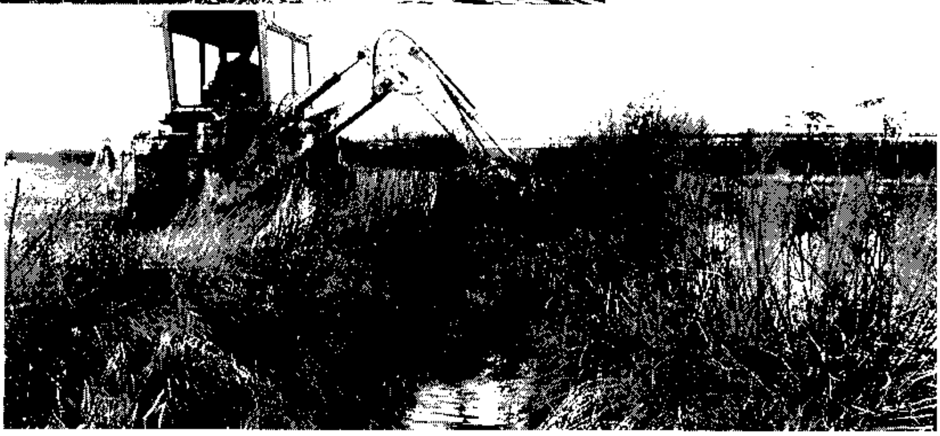
The next chapter discusses how to maintain watercourses in a manner that ensures their drainage capacity while at the same time ensuring good environmental conditions.

Clearing weed using a scythe

Clearing weed using a floating reaper



Clearing weed using a basket reaper



Dredging a watercourse

2. New ways of maintaining watercourses

The investigations in Voer Å stream and its tributaries showed that gentle weed clearance resulted in marked improvements in the watercourses. Good results were obtained at little cost. That gentle maintenance is a good means of attaining good watercourse quality has also been learned in other parts of the country. Many of the watercourses had been maintained so thoroughly that their cross-sectional profile was greater than stipulated in the Provisional Orders. It was therefore often possible to implement more gentle maintenance without coming into conflict with the Provisional Orders, there being room to lay stones, gravel beds and weed borders in the "excess" part of the profile.

In many places watercourse authorities and landowners have come to the realization that it is sufficient to clear weed in a current channel that is perhaps just half the width of the watercourse. This is sufficient to ensure free water flow. Dredging often becomes unnecessary because not as much material is eroded from the banks and bed as when all the weed is cleared. In addition, the strong current flushes away the sand and mud as soon as it is deposited.

When a current channel is cleared through the weed, the watercourse profile gradually becomes smaller because the weed borders gradually merge with the banks. In this chapter, examples are presented where the current channel method of weed clearance has transformed broad, channelized slowly flowing watercourses to narrow, winding watercourses with a strong current within the space of two or three years.

Gentle maintenance has made many watercourses better habitats for animals and plants. Physical conditions have improved and this is also of significance for the evaluation of their pollutional state. The self-purification process becomes more effective in these watercourses, and the presence of better habitats for invertebrates often upgrades the watercourses to a higher "class" when their pollutional state is evaluated.

Dredging can destroy habitats

In 1981, Ribe County investigated what impact hard-handed maintenance can have on the trout population of a brook.

The County investigated the trout population in Stårup Bæk brook, a small tributary of Sneum Å stream (1). The brook is channelized and dredging was undertaken at intervals. However, a reach of the brook was starting to revert to a more natural form because maintenance had been rather relaxed for some years. In this reach the brook had been allowed to develop a more narrow course alternating between deep and shallow parts. In September 1981 the trout were counted and weighed. Thereafter the trout were also counted and weighed in a downstream reach that because of regular maintenance was uniform, wide and shallow.

There was a considerable difference between the trout population in the two reaches. In the upper reach, where there were numerous hiding places, the population was extremely good, with up to 360 trout per 100 m². In the lower reach, however, the trout population was only one fifth of that in a corresponding length of the upper reach. The trout in the lower reach were smaller than in the upper reach, and the total weight of the trout was eight times less (Figure 2.1).

In October 1981, the upper reach with its many good hiding places was dredged with the same thoroughness as was nor-

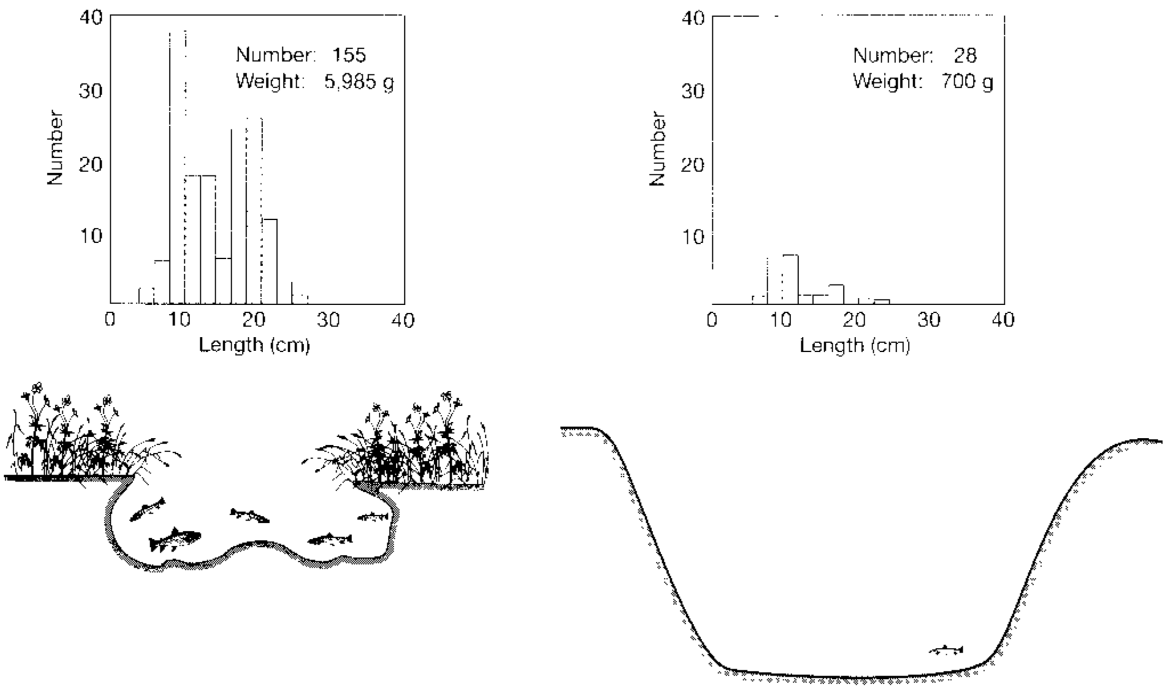


Figure 2.1 *There are more and larger trout in that part of Stårup Bæk brook in which physical conditions are best.*

mal in the lower reach. The weed borders, overhanging banks and bank vegetation disappeared. So did the majority of the trout.

In the lower reach, in contrast, the number of trout was greater than before. They had undoubtedly swum down from the upper reach after their hiding places had disappeared. Discharge was greater in October than in September, when the first study was undertaken. The lower reach of the brook was therefore deeper than during the September study. The greater water depth provided the trout with better hiding places than previously (Figure 2.2).

Figure 2.2 *The number of trout is greatest in that part of Stårup Bæk brook that is deepest.*

Better watercourses with gentle maintenance

The studies in Stårup Bæk brook showed that good hiding places and a good water depth in the watercourses are important factors if one wants to have a good trout population. Hard-handed maintenance can destroy that. The studies were the start of changed maintenance practice in many of Ribe County's watercourses. They began with gentle weed clearance in streams where there were no major drainage problems with the adjoining fields, e.g. watercourses that pass through meadows that are no longer cultivated.

Experience with gentle maintenance has influenced the new Provisional Orders that have been drawn up by Ribe County (2): The main feature is that it is important to evaluate conditions in the individual watercourses. One shall not attempt to give the watercourse a specific form or path as with the former watercourse maintenance practice. Instead, one should allow the watercourse to develop according to its own forces. It is generally sufficient to clear a current channel of 60-70% of the watercourse's width, and undertake weed clearance at two to three fixed intervals. One normally cuts the weed right back in the current channel. If a natural current channel that weed clearance can follow is lacking, one clears a pattern that

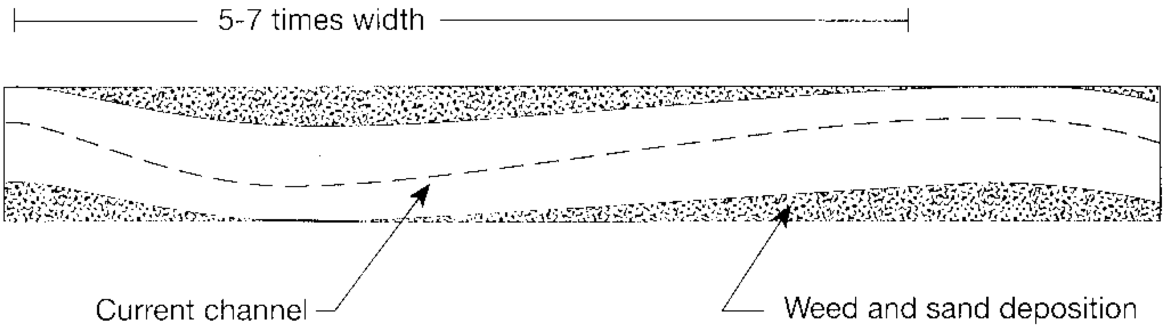


Figure 2.3 *An example of how one can clear a meandering current channel in a straight watercourse.*

corresponds to that shown in Figure 2.3. The wavelength of the current channel meanders should be 10-14 times the width of the watercourse, this being the path that flowing water normally follows.

How much weed should be cleared?

In 1982, Sønderjylland County undertook a number of studies of weed clearance in Surbæk brook, a small tributary of Arnå stream (3). The idea was to investigate whether the water could drain away effectively if a current channel was cleared through the weed instead of the weed being cleared away completely.

During the course of the studies frequent measurements were made of the discharge and water level. The water level was measured using graduated markers positioned in the brook at a fixed height above the watercourse bed relative to Danish Zero Level. It was important to investigate whether the current channel was good enough at draining the water effectively away that the water level did not rise so much that the fields adjoining Surbæk brook became wet.

There are two factors that determine the water depth in a watercourse. One is the amount of weed in the watercourse. The weed hinders the free flow of water and the more weed there is at a given discharge, the higher the water level will be (Figure 2.4).

The second factor is the amount of water that flows through the watercourse. The greater the discharge with a given amount of weed, the higher will be the water level in the watercourse (Figure 2.5).

Under the conditions that normally pertain in watercourses it is both the amount of weed and the discharge that are chan-

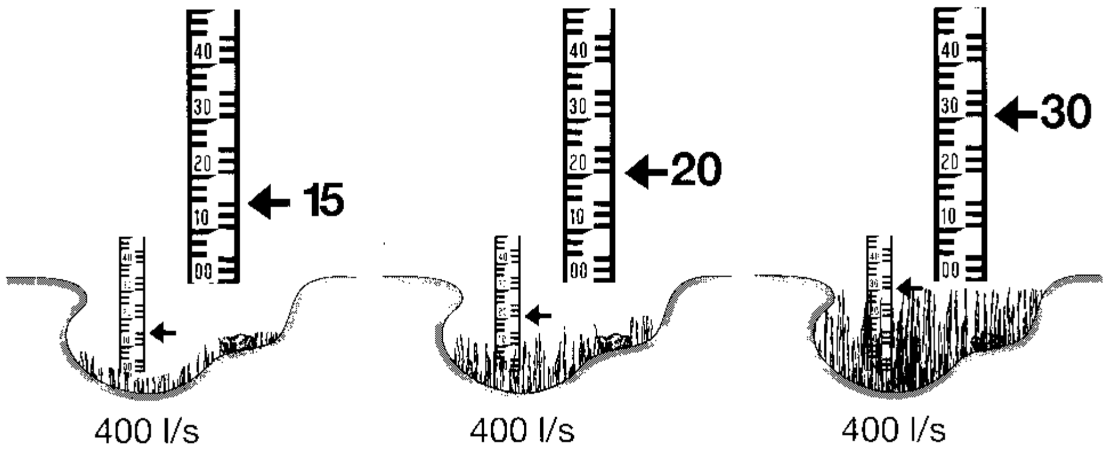


Figure 2.4 *Equal discharge: The greater the amount of weed, the higher the water level.*

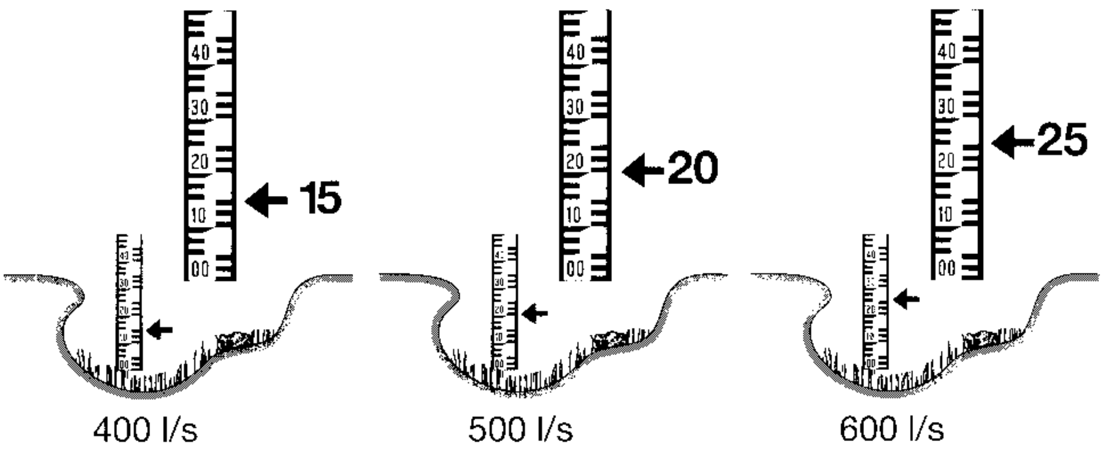


Figure 2.5 *Equal amount of weed: The higher the discharge, the higher the water level.*

ged. The water level in the watercourses is therefore determined by a combination of the two factors.

When one wants to investigate the impact of weed on the water level one has to undertake all measurements at exactly the same discharge. Otherwise one cannot tell whether an increase in water level is due to an increase in the amount of water or to an increase in the amount of weed, which hinders the free flow of the water. One cannot decide what the discharge will be. However, one can extrapolate the water level such that it corresponds to what it would have been if discharge in the watercourse had been at a specified rate.

In the Surbæk brook studies all water levels were extrapolated to a discharge of 400 litre/sec. This is called the "calibration" water level. It is this level that is used to calculate or adjust the discharge capacity of the watercourse.

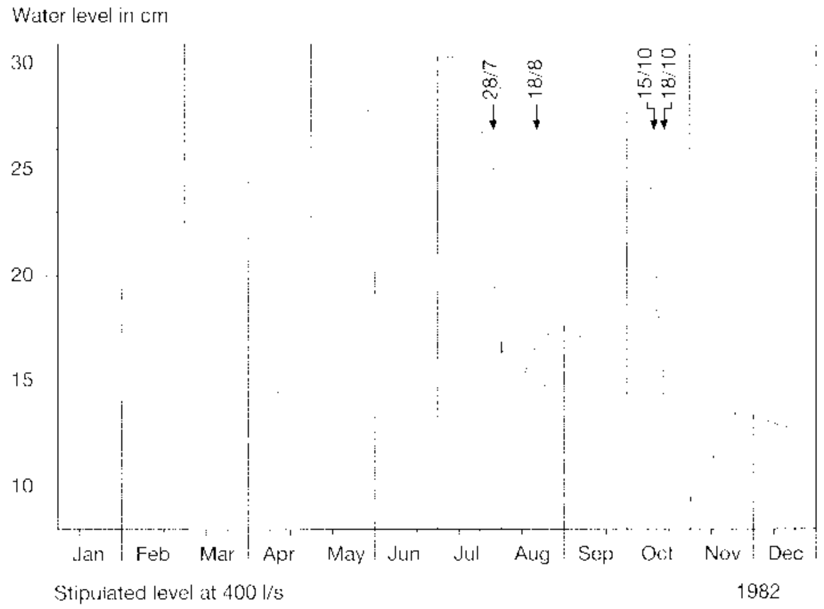


Figure 2.6 *The calibration water level in Surbæk brook at a discharge of 400 litre/sec. The arrows indicate weed clearance. The water level is extrapolated from the actual water level measured relative to Danish Zero Level using graduated water level markers fixed in the brook.*

The calibration water level in Surbæk brook at a discharge of 400 litre/sec is shown in Figure 2.6. The level shown is not that measured, but the level the water would have had if discharge had been constant at 400 litre/sec. The increase and decrease in the calibration water level is alone determined by how much resistance the water meets while flowing through the watercourse.

In the Surbæk brook studies weed was cleared in three different ways (Figure 2.7). On 28 July, a 1.5 m wide current channel was cleared corresponding to one third of the width of the brook. Figure 2.6 shows the water level that there would have been in the brook if discharge had been 400 litre/sec. The water level had been very high before weed clearance was undertaken, but had started to recede as the weed (water crowfoot) had flowered and was starting to wither. From Figure 2.6 it can be seen that clearing a current channel corresponding to one third of the brook's width causes the water level to fall to approx. 14 cm on the graduated marker. The water level then increases again because the weed (water crowfoot) grows up again. When a 3 m wide current channel was cleared of weed on 18 August, the water level fell to approx. 13 cm on the marker. This is less than 1 cm lower than when the narrow current channel was cleared, and a doubling of the width of the current channel only resulted in an insignificant improvement in discharge capacity. The small current channel thus appears to be sufficient to allow the water to flow freely. Final weed clearance was undertaken in October, at which time the weed was cleared across the whole width of the brook. The water level fell to just under 10 cm on the graduated marker, but soon returned to the same level as with a 3 m current channel.

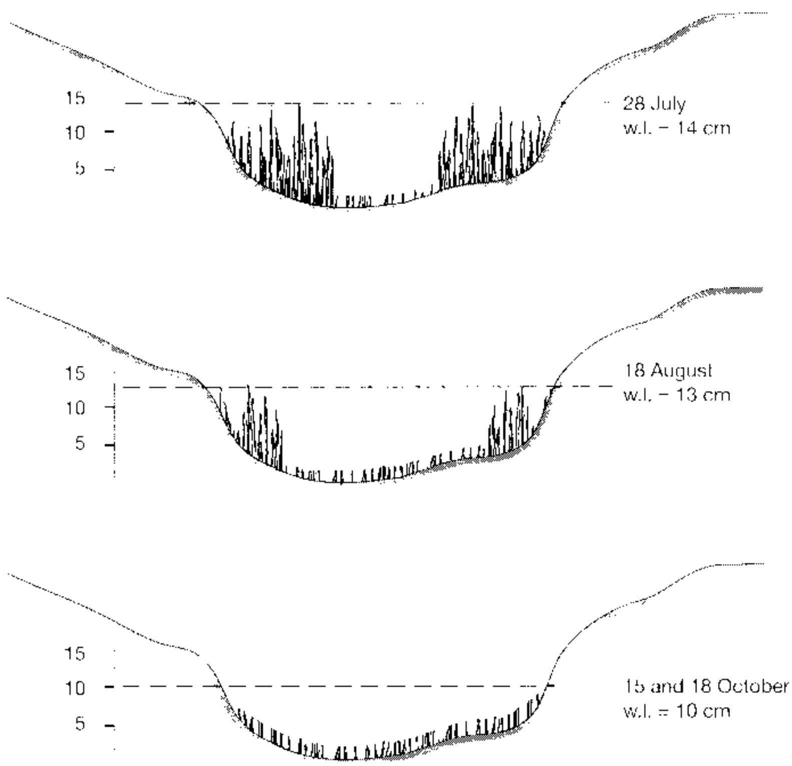


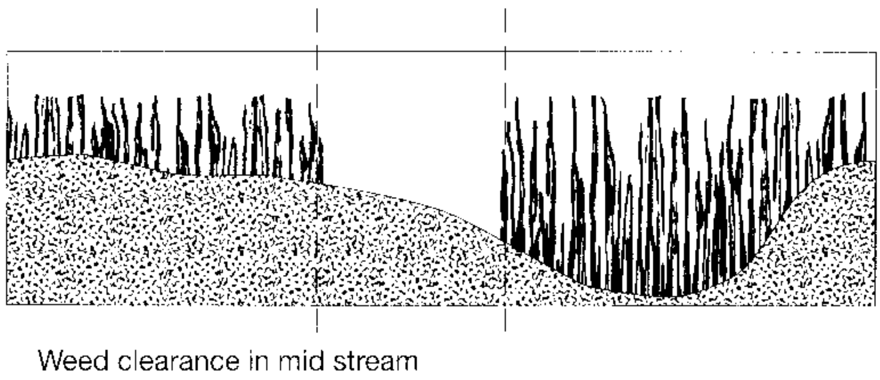
Figure 2.7 *The weed in Surbæk brook was cleared in three different ways.*

Good flow in the current channel

Clearing a narrow current channel through the weed in Surbæk brook significantly improved discharge capacity and reduced the water level so much that problems did not arise with water in the adjoining fields. A doubling of the width of the current channel from one third to two thirds of the width of the brook resulted in little further improvement in discharge capacity, and a correspondingly small extra fall in the water level. As in most other watercourses, the weed in Surbæk brook had hitherto been completely cleared by fixed deadlines.

The lesson learned from the studies was that weed clearance can instead be undertaken when it is necessary. This corresponds to what one does when one clears roads of snow in the winter: one clears the snow when it is necessary. By holding an eye on the watercourse's discharge capacity one can initiate weed clearance before the water level becomes so high as to damage the fields. At Surbæk brook, for example, one can initiate weed clearance when the water level approaches 25 cm at a discharge of 400 litres/sec. That is a water level that can threaten the fields. Figure 2.6 shows that from 15 May, the brook has insufficient discharge capacity to safeguard against such a high water level. In order to ensure a satisfactory discharge capacity it is therefore necessary to clear a current channel at the end of the first week in May.

It is important that the current channel one clears through the weed follows the natural current channel, i.e. the deepest part of the watercourse. This gives the most effective drainage of water (Figure 2.8). It is not enough just to clear a channel mid stream.



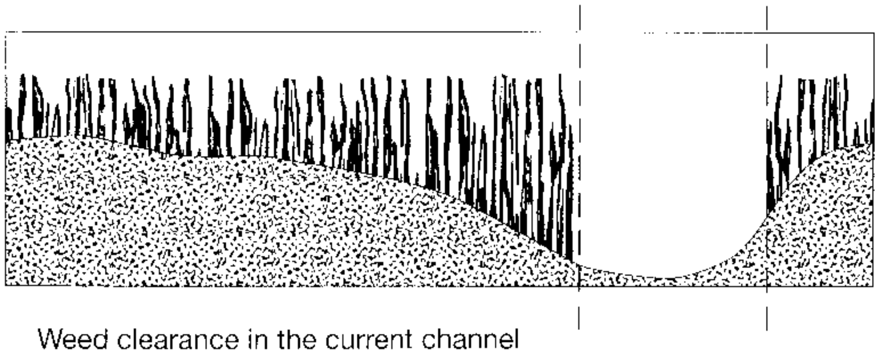


Figure 2.8 *The current channel should follow the deepest part of the watercourse, which is not always mid stream. Adapted from (4).*

The studies in Surbæk brook were the start of gentle weed clearance practice by Sønderjylland County.

Other studies of the current channel method of weed clearance have since been undertaken. In the 2 m wide Herredsbæk brook in Himmerland (5), studies have been undertaken of the effectiveness of current channels cleared through a weed growth of bur reed. It was found that a current channel of only a quarter of the width of the brook was sufficient to ensure a fall in water level equivalent to 50% of the maximum attainable upon complete clearance of the weed.

Weed in the current channel

In watercourses in which an actual current channel has not been cleared, the majority of the water tends to run in a current channel that meanders from side to side. In towards the sides, where the water is shallow, resistance against the flow of water is greater than in the deeper parts. Only a minor fraction of the water runs close to the sides.

Water flow in the current channel is good even if there is weed growing in it. The resistance against water flow afforded by weed is less in a deep current channel than in a wide and shallow watercourse, even if weed density is equal in the two.

The more weed that fills the watercourse cross-sectional profile, the greater the resistance to the flow of water. This applies primarily to watercourses that are wide and shallow. The long leaves of bur reed are particularly good at hindering the flow of water in such watercourses. In contrast, if these same leaves are present in a narrow deep current channel they have a different effect on water flow. The resistance they afford becomes less. When discharge (and hence the current) increases, the resistance afforded by the bur reed leaves falls. The current presses the leaves down against the bed such that the water can flow freely over them (Figure 2.9). In a deep current channel lined with bur reed the discharge capacity can increase when the current becomes stronger (6).

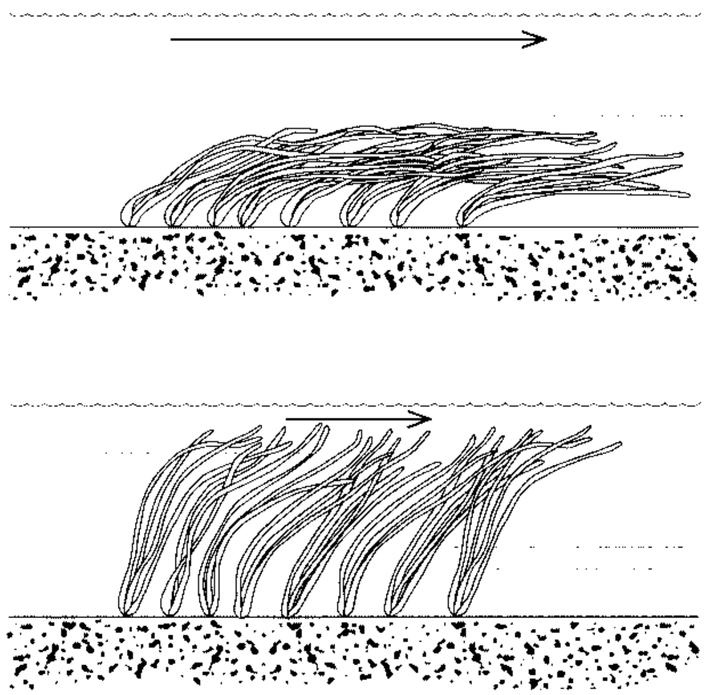


Figure 2.9 *In the current channel bur reed leaves will be pressed down against the bed when the current increases. As a result, they afford less resistance to water flow.*

This is one of the reasons why water flow problems are so rare when weeds are cleared to form a current channel.

There is one further reason why a deep current channel can have a good discharge capacity even if there is weed in it. Some weed species grow differently in a deep current channel than in a broad shallow watercourse. This applies to plants such as the water crowfoot. In the wide, shallow watercourse their finely branched crowns fill almost the complete cross-sectional profile of the watercourse. In the deep narrow watercourse, in contrast, the branched crowns lie near the surface, and are fastened to the bed by long thin stems that occupy little of the watercourse's cross-sectional profile. Below the crowns there is therefore only a small amount of weed to hinder the flow of water (Figure 2.10).

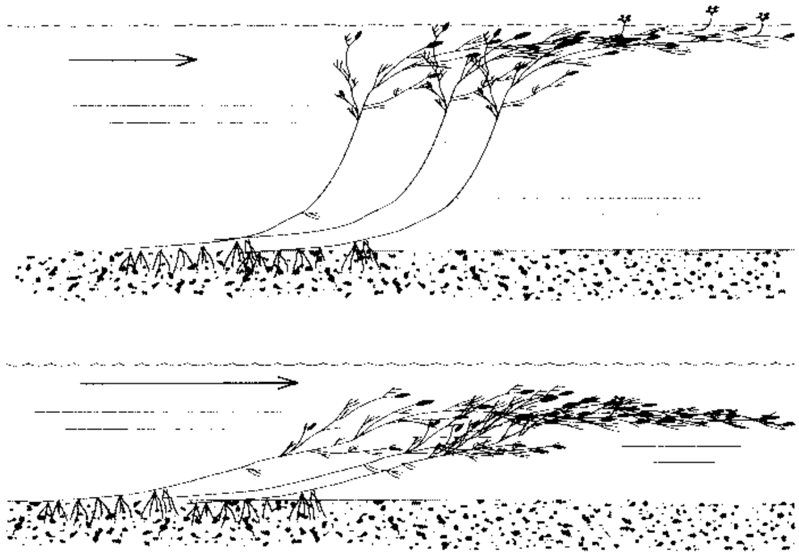


Figure 2.10 *In deep watercourses the majority of the water crowfoot plant is near the surface. Lower down there are only the thin stems to afford resistance, and it is here that the majority of the water flows.*

Several types of weed

In the Surbæk brook studies it was seen that the calibration water level had already started to fall when clearance of the water crowfoot plants was initiated in the early summer. It was also seen that the water crowfoot rapidly grew again such that the water level rose once more.

Since the Surbæk brook studies, Sønderjylland County has investigated when best to undertake weed clearance (7). Two main types of weed were studied: water crowfoot and bur reed. Both are among the most common plants in watercourses, and they can form such dense growths that the water has difficulty in flowing away.

The water crowfoot can be one of the useful watercourse plants, especially when it is present as isolated beds. It is a good habitat for watercourse invertebrates and provides good hiding places for fish. In these beds the fauna can be diverse. If the beds are not too close to each other, a good current channel can form between them.

Silkeborg Municipality has good experience of re-establishing water crowfoot in watercourses. A clump of the plants is set out held in place by a stone. Before long the plants root, and within 3-4 years the plant has spread several kilometres downstream.

Bur reed is one of the watercourse plants that can cause serious problems, both with respect to flow, the bed and the flora and fauna. The leaves are a poor habitat except for a few invertebrates that can affix themselves to the leaves, e.g. the larvae of the buffalo gnat. They can be present in very great numbers. The fauna inhabiting the plant is very uniform. When bur reed occurs very densely, the current is weak near the bed and mud is deposited. The plants thrive in such a bed, while the water crowfoot prefers a gravel bed. Water crowfoot plants growing downstream of bur reed are sheltered from the current and mud therefore deposits around them. As they thrive badly under such conditions, they can be driven out by bur reed (Figure 2.11).

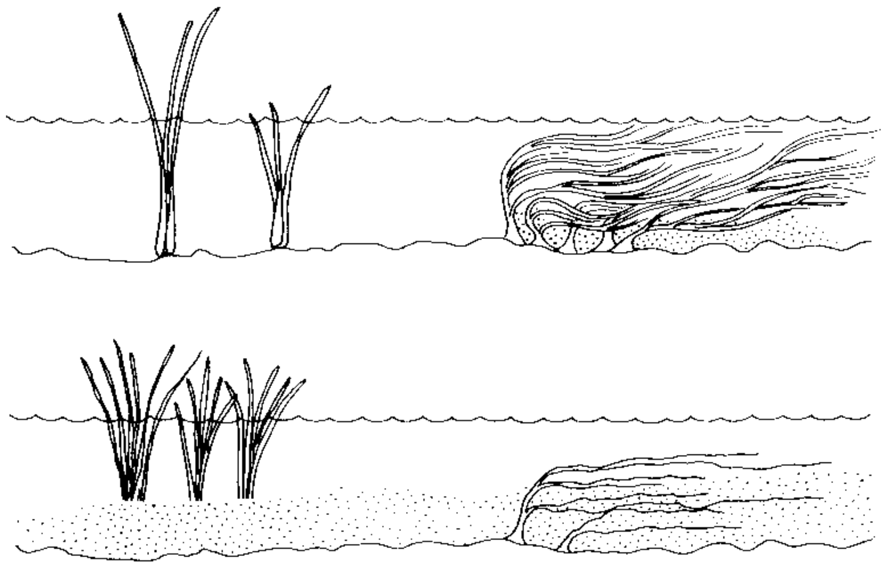


Figure 2.11 *Bur reed thrives on a muddy bed. It can drive water crowfoot out because it causes mud to accumulate. Adapted from (8).*

When should the weed be cleared?

The study by Sønderjylland County (7) showed that water crowfoot grows very rapidly in the spring, when there is plenty of light and the water becomes warmer. It begins to wither early in the summer, though, after it has flowered. If one just leaves the weed alone at that time, the current itself will thin out the older parts of the plant; however, if one instead starts to clear the weed early in the summer, light will be able to penetrate to the lower parts and they will spring to life again, thereby rapidly filling up the watercourse again. It grows well because there is much light and the water is warm.

It is best to clear water crowfoot as late in the summer as possible. Clearing the weed too early just helps it to grow, or provides bur reed with the chance to take over because light reaches the small shoots.

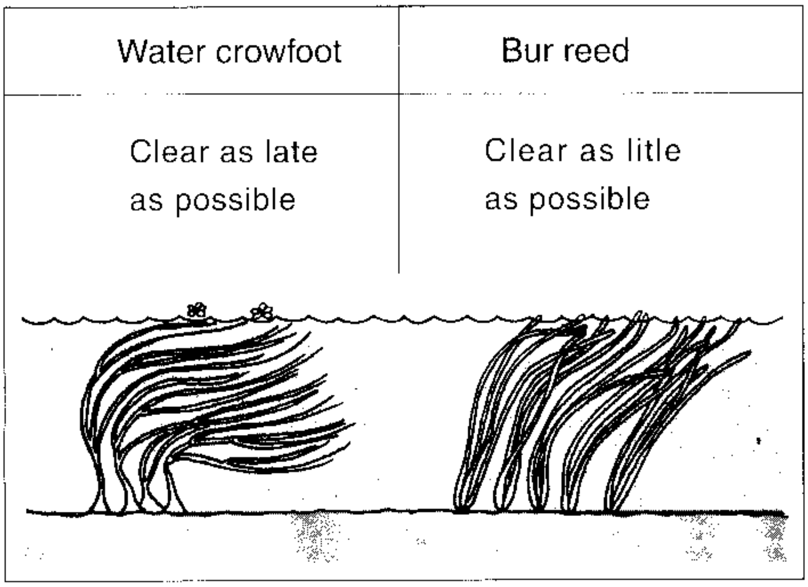


Figure 2.12 *Water crowfoot should be cleared as late as possible while bur reed should be cleared as little as possible.*

Bur reed grows throughout the summer if there is sufficient light. There is always a fresh supply of small shoots waiting to grow up from the foot of the plants. When the leaves are cleared at any time during light periods of the year, the new shoots rapidly grow because light reaches them. If, however, one refrains from clearing or only undertakes what clearance is essential, then there is usually so much shade at the foot of the plants that the small shoots cannot grow.

The studies showed that the most serious problems with weed occurred in watercourses that were channelized and in which the weed was cleared frequently. The fewest problems occurred in those watercourses that were left untouched as much as possible. Frequent weed clearance promotes plants such as bur reed at the expense of other plants.

When planning weed clearance it is important to understand how the various species react to clearance.

Care of the current channel

The current channels that have now been formed in many of our watercourses have made these narrower and deeper, and have given them a meandering or rather a winding path.

When a current channel is first made, weed remains along the sides of the watercourse. This provides good habitats for fish and invertebrates. However, the weed borders gradually become overgrown and merge with the banks such that what started as weed borders becomes part of the land adjoining the watercourse (Figure 2.13).

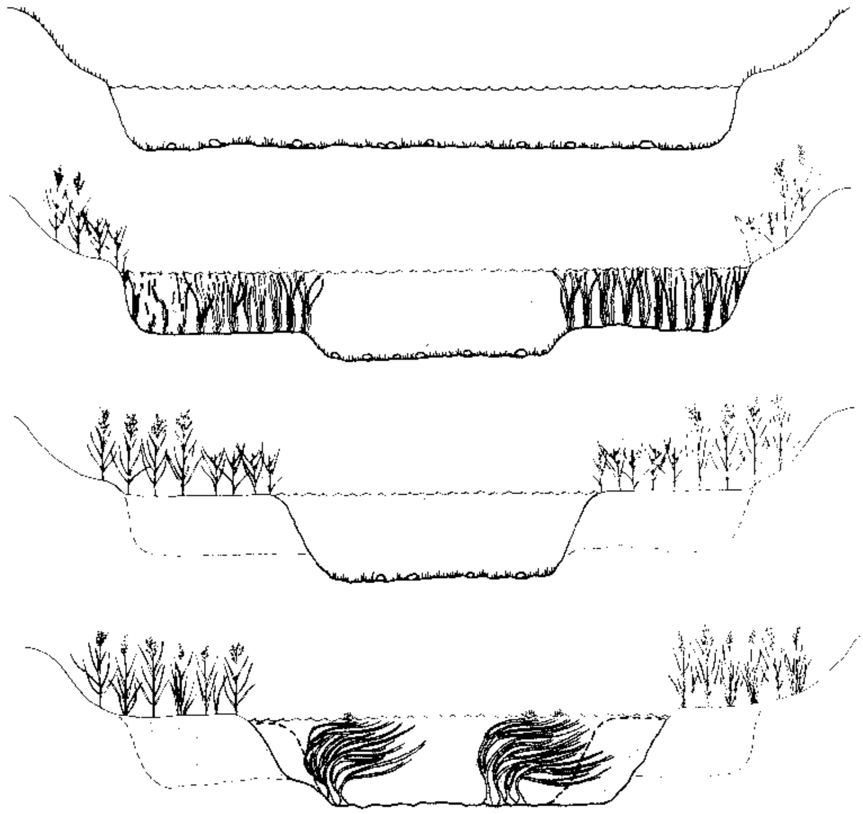


Figure 2.13 *Transformation of a watercourse from one that is wide and managed in a hard-handed manner to one with a narrow current channel with room for weed beds in the channel.*

The current channel ends up being the new watercourse. It has both to ensure an adequate discharge capacity and provide a good habitat for fish, plants and invertebrates. It is therefore important to clear the weed in the current channel so that sufficient water can flow through. If the current channel is narrow, however, the channel might just be a bare canal after the necessary weed clearance has been undertaken, thereby bringing us back to the situation under the former maintenance practice, i.e. the canal would be smaller than before, but just as bare and devoid of habitats for invertebrates and fish.

It is therefore necessary to maintain or care for the current channel in such a way that it does not become so narrow that there is no room for weed to grow in it. Some weed species, especially watercress and bur reed, can rapidly spread in from the sides. Maintenance therefore switches from keeping the current channel free of weed to keeping it so wide that there is room for weed to grow in it. In the current there needs to be room for those fish and invertebrates that require a fast current and oxygen-rich water.

In sufficiently wide current channels, the weed can be cleared in a reticulate fashion (9) or such that it occurs as an array of islands. The current channel will then be a network of small current channels in between the weed islands.

Gentle weed clearance

The aim of gentle weed clearance is to create better habitats for fish and invertebrates, and to have a watercourse that is to a certain extent able to maintain itself.

One of the methods of undertaking gentle weed clearance is to clear a current channel through the weed. This improves the current and the bed from the point of view of the requirements of the fauna, and the weed borders left along the sides of the watercourse provide good habitats. The method also increases the self-purification capacity of the watercourse and protects the banks against the current.

The experience so far gained indicates that drainage is adequate in watercourses in which weed clearance is restricted to a current channel.

In the following a number of examples will be presented of how Counties and Municipalities have undertaken gentle weed clearance under different conditions. A common feature is that the watercourses have become narrower with more natural conditions. However, in order to create a good habitat for fish and invertebrates it is not sufficient just to reduce a watercourse's width - there have also to be good habitats in the watercourse. It is therefore necessary to plan weed clearance such that there is also room for weed in the current channel.

A watercourse between cultivated fields

Bjerge Å stream in Vestsjælland County runs through an area where the fields are cultivated right to the edge of the watercourse, or more correctly to a distance of 2 m from the watercourse. A new Provisional Order has been drawn up that requires Bjerge Å stream to meet a specified discharge capacity (10). This is measured with the aid of graduated water level markers erected at 3 different locations along the course of the stream. In addition, the water level is measured at a further 7 water level markers where for a given water level, discharge should meet a specified minimum rate.

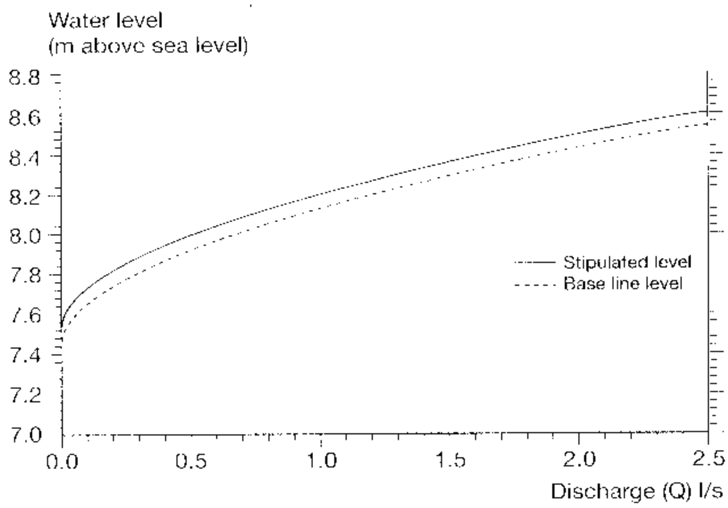


Figure 2.14 *Q/H graph showing the water level at various discharge rates. The baseline level is the situation when the watercourse is devoid of weed. The stipulated level is that stipulated in the Provisional Order for Bjerge Å stream.*

The discharge capacity of Bjerge Å stream has to be checked during the winter period from 15 October to 30 April. The water level at a given discharge rate must not exceed the value stipulated in a Q/H graph for the watercourse (Figure 2.14). If the water level exceeds the stipulated level, weed remains have to be removed or the stream has to be dredged of any sand and mud that has washed into the stream. However, the Provisional Order stipulates that gravel and stone beds must not be touched. Dredging is only allowed from 1 August to 15 October, the latter date being chosen because this is when the eel start to hibernate in the mud and the trout start to lay their eggs in the gravel spawning grounds - otherwise the sand and mud that is whirled up by dredging could destroy the spawning grounds (see Chapter 3).

In the summer period a meandering current channel is to be cleared through the weed in Bjerge Å stream. The current channel has to meet specified dimensions in the various parts of the watercourse (Table 2.1).

Table 2.1 *Stipulated current channel in the various reaches of Bjerge Å stream.*

Reach (m)	Current channel (m)
0-1,125	2.8 - 3.2
1,125 - 2,660	2.4 - 2.6
2,640 - 3,940	1.8 - 2.0
3,940 - 5,230	1.9 - 2.2
5,230 - 6,145	2.2 - 2.4
6,145 - 7,495	1.2 - 1.4
7,495 - 8,215	1.9 - 2.2

The water level is checked using the graduated water level markers. If the stipulated "normal maximum water level" is exceeded, the landowner can request that extraordinary weed clearance be undertaken. Whether or not this will be undertaken depends on the County's evaluation of the cause of the high water level. The latter could be due to excessive discharge, excessive deposition on the bed or too much weed.

A watercourse between uncultivated meadows

Holtum Å stream in Ringkjøbing County is surrounded by meadows that are no longer cultivated. There is therefore no need to maintain the watercourse for agricultural reasons. However, maintenance can be desirable for other reasons, e.g. if the watercourse is not to become completely overgrown. Ringkjøbing County decided to maintain the stream in such a way as to ensure that its physical condition is in accordance with the quality objective stipulated for it, i.e. that trout can inhabit it (11). A 3-4 m wide meandering current channel is cleared through the weed, this being much narrower than the width stipulated in the former Provisional Order (Figure 2.15).

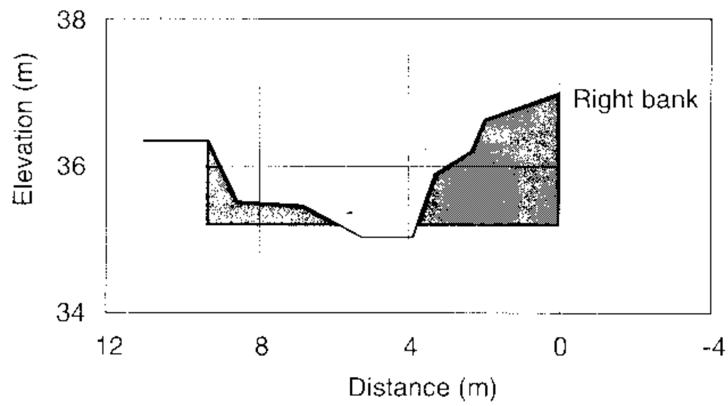


Figure 2.15 *Holtum Å stream is now narrower than when the weed was cleared in accordance with the former Provisional Order.*

According to the new provisions, removal of the fish hiding places present in the stream should as far as possible be avoided. This applies, for example, to the overhanging banks and weed beds. Bank vegetation should also be left in place unless it grows in over the current channel.

The provisional Order governing Holtum Å stream is an example of current management of a watercourse that is no longer of great interest from the point of view of agricultural drainage.

New maintenance practices in municipal watercourses

From the beginning of the 1980s it was the Counties who showed greatest interest in the new ideas on environmentally sound watercourse maintenance. However, some of the Municipalities also showed an early interest in the new ideas in the new Watercourse Act. One of these was Nørager Municipality (12), which is responsible for the upper reaches of some of the large Himmerland watercourses, e.g. Sønderup Å stream, Lerkenfelt Å stream, Simested Å stream and Lindenborg Å stream. Some of them had been maintained in such a hard-handed manner that they had become 2 m wide where the natural width was 0.5 m. Moreover, a month or two after weed clearance had been undertaken, the weed had regrown to its former density.

In 1983 the Municipality selected 30 km of watercourse for a trial of the new environmentally sound methods. The watercourses were to be dredged and the weed cleared by hand, and the bank vegetation was to be left in place. Weed clearance was to be undertaken when necessary, which could mean undertaking clearance several times more than previously. The watercourses were narrowed in to increase the current. There was very close contact with the landowners who generally viewed the new methods positively. After the two-year trial period in 1985, it was ascertained that environmental conditions had improved in many places in the watercourses. Moreover, there had not been serious problems with water flow. In one case accumulation of water was simply solved by raking the weed aside so that the water could drain freely away in a current channel.

A new watercourse in three years

A few years ago Skiveren stream in Thisted Municipality resembled most other small watercourses that had been maintained in a hard-handed manner using machines. It was 3.5 m wide - much wider than stipulated in the Provisional Order. The environmental conditions were accordingly poor: A weak current, a uniform bed and poor habitats for fish and invertebrates.

In 1987, a start was made on only clearing part of the weed in the watercourse, namely in a current channel. By 1990 the watercourse had already become 2 m narrower and with a winding current channel (Figure 2.16) (13). The water depth had increased, the current had become stronger and the bed more varied. Discharge capacity had not diminished, but it was necessary to clear weed more frequently than before - four times annually as compared with twice annually. Otherwise the current channel would become completely overgrown. All in all the new weed clearance practice was somewhat more costly than the former practice because weed clearance has to be undertaken more frequently.

Figure 2.16 *Skiveren stream in Thisted Municipality was transformed between 1987 (upper left) and 1990 (lower right) by switching to the current channel method of weed clearance. Photographs by Frank Eliasson.*

More pleasant watercourses with more fish

In 1989 Vejen Municipality passed a supplementary Provisional Order, the aim of which was to ensure that its watercourses were managed in such a way that they could meet the requirements of the quality objectives (Box 2.1). A main feature is that some of the watercourses are to be gently maintained by clearing a current channel through the weed and leaving the bank vegetation intact.

As early as 1986, trials had been undertaken with more environmentally sound maintenance in the high quality objective watercourses; the results of this became apparent in several ways. A series of photographs of Tranekær Bæk brook is shown in Figure 2.17 (14). As with Skiveren stream in Thisted Municipality, Tranekær Bæk brook was transformed within the space of a few years from a uniform canal to a winding brook. The brook had been a broad straight canal until 1988, when gentle maintenance was introduced. The width of the watercourse bed has been halved and whereas the bed was formerly only of mud, there are now several parts with a gravel bed.

The endeavours of Vejen Municipality have also shown result in another way. The trout population in the watercourses is monitored by Ribe County. After environmentally sound maintenance of the watercourses was introduced there has been a clear improvement in the trout population, not only in Tranekær Bæk brook, but also in other watercourses (Table 2.2). In 1981-83, before gentle maintenance was introduced, there was a good trout population at 27% of the locations investigated in the watercourses. In 1988-90, by which time gentle maintenance had been practised for some years, there was a good trout population at 66% of the locations investigated (15). What is understood by a good trout population is explained in Chapter 3.

Table 2.2 *After gentle maintenance had been practised for some years in Vejen Municipality, there was a good trout population at more than twice as many locations as previously.*

	1981-83		1985-87		1988-90	
	Good trout stock	Small or no trout stock	Good trout stock	Small or no trout stock	Good trout stock	Small or no trout stock
No. of stations	8	20	19	16	21	14
%	27	73	54	46	66	34

Figure 2.17 *Tranekær Bæk brook in Vejen Municipality was transformed into a narrow winding current channel from 1986 (upper) to 1990 (lower). Photographs by Laila Nielsen.*

Box 2.1 *Watercourse maintenance principles stipulated by Vejen Municipality.*

Maintenance categories

Category I

1. If possible no real maintenance should be undertaken. The watercourse reaches should be checked over at least once a year for the removal of any items that obstruct the free flow of water, e.g. fallen branches, toppled trees, etc.

2. This form of maintenance should primarily be applied in the case of "A" watercourses, i.e. watercourses where the quality objective is an area of special scientific interest.

Category II

1. The weed is cleared close to the bed in the watercourse's natural current channel and in a width sufficient to ensure that the stipulated discharge capacity is met.

As far as possible the weed should not be cleared near the banks of the watercourse, and as far as possible the current channel is to be cleared in a meandering fashion.

2. The weed borders outside the current channel must not be cleared or removed unless they hinder free flow into the watercourse from drains, other pipes or open ditches.

3. In places where the actual dimensions of the watercourse are greater than the stipulated dimensions, and where this ensures a greater discharge capacity than provided for, the weed is only to be cleared in a current channel that corresponds to the stipulated dimensions.

4. Weed refuse shall be removed unless the weed will not be detrimental to the watercourse or the water bodies into which the watercourse flows.

5. Clearance of vegetation on the banks of the watercourse is to be restricted as much as possible, and should only be undertaken if the vegetation significantly reduces the stipulated discharge capacity.

6. Weed clearance is to be undertaken during the period 15 May to 31 October and clearance is to be undertaken on whole reaches or parts of reaches if the current channel becomes more overgrown than allowed according to point 1 above.

Weed clearance is to be initiated in response to the watercourse authority's normal supervision of the watercourses or upon the request of the affected landowners.

7. Removal of sand and smoothing out of the banks should be avoided as far as possible. If as an exception such measures must be undertaken, they should wait until the first-coming August/September. Minor deposits that obstruct free flow from drains, etc, can be removed all year, however.

Dredging shall be undertaken in such a way that stone and gravel beds are as far as possible neither disturbed nor removed. Overhanging banks must not be damaged during dredging.

8. Category II maintenance should primarily be applied in the case of watercourses whose quality objective designates them as fish waters.

9. Maintenance is to be undertaken manually.

Category III

1. The watercourse is to be maintained in accordance with the dimensions stipulated in the Provisional Order.

2. In places where the actual dimensions of the watercourse are greater than the stipulated dimensions, and where this ensures a greater discharge capacity than provided for, the weed is only to be cleared in a current channel that corresponds to the stipulated dimensions.

3. Clearance of vegetation on the banks of the watercourse is only to be undertaken where this is necessary to ensure the stipulated discharge capacity in accordance with point 1, but may be undertaken by machine.

4. Watercourse maintenance is to be undertaken once annually prior to 1 November.

5. Dredging of the bed and smoothing out of the banks may be undertaken by machine all year round.

6. Category III maintenance is primarily to be applied in the case of watercourses whose designated quality objective is C, D, E or F, i.e. watercourses that are intended for drainage purposes, watercourses affected by sewage, watercourses affected by water abstraction and ochreous watercourses.

In Børkop Municipality, hard-handed watercourse maintenance was practised until late in the 1980s. However, in 1988 there was a switch to gentle maintenance involving clearance of a current channel through the weed. The work is undertaken by a river keeper with a thorough knowledge of watercourses. In addition to maintaining the current channel he has to solve acute problems with water flow. The results are already visible in the watercourses, for example in Skærup Å stream. It had originally had a natural width of 60 cm but hard-handed maintenance had enlarged it to 3 m. It is now down to a width of 1 m (Figure 2.18) and in 1992 there were 10 times as many trout as in 1988 (16).

Figure 2.18 *The river keeper in Børkop Municipality has now created a new watercourse with 10 times as many trout as before. Photograph by Jan Nielsen.*

The private watercourses

By far the majority of Danish watercourses are private. Some of them are small brooks that can contain very good habitats for invertebrates, and which are good spawning places for trout. The Watercourse Act also applies to these watercourses. It is the Municipality that is the watercourse authority, but it is the landowners who are responsible for maintaining

Box 2.2 *Good advice on the maintenance of small private brooks.*

10 pieces of good advice from Holstebro Municipality on the maintenance of watercourses

1. Go for a walk along the watercourse and evaluate the need for maintenance. Find the places in the watercourse that hinder free flow of water - start by dealing with them. If in doubt, then seek advice before you begin.
2. Limit maintenance as much as possible, and maintain the watercourse in such a way as not to channelize it, i.e. do not deepen or widen it in relation to its original form.
3. Undertake maintenance by hand, and only use machines if absolutely necessary.
4. Only clear weed in the current channel and at maximum in two thirds of the width of the watercourse.
5. Do not let the weed refuse float down the watercourse. It is best to cart it away (use it as fertilizer), but if that is not possible, then throw it up onto the bank a good distance from the watercourse.
6. Limit dredging to the current channel and only remove mud and sand deposits.
7. Dredging and weed clearance may only be undertaken in July and August.
8. Do not dig into the banks unless absolutely necessary. If digging is necessary, then make the slopes as flat as possible.
9. Leave the bank vegetation intact as well as shade-giving trees and bushes along the watercourse.
10. Leave free a good distance from the upper edge of the banks of the watercourse. Remember to erect fences along grazing meadows.

the watercourses. The private watercourses for which a quality objective has been stipulated (see page 30) have to be maintained in such a manner that the physical conditions meet the requirements set by the quality objective. The Danish Environmental Protection Agency has published a pamphlet giving good advice on how to maintain small watercourses (17) and in the winter of 1994/95 distributed a video programme on the same topic. The good advice that Holstebro Municipality gives to landowners who have to maintain such brooks is shown in Box 2.2 (18).

Types of Provisional Order

A review of Provisional Orders, instructions and supplementary Provisional Orders issued by various Counties and Municipalities indicates that the maintenance principles follow the lines of reasoning and ideas expounded in the new Watercourse Act. It is worth noting that even though new Provisional Orders have not been drawn up for all watercourses, this has not hindered the implementation of the new regulations on maintenance (see Chapter 6). An overall evaluation of the Provisional Orders that have been processed by the Danish Environmental Protection Agency (19) indicates that most interest has been shown in the new regulations on how watercourses should be maintained so as to bring watercourse quality in line with the requirements of the quality objectives. There are two ways of regulating maintenance. One is to require that the watercourse should have a specified discharge capacity, and the other is to require that the dimensions of the watercourse meet specified measurements.

Provisional Orders based on discharge capacity were rather common soon after the new Watercourse Act entered into force. With this method one can stipulate correlated values for discharge and water level, the so-called Q/H relationships (Figure 2.14). It is then possible to plan maintenance so as to meet preassigned requirements to the Q/H relationships. This ensures that the weed is cleared when necessary with respect to drainage interests. It provides the possibility for weed beds to be left in the watercourse, for the watercourse to be narrowed, for the watercourse bed to be raised or for the watercourse to be modified in other ways that improve watercourse quality within the bounds of the stipulated discharge capacity.

Maintenance on the basis of Q/H relationships can be costly as frequent measurements have to be made at many stations, both during the planning stage and during the follow-up period. It also requires time-series of correlated data on water flow conditions.

This has meant that the interest in the Q/H method has diminished. Its primary use now is probably for especially high quality objective watercourses that run through important farming areas.

The second means of regulating maintenance is through the dimensions that are stipulated for the watercourse's cross-sectional profile. In this case maintenance has to be undertaken in such a way as to comply with a minimum depth and width. Provisional Orders of this type were normal under the former Watercourse Act. The profile method can still be used advantageously today in the case of watercourses whose primary quality objective is effective drainage. In contrast, the method would not be appropriate in the case of watercourses where good environmental conditions are desired.

In the case of high quality objective watercourses, a modified profile method has gradually been developed. Instead of concentrating on compliance with a specified width and depth, one concentrates on compliance with a specified cross-sectional area. After all, that is what is import as far as concerns discharge capacity. With this method it is therefore permissible to undertake maintenance using say a current channel that is narrower but deeper than if the watercourse was maintained in accordance with a specified width and depth.

As mentioned on page 26, many Danish watercourses are both wider and deeper than the dimensions stipulated in the Provisional Orders. In such cases it is allowable without further ado to undertake maintenance based on current channels and weed borders in that part of the cross-section that lies within the profile stipulated in the Provisional Order. However, the watercourse authority has neither the duty nor the right to maintain that part of the watercourse outside of the stipulated profile.

A further variation on this method of regulating maintenance is the increasingly frequent case where a current channel is allowed that is narrower than the width stipulated in the Provisional Order. This is compensated for by undertaking more frequent weed clearance than required in the old Provisional Order. In many instances this gives an enhanced safeguard against flooding.

The weed refuse

The Watercourse Act states that weed cuttings are to be removed if it is detrimental to the watercourse or the water body into which the watercourse flows. This provision was included in the Act in 1982. The problem had been known much longer, however. For example, weed refuse has been removed from the river Nørreå at Randers since 1921 because it causes problems for the fishermen in Randers Fjord: It gets tangled up in their fishing nets.

Figure 2.19 *Weed clearance produces very great quantities of weed refuse. It must normally be removed from the watercourse.*

In the majority of county watercourses the weed refuse is collected. An analysis made in 1990 showed that this was the case in 90% of the watercourses (20). There is no overall assessment of the removal of weed refuse in municipal watercourses. However, in the municipalities discussed in Chapter 6, removal of the weed refuse is considered a part of gentle maintenance practice.

In some cases the weed refuse is laid up on the bank in step with weed clearance, e.g. when the weed is cleared using a basket reaper. Under the powers of the Watercourse Act, the watercourse authority can instruct the landowner to remove this refuse from the watercourse bank. If it is left to lie, it can in time fertilize the underlying soil thereby possibly promoting a dense growth of stinging nettles. This is not particularly good for the watercourse as the plant roots do not bind the soil together and nettles are a poor habitat for insects, birds and small mammals.

One can also let the weed refuse drift downstream and then catch it at intervals using floating restraining devices. The most simple weed restraining device is a beam tied to the banks that floats on the surface of the water. Such a restraining device can catch the weed that is so light that it floats on the surface of the water, e.g. water crowfoot.

However, other types of weed, e.g. Canadian pondweed, drift along the bottom. In order to catch such weed refuse it is necessary to use a restraining device that projects down into the water such as that shown in Figure 2.20.

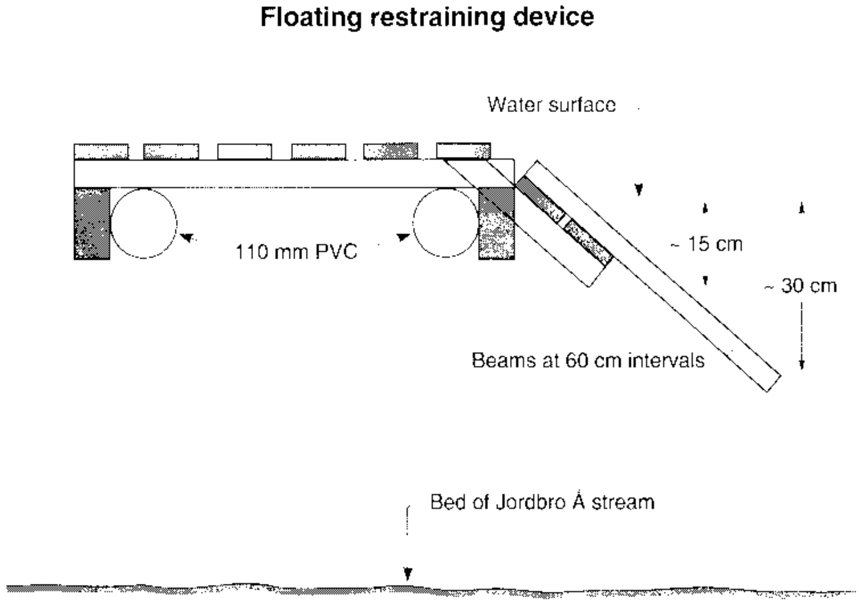


Figure 2.20 *A weed refuse restraining device that can catch Canadian pondweed and other types of weed refuse that drift deep down in the water. Adapted from (21).*

How long can the weed be left to lie?

Many small eel can be caught up in the weed when it is removed. They should be given a chance to return to the watercourse before the weed is carted away. They usually manage to get away within 24 hours (21).

During the course of that time, much water drains off the weed refuse (Figure 2.21). It is important that as much water as possible drains out of the refuse before it is carted away. On the other hand, the weed should not be left to lie too long or the sap will start to seep out of the weed; it is somewhat like silage seepage water, and can cause considerable pollution. The sap starts to seep out of the weed refuse after it has been lying about 24 hours (Figure 2.22).

Figure 2.21 *Most of the water drains from the weed refuse stack during the first 24 hours. Adapted from (21).*

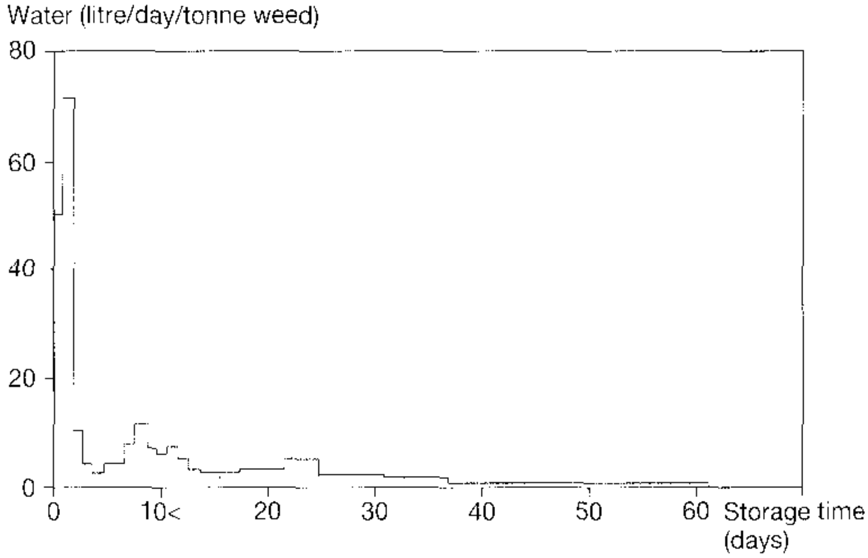
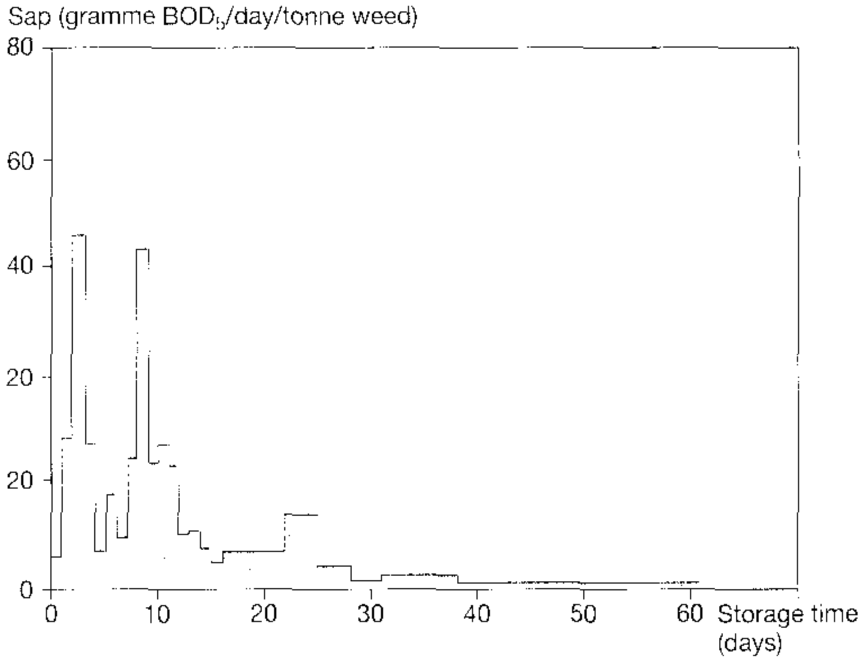


Figure 2.22 *In the course of a few days sap starts to seep out of the weed refuse. It consumes oxygen (measured as BOD_5) if it enters the watercourse. Adapted from (21).*



The weed refuse should be transported to a storage site that complies with the requirements on the storage of animal manure. There has to be a watertight base and a watertight container in which the sap can be collected.

The weed refuse can be used as fertilizer or as soil improver in fields and forests. It could also be used together with straw, etc., to make compost.

Bank vegetation can improve watercourse quality

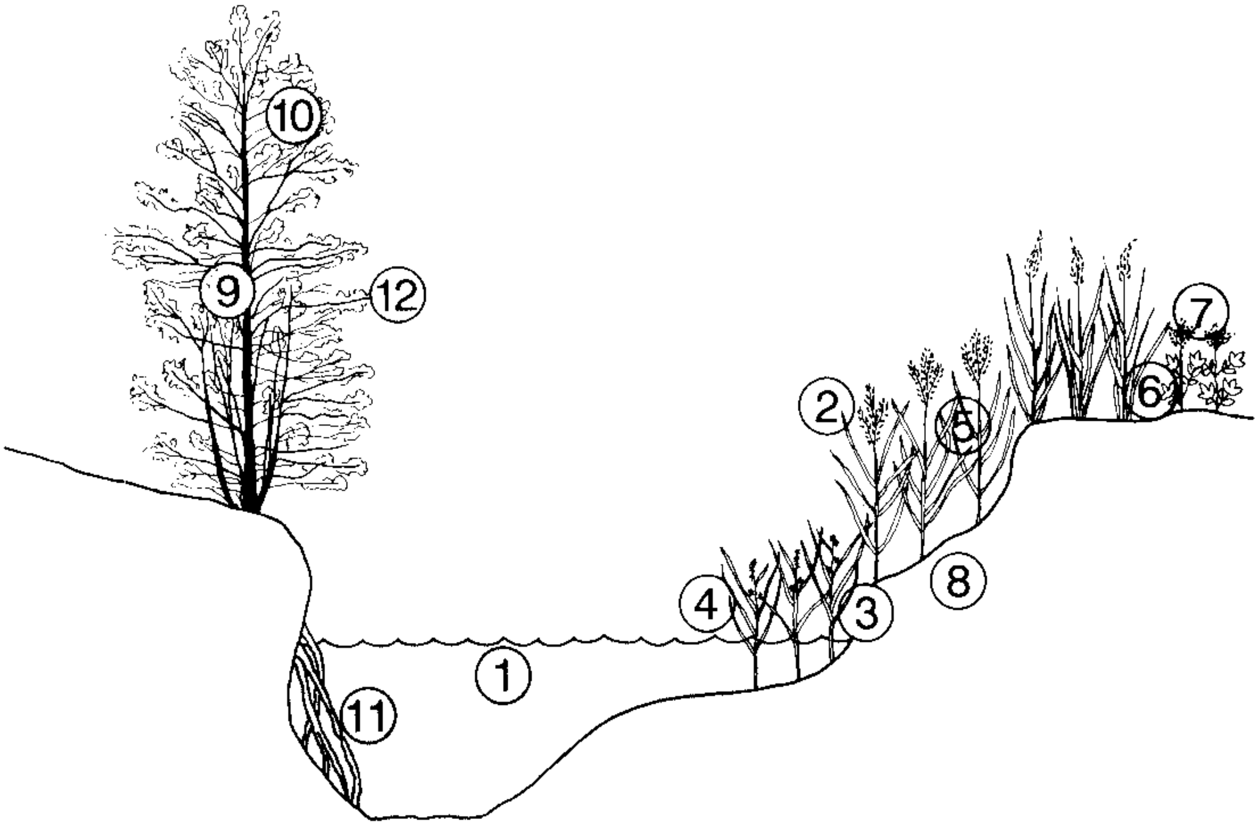
Table 2.3 *A study undertaken in Haverslev Municipality revealed that shading by bank vegetation could be used to hold down weed growth.*

A common feature of gentle maintenance is that the bank vegetation is not usually cleared any more. The Watercourse Act provides good possibilities for this, the reason for including this provision being that the bank vegetation could shade out some of the weed in the watercourse (Table 2.3 (22)), thereby saving on maintenance. Bank vegetation provides other advantages as well, though, and conditions on the bank have a decisive impact on watercourse quality as a whole (Figure 2.23).

	20.08.1981 Normal bank clearance		17.08.1982 No bank clearance	
	Wet weight	Dry weight	Wet weight	Dry weight
Brooklime (+ water celery)	6.07 kg	558.5 g	1.60 kg	115.0 g
Grasses	0.90 kg	121.0 g	1.03 kg	109.0 g
Filamentous algae	0.07 kg	4.7 g	0	0
Total	7.04 kg	684.2 g	2.63 kg	224.0 g
Weed per m^2	0.37 kg	36.4 g	0.14 kg	11.9 g

In the case of small watercourses, the shade can hold down the water temperature on warm summer days; as a consequence, the oxygen content of the water is higher, thereby benefitting the fish. Moreover, fish require less oxygen to thrive at lower temperatures. The value of shade is illustrated by a study in Kalvemose Å stream at Holbæk (23). The current channel method of weed clearance has been practised there since 1988, and the bank vegetation has been left untouched so that its shade could hinder the sun in overheating the water. Studies of the trout population in the stream over the period 1990-92 revealed that the population had increased markedly and that the trout had survived the hard summer conditions (Table 2.4).

Particularly noteworthy is the large number of trout in 1992, when the summer was very dry and discharge was very low. With the former maintenance practice, in which all the weed in the watercourse and on the banks was cleared, it is unlikely that the trout would have survived such a summer. However, with the new practice the shade from the bank vegetation kept the water cool and the current channel ensured that despite low discharge, there was sufficient water in the occasional deeper parts for the trout to survive the dry, warm summer.



1 The shade keeps the water cool and oxygenated

2 Insects and other small animals from among the plants are caught by trout when they fall into the water

3 The larvae of aquatic insects crawl up and metamorphose into adults

4 Aquatic insects lay their eggs here, and the small larvae fall into the water

5 The stream's adult insects seek shelter here

6 Birds from the fields nest here

7 A good habitat for butterflies and beetles

8 The roots reinforce the banks

9 Birds find food in the alder tree

10 Many insects solely inhabit alder trees

11 The roots of the alder tree are a good hiding place for trout

12 Dead leaves are a good food source for the aquatic invertebrates

Figure 2.23 *Bank vegetation is of great significance for watercourse quality.*

Table 2.4 The trout population in Kalvemose Å stream in Holbæk Municipality increased when bank vegetation was no longer cleared. The figures are trout per 100 m^2. Adapted from (23).

It has now become almost a general rule to leave bank vegetation untouched at watercourses where gentle maintenance is practised. This notwithstanding it is sometimes necessary to clear bank vegetation, for example that growing on the lowermost part of the bank if it hinders the free flow of water. Moreover, clearance of vegetation in the autumn can sometimes be useful for "renewing" the vegetation so that it does not end up as high "herbaceous borders" with stiff dry stems much of the year. Much can undoubtedly be learned from the maintenance of roadside verges.

	1990			1991			1992		
Location	0.5 yr	1.5 yr	older	0.5 yr	1.5 yr	older	0.5 yr	1.5 yr	older
Stradebro	0	0	0	38	0	0	32	0	0
Søstrup	4	0	0	7	0	0	33	1	4
Borup	21	3	0	31	1	4	129	4	0
Severinsmindevej	16	2	1	22	0	0	142	6	8
Butterup	20	1	2	35	1	0	33	5	0
Mean	12.2	1.2	0.5	26.6	0.4	0.8	73.8	3.2	2.4

Dredging

Hard-handed dredging can destroy many of the environmental conditions that are of great importance to the watercourse fauna. In some cases maintenance is so intense that it is really (unlawful) channelization; the watercourse is straightened out and the bed dug deep (Figure 2.24). Hard-handed maintenance involving smoothing out of the banks and removing the weed beds and stones can remove the hiding places for trout. The damage caused by dredging can also be far-reaching, namely when the gravel beds in which the trout spawn and where the fry shall live are removed (see Chapter 3).

The new regulations on gentle maintenance endeavour to keep dredging to a minimum by only allowing the dredging of sand, soil and mud that has deposited in the watercourse. As an example, the supplementary Provisional Orders issued by Nordjylland County state "In high quality objective watercourses, i.e. areas of special scientific value or salmonid waters, necessary dredging should preferably be undertaken in the month of August or September. Stone and gravel beds must not be dredged and overhanging banks, stones and roots in the watercourse should as far as possible be preserved".

Figure 2.24 *An "over-dredged" watercourse. Photograph by Jan Nielsen.*

Dredging and weed clearance

It can sometimes be necessary to dredge watercourses if deposits of sand and mud have accumulated that the watercourse is unable to remove itself. The material could have been eroded from the banks and bed of the watercourse itself (see page 26), or could have entered the watercourse from the surroundings. It could have been blown in with the wind, washed in with the rain, or have been flushed in through drainpipes. In the long term it is necessary to safeguard against more material entering the watercourse than the current is able to flush away.

In some places gentle weed clearance has already diminished the need for dredging. An example is the uppermost part of the river Gudenå where Vejle County has established artificial spawning grounds (see page 109). Sand traps have been established upstream of the spawning grounds to catch the migrating sand that might otherwise bury the spawning grounds. At the beginning of the project, the sand traps had to be emptied 5 times annually. However, when weed clearance was ceased in that part of the river Gudenå, the frequency at which the sand traps had to be emptied decreased markedly.

Figure 2.25 *The need to dredge sand from the watercourses in Vejen Municipality decreased when gentle weed clearance was introduced. Adapted from (24).*

Vejen Municipality has also had good experience with a reduced need for dredging watercourses where gentle weed clearance has been undertaken. Figure 2.25 shows that the reaches that still have to be dredged are only a fraction of those that had to be dredged before gentle weed clearance was introduced. One of the reasons is that the banks of the watercourses are now protected by the bank vegetation, and the current is no longer able to erode material from them. Another reason is that the water now contains so little sand and the current is so strong that any material that does deposit is immediately flushed downstream.

It is also important that the edges of the banks are well vegetated with plants whose roots hold the banks together. Dense vegetation can protect the banks of the watercourse against the frost, the latter being an important reason why the banks collapse causing soil and sand to enter the watercourse. The new regulations introduced in 1992 requiring a 2 m wide uncultivated border alongside all natural watercourses might have a considerable positive impact. However, there is not much new about treating the edge of the banks well in order to prevent sand and soil from entering the watercourse. Many of the former Provisional Orders stipulated that the edge of the banks should be respected. Thus the 1886 Provisional Order for the river Karup Å states that it is not allowed to plough closer than 6 feet from the river and that the adjoining landowners had to ensure that there was sufficient vegetation to hold the banks together to prevent soil and sand from collapsing into the river.

Maintenance of ochreous watercourses

Many watercourses, especially in the counties of western Jutland, are affected by ochre. This is derived from iron dissolved in the water (especially drainage water) that flows into the watercourses. In the watercourse the ochre is converted to fine particles when it becomes oxidized and comes into contact with the weed. The iron precipitates out as ochre which covers the bed and the plants.

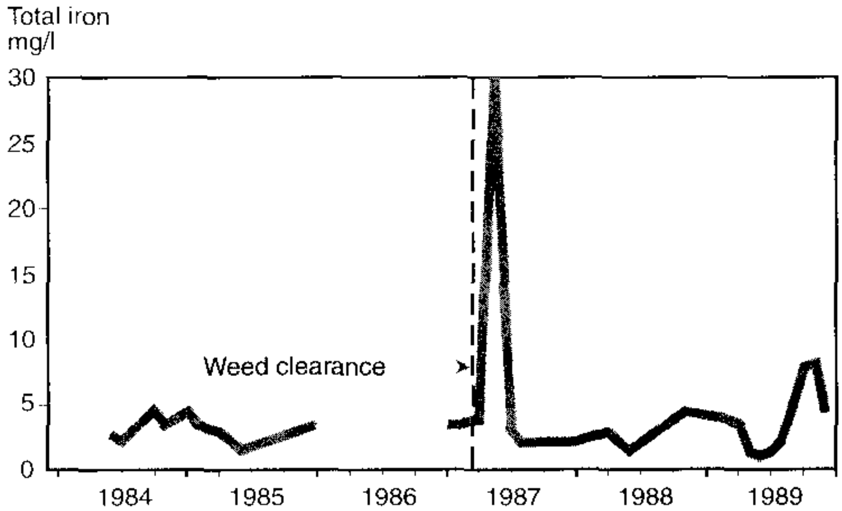


Figure 2.26 *Clearing weed in an ochreous watercourse can release much ochre into the water. Adapted from (25).*

One has to be especially careful when maintaining ochreous watercourses as the ochre collected on the weed resuspends and flushes down through the watercourse (Figure 2.26). This is particularly dangerous if there is a fish farm downstream, but the fish that naturally inhabit the watercourse can also be harmed.

Watercourses that contain much ochre do not provide habitats for trout, and the invertebrate population is impoverished. This is partly because the dissolved iron is toxic, and partly because few animals can live where ochre has precipitated out.

Since only few macroinvertebrates can inhabit places where there is iron in the water or where ochre has precipitated out, it is not possible to evaluate the environmental state of such watercourses by the usual methods (see page 33). Ochreous watercourses are therefore classified as "non evaluable".

There are many ochreous watercourses in Grinsted Municipality. Changes have taken place since gentle maintenance of the watercourses was introduced, however. Thus while 52% of the watercourses were classified as "non evaluable" in 1986, the corresponding figure in 1990 was only 41% (26). This means that invertebrates can now inhabit some of the former ochreous watercourses. Moreover, many of the invertebrates present are the so-called clean water invertebrates. The type of weed present in the watercourses has also changed. For example, water crowfoot now grows in the majority of the former ochreous watercourses.

One of the reasons for this improvement is that the watercourses now have a current channel with weed borders along the sides. The ochre precipitates out quickly. Some of it deposits among the weeds but whatever comes out into the watercourse is flushed away by the strong current in the current channel. Deposition on the bed and in the vegetation that grows freely in the current is so insignificant that invertebrates are now able to live there.

Another reason why there are fewer problems with ochre might be the higher water level in the meadows from which the ochre derives. Many of the ochre problems are attributable to the drainage of wet meadows with iron-containing (or more correctly pyrite-containing) soil layers. Pyrite is a compound of iron and sulphur. Draining such soil sinks the water level with the result that oxygen penetrates down to the pyrite-containing layers. When the pyrite is oxidized, the iron leaches out (Figure 2.27).

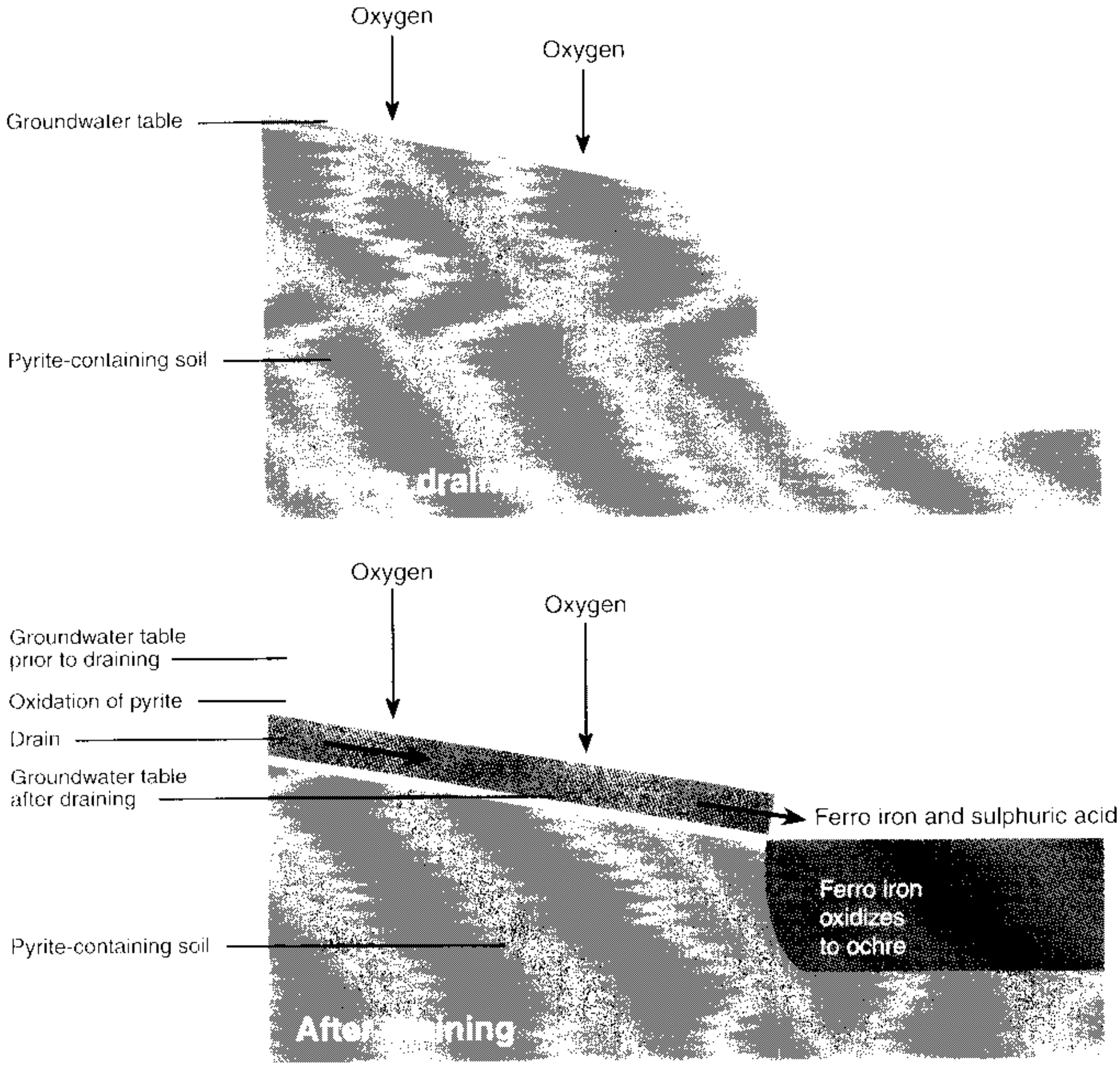


Figure 2.27 Ochre can be formed when the water level is lowered in meadows with pyrite-containing soil. Leaching of ochre can be hindered by raising the water level. Adapted from (25).

When the water level in the meadow increases again, oxygen does not penetrate down to the pyrite; as a result, less iron leaches out.

The level of the groundwater near a watercourse can be raised by reducing the discharge capacity of the watercourse and hence raising the water level in the watercourse. One way of doing so could be to cease or limit weed clearance, a method that is particularly applicable in cases where the meadows adjoining the watercourse are no longer cultivated.

This might perhaps be one of the reasons why ochre pollution is on the decline in some parts (27).

Box 2.3 There is nothing new in gentle maintenance. Here is an excerpt from an article in a 1907 freshwater fishery magazine. The charm of the old-fashioned Danish is lost in the translation, however.

Rational management of watercourses when farming brown trout

In places where weed clearance and dredging is undertaken, especially when undertaken several times a year, it is, as already mentioned, obvious that proper farming is out of the question. However, it is worth considering whether one could not try to do something to improve the situation in such places. Weed clearance has to be undertaken so that the aquatic plants do not grow so much as to hinder the free flow of the water. Weed clearance and dredging are therefore necessary for agricultural reasons, and cannot be avoided in such watercourses.

However, the question is whether the same result could not be obtained without undertaking completely radical weed clearance. This can naturally only be determined by experimentation.

Based on my observations, I have come to the opinion that here and there a certain amount of weed could be tolerated without detrimentally affecting the water flow. It would be best if the fish farmer himself undertook weed clearance and dredging; he would then leave as much weed in place as was possible and permissible. When persons without an interest in fishery undertake maintenance, they naturally do so by clearing out the brook completely. Maintenance requires labour, of course, i.e. it costs money, and hence reduces the net profit from the brook. This is not as bad as it appears, though.

The regulations require that the owners, neighbours or certain specified persons undertake maintenance. They naturally do not do so willingly but regard the task as a burden, and would no doubt willingly pay the fish farmer to take over maintenance. Much could probably be achieved by that means.

The path to better watercourse quality

The experience that Nordjylland County gained from the studies in Voer Å stream and its tributaries (see Chapter 1) has been confirmed by many other weed clearance studies throughout the country, and is also confirmed by the practice that now pertains in a very great part of our watercourses: Gentle weed clearance gives a better watercourse quality while at the same time ensuring effective water flow.

The current channel is that part of the watercourse where water flow is greatest. This is where the watercourse is deepest and where resistance to water flow is usually least. Natural watercourses have a current channel that can be developed by appropriate weed clearance.

Figure 2.28 *Machines also have a place in gentle maintenance, but they have to be used with special care.*

Experience shows that even a quite narrow current channel can lead away sufficient water. One of the reasons is that the current in the current channel can be so strong that it changes the resistance of the weed. For example, it can press bur reed down against the bed such that resistance falls and more water can flow away. Another reason for the good flow can be that weed species such as water crowfoot growing in the deep current channel have most of their foliage up near the surface of the water, and are only anchored by long stems that offer little resistance. The water can flow freely down below the foliage.

In many places the current channel method of weed clearance necessitates more frequent weed clearance in order to prevent the current channel from closing up.

The resultant improvement in watercourse quality is reflected by among other things, better populations of fish. The current channel and weed borders provide them with better habitats. The weed borders also protect the banks against erosion by the current, thereby reducing sand migration. Examples of this are presented in this chapter, as well as in Chapter 6.

One of the most noticeable effects of the current channel method of weed clearance is that the watercourse changes its appearance. In the course of only a few years, and often less than three, wide shallow watercourses can be transformed to narrow deep channels. In the present chapter there are examples of this having led to watercourses being restored to the dimensions they had before the introduction of hard-handed maintenance.

To obtain a narrow watercourse with a current channel is not always a goal in itself. If the current channel is so narrow that frequent weed clearance is necessary to ensure free water flow, the watercourse can end up being just as poor a habitat for fish and invertebrates as when it was a wide, hard-handedly managed watercourse. It is important that the watercourse that results from gentle maintenance is so wide that there is room for weed borders that the fish and invertebrates can shelter in.

A characteristic of the new maintenance practice is flexibility. The former maintenance practice was characterized by rigid guidelines. Nowadays the river keeper must to a greater extent evaluate the conditions in and around the watercourses. The river keeper has to plan the maintenance so as to take account of the differences that there are between the individual watercourse reaches, differences in precipitation, differences in the use of the watercourses and differences in cultivation of the surrounding fields.

Gentle maintenance is rapidly taking over and the watercourses are once again on the path to becoming good habitats for invertebrates and fish.

The next chapter deals with the requirements that have to be met for trout to thrive in the watercourses.

3. The trout - the quintessential watercourse fish

Trout and other salmonids are an integral part of watercourses. Running waters of good quality provide the good supply of oxygen they need. Brown trout spend their entire life in watercourses whereas sea trout and salmon spend a large part of their life in the sea. Eventually though, seagoing salmonids return to watercourses to spawn, and it is here that the next generation will spend the first year or two of their existence.

A large population of trout is a good indicator of whether watercourse quality is good. Many conditions need to be in order for trout to have satisfactory living conditions. Because trout are so dependent on good environmental conditions, they are used in the description of watercourse quality objectives.

In many watercourses the number of trout is lower than could be anticipated. Thus stocking is often undertaken with hatchery reared trout. One reason a population of trout may be poor is a lack of suitable spawning grounds where the trout can lay their eggs and where the fry can live the first months after hatching. Thus not all watercourses contain a natural trout population. However, it is generally a relatively simple matter to recreate viable spawning grounds.

New spawning grounds are made from a mixture of gravel and pebbles of a size and shape that ensures the presence of pores through which the water can percolate. This is necessary as eggs are dependent on a continuous flow of fresh water to satisfy their oxygen demands and remove waste products.

This chapter explains how one can help re-establish natural trout populations in watercourses.

How many trout in a watercourse?

For trout to live in a watercourse, the water needs to be clean and rich in oxygen. But this is not the only parameter that determines the number of trout in a watercourse. The cleaner the water, and the better the physical conditions with regards to weed beds, stones, undercut embankments and other hiding places, the greater the number of trout that can inhabit the watercourse.

Table 3.1 Classification scale for watercourses based on their quality for trout. Adapted from (1).

0: Not suitable for trout
1: Trout can survive but conditions are poor
2:
3: Average conditions, with some hiding places and good water quality
4:
5: The best conditions for trout, with good hiding places and good water quality

The number of trout in a watercourse depends on the number of hiding places and amount of food available. Danish fish biologists have been estimating the carrying capacity (i.e. how many trout a stretch of watercourse can carry) for more than 50 years. This is done using a "classification scale" from 0 to 5. The fish biologists call the evaluation the watercourse's "quality" (Table 3.1). The term quality can be compared to an agricultural field's fertility, but in the case of a watercourse, quality is primarily determined by the number of suitable hiding places such as weed beds, undercut embankments and stones.

The struggle for hiding places

Trout lay their eggs in gravel beds during the late autumn and early winter months. In the spring, the small trout (fry) emerge from the gravel and mingle with all the other newly emerged trout fry on the bed of the watercourse. So begins their fight for survival. The fry struggle against each other in an attempt to secure a "private area" or territory. They cannot stand the sight of each other, and those fry unable to find a territory obscured from the view of other fry will be chased away, and will quickly die of hunger and stress.

The more hiding places there are in a watercourse the greater the number of trout it can carry (Figure 1.5). The way in which a watercourse is maintained therefore helps determine its carrying capacity for trout. Nevertheless, even if living conditions for the newly emerged fry are optimal, the majority will not survive their first year (Table 3.2). Of a total of 1,000 emerged fry, only 125 were still alive after their first year.

The mortality rate for trout is also high in subsequent years. In addition, many 2 and 3 year olds leave the watercourse to migrate out to sea.

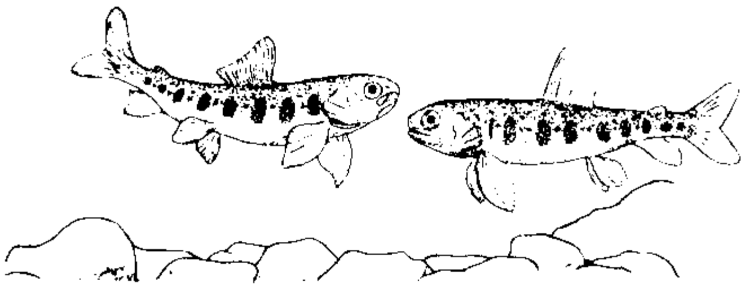


Figure 3.1 *The trout fry are aggressive. Adapted from (2).*

Table 3.2 *Survival of 1,000 trout fry emerging from the spawning nests. The majority die. The figures marked with an asterisk include trout that roam out to sea. Adapted from (3).*

Emerged from the spawning nest	1,000
3 months	250
1 yr	125
2 yr	75*
3 yr	30*
4 yr	9
5 yr	5

Stocking of trout

Many watercourses have not yet attained the natural population of trout they once had when they were clean and in their natural state. The explanation often lies in the lack of suitable spawning grounds or that passage to spawning grounds is blocked by weirs and similar obstructions (Chapter 4). In order to attain a good trout population in such watercourses, one has to stock them with trout originating from hatcheries, etc. The trout are released according to specific stocking schemes drawn up by the Inland Fisheries Laboratory under the Ministry of Agriculture and Fisheries.

Large numbers of trout are stocked in the Danish watercourses. In Ribe County alone, more than half a million trout have been released annually since the beginning of the 90's. Although the majority of trout stocked are fry, larger trout are also released. Plans for stocking schemes are based on the carrying capacity of the release sites with respect to the various sizes of trout. Examples from the Ribe County stocking scheme are shown in figure 3.2. Fry and small trout (yearlings) are released in the small watercourses while larger trout are released in the larger watercourses. Evaluation of the trout carrying capacity of individual reaches of a watercourse is based on its quality (Table 3.1).

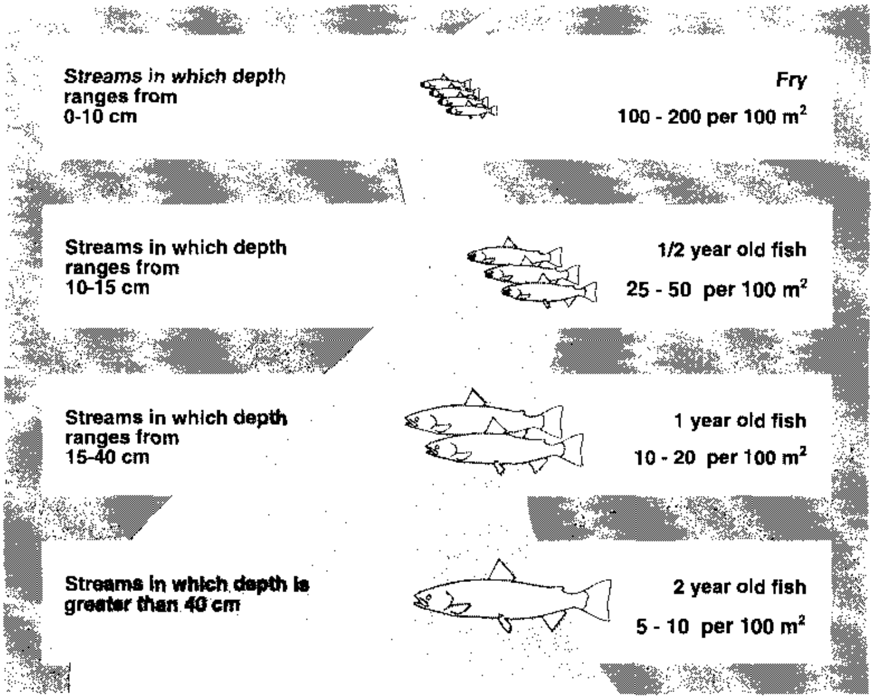


Figure 3.2 *Fish are stocked in sizes according to the depth of the watercourse. Adapted from (4).*

When trout spawn

Trout and other salmonids spawn (i.e. lay their eggs) in late autumn and early winter. During this period water levels are high and the water is cold and oxygen-rich. The eggs are laid in gravel beds that are usually located in riffles. The gravel beds in which eggs are laid are called spawning grounds.

The female trout selects a suitable spawning ground site and then begins to dig a hole by a vigorous flapping of her tail. Gravel, pebbles, sand and mud are thrown up into the current, where the fine particles are carried away while the gravel and pebbles accumulate in a pile immediately downstream of the hole. The resultant hole, or egg pocket, is referred to as the "nest". One or more males wait close by while the female is digging (Figure 3.3). When the nest has reached a suitable depth, the female sinks into the depression. She then lays her eggs and at the same moment, a male joins her and extrudes a portion of sperm over them. The current swirls the sperm around, thereby ensuring that the majority of eggs become fertilized.

Immediately thereafter, the female beats her tail feverishly from a position directly upstream of the nest. Gravel and pebbles are then slung into the nest and cover the eggs while sand and mud are carried away. The eggs thereby become buried under clean gravel, usually in a layer 15 to 20 cm thick.

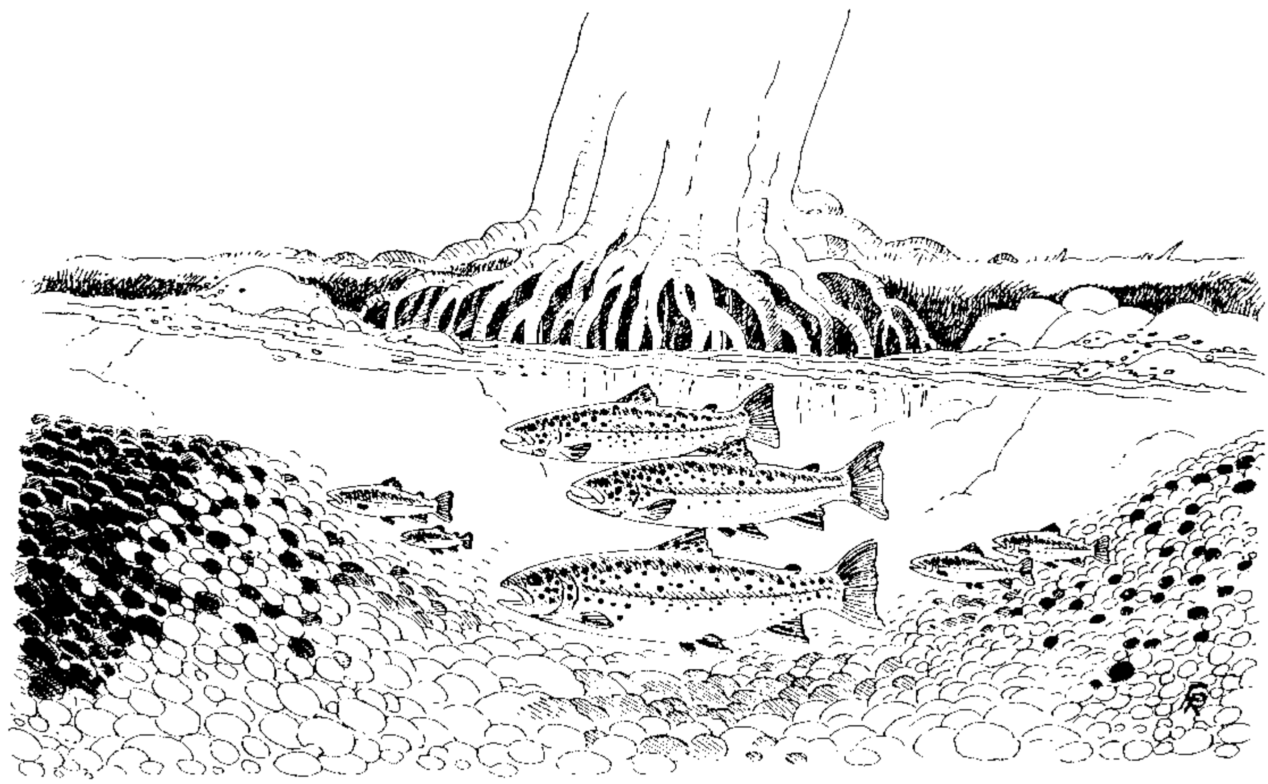


Figure 3.3 *The female trout digs a hole in the spawning ground while the males wait. Adapted from (5).*

This spawning process is repeated several times, the female digging a new nest each time. Each nest is dug immediately upstream of the previous one such that a large part of the spawning ground is utilized. As a rule it is easy to see if spawning grounds have been used as they are a shade lighter in comparison to their surroundings. This is because pebbles dug up by the female trout are light in colour while the stones that have been lying on the surface of the bed for some months are discoloured by algae growths (Figure 3.4). The spawning nest becomes so full of gravel and pebbles that it often protrudes above the level of the bed. Upstream of the nests there is usually a depression or "cuthole", this being the hole created when the last portion of eggs was covered.

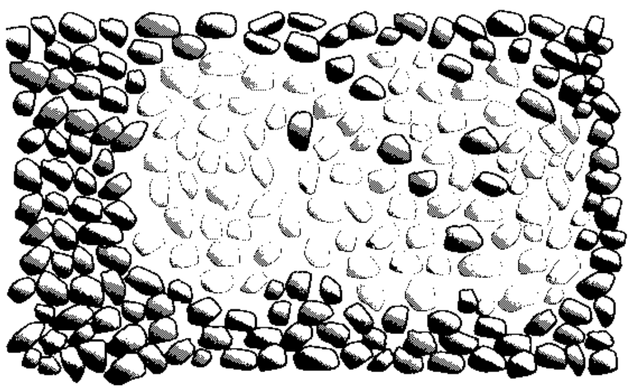


Figure 3.4 Spawning grounds in use have a lighter shade than the surrounding bed. Adapted from (6).

The eggs lie well protected in the egg chamber, deep inside the spawning ground. They hatch during the course of winter and early spring, the interval between spawning and emergence of the fry being dependent on the water temperature. Trout eggs need to undergo 459 "degree-days" before the young trout (alevins) can hatch. For example, if the average temperature is 5 °C, then at least 3 months will have to pass before the eggs can hatch (459 degree-days divided by 5 degrees being 92 days). Newly hatched alevins have a reserve of nourishment contained in a yolk sac sufficient for approx. 20 days. It is not until this nourishment is depleted that the small trout (now called fry) will begin to emerge from the gravel. In all, the young trout spend approximately their first 4 months buried in the gravel bed.

Spawning grounds

The bed material is sorted by the current twice - once when the female trout digs the hole in the spawning ground, and again when she covers the eggs. As the fine particles are washed away, nests have fewer fine particles than the bed on which the nests lie. Eggs need to be covered with clean gravel to allow for water to freely percolate through to the egg chamber during the 4 months the eggs and the newly hatched alevins remain in the nest. The water carries oxygen down to the eggs and removes waste products.

It is the excavation work carried out by the female trout that is responsible for creating pores within the coarse bed material. However, it is not only fresh oxygen that the water carries to the eggs, but also sand and fine particles. This can cause pores to become blocked, the result being that the eggs die due to lack of oxygen. It is therefore important that the water flowing through spawning grounds does not contain too much sand and other fine particles that can block pores or completely cover the nests.

The morphology of the spawning grounds relative to the direction of the current is an important determinant of how well water can percolate to the eggs. When the nest slopes up facing the current, water is pressed into and through the gravel; in contrast, when it slopes down, a vacuum is created sucking water out (Figure 3.5). The somewhat domed shape that nests attain when the female covers her eggs therefore helps to ensure effective water flow into and out of the egg chamber.

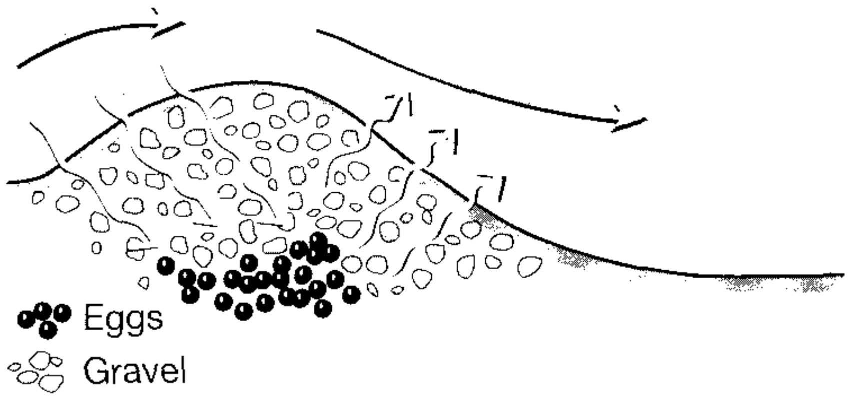


Figure 3.5 The water should percolate freely through the nest.

When the fry emerge from the surface of the nests in the spring, so begins the fight for survival. They need to find a hiding place "territory", and so seek refuge behind small stones, branches and weeds (Figure 3.6). Fry that are unsuccessful in quickly establishing a territory soon die, indicating the importance of the availability of good hiding places in and near the spawning ground.

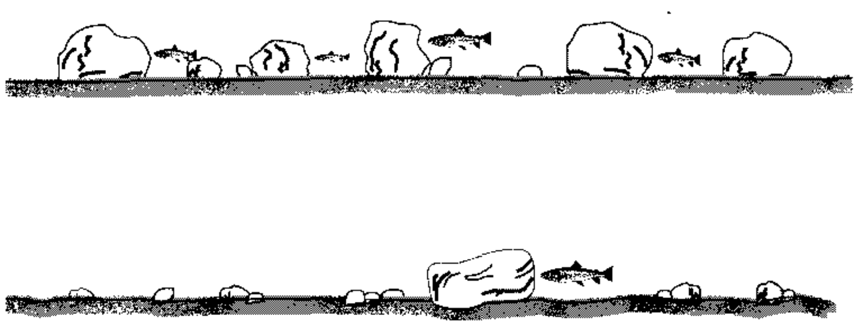


Figure 3.6 The small trout hide behind stones.

The fry generally inhabit the riffles, the pools usually being the preserve of larger trout. If fry venture down into a pool, they will be eaten by their larger relatives. On the other hand, if a watercourse is devoid of larger trout, then fry will also inhabit the pools (7), as illustrated in Figure 3.7.

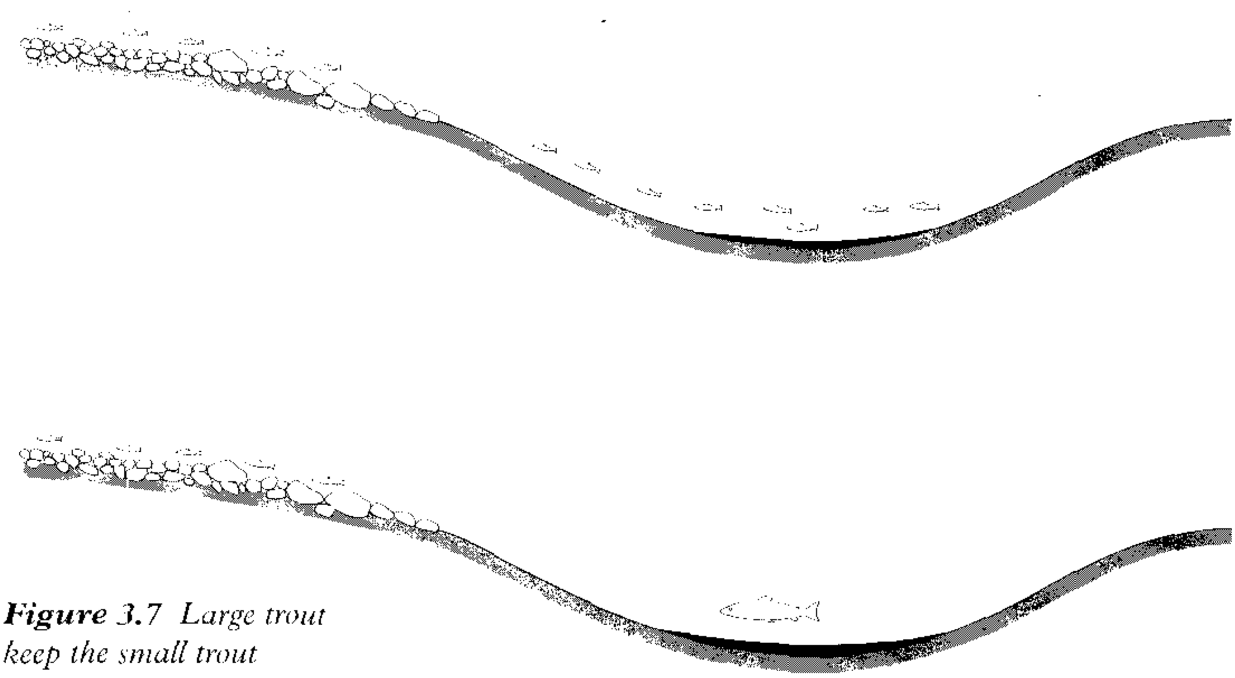


Figure 3.7 *Large trout keep the small trout away from the pools.*

New spawning grounds

The number of spawning grounds in our watercourses has diminished considerably. They have been dug up during channelization and regulation and many have been destroyed by hard-handed maintenance practices. In Kastbjerg Å stream north of Randers Fjord, only 122 spawning grounds were found to be in use along the 17 km long main course during the 1990/91 spawning season. Ninety percent of this stretch is regulated and in these reaches there were on average only 5.2 spawning grounds per kilometre. In unregulated reaches, in contrast, there were 22.2 spawning grounds per kilometre (6).

Ninety-two percent of all the spawning grounds were concentrated along 8 core reaches totalling 1.5 km, i.e. only 8% of the Kastbjerg Å stream.

New spawning grounds can be created by laying out gravel and stone banks in a watercourse. It is important to choose a location with the correct environmental conditions, however. The current has to be strong enough to ensure that sufficient water reaches the buried eggs through the pores, and must not carry so much sand and fine material that pores become blocked. Moreover, the spawning grounds must lie correctly in the watercourse, and have the correct gradient and correct length. The water must be clean, i.e. must fulfil at least the demands of pollution class II, and must not contain much dissolved iron. Iron in this form is poisonous, and can precipitate and block the gravel pores. The concentration of dissolved iron (ferrous iron) should be under 0.5 mg per litre and preferably not over 0.2 mg per litre.

The material in the spawning grounds should have a size capable of resisting erosion during periods of high discharge in winter. It is also important that the spawning bed contains material of different sizes so that the individual particles can support each other. This renders the spawning grounds more stable and creates larger pores between the bed particles, thereby facilitating passage of the water. The material for new spawning grounds should be laid out during the summer or early autumn so as to allow the current to rearrange and settle the bed before trout begin digging their nests.

Conditions in natural spawning grounds

A good indication of how spawning grounds should be established in a particular watercourse can be obtained by studying natural spawning grounds in similar watercourses, as has been done at several locations in Denmark. The Danish Land Development Service has undertaken such studies in 6 Danish watercourses (8). It was found that the water depth over spawning grounds was typically 10-20 cm, and seldom over 30 cm. The average current speed was 50-70 cm/sec, but varied from 30-110 cm/sec, the currents over the grounds typically being swirling and wavy. The water surface gradient over the length of the spawning grounds was between 2‰ and 17‰. The gravel layer that the trout used for spawning was typically about 25 cm thick, but varied from 10-50 cm. Seventy percent of the gravel has a grain size of between 2 and 63 mm in diameter, the average being 16 mm. Most of the gravel is between 10 to 20 mm in diameter. The majority of the particles are irregular, this being an important characteristic since irregular particles form more and larger pores than do rounded particles (Table 3.3).

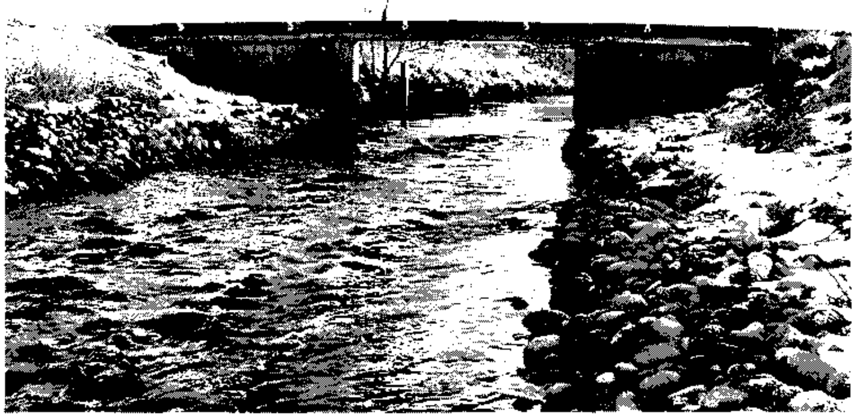


Figure 3.8 *New spawning grounds in Tarm Møllebæk stream.*

Table 3.3 *Grain sizes of the bed material in spawning grounds.*

Watercourse	No. of samples	Diameter (average)	% under 2 mm	% over 63 mm
Hagenstrup Møllebæk	6	17.3	20.5	7.8
Skibelund Bæk	3	18.3	18.0	4.7
Bur Møllebæk	5	13.7	25.6	3.4
Jordbro Å	3	16.0	27.7	10.0
Tungelund Bæk	3	21.7	15.8	20.0
Rabis Bæk	3	11.3	31.0	2.0

The Danish Environmental Protection Agency Freshwater Laboratory in collaboration with Sønderjylland County and Århus University have also investigated the physical conditions along natural spawning grounds in a number of watercourses (9). The results of these studies resemble those found by the Danish Land Development Service: The thickness of the spawning grounds was between 12 and 36 cm, with the average being 22 cm. The bed material grain sizes are shown in Table 3.4. The studies showed that the distance between individual spawning grounds were often approx. 5-7 times the width of the watercourse, or roughly the distance between natural riffles.

Table 3.4 *Grain sizes in the upper bed material of spawning grounds (SG) and in the underlying river bed (RB). Adapted from (9).*

Watercourse	Upper 10 cm				Thickness	
	Diameter (mm) (average)		% by wt. of grains under 4 mm		(cm)	
	SG	RB	SG	RB	SG	RB
Mattrup Å	>32	<4	2	69	28	0
Bjergskov Bæk	15.3	11.0	22	32	19	23
Tjærbæk	15.5	7.4	19	41	36	13
Granslev Å	-	<4	-	72	-	0
Sejbæk	-	6.4	-	45	-	6
Bording Å	15.5	<4	18	88	20	0
Trap Bæk	10.0	<4	35	59	16	5
Rabis Bæk	8.6	11.8	33	22	12	12
Average	>16.2	<6	22	53	22	7

The distance between adjacent natural spawning grounds is a good rule to follow when establishing new spawning grounds. The closer one comes to conditions in a natural watercourse, the better one is able to utilize the natural forces at work in the watercourse to stabilize the material and render it suitable for spawning.

Procedures for establishing spawning grounds

The establishment of new spawning grounds is one of the restoration measures described in Part 8 of the new Watercourse Act. Experiments were soon initiated aimed at determining how to establish well-functioning spawning grounds. The first studies were undertaken at weirs because the gradient provides good possibilities for experimenting with different forms of spawning ground (10). One could preserve the weir and yet still create spawning grounds by replacing the concrete steps with a weir of stones and laying out a suitable mixture of coarse gravel before and after the weir. The mixture consisted of 3/8 pea gravel (1 cm), 1/2 nut gravel (2 cm), 1/8 shingle (3-12 cm), and the occasional fist-sized pebble. However, one can also replace the weir with a long riffle of coarse gravel held in place by stone supports.

The Danish Land Development Service established a number of spawning grounds in the strongly regulated Tarm Møllebæk stream (11). These were laid out at the weirs, which were V-shaped. The weirs were modified such that water is now able to flow freely over the entire cross-section. The fine bed material was replaced with a layer of packing gravel topped with a layer of spawning gravel. The two types of gravel were separated by a layer of "fibertex" material to prevent the finer packing gravel from mixing with the spawning gravel. To ensure sufficient current a two-step profile was formed with a 2.5 m current channel mid stream. In addition, the banks were stabilized with stones to withstand and contain high winter discharge. A band of fist-sized pebbles was laid perpendicular to the current channel every 7 or 14 m to restrain the spawning gravel and increase water flow through the gravel.

Sønderjylland County establish spawning grounds in a slightly different manner. Since it is difficult to determine beforehand how to establish a spawning ground in such a way that it functions, they lay out spawning grounds in many parts of the watercourse where the current is so strong and sand migration so minor that there is a good probability that trout will spawn in some of them, and that fry will emerge. Some of these spawning grounds function one year while others function another year. The net result is a watercourse with an appropriate number of functional spawning grounds (12).

Several types of spawning grounds

The spawning ground studies undertaken by the Danish Environmental Protection Agency Freshwater Laboratory in collaboration with Sønderjylland County and Århus University during the mid 80's were followed up by a series of experiments involving the

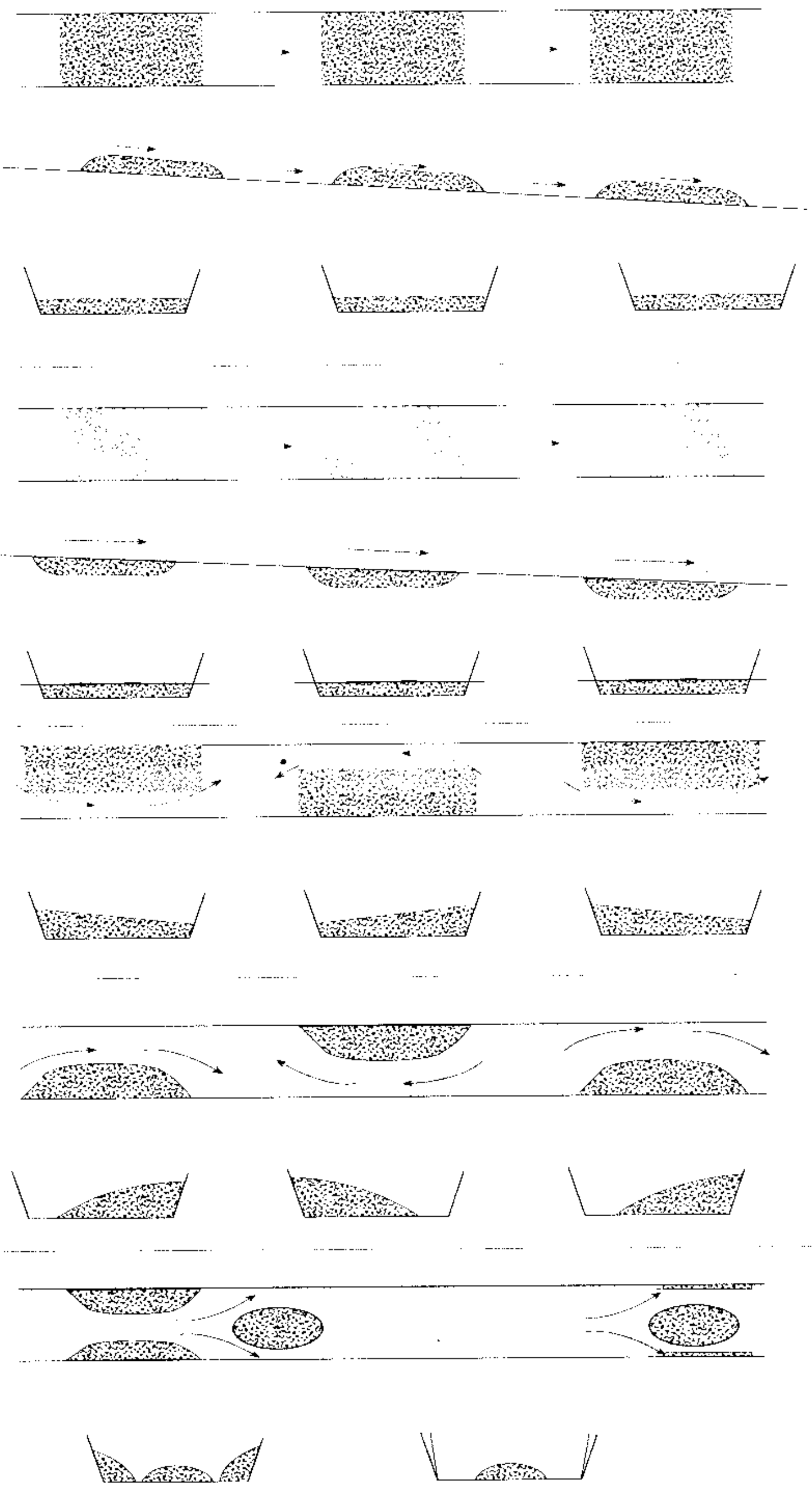


Figure 3.9 *Experiments with different forms of spawning grounds. Adapted from (9).*

establishment of different forms of spawning grounds. These artificial spawning grounds were made 20 cm thick to duplicate conditions found at natural grounds. The grain sizes of the material used (Table 3.4) were also based on sizes found in natural grounds.

The new spawning grounds were laid out in late summer, when fields are usually sufficiently dry to support vehicles carrying stones and gravel. This also allowed the forces at work during autumn periods of high discharge to shape and settle the material before the trout began to use the grounds for spawning. The investigations undertaken by the Danish Land Development Service revealed the advantage of laying out the spawning grounds in sufficient time to allow the current to reorder the gravel so that it can withstand the impact of high winter discharge.

Five different types of spawning grounds were established (Figure 3.9). Some were mats laid across the entire width of the bed sloping along the axis of flow. Some were laid directly on top of the watercourse bed, where they rose up creating riffles, while others were sunk into the watercourse bed with their upper surface flush with the bottom. This can be a good solution in places where too high water levels can be a problem. Grounds were also laid out that sloped alternately from one side and then the other. In addition, small grounds were laid out that did not cover the entire width of the watercourse, either alternately on one side of the bank then the other, or along mid stream.

The current velocity over the spawning grounds can be increased by reducing the width of the watercourse where they lie. In such cases it is often necessary to stabilize the banks with stones or fascines so that the current cannot erode material free. It is also important to provide suitable hiding places for the coming fry, as well as for the trout that will spawn there.

The best spawning grounds

The investigations showed that the gradient along the reach in which the new spawning grounds are to be laid out needs to be sufficiently great that the grounds can be given the necessary varying slope without too much water accumulating in front of them. The gradient necessary depends on the size of the watercourse. Small watercourses should have a gradient greater than 4‰ while that in large watercourses should not be less than 1.5‰. The spawning grounds should be placed where the gradient along the bed of the watercourse is greatest. The flatter the reach is, the greater the distance between neighbouring spawning grounds has to be since an upstream ground could otherwise be affected by water accumulating in front of a ground further downstream. The size of the spawning gravel used was chosen according to that of spawning gravel found in natural grounds (Table 3.3 and Table 3.4).

The best kind of spawning grounds are flat mats covering the entire width of the bed. If the mats do not cover the entire width, the current will often become concentrated in channels flowing around the grounds. Those that covered the whole width of the watercourse did not become covered with sand during the course of the experiments and were not washed away, and it was in them that fry were found.

The length of the spawning grounds is important if the sedimentation of sand is to be avoided. The larger the watercourse, the longer the spawning grounds can be; however, if the grounds are too long, sand can settle on the surface of their downstream parts. In larger watercourses they can be 10-15 m long, while in smaller watercourses they should not be longer than 4-5 m unless the gradient is considerable.

The distance between neighbouring spawning grounds also helps determine whether or not sand will settle on the grounds. If they are laid too close to each other, the damming effect of a downstream ground will limit the current over the ground upstream such that the sand is not washed on downstream (Figure 3.10). The distance between spawning grounds in larger watercourses should therefore be at least 4 times the length of the mats. In smaller watercourses with a sufficient slope, the distance needs only be 1-2 times the length of the grounds.

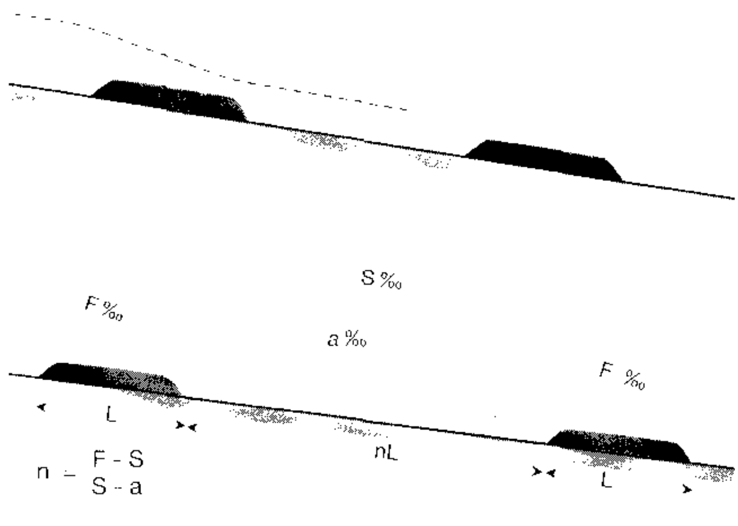


Figure 3.10 *If neighbouring spawning grounds are too close to each other, they may have a damming effect. The optimal distance can be calculated using the formula at the bottom of the illustration. S = the reach slope. F and a = the water surface gradient. Adapted from (9).*

The surface of the spawning grounds must slope in the direction of the current and the gradient of the water surface should be so great that the current has sufficient energy to flush away the sand. In order to minimize damming of water the grounds should cause a water surface gradient of 10-12‰ in a small watercourse and 6-10‰ in a large watercourse.

Sand can ruin spawning grounds

It is not enough to keep the surface of the spawning grounds free of sand. It is also important to ensure that the pores in the grounds do not become blocked with sand and other fine particles. Studies undertaken in a number of watercourses in west Zealand including Bjerge Å stream have revealed how little sand is needed before spawning grounds become ruined (13).

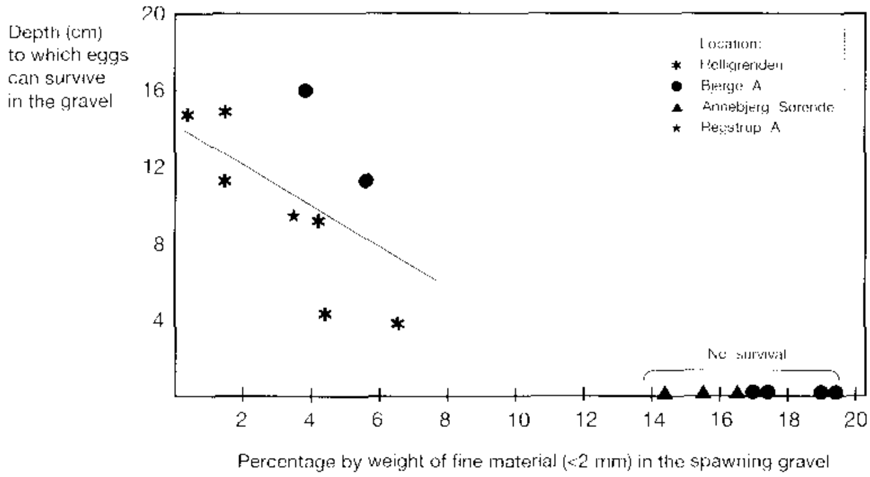


Figure 3.11 *The coarser the material comprising the spawning gravel, the better the survival rate of eggs at increasing depth. When fine material exceeds 14%, no eggs survive.*

In the studies, baskets containing suitable spawning gravel and fertilized trout eggs were buried in the gravel bed of some of the watercourses. The baskets were equipped with a rolled-down plastic curtain which could be pulled up over the basket by means of a string. The baskets with gravel and eggs remained in the spawning grounds until the fry were expected to emerge. The baskets could be retrieved to examine whether the eggs were still alive and developing; before retrieval the baskets were closed within the plastic curtain so as to ensure any fine particles were not washed away. Thereafter, the number of dead eggs was determined and the amount of sand and other fine particulate matter that had sifted into the gravel was measured.

It was found that when the amount of sand and other fine material (under 2 mm in diameter) in the spawning gravel was under 7%, live eggs were present. This indicates that sufficient water flowed through the pores to supply the eggs with enough oxygen. When the amount of fine material exceeded 14% all the eggs died, even if the surface of the gravel appeared to be clean (Figure 3.11).

The amount of sand that settled in the baskets was independent of whether the current over the spawning grounds was strong or weak. A strong current is apparently not always sufficient to keep the pores free of sand. The fine material content of the spawning gravel was found to depend solely on how much sand was transported over the spawning grounds.

It is therefore important to keep migrating sand to a minimum if spawning grounds are to be kept functional. This can be achieved either by undertaking gentle weed clearance (see p 86), or by constructing a sand trap upstream of the spawning grounds.

New spawning grounds in the river Gudenå

In the early 80's the trout and grayling populations of the upper part of the river Gudenå were much smaller than could be expected considering the character of the watercourse. Vejle County considered this to be caused by a lack of spawning grounds.

It was therefore decided to establish new spawning grounds. In 1986 five new spawning grounds were laid out in the upper reaches of the river Gudenå between Tørring and Hammer Mølle. The gravel combination used matched that found in other spawning grounds in the Gudenå (14).

The new spawning grounds were 20 m long and 40 cm thick. Half of them were sunk into the river bed such that they protruded 20 cm over the surrounding bed. The gradient over the spawning grounds generated a current velocity of at least 40 cm/sec. Parts of the river wider than 3 m were narrowed with fascines and fibertex was laid under the gravel in parts where the original bed was comprised of loose peat.

Figure 3.12 *New spawning ground with turbulent water in the river Gudenå.*

Upstream of the spawning grounds two sand traps were constructed to catch sand migrating from the upper reaches. They were emptied 5 times in 1987, 3 times in 1988 and only once annually thereafter. This decrease in migrating sand coincided with cessation of weed clearance in that section of the river Gudenå.

When the weed is allowed to stand in a watercourse, the erosion capacity of the water apparently diminishes.

Live eggs of both trout and grayling were found to be present in the spawning grounds, as was soon reflected in the river. Thus there was already a large population of trout fry in the vicinity of the spawning grounds in 1988.

The grayling, a salmonid that spawns during the spring, also uses the new spawning grounds. As a result there is now a large population of grayling in the upper reaches of the Gudenå, not just in and around the spawning grounds, but also downstream (Figure 3.13) (15).

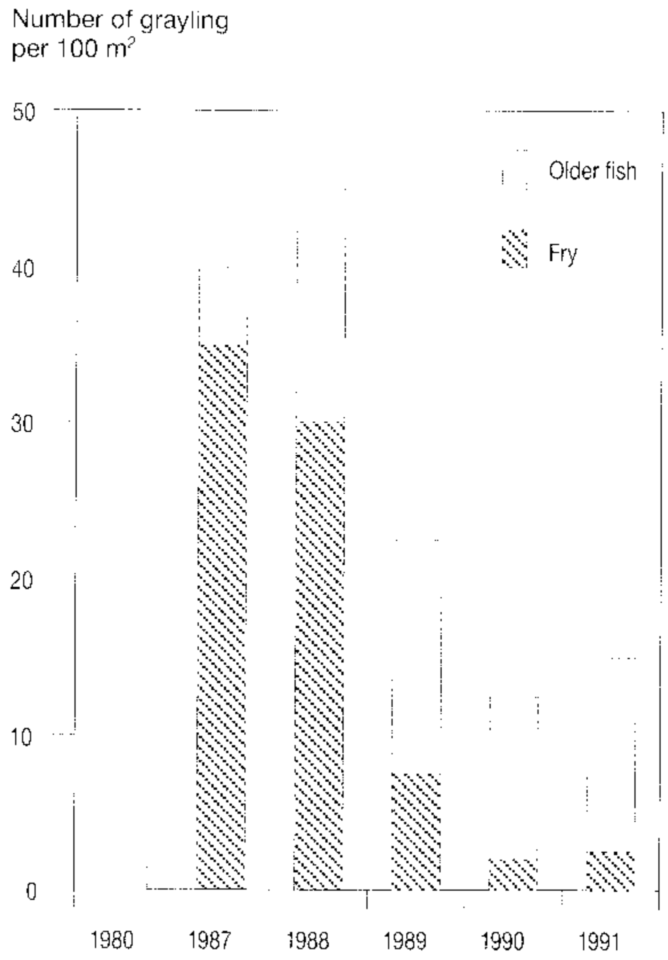


Figure 3.13 *A strong population of grayling has now re-established in the upper section of the river Gudenå.*

Restoration of spawning grounds in the river Kongeå

Many spawning grounds are so tightly cemented together by ochre and sand that trout are unable to dig spawning nests in them, an example being those in the many large riffles found in the river Kongeå. They have a hard surface and are overgrown with leaves of bur reed which trap the sand so that it covers the riffles.

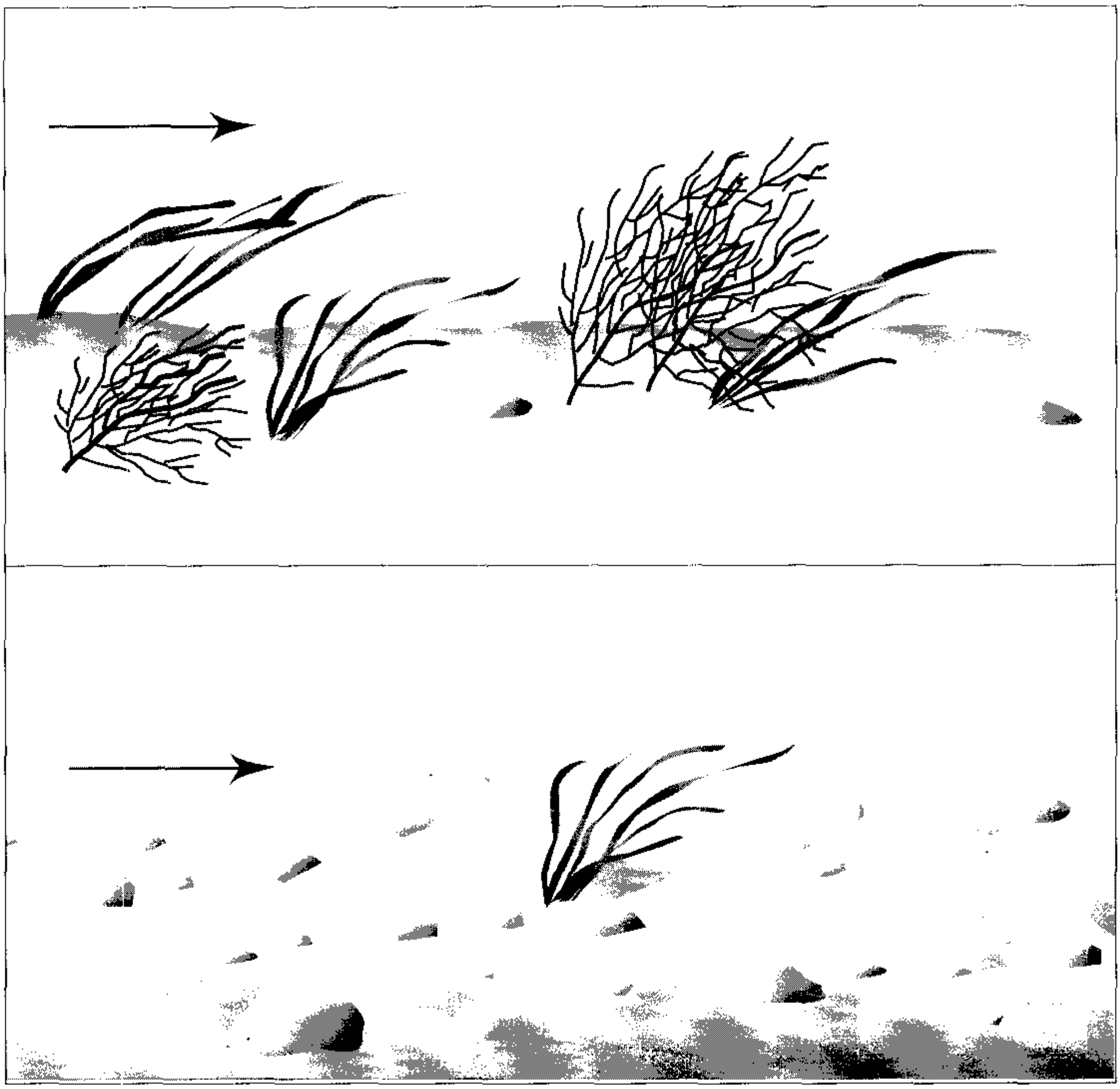


Figure 3.14 *The re-establishment of riffles in the river Kongeå in 1991-1992 changed its bed profile markedly such that spawning grounds suitable for trout are now present (Adapted from 16).*

In the winter of 1991-1992, Ribe County in collaboration with the Vejen District Anglers Association turned over three large but ruined riffles with a dredging machine, the shovel of which was perforated to allow the finer particles to fall back into the watercourse. Digging was commenced upstream of the riffles so that the fine material was flushed downstream. The bed was dug through deep enough to ensure the removal of weed roots. The structure of the new bottom was loose and undulated in comparison to the hard and flat bottom of the old bed. In the summer of 1992 the bottom was found still to be loose, and the current over the riffles was stronger than before because many parts of the bed were elevated and vegetation was lacking. The stronger current and absence of vegetation prevented the riffles from becoming covered with sand.

The impact of the restoration work on trout spawning has not yet been studied, but it is clear that the restored riffles have become better and more varied habitats for trout and carrying capacity has consequently increased. In one comparative study of three restored riffles and three ruined riffles, twice as many fish were found in the restored riffles.

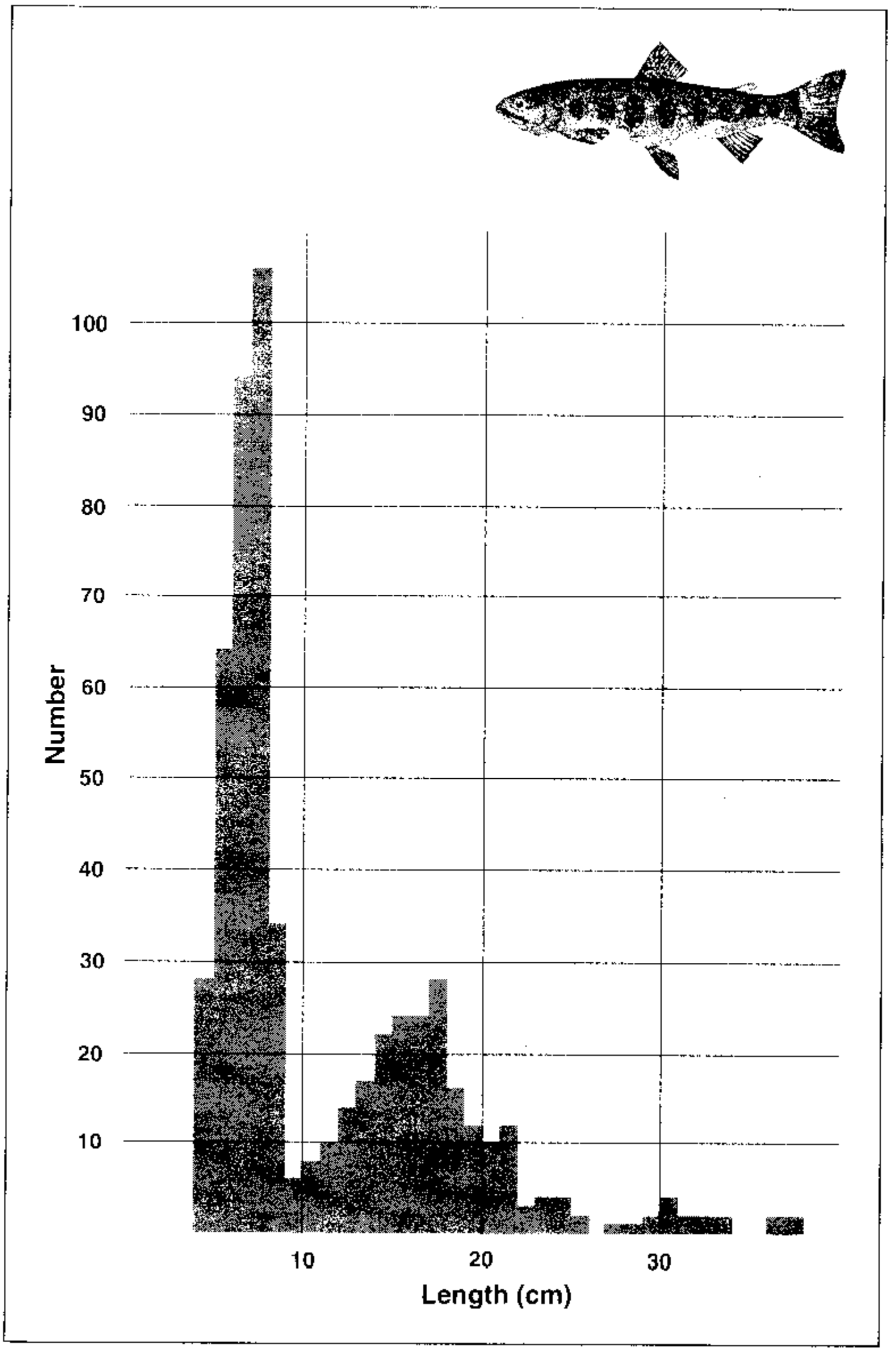


Figure 3.15 *A self-reproducing trout population has now become re-established in one of the tributaries of the river Kongeå. Adapted from (17).*

The new spawning grounds work

The beneficial impact of the new spawning grounds is now starting to make itself apparent. In an increasing number of locations, self-reproducing trout populations have become established. For example, small trout are found in a tributary of the river Kongeå that originate from the new spawning grounds (Figure 3.15), albeit that the parental fish are derived from stocking operations. New spawning grounds are an important means to improve conditions for the trout that inhabit a watercourse.

However, it is not enough just to provide good spawning grounds, good hiding places and clean water - the trout have also to be able to reach the spawning grounds. Access to many of the good spawning grounds is still prevented by weirs, dams, etc.

The next chapter provides examples of how such problems may be overcome.

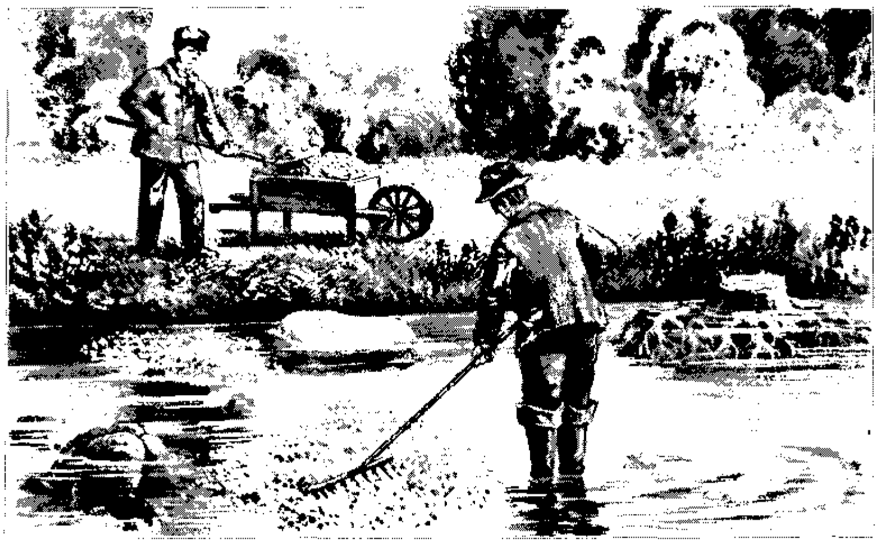
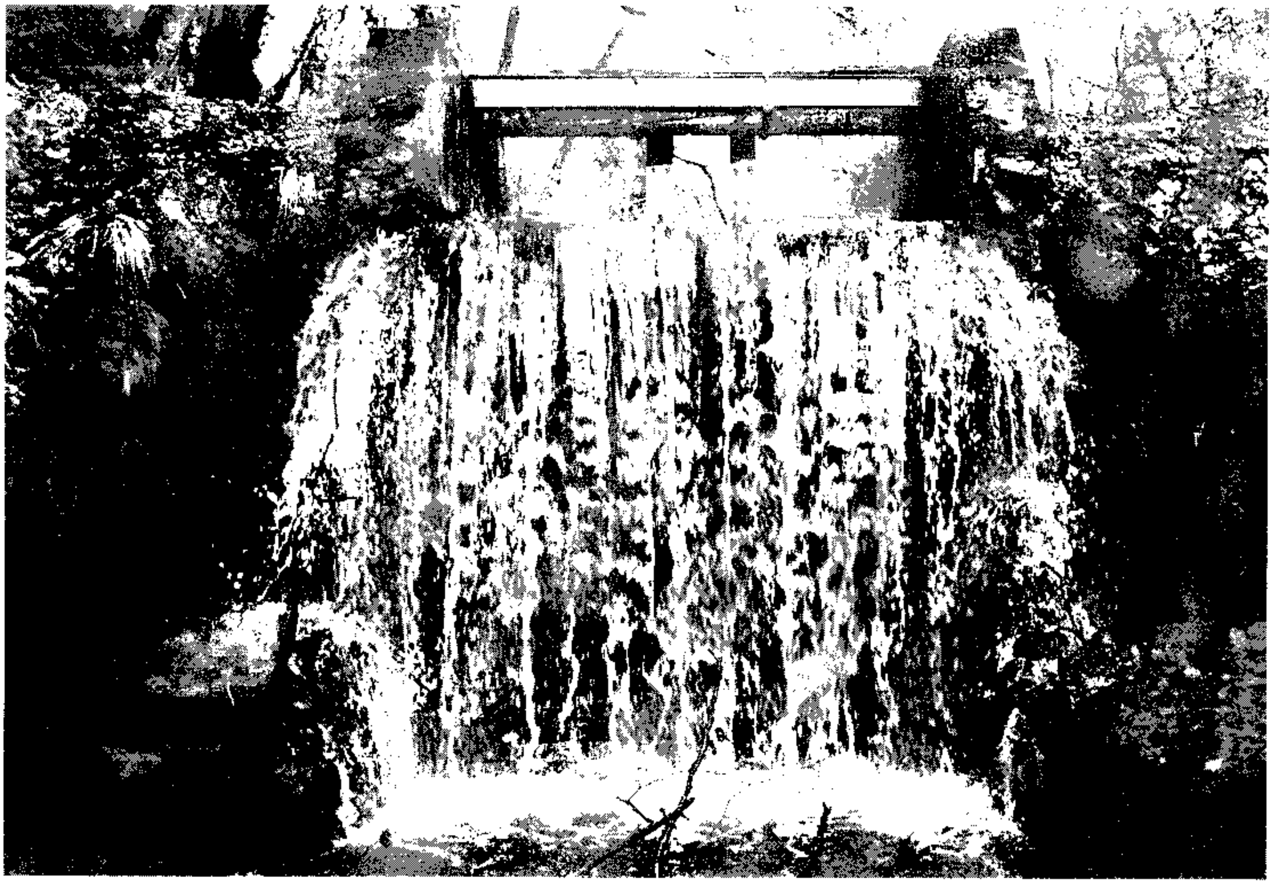
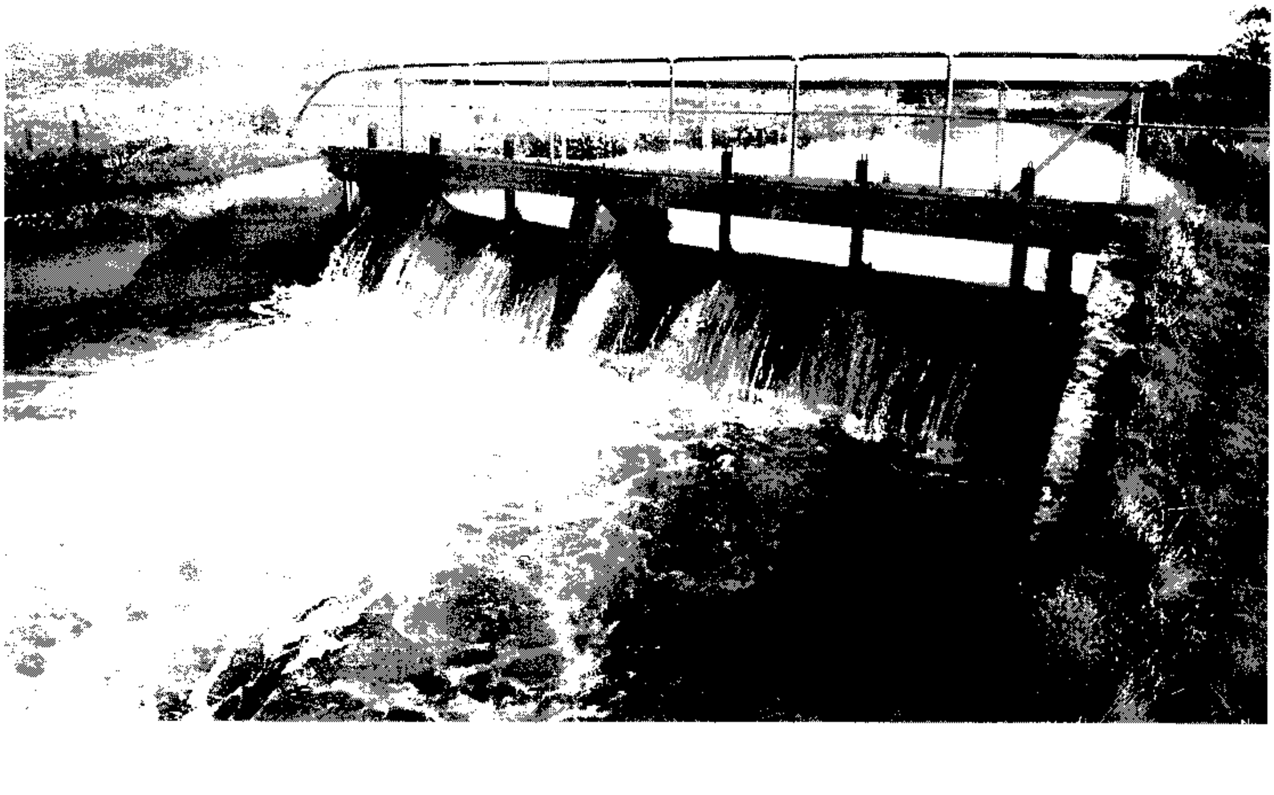


Figure 3.16 *Spawning grounds were also established and maintained in the old days.*





4. Free passage for fish

Many stream fish are "migratory". This means that they do not spend their entire life in the same section of the watercourse. Some fish actually live a large part of their life in a completely different place. Salmon and sea trout live much of their life in the sea, lake trout in lakes, and eels are born in a distant marine area. They spend only part of their life in the watercourse. All these fish have to be able to move freely, i.e. migrate, up and down the watercourse.

However, the way is often barred, especially the way up against the current. This could be due to part of the watercourse being culverted, for example short sections under roads or longer sections where a watercourse is culverted so as not to hinder work in the felds.

The many weirs constructed in regulated watercourses can bar the way for most types of fish. Even if the weirs are not very high, the fish are often unable to spring over them because the concrete spillway onto which the water falls limits the water depth and thereby hinders the fish in gaining sufficient spring for the jump.

Real dams, such as those at millponds, are impossible for fish to pass. For this reason it has for many years been customary to build fish ladders. Nowadays, passageways are constructed that better blend in with the natural surroundings.

Efforts to deal with such obstructions have already shown good results in Danish watercourses.

Culverted watercourses

One of the most common obstructions in small watercourses are culverted sections under roads. If there is sufficient water and the current is not too strong, trout can usually swim through them. However, in many instances they are unable to enter the culvert because the outlet is positioned so far above the watercourse that the water exits the culvert as a miniature waterfall.

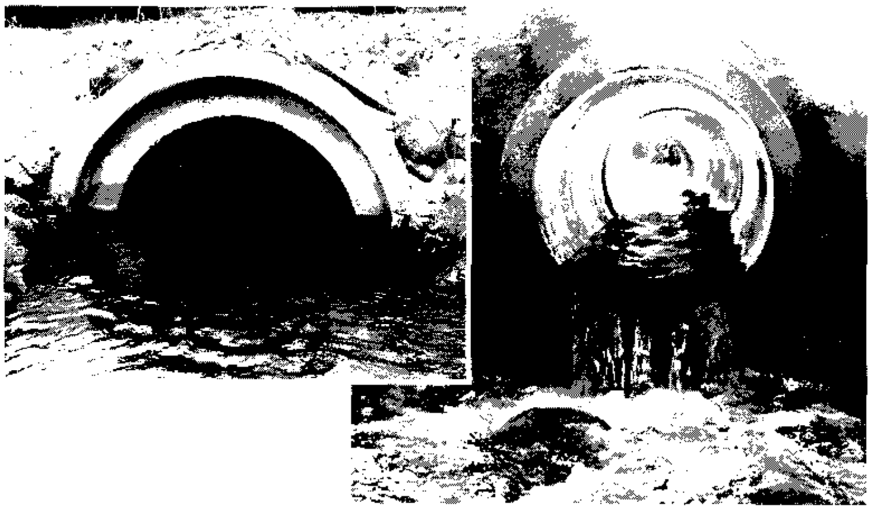


Figure 4.1 *Here is a picture of a sensibly constructed culvert... and a badly constructed one!*

A brook can therefore have a good population of trout up to a culverted section, but few if any trout above that point. They are stopped by the culvert. In Kraftdal Bæk brook, near Fredericia, 25 trout were found below a culvert but only 1 above it (1). As a rule it is a simple matter to ensure that fish and invertebrates can enter such a culvert; the pipe just has to be laid so deep as to eliminate a fall at the outlet, or the fall can be neutralized by constructing a riffle of stones (Figure 4.3). It is common to use fist-sized pebbles from fields. However, such stone riffles may dry out during dry summers because the water trickles down between the stones.

Figure 4.2 *Many watercourses are interrupted by culverted sections.*

Even strong swimmers such as sea trout have to abandon swimming against the current if the culvert is too long. It is therefore important to weaken the current or provide areas of refuge from the current within the pipe.

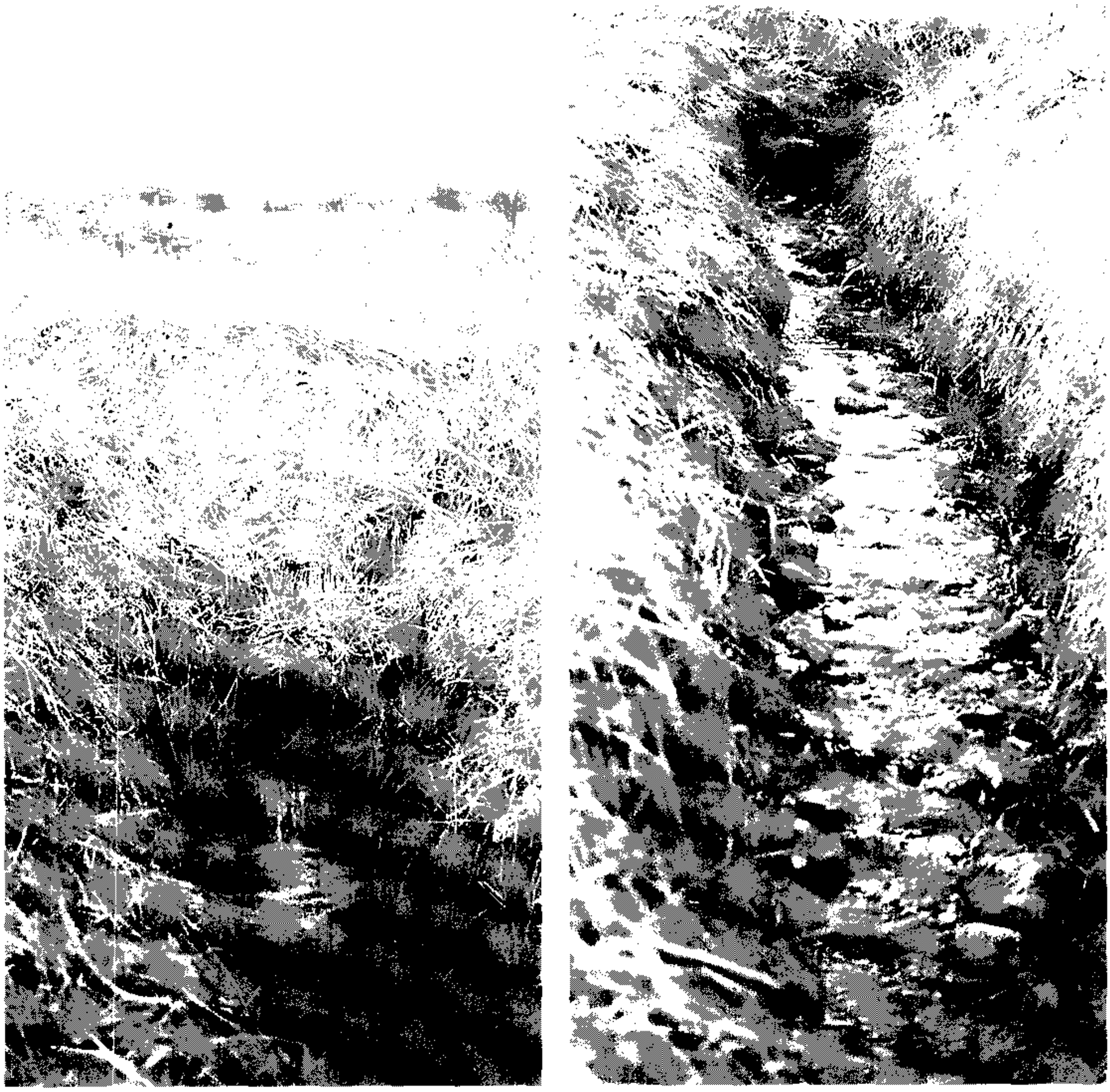


Figure 4.3 *This is how Thisted Municipality improves poor passage at culverts. Photograph by Frank Eliasson.*

Vejle County has made a simple but effective inset that can be fitted in culverts to create refuges and resting places for fish attempting to swim through them. The insets are comprised of a wooden plank with a centrally positioned notch that is fixed in an iron bracket having the same form as the culvert. The insets are screwed onto the inside of the culvert at 1-2 m intervals such that the boards sit on the bottom like lamellae (Figure 4.4). They are angled against the current such that trout and other fish can swim through the notch in the boards and rest in the basins between adjacent boards (2).

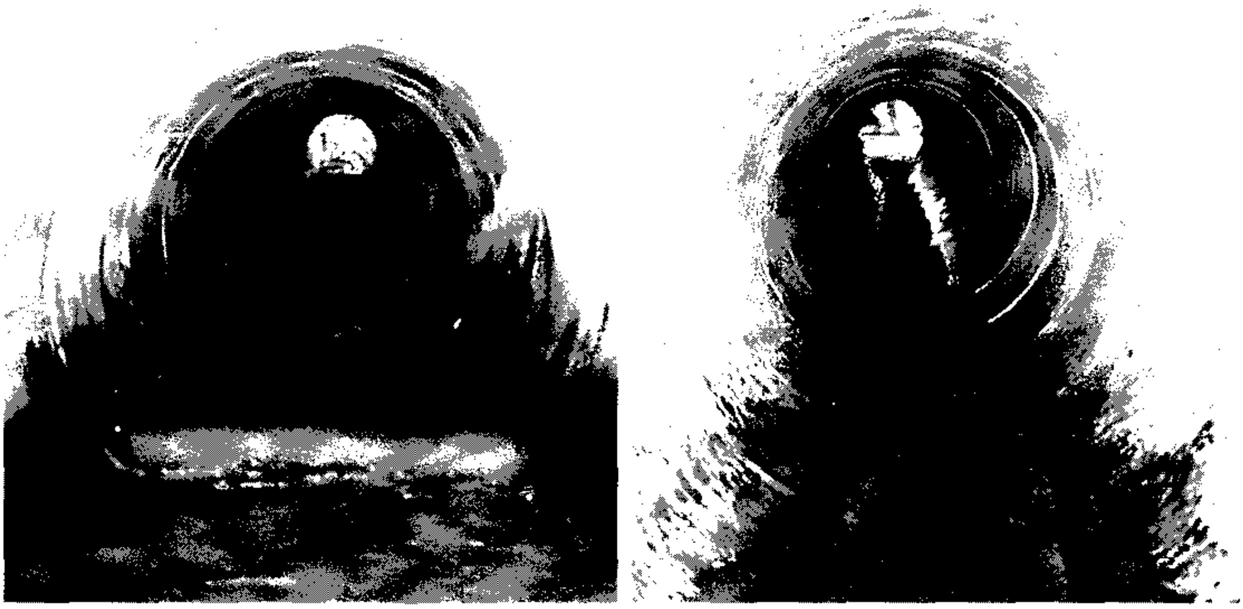


Figure 4.4 Vejle County mounts wooden lamellae in culverts to create resting basins. The photograph on the right shows the same culvert before lamellae were installed. Photograph by J. Wolf Jespersen.

Access to new spawning grounds

Truds Å stream, a tributary of Kolding Å river, runs through a 68 m long culvert under a motorway. The gradient of the culvert is so steep and the current so strong that even sea trout could not traverse the culverted section. During the autumn, when they attempted to migrate up Truds Å stream to the upstream spawning grounds, they were stopped by the culvert under the motorway. The many trout therefore had to be content with using the spawning grounds in the lower 300 m of the stream. The trout could not pass through the culvert and utilize the good spawning grounds that stretched over an approx. 1.5 km reach upstream of the culvert. The trout literally queued up at the few spawning grounds available in the lower reaches of the watercourse. This resulted in the laying of many more eggs than such watercourse reaches can normally carry, which is approx. 80 eggs m^2 (3). This was reflected in the large number of fry observed the following year. There was absolutely no space for the large number of alevins that hatched from the eggs and there was excessive mortality when they emerged from the stream bed. A large number of the fry perished simply because of the shortage of space.

In 1990, Vejle County established a simple weir with a retaining wall below the culvert (4). This elevated the water level within the culvert and the current thus became so weak that sea trout could swim through. In the 1990 spawning season the sea trout were therefore able to utilize the many spawning grounds in the upstream reaches. The number of sea trout that entered the stream was no greater than the previous year, and the number of eggs laid was therefore no greater; however, the eggs were laid over a much larger area and the density of both eggs and fry was therefore more in line with the carrying capacity of the stream. In that spawning season, many more fry therefore survived in the stream. When the fry population was estimated in 1991, there were 3 times as many fry per 100 m^2 of the stream than in 1990 (Figure 4.5). In contrast, the number of older trout, which originate from the time when only few survived, was the same in both 1990 and 1991.

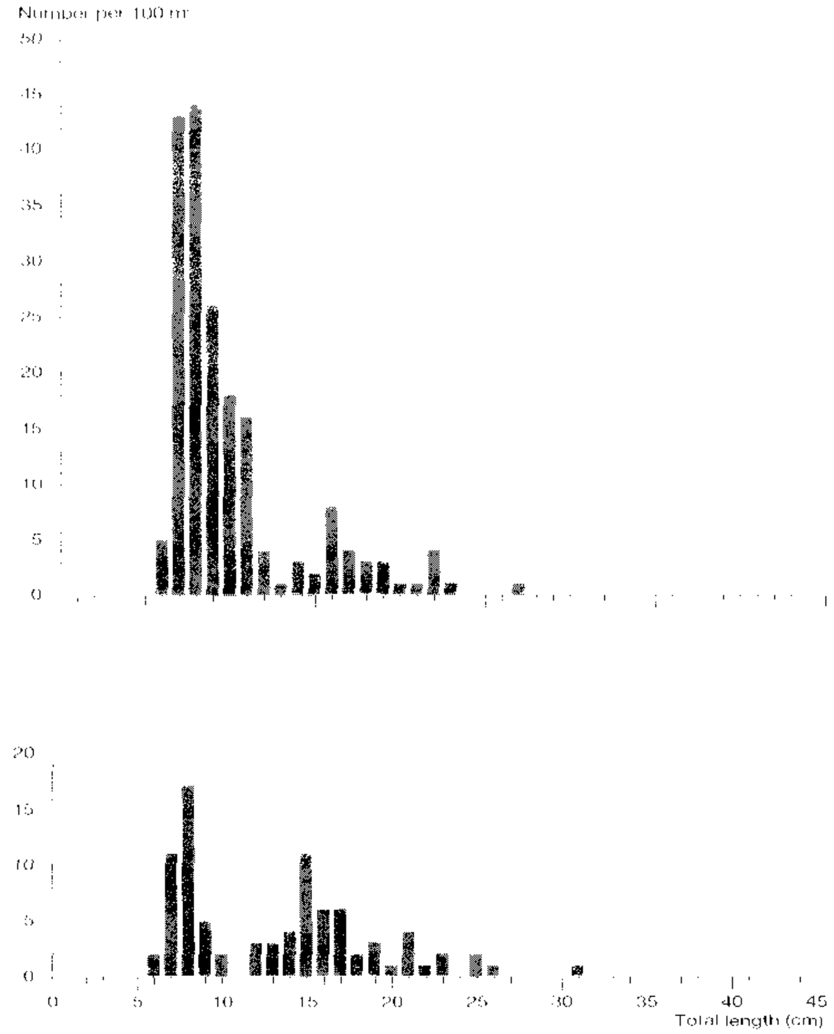


Figure 4.5 *Trout size distribution before (lower panel) and after (upper panel) the restoration of access to the spawning grounds upstream of the culverted section of Truds Å stream. Notice the difference in the number of small trout. Adapted from (4).*

This finding indicates that the small tributaries are of decisive importance for the trout population. This applies, for example, to many of the small tributaries whose course mainly runs through hills or forests, but of which the last flat reaches before the main stream are culverted. Such culverted sections can block access to good trout spawning grounds in upstream tributaries. Another effect showing the importance of access to new reaches in Truds Å stream can be seen in Figure 4.6. In June 1992, the upper reaches of the stream were strongly polluted by slurry, resulting in trout death in a very long section. In 1993 a good trout population had re-established, the fish being derived from the new fry (5).

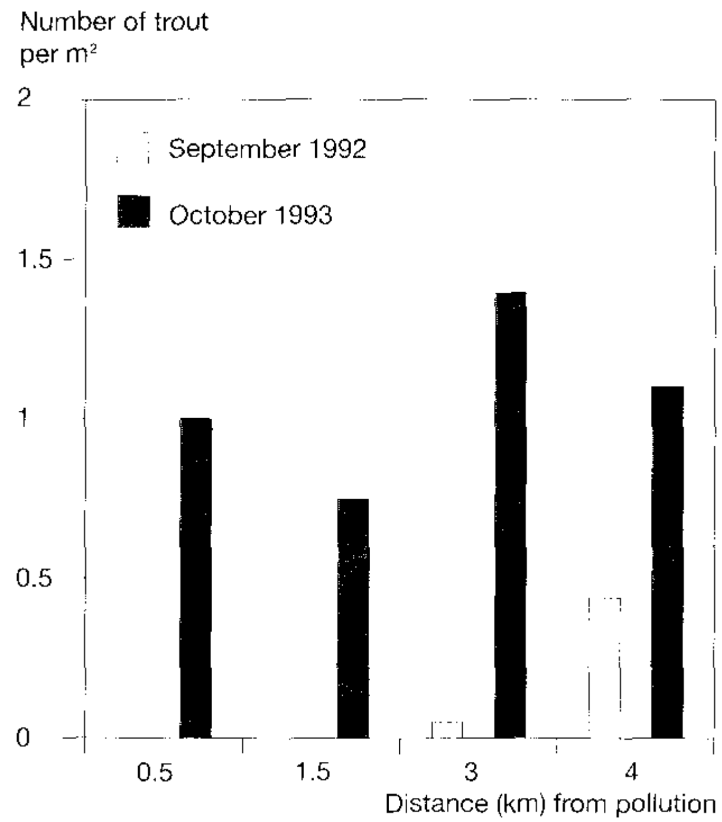


Figure 4.6 *Even though the 1992 trout population of Truds Å stream died as a result of slurry pollution, a new natural population re-established in 1993.*

Exposing buried watercourses

When long sections of a watercourse are culverted it is not only the current that can hinder the passage of fish. Thus some fish, e.g. whitefish, will not pass through a dark culvert (1). Many of the watercourses that are culverted over long stretches have drop manholes to even out the gradient in the culverted section (Figure 4.7). No trout can move upstream past such an obstruction.

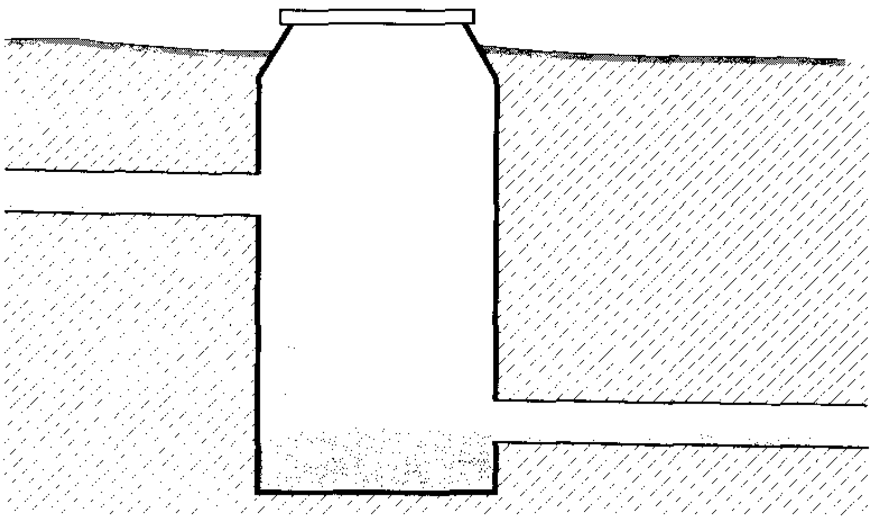


Figure 4.7 *Drop manhole. The culverted watercourses' equivalent of a weir.*

Thisted Municipality has been systematically removing watercourse obstructions. One of the watercourse systems that they have opened for the passage of fish is the brook Isholm Landgrøft, a tributary of Sundby Å stream.

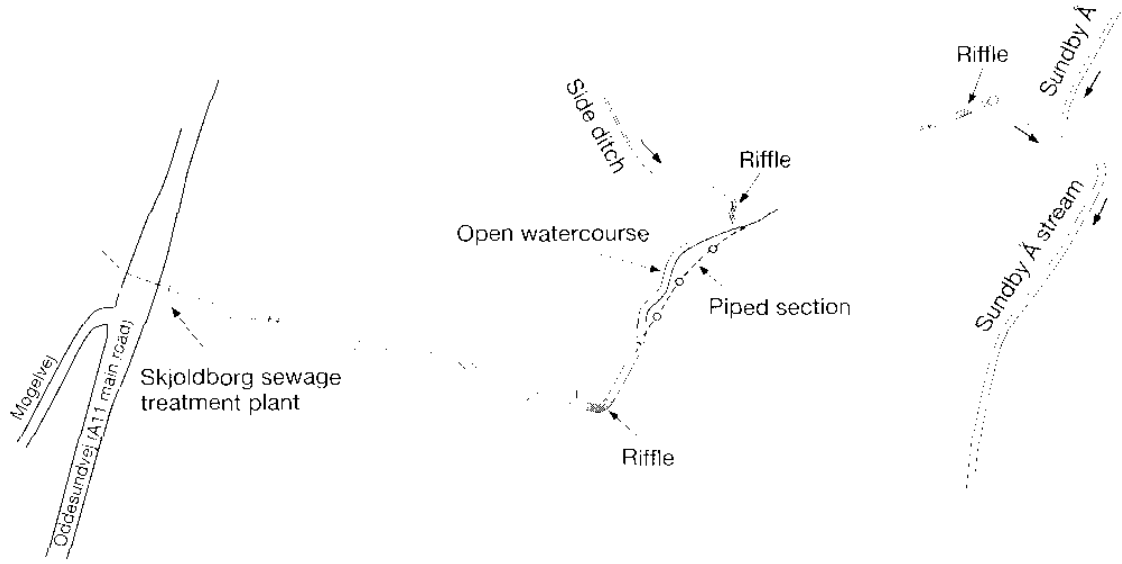


Figure 4.8 On its way to becoming an open watercourse system: the brook Isholm Landgrøft in Thisted Municipality. Adapted from (6).

The objective was to create continuity and free passage in the watercourse system, as well as to provide trout with access to an old spawning ground in the upper reaches, which run through a small valley with a good gradient (Figure 4.8). The central section of the brook Isholm Landgrøft was culverted and included two drop manholes. The eastern drop manhole, which had a fall height of 77 cm, has now been replaced by a 20‰ gradient riffle of field stones. Immediately downstream of the riffle the brook runs through a 20 m long culvert under a small field road. However, as the culvert gradient is only 0.5‰ and the pipe is sunk into the brook bed, fish have no difficulty in passing. The western drop manhole has also been replaced by a riffle, although in this case the culvert has not been dug open. Instead, a new section of watercourse was excavated that bypasses the culvert, which was thereafter closed. This approach had the advantage, among others, that the excavation work could be undertaken under dry conditions (Figure 4.9). The new section of watercourse has a gradient of 3‰ and a bed width of 65 cm.

It is rather unlikely that trout will be able to find spawning grounds in this little spring brook, but invertebrates can now wander freely. In fact, the day after the Isholm Landgrøft project had been completed, the riparian observed trout in the brook for the first time since it had been culverted in 1950. At the end of 1993, the sewage effluent that had been polluting the upper reaches of the brook was redirected to Vilsund sewage treatment plant. Thus Isholm Landgrøft brook is once more ready to host spawning trout.

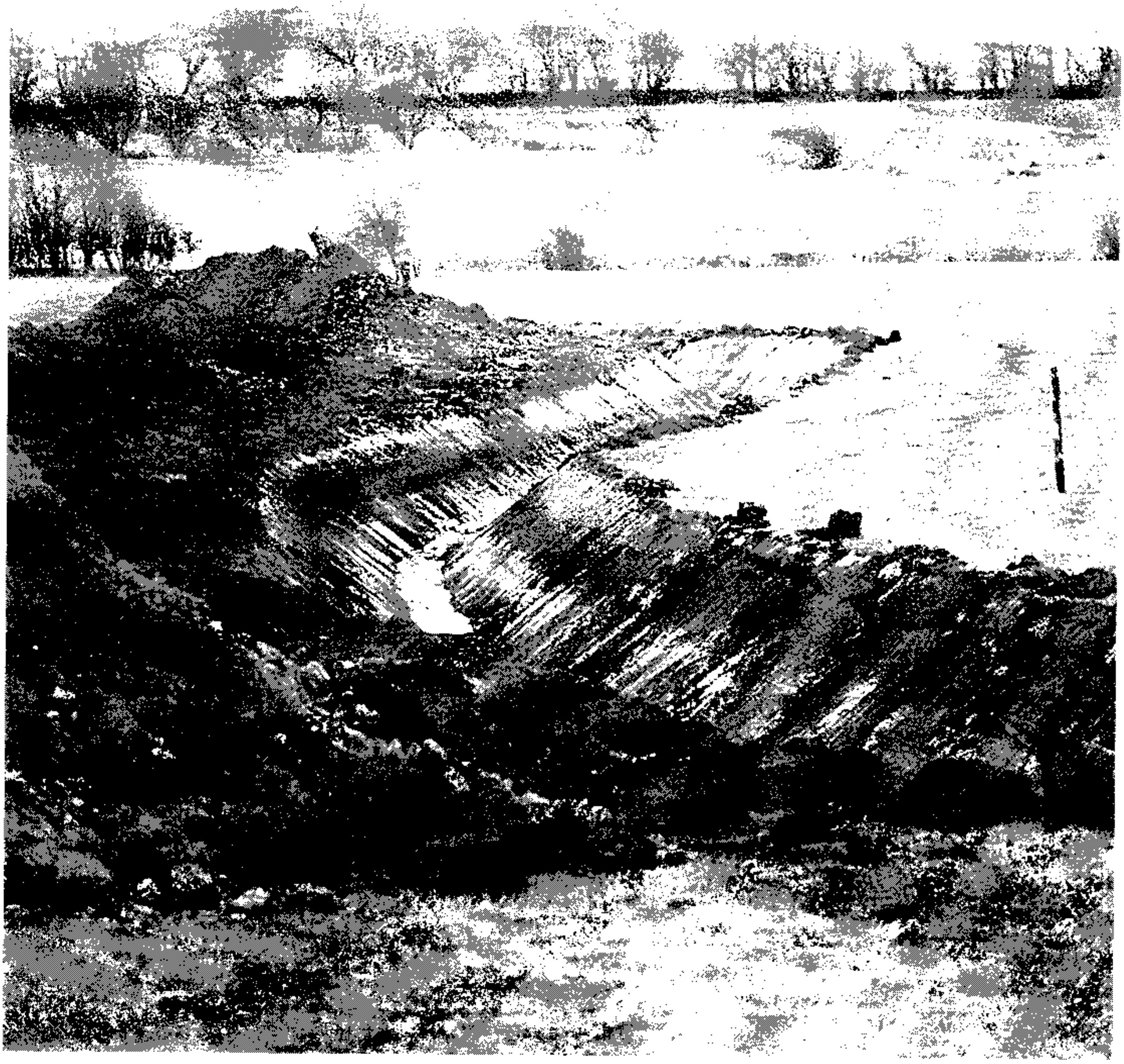


Figure 4.9 A meandering brook was excavated alongside a culverted section of Isholm Landgrøft brook. Photograph by Frank Eliasson.

Thisted Municipality uses its own manpower and machines for as much watercourse restoration work as possible. The work is carried out as employment projects supplemented with help from contractors. The budget for opening up the culverted section of Isholm Landgrøft brook is shown in Table 4.1.

Table 4.1 The budget for a Thisted Municipality restoration project: Opening up of a culverted section of Isholm Landgrøft brook.

Estimate:	
1,100 m^3 excavation and levelling DKK 25/m^3	= DKK 27,500
3 pc. 80 cm dia. crossings - 26 m DKK 550/m	= DKK 14,300
12 hours DKK 400	= DKK 4,800
50 m^3 stone and gravel levelled DKK 175/m^3	= DKK 8,750
Total, excluding VAT	= DKK 55,350
+ 22% VAT	= DKK 12,177
Total, including VAT	= DKK 67,527
+ unexpected expenses	= DKK 7,473
Total	= DKK 75,000

Animals find the new brooks and streams

Stream invertebrates live a dangerous life; the current can easily flush them downstream. The water can sometimes be full of drifting invertebrates, especially during the evening and morning hours. This is exploited by trout, which wait in the shelter of weed beds and stones to catch any invertebrates that drift by (Figure 4.10).

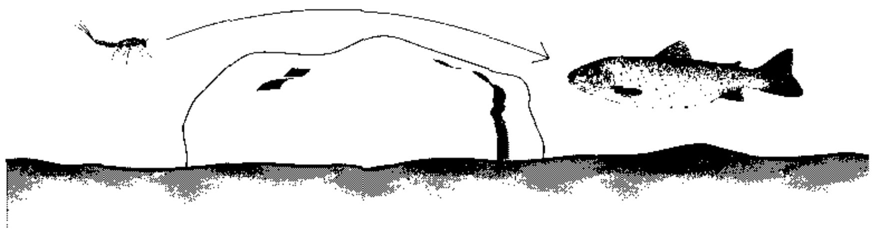


Figure 4.10 Trout catch invertebrates that drift with the current.

The current sweeps so many invertebrates downstream that the danger could arise that they completely disappear from the brooks and streams, and end up in the lakes and fjords. However, this does not happen since most invertebrates are able to continually replenish the upstream population by some means or other.

Some species do so by swimming upstream against the current. One example is the freshwater shrimp, one of the most common stream invertebrates. It is an important food resource for trout, and it is substances in its skin that colour trout flesh red. The freshwater shrimps are flushed downstream when the current is strong. However, large flocks of freshwater shrimps periodically migrate upstream against the current, moving close to the banks, where they are sheltered from the main current.

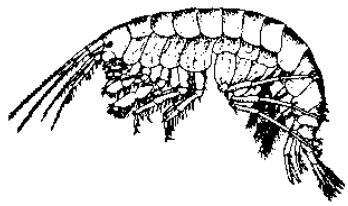


Figure 4.11 *The freshwater shrimp.*

Most insects wait to migrate against the current until they are adults and change to life on land. Then the females fly upstream and lay their eggs there, i.e. they carry the next generation upstream to counterbalance their downstream displacement by the current (Figure 4.12).

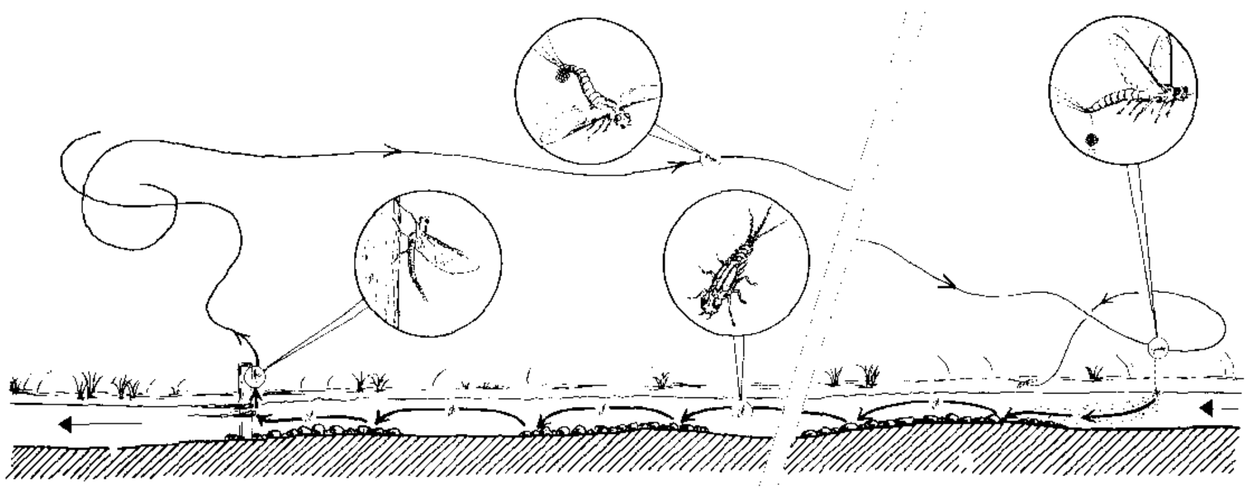


Figure 4.12 *Adult insects fly upstream against the current and lay their eggs further up in the watercourse than where they themselves hatched.*

However, not all aquatic invertebrates can easily find their way back to watercourses from which they have disappeared. Even flying insects can have a difficult time recolonizing barren watercourses. For example, some species of Caddis fly remain very close to their watercourse of origin, and it can therefore take a very long time before they migrate into other watercourses (7).

Nevertheless, many animals quickly colonize culverted brooks that have been opened up; they either drift down from open reaches upstream, or travel up from downstream reaches.

In Enggård Bæk brook (Figure 4.13), a flock of freshwater shrimps numbering in the thousands was observed migrating upstream through the brook as early as October of the year the formerly culverted brook was opened up. Moreover, both mayflies and buffalo gnats laid eggs in the brook only a few months after it had been opened up.

Figure 4.13 *Enggård Bæk brook; formerly culverted, now open and meandering.*

Migration by freshwater shrimps leads them into new and old watercourses as long as their passage is not blocked by obstacles such as culverts that they are unable to pass.

Figure 4.14 *Although a brook may dry out, this is not always the same as losing the animals for ever. New ones will migrate upstream against the current. However, a culvert such as the one shown will prevent the passage of animals such as fish and freshwater shrimps.*

If part of a brook is blocked, an animal such as the freshwater shrimp cannot pass through. A good example of this is Ibæk brook near Vejle. The brook was divided into two by an obstruction that prevented both fish and invertebrates from moving further upstream. The brook dried out in the summer of 1989, and the freshwater shrimps died out. In the years that followed a new population only recolonized the section of the brook downstream of the obstruction (Table 4.2).

Table 4.2 Freshwater shrimps disappeared from Ibæk brook when it dried out, and only recolonized the reaches downstream of an obstruction that prevented their passage. Adapted from (8).

Season	Downstream (No./sample)	Upstream (No./sample)	
Spring 89	61	45	Brook dries out
Spring 90	38	0	
Autumn 90	72	0	
Spring 91	31	1	

Riffles instead of weirs

One of the most common types of watercourse obstruction in Denmark is the weir, weirs often serving as "steps" in regulated watercourses. In many watercourses throughout the country they have been systematically removed or altered to allow fish to migrate to upstream reaches. One of the first watercourses in which the weirs were removed was Hjortvad Å stream. It is a tributary of Ribe Å stream, and runs through both Sønderjylland and Ribe Counties. When Hjortvad Å stream was regulated in the 1950's, 14 concrete weirs were constructed (Figure 4.15).

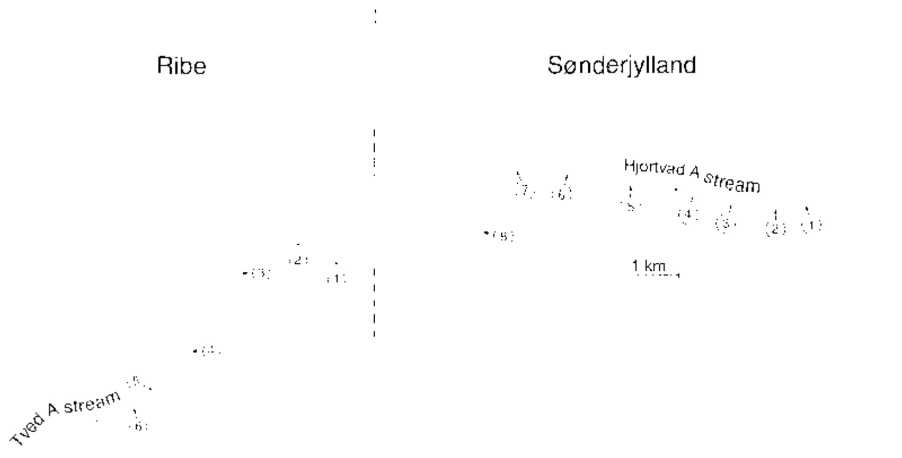


Figure 4.15 Weirs in Hjortvad Å stream, which runs through both Ribe and Sønderjylland Counties.

One of the main reasons why restoration efforts started with Hjortvad Å stream was that the stream had been an important spawning ground for houting (the Wadden Sea salmon), which was close to becoming extinct.

First, Ribe County removed the six large weirs in their part of the stream in 1987-88 (9). To gain experience on how to best convert the weirs, three different firms of consultants were invited to put forward proposals. The latter were so different from each other that the three firms were each given responsibility for transforming two weirs. The total cost of replacing the six weirs with riffles was DKK 1.4 million. The new riffles were soon colonized by weeds such as water crowfoot and pondweed, which provide good hiding places for the fish and good living conditions for the invertebrates; however, weed also traps sand because the current is attenuated so much that the sand cannot be flushed further downstream.

Table 4.3 *The number of trout increased after the weirs in the Ribe County section of Hjortvad Å stream were replaced by riffles. Adapted from (9).*

	Before rebuilding, 1987	After rebuilding, 1988
Riffle 1	8	55
Riffle 2	10	54
Riffle 3	16	52
Riffle 4	6	17
Riffle 5	2	29
Riffle 6	>1	21

Before the riffles were made, there were only few trout in the vicinity of the three uppermost weirs in the Ribe County section of the stream. The year following the changes, the population was considerably larger (Table 4.3). Moreover, in the three uppermost riffles the number of young fry increased 6- to 15-fold relative to the number previously observed. In both the winter of 1988/89 and 1989/90, large sea trout have been seen in the new riffles and in the winter of 1988/89 approx. 50 spawning grounds were counted. Houting can also pass the new riffles, and in the winter of 1990, schools of 600-1,000 fish were seen ready to spawn there.

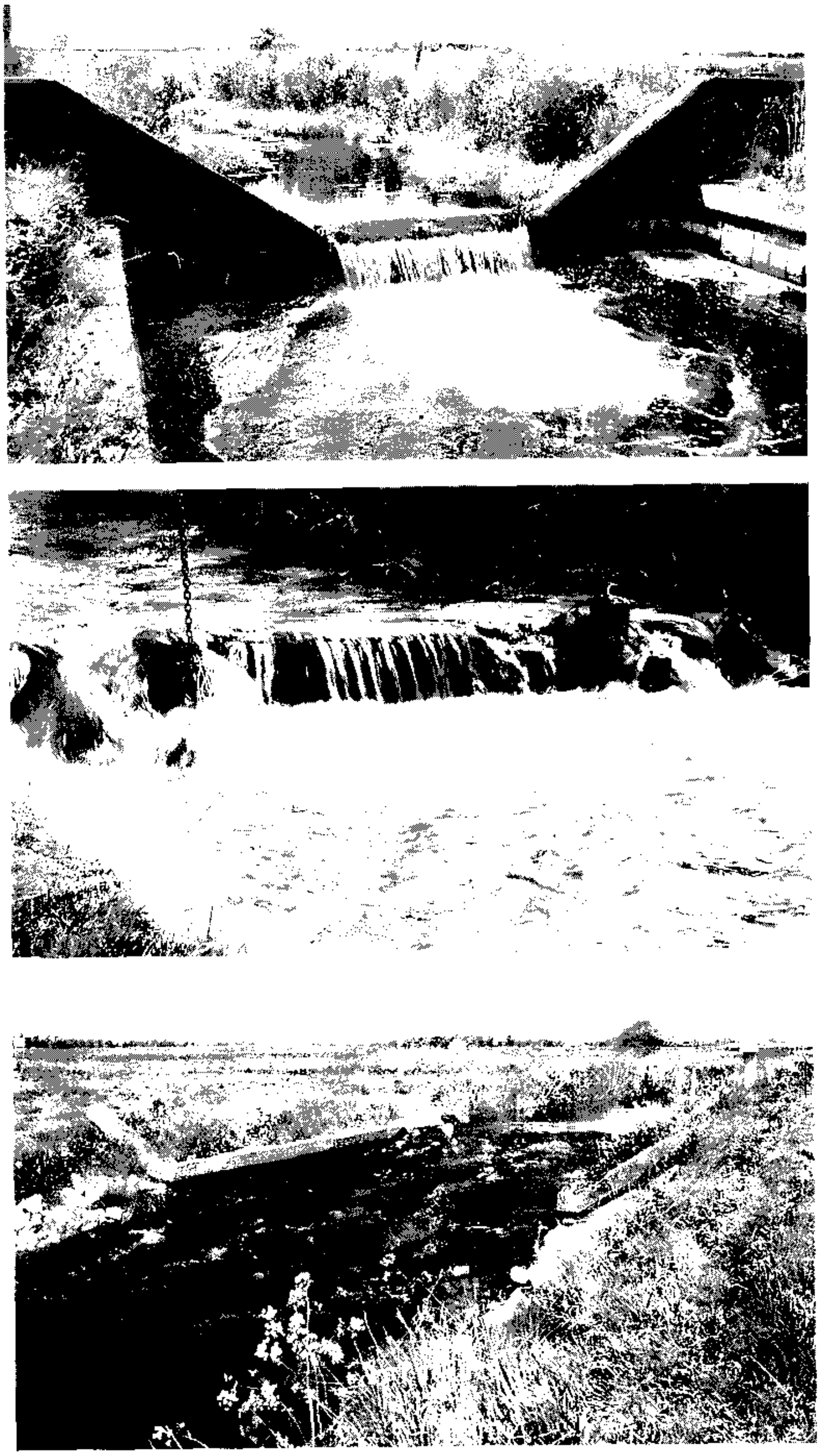


Figure 4.16 *This is how weirs were modified in Sønderjylland in 1993; they were broken up and replaced by riffles.*

Cheaper restoration measures

The experiences gained in Ribe County have subsequently been applied to cheaper measures. For example, Sønderjylland County replaced the remaining weirs in Hjortvad Å stream with stone riffles in 1990. Field stones were simply unloaded in such a way as to form a long stone ramp from the weir and on downstream. As a result trout and houting now have access to the entire length of Hjortvad Å stream.

Thisted Municipality have also developed inexpensive and effective solutions whereby the work is undertaken as employment projects. Riffles have been constructed using field stones, the only additional costs being for loading the stones.

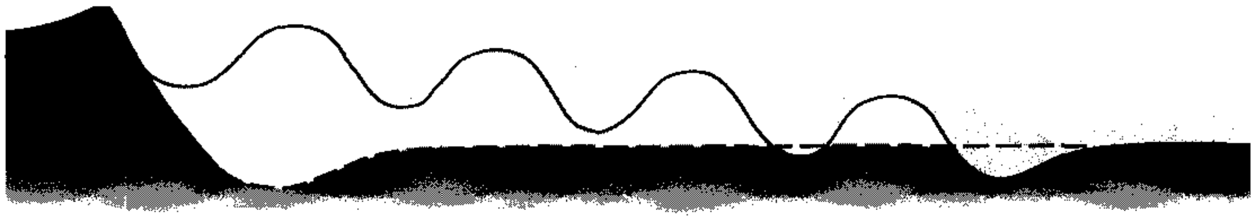


Figure 4.17 *A stepped riffle has refuges, where fish can rest.*

If the weir is high, the riffle has to be sufficiently long that the gradient does not hinder the fish in traversing the riffle (see page 133, however). A riffle can be made shorter by establishing stone ramparts perpendicular to the current with basins between them (Figure 4.17). Fish can rest in the basins after having passed through the strong currents running over the ramparts. This type of riffle is termed a stepped riffle (10).

Viborg County has also systematically removed watercourse obstructions, priority having among other things been given to how great an effect the obstructions have (Table 4.4) (11).

In establishing priorities, weight is placed on how large an area the fish will gain access to when the obstruction is ameliorated, as well as on how serious the obstruction is. Some obstructions are classified as "total obstructions", i.e. no fish are

Table 4.4 *Grades of obstruction recognized in Viborg County.*

Total obstruction:	Structures that fish other than eel cannot pass.
Serious obstruction:	Structures that hinder most of the fish stock in utilizing the area.
Selective obstruction:	Structures such as small falls which, even though they have a good water depth in front of them from which fish can spring, are a total or serious obstruction to small fish and fish species that do not spring, but only occasionally a hindrance to larger springing fish.
Less serious obstruction:	Structures that only have limited impact on the optimal use by the fish stock of the area above the structure.

able to pass them except eels at eel weirs. Other obstructions are described as being "serious", i.e. they hinder a considerable number of the fish from passing. Still other obstructions are classified as "selective", i.e. they do not hinder the passage of trout and other fish able to spring, but do hinder the passage of most other fish. Finally, there are the "less serious" obstructions that only slightly hinder the passage of fish.

Many of the obstructions can be ameliorated by building a simple riffle in extension of the weir or whatever other structure is impeding passage. The gradient of the riffle is approx. 10‰, and the riffle is stabilized with railroad sleepers laid perpendicular to the watercourse (Figure 4.18). In Thisted Municipality, surplus kerbstones have been used instead of railroad sleepers (12).

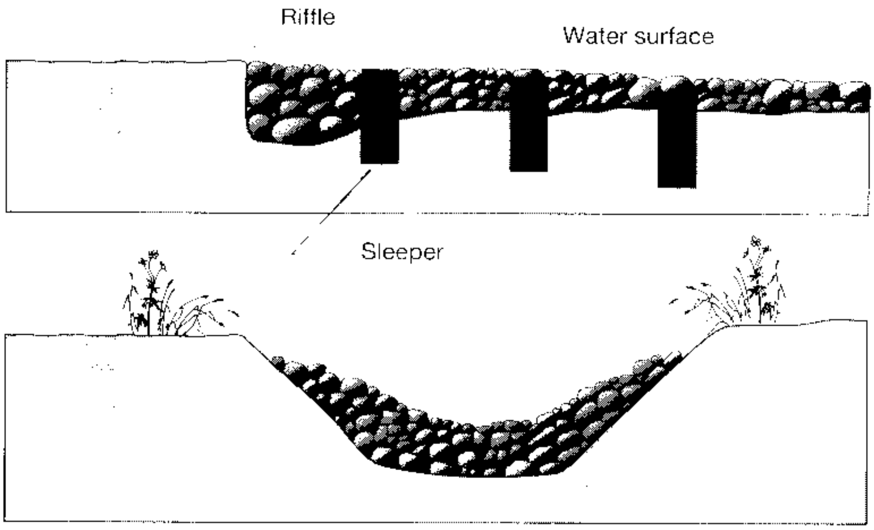


Figure 4.18 *Illustration of how weirs are modified in Viborg County. Longitudinal section and cross section.*

A better bed in Tvede Å stream

In Tvede Å stream, which lies north of Randers Fjord, Århus County converted seven weirs to riffles in 1987/88. Thorough conversion plans were drawn up in the case of four of the weirs, whereas the other three were converted using common sense and experience gained from the first four. The cost per weir was approx. DKK 9,000. Studies of which invertebrate species inhabit Tvede Å stream have been undertaken since 1977 (13). It is therefore possible to follow the trend after conditions in the stream have been improved. The parts where there are once again stones have been recolonized by invertebrates that live on stones (Table 4.5 and Figure 6.20).

The fish population of Tvede Å stream (near Gjesing Mill) has also been studied both before and after conditions were improved. In 1987, there were 0.4 trout per 100 m^2. Shortly

Table 4.5 Invertebrates in Tvede Å stream 1977-91

	77	78	80	82	85	86	87	88	89	90	91
River limpet	0	0	0	5	10	5	15	25	10	75	250
Caddis fly	5	1	1	5	2	6	5	20	15	8	45
Riffle beetle	0	0	0	0	0	0	0	3	1	2	5

after conditions were improved there were 1.3 trout per 100 m^2, which is still a very small population. However, in 1993, 5 years after the improvements were made, the population was up to 36 trout per 100 m^2, i.e. a 90-fold increase relative to the population before the improvements were made (14).

Passes at dams

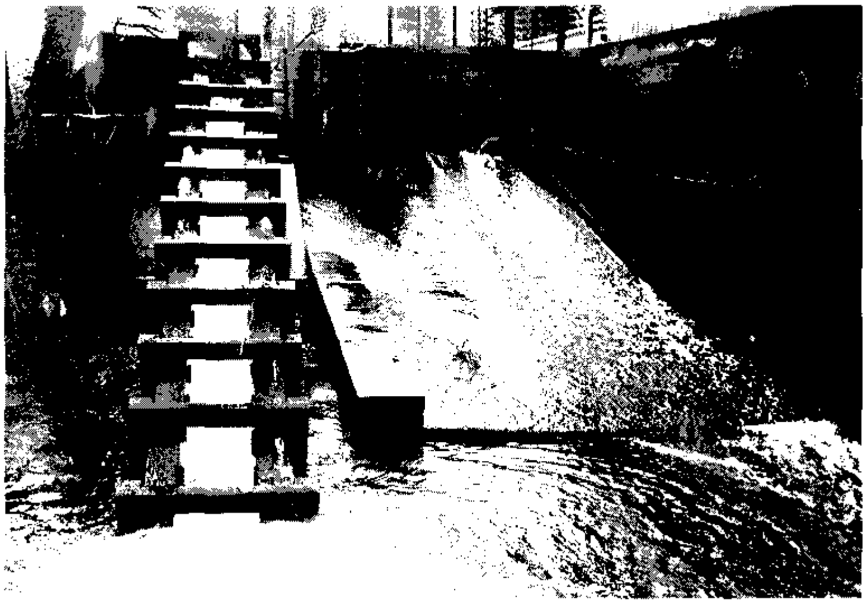


Figure 4.19 *Fish ladders will be an exception in future Danish watercourses.*

Until a few years ago, it was customary to construct fish ladders at those dams that fish needed to pass. The ladders have not always lived up to expectations, however. The fish can have difficulty in finding the ladder entrance, and it is often only the strongest swimmers that can climb the ladder, the weaker fish being unable to do so. Moreover, invertebrates cannot use the ladders at all. Today, the intention is that fish passes should enable all types of fish and invertebrates to pass. Thus fish ladders are nowadays only built in places where there is not enough room for alternative solutions such as bypasses or riffles. Another reason why fish ladders are unpopular is that they are as much out of place in watercourses as are the restoration measures shown on page 48.

Figure 4.20 *Bypasses are a good solution for passes at dams. Here is a well-functioning bypass in the river Skjernå.*

Passes can be created at dams by leading part of the water around the dam in a bypass - a new, small watercourse (Figure 4.20). In this way one can both preserve, for example, a millpond, and yet guarantee the free passage of fish and invertebrates up and down the watercourse. Such bypasses have been constructed in many parts of Denmark.

In Vejle County, the effects of such bypasses on fish have been investigated in more detail (15, 16). One of the examples given is that of Kvak Møllebæk brook, which is a tributary of the river Vejle Å. A dam at Kvak Mill has prevented trout from reaching the good spawning grounds above the millpond for many years. Since the autumn of 1991, a bypass has led Kvak Møllebæk brook around the millpond. The bypass is 170 m long and has a gradient of 14‰. Two sea trout were caught upstream of the pond as early as November of the same year. When the fish population was investigated in the summer of 1992, it transpired that there were just as many trout upstream of the pond as there were downstream; in the bypass itself the trout population was even greater (Figure 4.21), it being a good habitat and there being food for the trout fry. Invertebrates also rapidly colonized the new watercourse.

Vejle County has also established bypasses in other watercourses. As with Kvak Møllebæk brook, it was found that not only are the fish able to easily pass, but the new watercourses prove to be good habitats for them. The bypasses are part of the watercourses and often provide a better habitat than the reaches they connect.

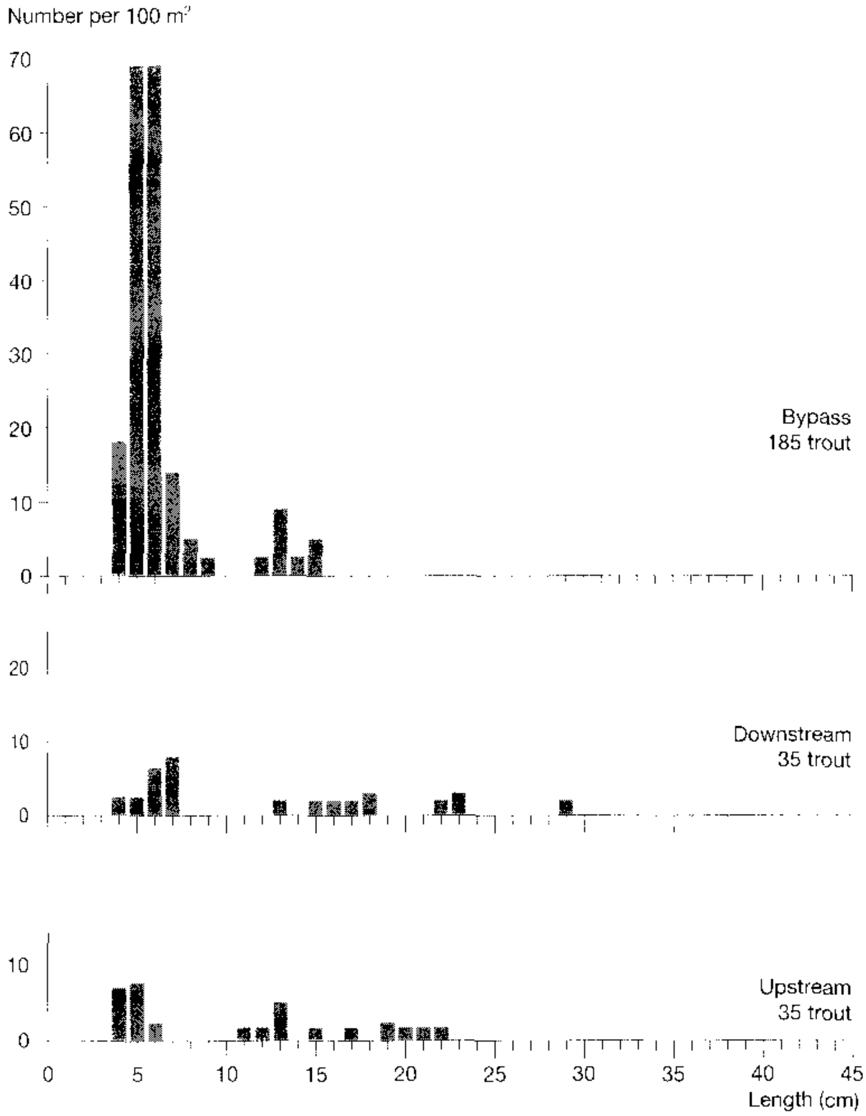


Figure 4.21 *Trout size distribution within, below and above the bypass at Kvak Mill.*

Vejle County has also replaced dams with riffles. Even though the gradient at some of the riffles is steep (up to 30‰), more trout inhabit the riffles than the upstream and downstream reaches (Figure 4.22). The stones in the riffles create such good refuges that fish can withstand the strong currents. In addition, the fish have easy access to food such as the invertebrates that drift by.

Other fish, such as eel, roach and perch, can also survive in the riffles. The studies in Vejle indicates that a riffle gradient of at least up to 30‰ does not hinder the passage of even weakly swimming fish.

Up until 1993, Vejle County had established riffles or bypasses at 41 dams. The costs per project ranged from DKK 100,000 to 400,000.

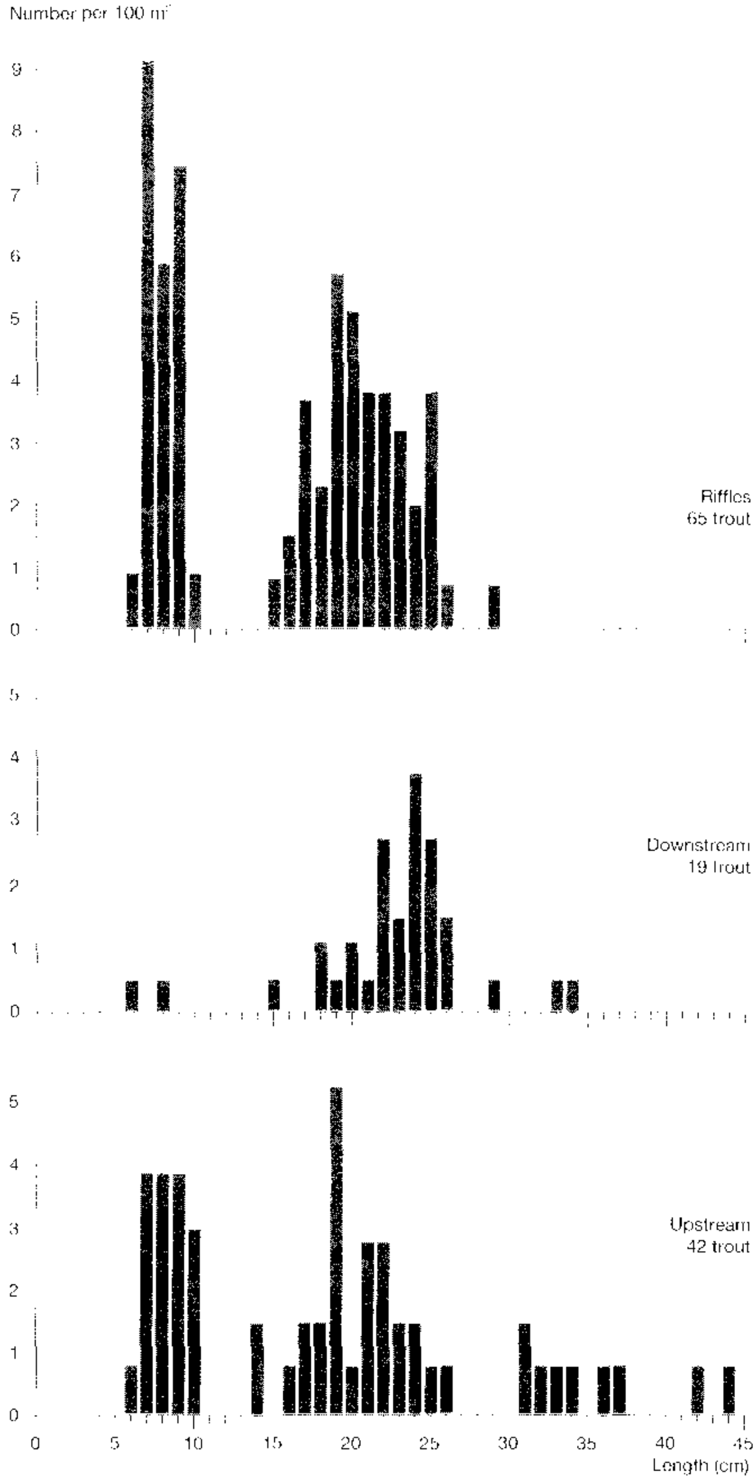


Figure 4.22 *Trout size distribution within, below and above the riffles in Mattrup Å stream.*

Adequate water depth - all year round

Discharge in the bypasses has to be sufficient that the fish can pass and perhaps find refuge. In Egå stream at Nymølle mill near Århus, it has been calculated how much discharge is necessary to ensure an adequate water depth all year round, including periods when there is little water in Egå stream (17).

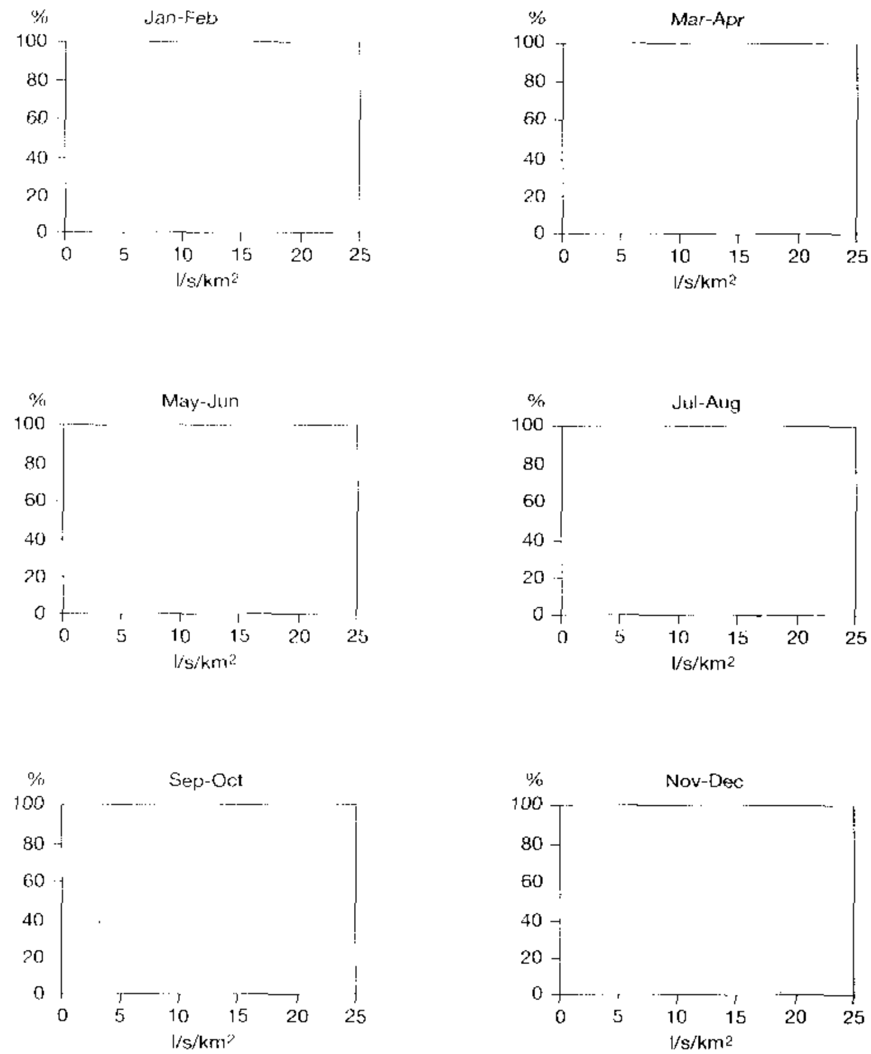


Figure 4.23 Flow-duration curves for different times of the year in Egå stream.

The width of the bypass was planned to be 1.5 m. At discharge rates of 150 litre/sec, the water depth would be 20 cm, which is adequate to allow trout to pass. In order to determine how often and for how long that depth could be sustained, runoff to the stream was examined in two-month intervals. This data was presented as so called flow-duration curves (Figure 4.23).

It transpired that with the planned width, it would only be possible to ensure an adequate water depth 30% of the time during the part of the year when water is plentiful, and even less during the remainder of the year. It was therefore necessary to redimension the bypass so as to ensure an adequate water depth for a greater period of time. Figure 4.24 shows the water depth that can be obtained at different discharge rates at bypass widths of 1.5 and 0.5 m. By comparing this figure with the flow-duration curves, it is possible to determine whether the smaller width can ensure an adequate water depth at all times. However, not even the narrow bypass could satisfy the water depth requirements.

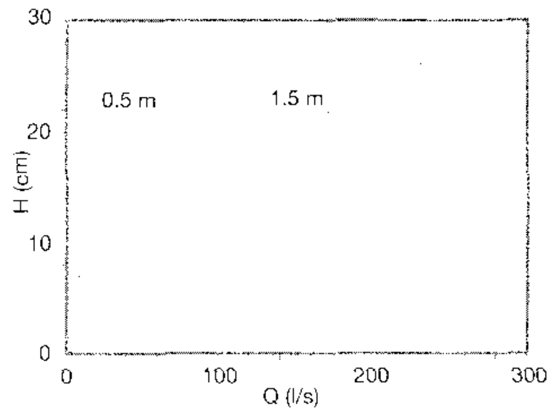


Figure 4.24 *Water depths at two bypass widths in Egå stream.*

The alternative is to reduce the bypass gradient, thereby slowing the discharge rate, in other words, to give the bypass a more meandering course. At Nymølle mill a course was found that would ensure an adequate depth 95% of the time. To alleviate the problems caused by low water depth during periods of low discharge, a series of deeper areas (pools) can be created in which fish can find refuge.

Examples of large projects

In the river Suså, near Holløse mill, a pass was made by creating a 136 m long riffle that has a gradient of 14.5‰ and a resting basin in the middle. The riffle was given a two-step profile to ensure an adequate water depth during the drier summer months. As the river Suså is subject to considerable differences in discharge in the summer and winter, it is necessary to reduce the strain on the riffle when discharge is high. This is done by diverting part of the flow through a sluice system. The new riffle was constructed such that it not only ensures the passage of fish, but also ensures a sufficiently high water level in the upstream lakes to allow the continued operation of the mill. In this way the interests of angling, nature and history have all been preserved.

One of the largest bypasses in Denmark has been established at the hydroelectric power station in the river Storå, near Holstebro. It is 655 m long and 2.75 m wide. The average bed gradient is 10‰, but there are six level resting basins. The bypass evens out a difference in height of 5.34 m.

A number of studies have been made concerning the extent to which fish pass through the river Storå bypass. As is apparent from Table 4.6, even weakly swimming fish such as whitefish are able to use the bypass (18).

Table 4.6 Analysis of fish that passed through the river Storå bypass near Holstebro in 1991. Adapted from (18).

Species	Catch (no.)				
	Period				Total
	26.06-09.07	07.08-20.08	25.09-18.10	02.11-10.12	
Bream	2	1	94	439	536
Dace	115	13	1	17	146
Eel	12	35	16	0	63
Flounder	20	8	0	0	28
Grayling	1	0	0	20	21
Gudgeon	3	0	5	0	8
Laveret	0	0	0	4,695	4,695
Perch	29	12	65	2	108
Pike	0	0	25	16	41
Rainbow trout	1	0	1	0	2
River lamprey	0	0	3	0	3
Roach	26	7	389	14	436
Ruffe	9	53	1	0	63
Salmon	0	0	6	2	8
Sea lamprey	5	0	0	0	5
Sea rainbow trout	0	0	2	0	2
Sea trout	0	0	2	1	3
Tench	0	1	1	0	2
Trout	2	0	1	1	4
Total	225	130	612	5,207	6,174

At the outlet of the bypass to the watercourse there has to be a sufficiently perceptible current that can guide the fish into the bypass. This is a problem bypasses have in common with fish ladders. Table 4.7 shows the discharge rates that were found to be best for different fish species at the river Storå bypass.

Table 4.7 Each species of fish has a preferred current speed. Adapted from (18).

Preferred discharge		
1,000 (l/s)	400 (l/s)	Discharge unimportant
Perch	Gudgeon	Bream
Pike	Roach	Dace
Salmon		Eel
Sea trout		Flounder
Steelhead		Grayling
		Laveret
		Ruffe

Discharge rate thus needs to be varied between 400 and 1,000 litre/sec in order to accommodate the conditions preferred by the different fish species. It was therefore decided to lead 1,000 litre/sec through the bypass from 1 October to 31 May, while from 1 June to 30 September, 400 litre/sec is led through the bypass during the day and 1,000 litre/sec at night. The guiding current can be strengthened by making the lower part of the bypass more steep than the upper part. Only approximately one third or less of the flow through the river Storå is led through the bypass, the remainder being utilized for the hydroelectric turbines.

Trout return to lake Hald Sø

Lake Hald Sø near Viborg is now so clean that lake trout can once again inhabit it. It is not enough, though, that the lake is clean; lake trout spawn in small brooks, and the condition of the latter must also be good. However, the brooks were blocked, and were ruined by pollution and hard-handed maintenance. The Lake Hald Sø Boating Association, which is actually an angling society, has, in collaboration with the landowners, made considerable effort to restore the brooks where the lake trout can spawn. They have created good living conditions in Dollerup Møllebæk brook and Dollerup Bæk brook by instigating gentle maintenance practices. The brooks have been transformed from wide lazy watercourses to narrow briskly flowing brooks. When a fish farm in the upper reaches of one the brooks closed, good spawning grounds became available there. All that remained was for trout to find their way up to these reaches, the route having been obstructed for 400 years by a mill dam.

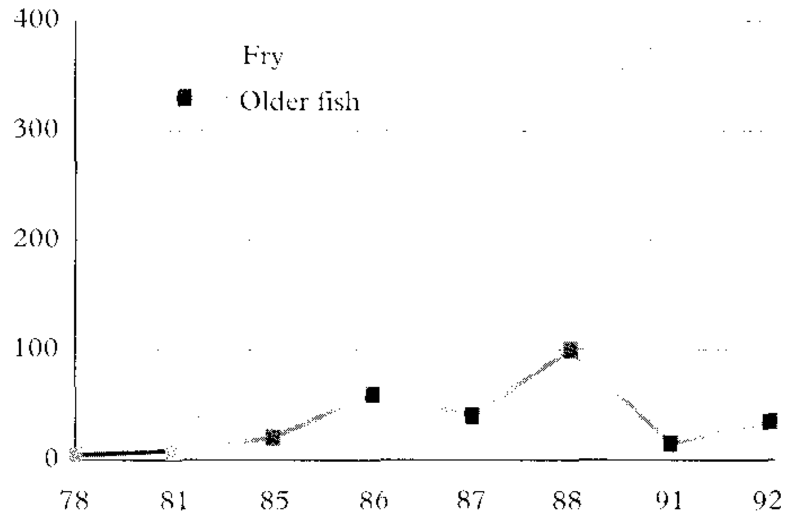


Figure 4.25 *The number of fry has increased in step with habitat quality. The data is from Dollerup Bæk brook. The figures are per 100 m (= 250 m^2) of brook. Adapted from (19).*

At the mill a bypass was constructed so that lake trout could migrate to the spawning grounds in the upper reaches of the brook. The bypass had the form of a 154 m long meandering stream with a gradient of 15‰, a width of between 40-90 cm and a depth of 10-30 cm. The cost was minimal as the work was undertaken by members of the Boating Association.

For the first time in 400 years, lake trout had access to the uppermost spawning grounds. Fry were produced there already in the first season, and the trout population is now so good that stocking is no longer required (Figure 4.25). This demonstrates that many factors need to be in order before results can be seen, for example, clean water in the lake, good watercourses and access to the spawning grounds.

A new course

Many weirs and falls were constructed in order to even out the gradient in places where watercourses had been channelized, such watercourses being shorter and therefore steeper than meandering watercourses.

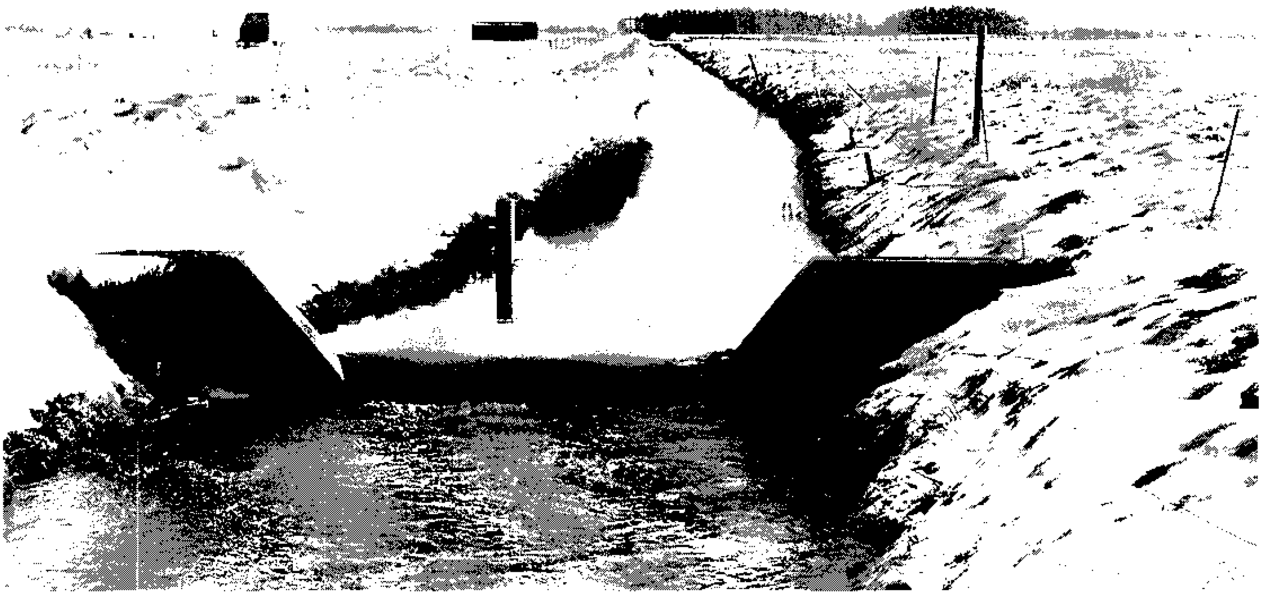
Weirs and falls can be removed by restoring a watercourse to its former meandering course. An example is Landeby Bæk brook near Løgumkloster (Figure 4.26). The steep gradient of the 475 m long, channelized reach was replaced by a new 775 m long, meandering reach with a gentle gradient and no weirs (Figure 4.27).

Figure 4.26 *This weir has now been replaced by a meandering watercourse.*

Figure 4.27 *The outlet of Landeby Bæk brook as it now appears (1993).*

Figure 4.28 *A 52 m reach of Lundgård Bæk brook was restored to its former 250 m meandering course, two weirs were removed, and the disused fish farm was converted to a small lake.*

In 1953, a 250 m long, meandering reach of Lundgård Bæk brook, a tributary of Villestrup Å stream in Himmerland, was shortened to 52 m. The gradient was utilized in two weirs totalling 110 cm in height that channelled water through an adjacent fish farm. The reach has now been restored to its former meandering course and the weirs have been removed. Not only has the old watercourse been restored, but the disused fish farm has been converted into a small lake (20).



Many of the problems with watercourses arose when their natural course was altered. Thus, many problems can be solved by restoring watercourses to a more natural, meandering course. Several examples of such restoration are given in the next chapter.

5. Giving watercourses a new form

Only very few watercourses still have their natural form. Many have been regulated, and even more have lost their meanders and riffles as a result of maintenance. They are often too wide and lie too deep in the landscape, and are often unstable, with collapsing banks and migrating sand. Moreover, they have become poor habitats for fish and invertebrates and are obstructed by many weirs.

While regulated watercourses will attempt to revert to a natural form, there are many ways in which one can help.

Chapter 2 gives examples of how good biological conditions can be restored in channelized or rigorously managed watercourses through the use of gentle weed clearance techniques. One can also narrow a watercourse by constructing stone embankments that concentrate the current, thereby creating a more varied bed.

With only the natural forces at work in a watercourse, it takes a very long time for real meanders to re-establish. In many places, though, it has proved possible to successfully create new meanders and, as a result, provide better habitats, lessen transport of sand and ochre, and create a more varied and stable bed and sides.

Nevertheless, it is primarily the natural forces at work in the watercourses that we must harness since this will enable many watercourses to eventually revert to their own natural form.

Current concentrators

Current concentrators can be used to narrow a watercourse and to imitate a meandering path. One of the first Danish examples of this was Voer Å stream, as discussed on p 41. Another example is a 200 m reach of a brook in Vrold Vesterskov forest which was given a narrow winding course by using poles and branches to build out alternate sections of bank (Figure 5.1).

Figure 5.1 *The brook in Vrold Vesterskov forest was given a narrow winding course by using poles and branches to build out alternate sections of bank.*

The brook had previously been wide and lazy with a barren sand bed. The restoration work increased the current, soon resulting in a varied bed with plants and a good population of fish. The new brook has now existed for more than 10 years, and the fish population is still good. Work has now started on re-exposing a 460 m culverted reach further upstream.

Current concentrators have also been built in Tvede Å stream (Figure 5.2). The stream has been given a more varied course, thereby improving the habitat for invertebrates and the fish population (see page 131).

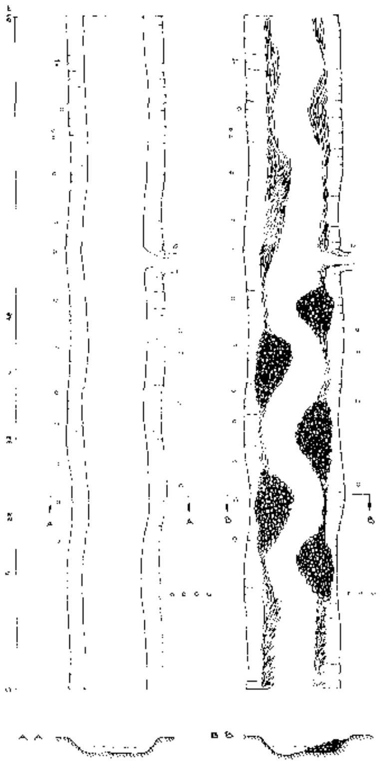


Figure 5.2 *A working drawing used in the restoration of Tvede Å stream.*

In Fald Å stream, which empties into the Limfjord near Lemvig, the local anglers have narrowed a channelized and uniform reach with stone embankments, that not only serve as current concentrators, but also protect the banks (1). Artificial hiding places for fish have also been made by placing small turf-covered platforms over parts of the watercourse with pools. The establishment of such hiding places can be necessary if other shelters do not form in the stream. The cost of the project was minimal as the labour was voluntary. The first results became apparent within the year, the reach having become much more varied with riffles and pools. A population of brown trout began to establish, and electrofishery in 1992 and 1993 showed that sea trout had also found their way to the restored reach.

In 1988/89, two reaches of Pøle Å stream in North Zealand totalling more than 800 m were given a meandering current channel within the confines of the relatively wide stream bed (2). The meanders were created by constructing current concentrators made of 20-50 cm diameter stones on alternate sides of the stream. The concentrators are approx. 7 m long and are placed at approx. 15 m intervals in the upper end of the stream and approx. 22 m intervals in the lower end. In the upper end they protrude approx. 1.75 m into the stream, leaving a current channel of approx. 2.25 m, while in the lower end they protrude approx. 2.5 m, leaving a current channel of approx. 1.5 m. Calculations based on a time-series of discharge rates indicate that no unacceptable damming up of water takes place. The constriction caused by the current concentrators should be counterbalanced by the increased depth of the current channel.

The effects of restoration have been followed for approx. 1.5 years (3). During the first 6 weeks, noticeable deposition occurred both in front of and behind the current concentrators. However, there was no noticeable erosion in the current channel alongside the current concentrators, the current being too weak. During the following 16 months deposition continued to such an extent that deposits also accumulated alongside the current concentrators; again, this was due to the current being weak, which is not unusual for watercourses in this part of the country. Despite the fact that deposition was considerably greater than expected, the restoration nevertheless enhanced physical variation in Pøle Å stream, and water depth is good even when discharge rate is low.

New meanders in Stensbæk brook

Stensbæk brook, a tributary of Gelså stream in southern Jutland, runs through a melt water sand plain. As a result of channelization an 800 m reach of the brook was very unstable, the current eroding to such an extent that banks collapsed and sand flushed downstream. The watercourse authority, Gram Municipality, would normally have stabilized the banks with fascines, a measure that is both expensive and somewhat unnatural. However, the new Watercourse Act provided other possibilities for dealing with such problems, and the decision was therefore taken in 1984 to solve the problem by removing one of its causes, namely the unnaturally steep slope.

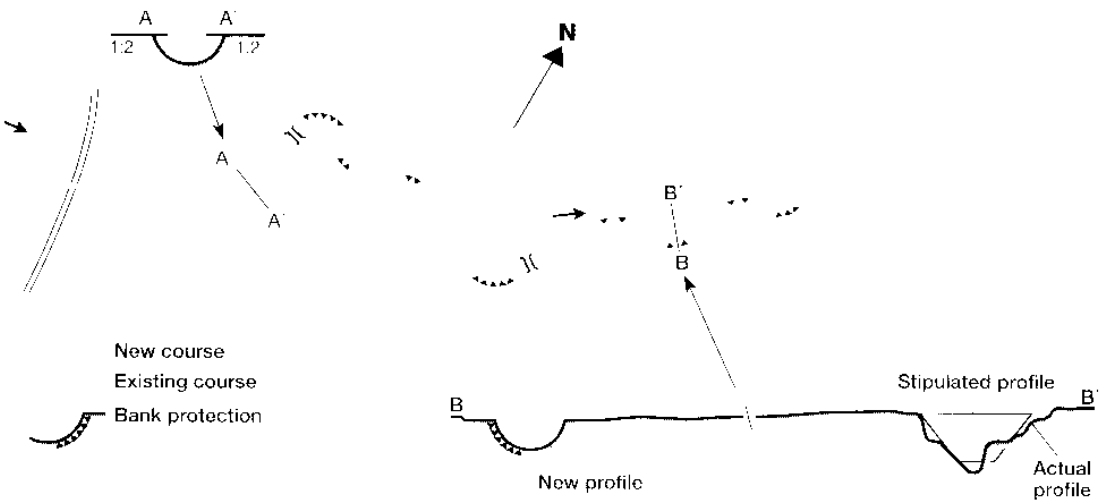


Figure 5.3 Stensbæk brook's new and old course and profile. Adapted from (4).

This was done by remeandering the watercourse (4). The brook's original path was found on old 1:25,000 and 1:2,000 scale maps. The planned path was checked against the terrain's natural contours. In order to ensure that the restored path is stable and that the current does not start to erode away at the bed and sides, it is necessary that both the slope and the cross-sectional profile are appropriate in relation to expected discharge in the brook (Figure 5.3).

While planning the slope and profile it is also important to take into account whether the discharge has changed since the brook was channelized, for example as a result of the connection of drains or stormwater outfalls to the brook. It is also important to ensure that the relationship between the depth and width are appropriate for the bed material the brook will run through (see page 24).

To determine the profile as accurately as possible investigations were undertaken to find traces of the brook's original profile. A series of small exploratory ditches were dug perpendicular to the original course of the brook. This revealed the original brook bed so distinctly that the profile could easily be measured. This was done in several places to obtain the dimensions of the profile in the various sections of the original meanders. The profile was lopsided in the meander bends, while it was even or straight mid way between the meander bends, exactly in accordance with the principles shown in Figure 1.8. As an extra precaution, the profile was measured in an unchannelized reach upstream of the reach that was to be given a new profile. In order to convert the dimensions of the upstream profile it was necessary to correct for the greater amount of water that would run through the new profile. The calculations fitted well with the original profile exposed by the exploratory ditches. Finally, profile measurements were made in a neighbouring brook similar in terms of catchment area and discharge. This confirmed the appropriateness of the planned profile.

The average gradient of the new course was determined from the contour lines on the 1:25,000 scale map. This was checked by surveying the bed of the exploratory ditches dug across the original path. The new path was dug to a depth determined partly from the trig points and partly from the original bed exposed during excavation.

In a new watercourse such as Stensbæk brook, the current will affect the bends until the vegetation becomes dense enough to reinforce the banks. With the outer side of meander bends, there is a particularly great risk that the current might erode so much as to ruin the new profile; however, they can be stabilized by stones laid out on the sloping side (Figure 5.4). The stones that were used to reinforce the bends in Stensbæk brook were fist-sized pebbles from nearby fields. The lowermost stones should be larger, and should be pressed tightly packed into the angle between the bed and side such that the stones support each other. The stones not only prevent the current from eroding the underlying material in the bends, but also help protect the bank downstream because their uneven surface attenuates the current's energy.

The Stensbæk brook restoration project stood its first real test before completion: on 31 January 1985, water from the spring thaw rushed through the brook in such large amounts that discharge reached a level normally only seen once every five years or so, and which could be expected to considerably shape the watercourse.

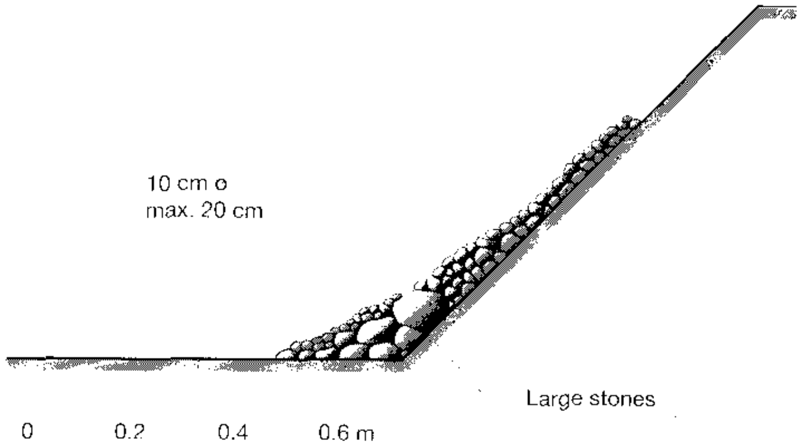


Figure 5.4 *The exposed bends are stabilized with stones. Adapted from (4).*

However, the brook's new profile and course successfully led away the water without the brook suffering any damage. The new form proved to be in harmony with the immense forces at work in the flowing water, i.e. the brook had been re-established with the characteristics it had prior to channelization. In 1985, gravel was laid out in several places along the bed to protect the sand from the current, as well as to provide good habitats for invertebrates and spawning grounds for trout. In 1987, additional spawning grounds were laid out in connection with the project discussed in Chapter 3 (pp 104-7). A study in 1989 revealed that there was a good population of both trout yearlings and fry - a good indication that the brook was regaining its original characteristics - as well as that the problem of migrating sand had been brought under control.

Figure 5.5 *The new path of Stensbæk brook held up against exceptionally high spring discharge. Photograph by M. Bjørn Nielsen.*

Figure 5.6 *Idom Å stream was remeandered.*

The remeandering of Idom Å stream

Idom Å stream is a tributary of the river Storå. Part of the stream is channelized and two fish farms had been located there for many years. In 1987, the fish farm furthest upstream closed and as a result, the water quality in the stream improved. The same year, weed clearance in the stream was ceased. In October 1990, Ringkjøbing County restored a 280 m channelized reach to its original course. The original meanders were clearly apparent in the meadow as depressions. As an extra control the original profile was searched for by boring simple test cores. The length of the remeandered reach was 570 m, more than double that of the reach when channelized (Figure 5.6).

Ringkjøbing County has studied the fish population both before and after the new meanders were excavated (Figure 5.7) (5). Since 1990, the studies have been undertaken in 3 different reaches: A still channelized upstream reach, the new remeandered reach, and a reach further downstream that had never been channelized. Two years after closure of the fish farm and cessation of weed clearance a good population of trout had started to appear. This trend continued in all 3 reaches after the new meanders were constructed in 1990. However, the increase was least in the remeandered reach, this being attributable to the relative lack of weed beds in which fish could seek shelter. However, since 1993 the population in the remeandered reach has equalled that in the non-channelized downstream reach. It thus appears to have taken no more than a couple of years for natural conditions to be restored in the remeandered reach.

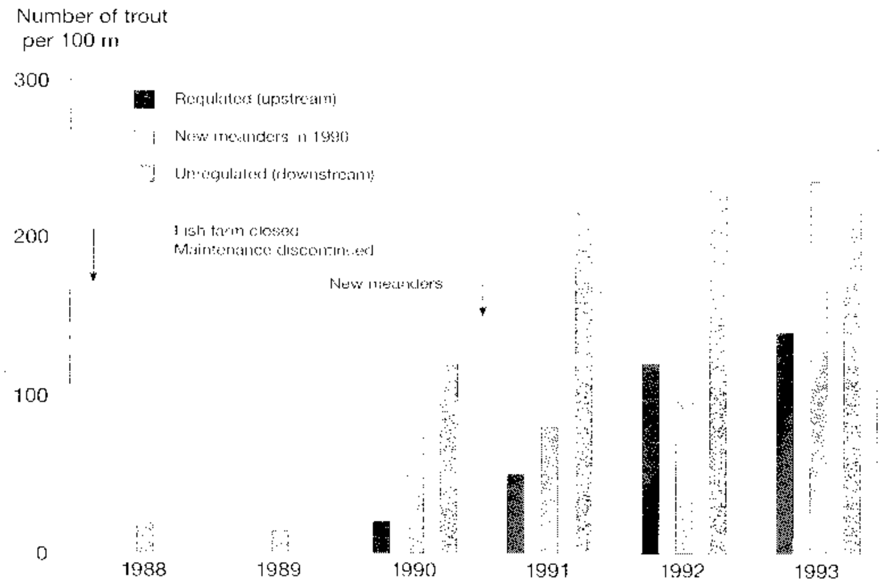


Figure 5.7 *Growth in the trout population of Idom Å stream.*

In Figure 5.7, the number of trout is expressed per 100 m watercourse irrespective of whether the reach is straight or meandering. Even if the number of places in which trout can live (hide) should be the same per 100 m of the channelized and remeandered reaches, the greatly increased length of the remeandered reach will augment the total number of trout in the latter.

The raising of Elbæk brook

Elbæk brook, one of the upper tributaries of Karup Å river, was channelized in the previous century. Since then Elbæk brook, like Stensbæk brook and so many other channelized watercourses in heath plains, has eroded deeper and deeper, the bed eventually having come to lie 2 m below ground level. The banks collapsed because of erosion by the current, and migrating sand drifted through the brook.

In 1986, Elbæk brook was restored (6, 7), the primary aim having been to stabilize the brook so as to prevent the banks from collapsing further. An additional aim, however, was that the brook should regain its former status as a trout spawning and nursery area. Ikast Municipality decided to remeander Elbæk brook so as to lessen its slope. The lower reach had a reasonably natural form; although it had been channelized, the gradient was so steep that the current had formed a new course whose profile and path were reasonably natural. Its cross-sectional area was approx. 1 m^2, and it had to be able to drain a catchment area of approx. 15 km^2. In contrast, the cross-sectional area of the upstream reach of Elbæk brook was approx. 3 times greater! In comparison, the cross-sectional area of Bording Å stream, a neighbouring watercourse that had to drain a catchment area of 17 km^2, was 1.2 m^2, i.e. just a little larger than that of the lower reach of Elbæk brook, which had a correspondingly smaller catchment area. The excessively large cross-sectional area of the upper channelized reach of Elbæk brook could therefore be reduced without there being any risk that it would be unable to accommodate the discharge. It was decided that the new cross-sectional area should be 1 m^2, as compared to the actual cross-sectional area of 3 m^2.

The brook was to be given a meandering path with a lopsided profile in the meander bends and an even profile between the bends. It was not possible to determine the original meandering path of Elbæk brook using old maps. However, based on the contour lines on a 1:20,000 ordinance map from 1913, the average gradient of the original Elbæk brook was estimated to be approx. 1.4 ‰. It was decided to construct new meanders in such a way that the gradient over the critical reach would be 1.8‰. This was half the gradient of the channelized brook, and would thereby reduce erosion of the bed and sides by the current. Because Elbæk brook had cut very deep below ground level, the decision was made to excavate a completely new path for the brook. There was room enough because cultivation of part of the land in a corridor bordering the brook had been abandoned. This made it possible for the bed of the brook to be raised to a more natural level.

The watercourse can develop within the corridor without flooding affecting surrounding fields. The corridor also protects the watercourse when discharge is excessive since it serves as a flood channel. During the dry summer period the narrow main channel ensures that water depth is reasonable even when discharge is low. In this channel weed is cleared to form an even narrower, 0.5-1 m wide current channel. A good population of trout was already present one year after restoration: approx. 25 per 100 m^2.

Meanders remove ochre in Rind Å stream

Rind Å stream, one of the tributaries of the river Skjern Å, was channelized in the 1940's. Because the stream washes ochre into the river during the winter, Ringkjøbing County decided to undertake a restoration project that both recreated meanders and cleaned the water of ochre (8). In 1992, an 1,800 m channelized reach was replaced by a meandering reach (Figure 5.8). The new course was approx. 550 m longer than the old channelized course. The stream runs in a meadow corridor in which a series of flat basins were dug and sown with grass. During the winter half year, stream water flows over into the basins, comes in contact with the grass, and the iron precipitates out. The first results from the autumn of 1993 showed that a large part of the ochre can be removed in this way. Thus in November 1993, at the most downstream measurement point (site 5 on Figure 5.8), 75% of the iron content had been removed (both ochre and dissolved iron) (Table 5.1).

Table 5.1 *Ochre removal in the restored reach of Rind Å stream, November 1993.*

Measurement point (see Fig. 5.8)	1	2	3	4	5
Total iron mg/l	2.0	0.68	0.66	0.38	0.50
Dissolved iron mg/l	0.56	0.23	0.24	0.38	0.11

With this restoration project Ringkjøbing County has revived the natural purifying effect previously common to many of the local watercourses. When watercourses flooded their banks, the ochre was "trapped" by the grass in the flooded meadows. The project is also remarkable in the way in which it was carried out. It started with Ringkjøbing County authorities being contacted by two landowners who wanted Rind Å stream to be restored to its former meandering course. The first meeting between the County and the landowners was held in April 1991, and by February 1992, the stream had been remeandered. The ochre-trapping basins were completed later.

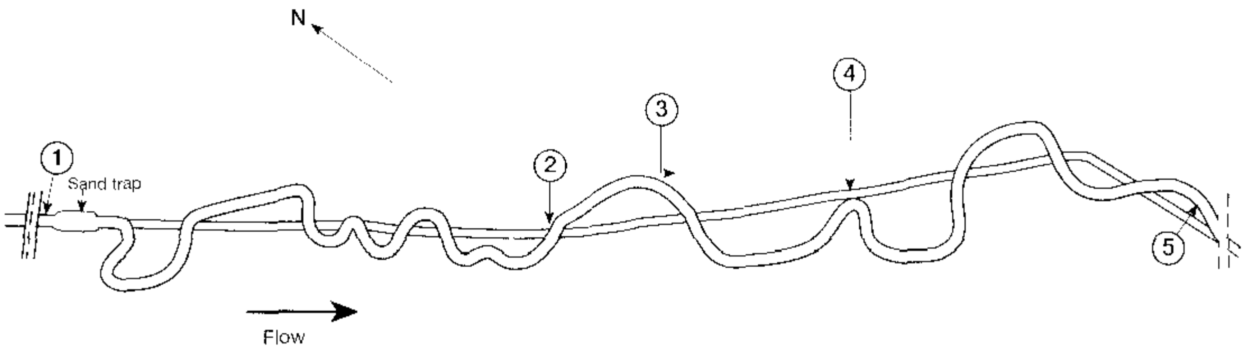


Figure 5.8 *Meanders have been restored in Rind Å stream and basins have been formed to trap and retain ochre. The figures indicate the measurement points referred to in Table 5.1.*

Figure 5.9 *Kikhanerenden canal prior to restoration,*

Some of the most modified watercourses in the country are in the vicinity of Copenhagen. In order to ensure that the water drains away as rapidly as possible, some watercourses were lined with flagstones. This had, for example, been done in the majority of Kikhanerenden canal, a 5.5 km long watercourse in Søllerød. The reason for lining the watercourse with flagstones in 1955 was to ensure that the water was rapidly led out to the Sound so that nutrients would not be retained by the weed in the watercourse!

Figure 5.10 *- and after. Photograph by Steen Rostrup.*

In 1988-90, Kikhanerenden canal was restored (9). The flagstones were removed except in a few soft reaches where they were used to stabilize the bed. Moreover, the cross-section was reduced from 2.25 to 0.75 m, thereby ensuring sufficient water depth even during the summer. Since one tenth of the catchment area is serviced by the sewerage system, discharge during downpours can be 50-100 times greater than normal. It was therefore necessary both to make retaining basins and to give the brook a two-step profile. In addition, during high discharge the water is led into an adjacent marsh so that nutrients and soil particles will be retained, thereby preventing them from reaching the Sound. To ensure reasonable discharge in the current channel during dry summers, it is possible to pump groundwater into the watercourse at a rate of up to 10 litre/sec. The watercourse was stocked with trout in 1991, and a subsequent study showed that even such a badly molested watercourse can be restored to a suitable habitat for fish.

In 1992, the restoration of Store Vejle Å stream in Copenhagen County was begun (10). This watercourse had also been lined with flagstones, in this case the reason being to prevent polluted stream water from seeping down to the groundwater from which drinking water is abstracted. The flagstones have now been removed in a 1,400 m reach upstream of lake Tueholm Sø. To hinder soil and sand from flowing into the lake, a sand trap was built upstream of the outlet. The new watercourse was given a two-step profile with a meandering current channel (Figure 5.11). To prevent water from seeping down to the groundwater, both the bed and the sides were lined with a compact layer of clay. The new reach is only part of a larger restoration project for the watercourse. Other reaches will also be restored, and both spawning grounds and fish shelters will be built.

Figure 5.11 *Store Vejle Å stream: From flagstones (right) to meanders (left).*

The remeandering of Gelså stream

Gelså stream is one of the main tributaries of Ribe Å stream. Like most watercourses, much of its course had been channelized. The reach near Bevtoft was channelized in 1952 at a cost of DKK 200.000 in order that a small meadow could be converted into a field. However, within a few decades the meadow lost its value, partly because the ground sank as a result of its diminishing peat content, and partly because the meadow was not very large. In 1989, some local citizens took the initiative to see to it that the stream was remeandered. The work was undertaken in conjunction with Sønderjylland County the same year (11).

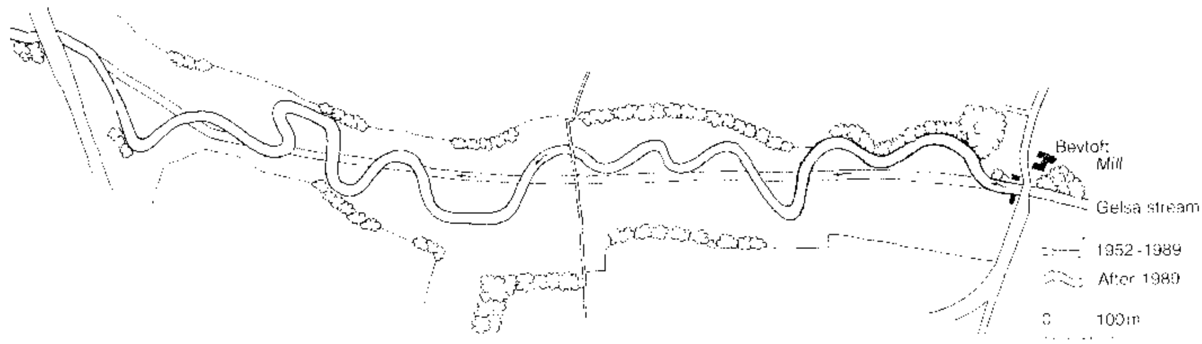


Figure 5.12 Gelså stream, before and after restoration.

The new course was excavated according to maps showing the stream's path before channelization (Figure 5.12). Whereas the channelized reach was 1,340 m long, the remeandered reach is now 1,850 m long. When calculating the new profile, great import was given to future drainage problems. The drainage capacity was to be 5 m^3/sec when the stream was weed-free. This means that the stream valley would flood once every second year, which is as would be expected in a natural stream valley.

Figure 5.13 The water still runs in the channel, although a new meander is under construction.

In order to ensure that the new stream could tolerate high discharge rates, meticulous attention was paid to ensuring that the various parts of the stream were given the appropriate profile. The rules governing the profile of meanders were followed and adjusted to the precise dimensions appropriate to a watercourse such as Gelså stream (12, 13). The slope of the bed and sides in various parts of the stream were as illustrated in Figure 5.14.

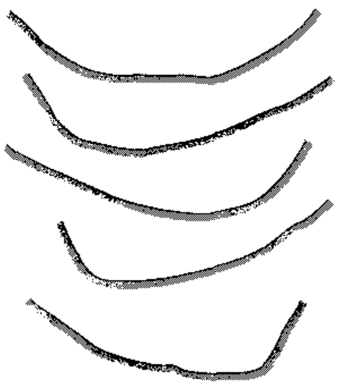


Figure 5.14 *Profile of various parts of the re-meandered reach of Gelså stream.*

The bed is lopsided (asymmetrical) in the meander bends, but even (symmetrical) in between the bends. In the straight stretches between bends, the bed is even, the width is 5 m and the banks slope at 45 degrees. In the meander bends, the width of the upper part of the profile is the same as in the straight stretches (5 m), while that of the bed is only half as much (2.5 m). On the other hand, the depth is up to half a metre greater. The profile in the meander bends is lopsided, being deepest on the outer side. The cross-sectional area was calculated according to the discharge rates that could be anticipated given the rainfall and the size of the catchment area. Those parts of the meander bends where the current would be expected to erode most have been stabilized with stone embankments similar to those built in Stensbæk brook (cf. Figure 5.4).

In the upper section of the reach to be restored there was a 60 cm high weir. This provided the slope needed when making meanders. Half the gradient was levelled out by a riffle, while the remaining gradient was utilized to raise the bed in the upper half of the watercourse.

The lowermost part of the stream was not changed, it being wanted to "save" part of the gradient until such time as downstream reaches could be remeandered. However, it subsequently transpired that the steeper gradient induced the watercourse to gradually erode away backwards through the restored reach, exactly as described on page 26. If part of the gradient is to be "saved" in future projects, it would be advisable to do so by building a riffle able to withstand the current.

This is how one excavates new meanders

To reduce the damage to the downstream reaches of the stream a sand trap was built in the lowermost section of the reach to be restored. The sand trap collected approx. half the material that was flushed downstream, while the remainder was only detectable at most 4 km further downstream.

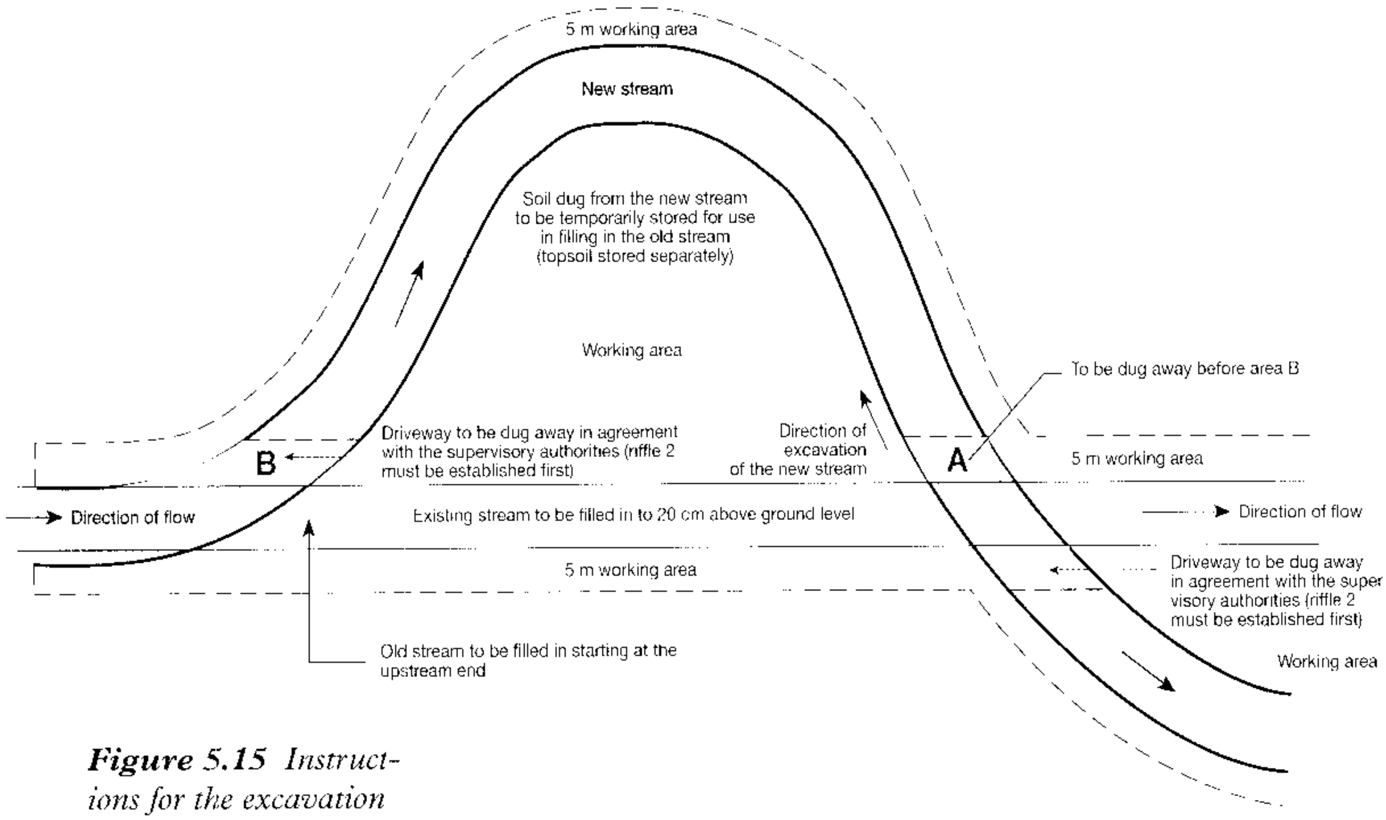


Figure 5.15 *Instructions for the excavation of new meanders in Gelså stream.*

Excavation of the new meanders was begun in the lowermost part of the reach, but the water was not allowed to flow through until all the meanders were ready. When a new meander approached the upstream channelized watercourse, excavation was halted, while the lower end of the meander was opened out towards the channelized section (Figure 5.15). When everything was ready to send water through the new reach, the new meanders were opened one by one working from the uppermost section on downwards, the soil being used to close the old channelized watercourse. Excavation work started on 10 July 1989, and was complete by 3 October of the same year. It is important to undertake the excavation work during a period when discharge is least, and it has to be finished before trout begin to spawn. The total budget for remeandering the reach is shown in Table 5.2.

The new banks were devoid of vegetation, and were therefore very susceptible to damage by the current and rain. In order to determine how most rapidly and effectively to get plants to stabilize the soil, the reach was divided into four sections that were each treated differently. One section was not planted, while the other three were planted with either rye, grass or a mixture of both rye and grass.

Table 5.2 *Budget for the Gelså stream restoration project.*

Cost of individual items	
Excavating sand trap	DKK 10,000
Excavating new watercourse	DKK 191,000
Filling in old watercourse	DKK 101,000
Spawning grounds	DKK 156,000
Bank reinforcement with stones	DKK 145,000
Construction of riffle at the mill	DKK 26,000
Technology (new bridge, joining sewers, water ducts and electricity cables, etc.)	DKK 336,000
Planning, preliminary studies and supervision	DKK 242,000
Compensation to ground owners	DKK 13,000

Follow-up monitoring

Follow-up monitoring of the stream over the two-year period following restoration revealed that it adjusted to its new form in the course of one year (13). During the first year the current eroded material away from the bends and many parts of the bed, while during the second year deposition occurred, especially when the stream flooded its banks (Figure 5.16).

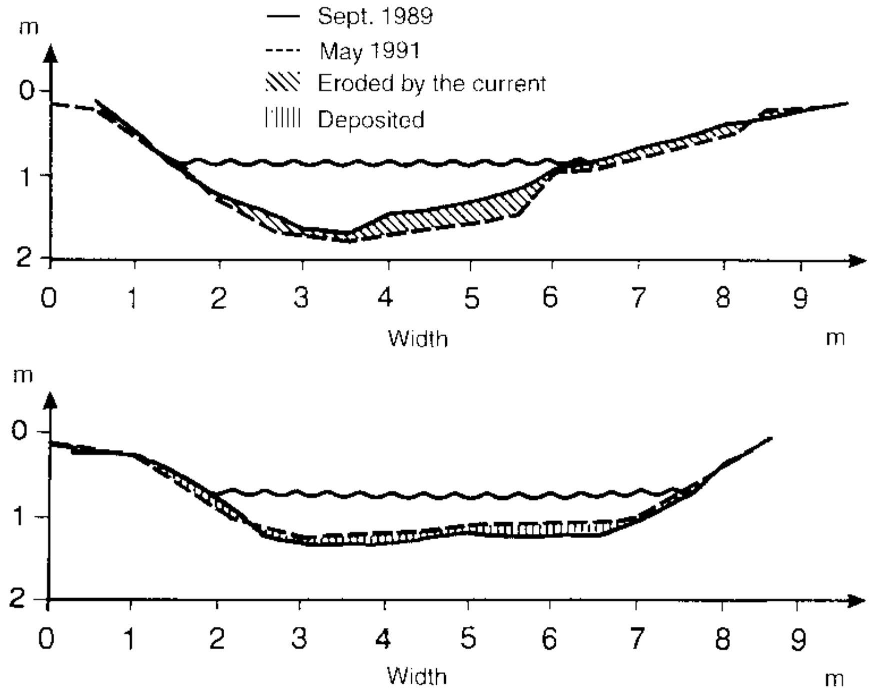


Figure 5.16 *Gelså stream adjusted the new profile through erosion and deposition of material. The profile in two parts of the newly established watercourse (solid line) is shown together with that after 1 year (broken line). Adapted from (13).*

The new form given to the stream was given the finishing touch by the stream itself over the first year; during this time it found a form in harmony with the forces at work in the current. The banks that were sown with grass or the mixture of grass and rye were the most stable (Table 5.3), while those left barren or planted with only rye were very much subject to the impact of the current and rain.

Table 5.3 *Percentage of the banks that were eroded away by the current.*

	Treatment			
	Untreated	Rye	Grass	Rye and grass
1990	0.5	14.8	2.5	4.3
1991	34.0	21.0	7.5	8.8

Plants quickly colonized the new reach, both in the watercourse and along its banks. In the beginning the vegetation was not as dense in the new reach as it was further upstream, which is not surprising since it needs time to establish a foothold. However, in the second summer there was roughly the same density of plants in the two reaches, although the density was less in the lower section of the restored reach than in the upper section. This was probably attributable to unstable bed conditions in the lower section.

The first year the number of plant species in the restored reach increased to more than that in the upstream channelized reach. In 1991, 2 years after restoration, there were 31 species in the new reach as compared with only 22 in the channelized reach (Table 5.4). As was also seen in Idom Å stream (page 149), it takes time for good living conditions to develop.

Table 5.4 *Increase in the number of plant species in the restored reach of Gelså stream as compared with an upstream reference reach.*

	Number of plant species	
Study year	Restored reach	Reference reach
1989	19	17
1990	24	19
1991	31	22

Invertebrates rapidly colonized the new reach, some drifting down from the upstream part of the stream. By 1990, the fauna in the two reaches was rather similar. However, species composition and density was less in the restored reach, this being because there were fewer plants among which they could live. By 1991, though, there was a clear tendency towards an increase in species composition and density in the restored reach, undoubtedly because of the greater availability of suitable habitats and because of the greater bank zone providing good living conditions for species such as the freshwater shrimp, etc. The restored reach was also colonized by many invertebrates that typically inhabit stone and gravel beds, just as was the case in Tvede Å stream (see page 131).

In another major restoration project in southern Jutland, the remeandering of a 3 km reach of Brede Å river (Figure 5.17), the number of species associated with stone and gravel bed habitats increased from 10 to 20 following restoration (14).

Figure 5.17 *Brede Å river is one of the many channelized watercourses in southern Jutland (upper panel). In 1991, work started on remeandering a 3 km reach (lower panel). Photograph by Sønderjylland County.*

Watercourses can restore themselves

It is the watercourses themselves that form their meanders, but this can take a long time. It is not quite clear just how new bends arise in a straight channel. There is some indication that meanders primarily arise at a focus in the form of an indentation that can have been cut by the current when forced against the side of the watercourse by a "bulge" on the opposite bank (Figure 5.18).

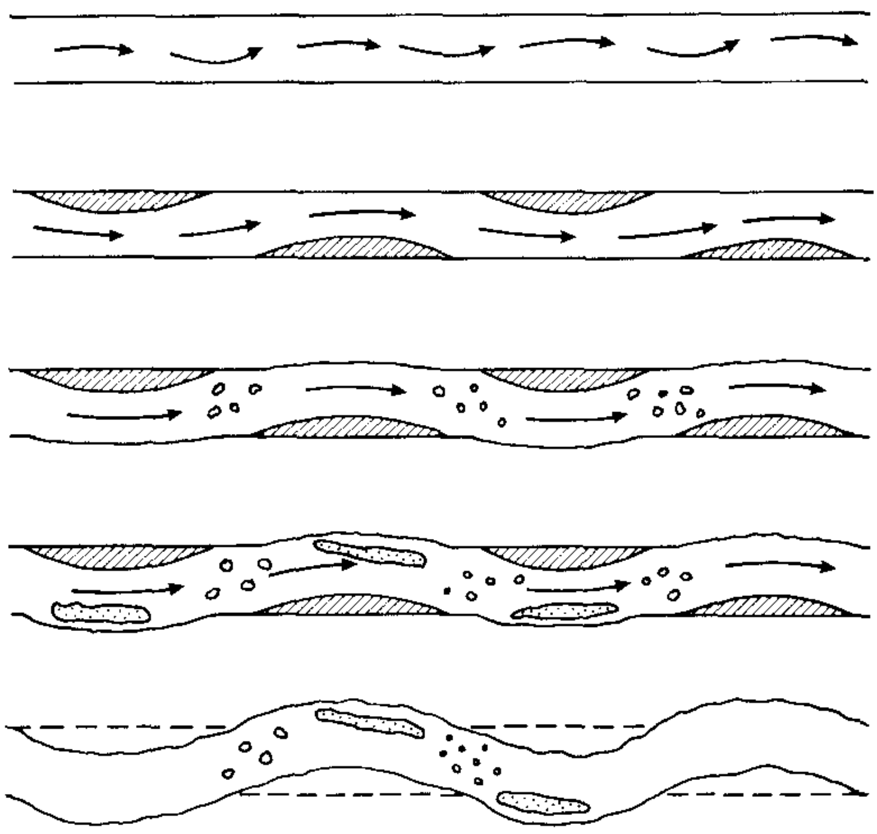


Figure 5.18 *Steps in the formation of new meanders.*

Within the confines of a channelized path the watercourse can create something that, while not exactly resembling the original meanders, nevertheless has some of their characteristics. With the current channels that are being made in the watercourses, the first bends are now starting to cut into their sides; however, it could take a long time before they become large. With the forces at work in Danish watercourses, it could take perhaps a hundred years, and in some places perhaps a thousand years, for a channelized watercourse to erode large meanders in the surrounding landscape.

In the next chapter, examples are given of how far we have come on the path towards good watercourses.

6. How much has been accomplished?

The new Watercourse Act has now been in effect for approx. 10 years. The watercourses were not changed overnight by the Act, though. In some areas, good progress has been made by introducing gentle maintenance practices. In other areas, however, the process has only just begun. The task has not been tackled in the same manner by the different watercourse authorities. Nevertheless, the path to more gentle treatment of watercourses is a process that is in motion. Gentle maintenance is not only practised where new Provisional Orders have been issued, but also in many watercourses for which new Provisional Orders have not yet been issued.

Many different forms of restoration have been undertaken. In most cases the aim has been to improve the fish population, e.g. by establishing new spawning grounds or by ensuring free passage at obstructions. There have been considerably fewer projects aiming at a more general improvement in the environmental conditions of watercourses, e.g. remeandering.

The combatting of watercourse pollution has necessitated considerable investment in sewage treatment plants, but this has seldom been sufficient to ensure a better watercourse quality. In this connection it is important to underline that clean water alone does not make a good watercourse. Gentle maintenance and restoration measures are also needed, and can often "upgrade" a watercourse to a higher class with respect to level of pollution. Combatting pollution and ensuring good physical conditions are two necessary steps on the path towards good watercourse quality.

This chapter provides an estimate of the extent to which our watercourses are maintained in a gentle manner, as well as examples of how much progress has been made with the different means of restoration, and what this means to our watercourses.

How many watercourses need to be gently maintained?

If one wants to recreate good physical conditions in watercourses it is necessary to concentrate efforts on those watercourses for which the watercourse quality objective requires especially good environmental conditions. The objects clause of the new Watercourse Act reads: "The stipulation and implementation of measures in conformity with the Act shall be conducted with deference to stipulations concerning watercourse environmental quality laid down in other legislation". By "measures" is mainly meant maintenance, and by "other legislation" is especially meant the environmental requirements that follow from the watercourse quality objectives given in each county's Regional Plan.

Gentle maintenance is particularly necessary in watercourses where the watercourse quality objective is fish waters (B) or watercourses of special scientific interest (A). Such watercourses should be given priority with respect to gentle maintenance, restoration and the re-establishment of natural conditions. Gentle maintenance is also of value in ochreous watercourses (see page 87) since weed borders and a higher water level can lead to the ochre being retained. Watercourses having A and B watercourse quality objectives will hereafter be referred to as high quality objective watercourses.

When evaluating how much work needs to be done and how much progress has already been made, a good starting point is the sum length of watercourses (divided into public and private watercourses) and their quality objectives (Figure 1.20, as discussed on page 35). Such analysis indicates that gentle maintenance should primarily be implemented in the just under 15,000 km of public high quality objective watercourse and as a minimum, in the 4,000 km of private watercourse so far designated as high quality objective watercourse. To this should be added a large number of small private watercourses of unknown sum length for which a watercourse quality objective has not yet been set.

When estimating how much of our watercourses is gently maintained, it is necessary to know what gentle maintenance is. The term is explained and defined at the beginning of this book (page 15), the definition being the basis for understanding what I mean when using the term elsewhere in the book. The information about gentle maintenance that has been gathered from Provisional Orders, instructions, etc., largely agrees with the description given on page 15. The requirements they make as to watercourse maintenance are largely in accordance with the expectations of the Watercourse Act, i.e. that maintenance shall be undertaken in a manner that ensures watercourses better environmental conditions than does traditional maintenance. This does not mean that gentle maintenance is undertaken identically in the various counties and municipalities, however. Thus maintenance can be adapted to the special conditions pertaining in the watercourses as influenced by nature and society, and can depend on how intensely the adjacent land is cultivated. Furthermore, maintenance can be adapted to local ideas of what it meant by gentle maintenance.

Thus as used below, gentle maintenance is maintenance where, depending on the nature of the watercourse, either the weed is not cleared at all, or is only cleared in a meandering or straight current channel. The bank vegetation is either not cleared at all, or only cleared during the autumn. If dredging is necessary it is done during the autumn, before trout spawn. Dredging must not damage the stone or gravel bed, nor overhanging banks. Gentle maintenance is usually undertaken with a scythe, or at times with a basket reaper. In larger watercourses it can be necessary to use a weed clearance boat. One common feature is that it is not the tool that determines whether maintenance is gentle or not, but the way in which the tool is used.

How much progress have the Counties made?

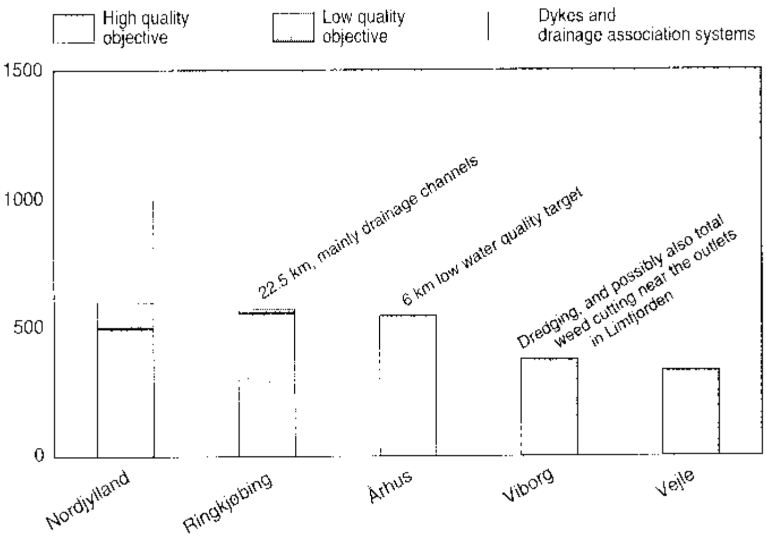


Figure 6.1 *Gentle maintenance is undertaken in virtually all high quality objective county watercourses.*

There are approx. 5,000 km of county watercourse in Denmark, the majority being accounted for by large watercourses. Most of these, approx. 4,600 km, are high quality objective watercourses, and it is therefore necessary to maintain them in a gentle manner to ensure fulfilment of the objectives. The deadline for bringing the Provisional Orders governing county watercourses in line with the new Watercourse Act was originally the end of 1992, but has since been extended to mid 1996. The Counties have long since initiated gentle maintenance, more or less independent of the final Provisional Orders.

Figure 6.1 illustrates the extent of environmentally sound maintenance in some counties (1). Examples of watercourses where gentle maintenance is not practised are channels in dyke- and drainage association systems.

The principles governing the way a County maintains its watercourses are laid down in the final Provisional Orders, in supplementary Provisional Orders or in instructions to the watercourse maintenance personnel. Characteristic of these principles is that they generally ensure watercourses better physical conditions for a varied flora and fauna than when they were maintained using traditional methods.

In Nordjylland County, a current channel is usually cleared through the weed in the high quality objective watercourses, although in some watercourses the weed is not cleared at all. The County also administers a number of slowly flowing watercourses, among others a number of dyke- and drainage association systems. In these cases the weed is normally cleared in the entire width of the watercourse and dredging is regularly undertaken to counteract deposition.

In Viborg County, a straight or meandering current channel is cleared through the weed depending on whether or not the watercourse is lined by dykes. Dredging is seldom undertaken and only very locally. Dredging was not undertaken during the period 1989-93, but this resulted in problems with deposition in the lowest 1-2 km of some streams running into Limfjorden fjord. Ringkjøbing County only dredges and uses traditional weed clearance practices in slowly flowing channels, etc., totalling 22.9 km. Vejle County has ceased weed clearance all together in some watercourses, for example in Bygholm Å stream, where weed was not cleared from 1988-93. The cost of maintenance has fallen with the shift to more gentle maintenance. Up to 1975, 23 maintenance workers were employed during the summer period and 6 during the winter period to maintain 110 km of county watercourse. From 1975 to 1985, 13 workers were employed year round to maintain 224 km of county watercourse. Since 1988, only 8 workers are employed during the year.

Figure 6.2 illustrates how Funen County maintains its 573 km of watercourse, 426 km of which are maintained in a gentle manner (Type 1 and 2 watercourses).

These examples show that the expectations of the new Watercourse Act with respect to gentle watercourse maintenance have largely been fulfilled for the high quality objective watercourses for which the Counties are the watercourse authority. The watercourses where traditional weed clearance and dredging is undertaken are watercourses with shallow gradients, for example in low-lying areas near outlets to fjords.

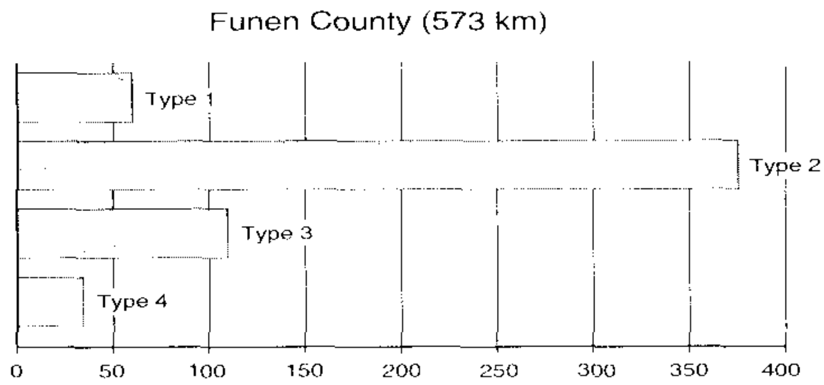


Figure 6.2 *Watercourse maintenance practices in Funen County depend on conditions in the individual watercourses. Type 1: No maintenance except removal of plastic litter, etc.; Type 2: Gentle weed clearance only; Types 3 & 4: Weed clearance and if necessary, dredging.*

How much progress have the Municipalities made?

Only a few Municipalities have so far brought their Provisional Orders in line with the new Watercourse Act. Thus at the end of 1992, new Provisional Orders had yet to be issued for approx. 11,000 km (75%) of municipal watercourse (2). The deadline for new Provisional Orders was originally the end of 1992, but has since been postponed until 1 July 1996. However, this does not mean that the new Watercourse Act has not had a positive impact on municipal watercourses; the examples given in Chapter 2 testify to this. Just as with the county watercourses, in fact, the transition has long been progressing.

Sønderjylland County has analyzed maintenance of municipal watercourses within the county (3). Of the approx. 3,500 km of municipal watercourse, new Provisional Orders had only been issued for 38.5 km (approx. 1.1%) by summer 1992. Nevertheless, the new Watercourse Act has still had an effect; in 18 of the 23 municipalities, changes from traditional to gentle maintenance have been implemented in a number of watercourses.

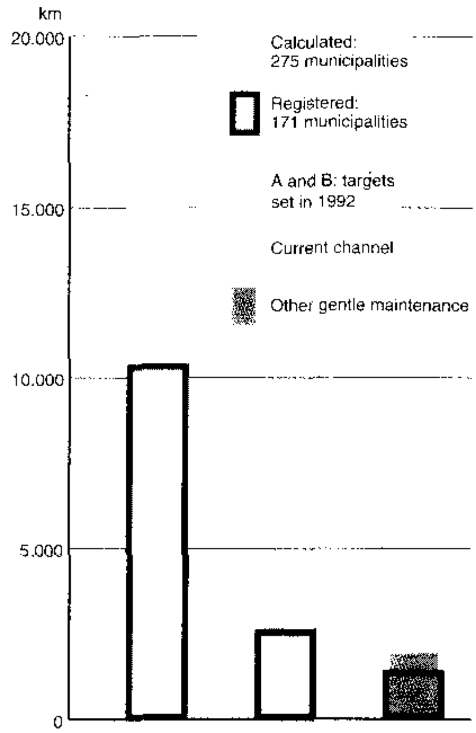


Figure 6.3 *Estimate of maintenance practices in municipal watercourses 1990.*

A survey of 171 municipalities in 1990 (4) gives an indication of how much progress had been made up to that time. The survey, hereafter referred to as the 1990-Survey, was based on questionnaires covering more than 10,000 km of municipal watercourse (Figure 6.3). In approx. 25% of these watercourses, weed clearance was restricted to clearing a current channel and in approx. 12% the weed was cleared in some other environmentally sound manner. Thus between one quarter and one third of these municipal watercourses are maintained in an environmentally sound manner. (The term "environmentally sound" was used in the questionnaire, and not the term "gentle").

Within a certain margin of error, the survey findings (which relate to 10,300 km of watercourse in 171 municipalities) can be extrapolated to cover watercourses in all 275 municipalities in Denmark. Simple projection of the 10,300 km in 171 municipalities to the full 275 municipalities gives a watercourse length of 16,564 km, which is close to the 17,500 km (including culverts) that stems from the Danish Environmental Protection Agency's 1992 watercourse inventory (see page 35). No information is available on the distribution of watercourse quality objectives for the 10,300 km of watercourse included in the 1990-Survey. However, there is reason to assume that environmentally sound maintenance is mainly directed at high quality objective watercourses.

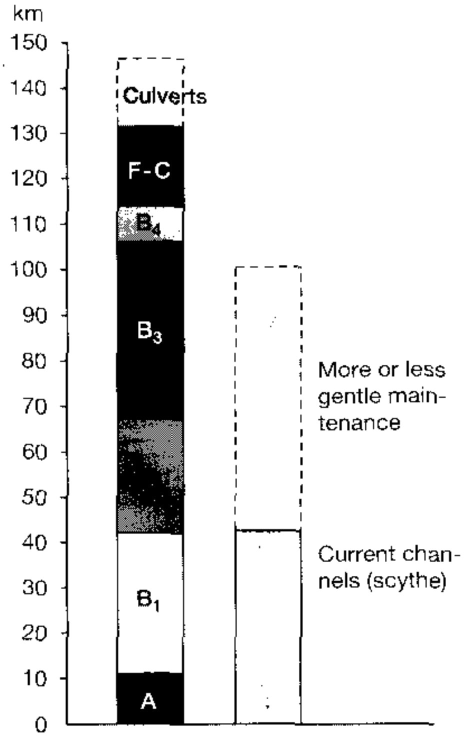


Figure 6.4 *Watercourse quality objectives and maintenance practices in Thisted Municipality. Adapted from (5).*

The 1990-Survey findings can also, with some reservation, be extrapolated to cover all municipal watercourses for which the quality objectives are so high that they should be maintained in a gentle manner, i.e. approx. 10,000 km, excluding ochreous watercourses. Extrapolation from the 25% of watercourses in the 1990-Survey in which weed clearance is restricted to clearing a current channel to all 275 municipalities indicates that approx. 4,000 km of watercourse is maintained in that way, i.e. one third of all municipal high quality objective watercourses. If one also includes the 1,300 km in which (according to the 1990-Survey) other methods of gentle weed clearance are used, and then extrapolates to all 275 municipalities, one finds that approx. 5,500 km of watercourse is maintained using more or less gentle weed clearance, i.e. approx. half of all the municipal high quality objective watercourses. The 1990-Survey supports the information given in Chapter 2 that Municipalities throughout the country are making good progress on implementing gentle watercourse maintenance practices. One can make the reservation that the 1990-Survey does not specify what is meant by gentle (environmentally sound) maintenance; however, that gentle maintenance is in fact being introduced in the municipalities is confirmed by more recent random checks (5).

In Thisted Municipality there are 135 km of municipal watercourse, of which 125 km are open. For the most part, just over 100 km, the watercourse quality objectives are high (Figure 6.4). Gentle weed clearance with a scythe is undertaken in 41.9 km of these watercourses. As shown on page 72, good results have been achieved. When evaluating the extent of gentle weed clearance it is necessary to take into consideration that many of the watercourses in the municipality have a very shallow gradient and that many of their beds are too soft to walk on; it is therefore not possible to use a scythe, and clearance has to be undertaken by basket reaper.

In Thisted Municipality, gentle weed clearance is no cheaper than traditional methods because more frequent weed clearance is necessary in order to ensure that the current channel does not close up. In Vejen Municipality, where gentle maintenance has been practised since 1986 (page 71), gentle weed clearance is undertaken in all high quality objective water-

Table 6.1 *1993 - Random checks of municipal maintenance practices.*

Municipality	km open watercourses	km high quality objective watercourses (A+B)	km gently maintained watercourses
Juelsminde	33		18
Randers	50	48	48
Silkeborg	160	60	53
Løkken - Vrå	143	102	90
Sæby	114	108	108
Holbæk	18	17	14
Viborg	50	45	43
Holstebro	105		88
Ringkjøbing	173	60,5	61
Ringsted	100		22
Thisted	121	100	42
Næstved	53	53	53
Vejen	132		106
Børkop	35	31	35
Haderslev	125		125
Esbjerg	127	95	95
Ryslinge	25	25	25
Græsted Gilleleje	30	30	30
Løgstør	36		24

courses (A and B), as well as in ochreous watercourses. Dredging is not undertaken in such watercourses either. An analysis shows that gentle weed clearance is practised in 52 watercourses totalling 105.8 km, while traditional maintenance (dredging, full-width weed clearance) is practised in 29 watercourses, of which 28 (26 km in all) have water drainage as their quality objective. Random checks made in a number of municipalities in 1993 show the same pattern, i.e. that gentle maintenance is gaining acceptance (Table 6.1). This progress can be observed in Næstved Municipality's 64 km of municipal watercourse, of which 53 km are open. Thus while gentle weed clearance was only practised in 14 km of the open watercourse in 1988, by 1993 it was practised in all 53 km, all of which is high quality objective watercourse (Figure 6.5).

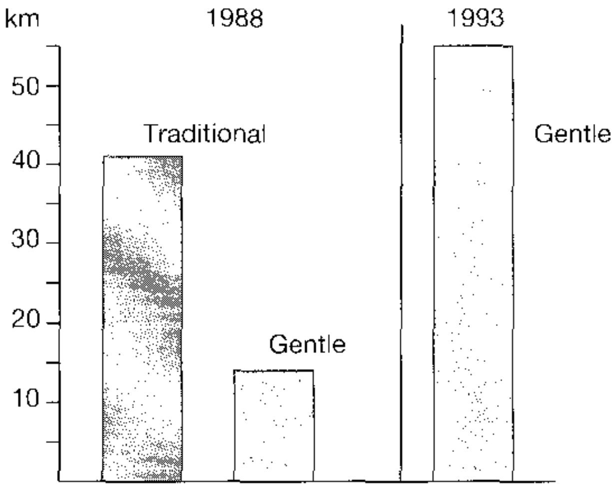


Figure 6.5 *Watercourse maintenance practices in Næstved Municipality 1988 and 1993.*

These examples indicate that the gentle maintenance required by the new Watercourse Act is also starting to become dominant in the municipal watercourses.

On the other hand, no information is available on the maintenance of private watercourses. To date, endeavours to introduce gentle maintenance have presumably been very limited in the private watercourses. Being the watercourse authorities for private watercourses, the Municipalities have to control that maintenance complies with the provisions of the Watercourse Act and, if one has been designated, that the watercourse quality objective is attained. The Counties are also able to influence the maintenance of the private watercourses that are registered as "especially valuable" (Section 3 of the Protection of Nature Act, and Section 43 of the old Conservation of Nature Act) in instances where maintenance involves such extensive dredging that it changes the physical form of the

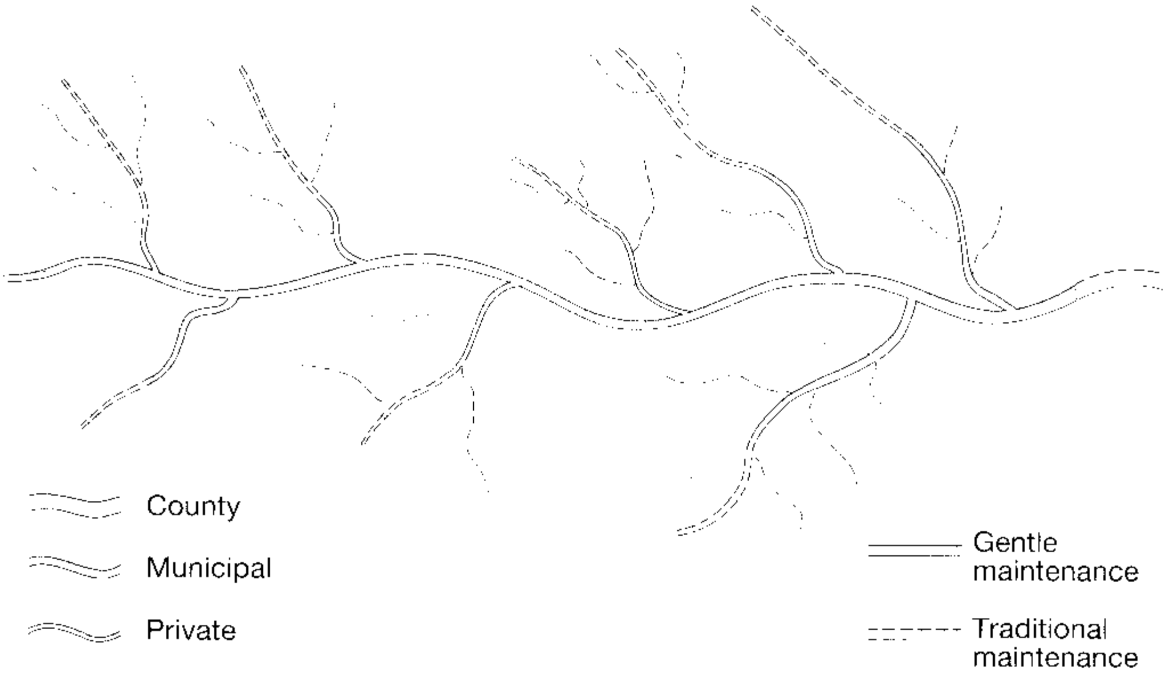


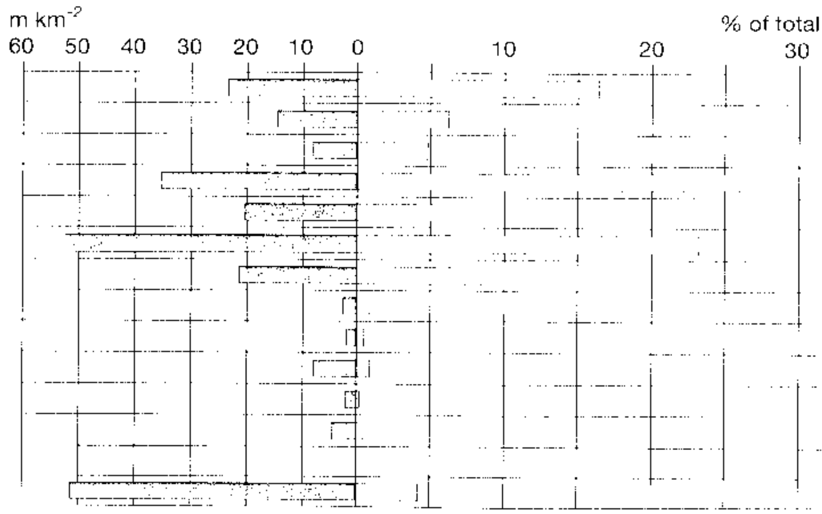
Figure 6.6 Estimate of the extent of gentle maintenance practices in county, municipal and private watercourses.

watercourse. The protection accorded by Section 3 does not apply to normal maintenance though, e.g. weed clearance and normal dredging. However, in step with the cessation of cultivation of many meadows along small watercourses, it can be presumed that interest in the latter for drainage purposes will decline and that maintenance of them will also cease.

It would undoubtedly be beneficial if the information campaign previously directed at public watercourses were also to be directed at private watercourses.

Figure 6.6 illustrates a preliminary estimate of the progress made with respect to gentle maintenance of both public and private high quality objective watercourses.

Figure 6.7 Distribution by county of watercourses that have retained their natural form (adapted from (6)), and of drained areas (adapted from (7)).



County	% drained	Drained area 1,000 ha
Nordjylland	30	129
Viborg	40	109
Århus	45	136
Ringkjøbing	34	112
Vejle	48	98
Ribe	32	67
Sønderjylland	62	183
Funen	55	135
Vestsjælland	78	162
Roskilde	57	33
Frederiksborg	71	45
Storstrøm	80	198
Copenhagen	64	>
Bornholm	60	>22

New meanders

Only few of the natural watercourses have preserved their natural paths. By studying detailed maps it has been estimated that Denmark has only approx. 880 km of watercourse left that have retained their natural meanders. There is no exact figure as to how many watercourses are of natural origin. One estimate is approx. 25-30,000 km, with the rest being man-made channels. In other words, approx. 3% of the original natural watercourses have preserved traces of their original form (6). There is considerable geographical variation in the distribution of Danish watercourses that maintained their natural form (Figure 6.7); almost none remain on the island part of Denmark, whereas there are still some natural watercourses in several parts of Jutland. This regional variation correlates with how intensively the areas in question have been cultivated through the ages.

In Chapter 2 it was discussed how watercourses will begin to wind along a current channel when gently maintained; however, it can take a very long time for a watercourse to form new meander bends. Thus if one wants to remeander a watercourse it is necessary either to wait a long time, or to excavate new meanders. Extremely good results have been obtained

Table 6.2 *Examples of Danish watercourse restoration projects involving remeandering. Adapted from (8).*

Location	Length (m)		Price DKK	Work in addition
	Before	After	thousands	to remeandering
Rind Å, Arnborg	1,800	2,350	1,000	Ochre treatment plant
Idom Å, Holstebro	280	570	70	
Brede Å, Bredebro	2,680	3,130	1.700	
Lundgaard Bæk, Arden	52	250		
St. Vejle Å, Albertslund	1,400	1,564	2,000	
Gelså, Bevtoft	1,340	1,850	1,000	Plant (400,000)
Landeby Bæk, Løgumkloster	475	775	1,500	Mill dam
Grøn Å	950	1,450	970	
Frøjk Bæk, Holstebro	650	1,100	650	Detainment basin
Guldager Møllebæk, Esbjerg	1,377	1,855	285	
Taps A	250	300	1,500	Fish ladder and dam
Kikhanerenden	420		5,500	Detainment basin
Holmehave Bæk, Funen	800	900	290	Sluice system (73,000)
Høsletbæk, Funen	300	450	61	
Lindved Å, Funen	1,000	1,800	940	Aqueduct (175,000)
Stokkebæk, Funen	508	640	477	Bridge (87,000)
Puge Mølleå	370	450	815	Bridge (91,000)

with the latter approach in several places in Denmark during recent years. Thus the remeandering of Rind Å stream has led to the ochre being retained, while in Idom Å stream the fish population has increased and in Brede Å river and Gelså stream the flora and fauna have become more diverse.

Examples of watercourses that have been remeandered are given in Table 6.2. In many others a winding course has been established within the confines of a more or less straight watercourse path. In addition to the remeandered watercourses shown in Table 6.2, several smaller watercourse reaches have been remeandered as part of various other projects.

The cost of remeandering a channelized watercourse varies considerably. An estimated average is approx. DKK 5-600,000 per km. The cost depends not only on the size of the watercourse, but also on what kind of follow-up work is needed. The Gelså stream restoration project cost approx. DKK 1 million per km, but that included expenses for relaying sewage drains, etc. The "pure" restoration work cost approx. DKK 600,000 per km. Watercourses can also be remeandered for considerably less, however, an example being Idom Å and Rind Å streams in Ringkjøbing County (page 149, 151), which were remeandered at a cost of approx. DKK 250,000 per km.

By the end of 1993, hardly more than 20-25 km of watercourse had been remeandered, an insignificant length in comparison to the many thousand kilometres of channelized watercourse. Regardless of whether the cost for remeandering is DKK 100,000 or DKK 1,000,000 per km watercourse, it is difficult to imagine that it is through such projects that good watercourse quality is to be restored to channelized watercourses, there being several cheaper yet good alternatives. One of these could be current concentrators. As of September 1990, that form of restoration had been undertaken in approx. 23 km of watercourse (9).

The means to improve watercourse form will in most cases undoubtedly be gentle maintenance. For the time being remeandering will probably be the exception in the work to recreate good watercourses. However, it might play a role in the restoration of especially valuable watercourses and, moreover, in creating a positive awareness of the way we treat our watercourses.

Table 6.3 *Some examples of culverted watercourses that have been re-exposed. Adapted from (8).*

Location	Length m.	Price DKK thousands	
Enggård, Gram	1,560	230	
Brook near Skjødstrup	810	104	
Smak Mølleå, Løgstør	300	338	1987, 1991
Smak Møllebæk	400	90	1993 (upstream)
Lindal, Ry	170	32	
Fiskebækken, Holmegård	300	40	
Isholm Landgrøft	290	75	Incl. inlets, etc.
Østkær Bæk, Blåvands huk	600	600	
Tjærby Bæk, Randers	500	250	Bank borders, etc.
Kestrup Bæk, Haderslev	673	121	
Bærmoseskoven, Århus	6,000	50	Depth of 1.3 m
- " - - " -	6,000	150	Depth of 2.5 m

Re-exposing watercourses

An unknown number of watercourses have been culverted. The 1992 watercourse inventory (10) shows that approx. 3,000 km of municipal watercourse and approx. 60 km of county watercourse are culverted, while the extent of culverted private watercourses is unknown. Several of the projects that the Danish Environmental Protection Agency has supported in recent years have involved the re-exposing of culverted watercourses. Some of the more important projects are listed in Table 6.3. An estimate of the extent to which culverted watercourses have been re-exposed indicates a total length of less than 20 km up to the end of 1993. The costs vary considerably, but an estimated average is DKK 100-200,000 per km.

As far as concerns culverted watercourses, however, there is no alternative to re-exposing them. It is therefore necessary to prioritize and carefully evaluate the value for the watercourse and its system of re-exposing the culverted section. An obvious example of a culvert to which priority should be given is when the final reach of a small especially valuable watercourse is culverted as it passes through a meadow before flowing into a larger watercourse.

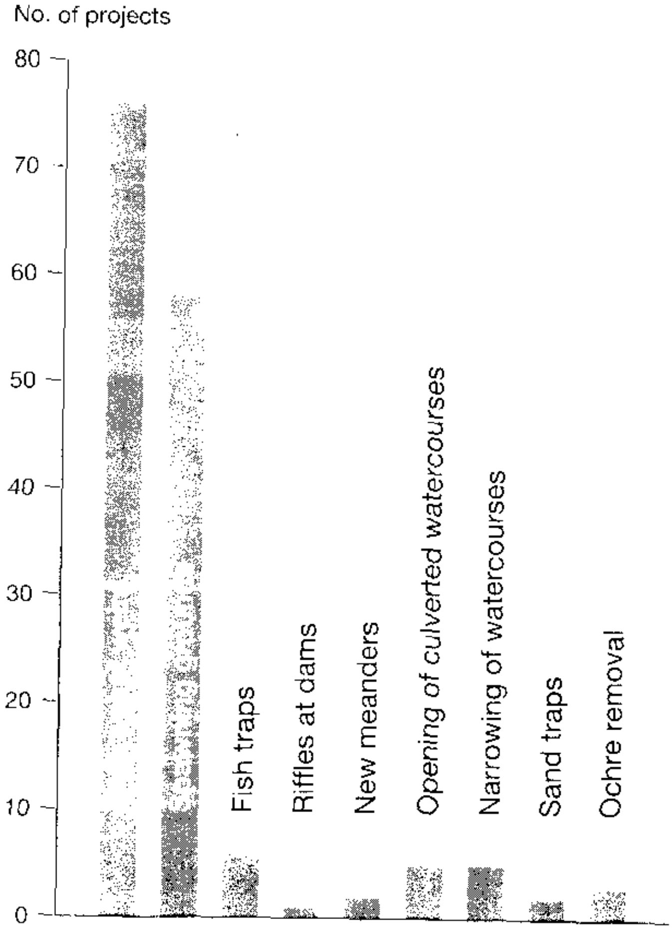


Figure 6.8 *Restoration projects in Ribe County.*

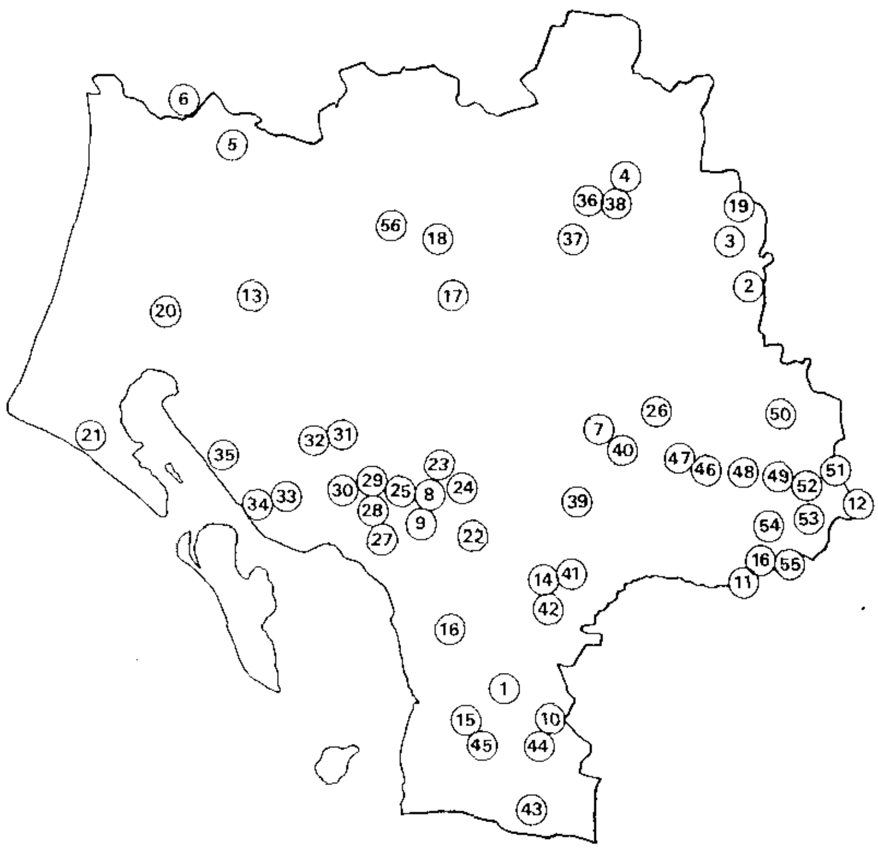


Figure 6.9 *Watercourse restoration projects in Ribe County 1987-92. Adapted from (11).*

Table 6.4 Watercourse obstructions eliminated in Viborg County grouped by type. Adapted from (13).

	Completed (as of 30.09.93)	Initiated (as of 30.09.93)
Road culverts	38	11
Field culverts, drains, etc.	6	2
Riffles	2	4
Weirs	19	11
Rail culverts	1	2
Dams	10	9
Total	76	39
Access to:	202.9 km + 4 lakes	59.7 km + 17 lakes

Table 6.5 Watercourse obstructions eliminated in Viborg County grouped by severity. Adapted from (13).

Extent of obstruction	Completed (as of 30.09.93)	Initiated (as of 30.09.93)
Total	19	8
Serious	13	5
Selective	34	25
Less serious	10	1

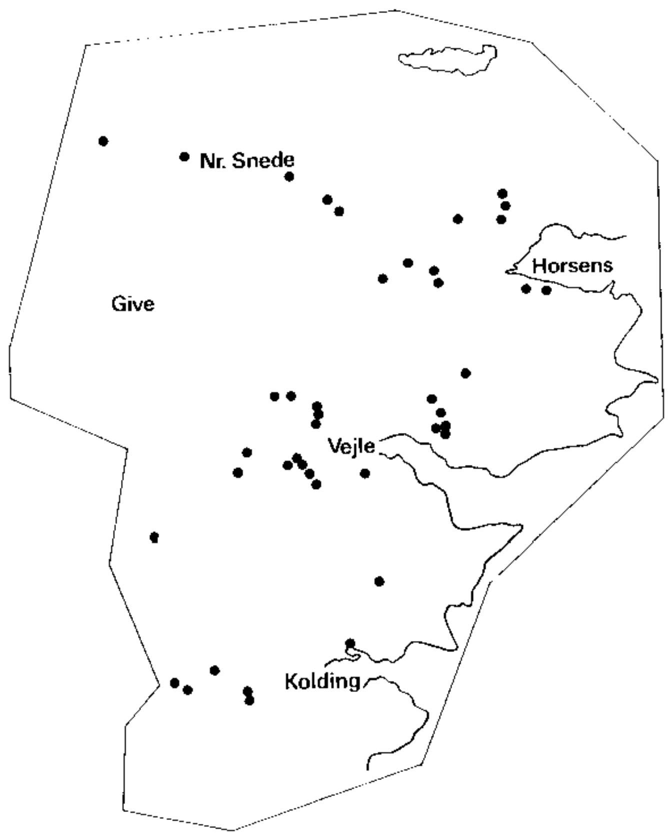


***Figure 6.10** Watercourse restoration projects in Vejle County 1987-92. Adapted from (12).*

Table 6.6 *Watercourse obstructions eliminated in Thisted Municipality: Status as of 1993. Adapted from (14).*

2	fish farm dams	›	lack 2
4	concrete structures		
17	road and field underpasses		
6	culverts	›	lack 3
5	Drop manholes		
34	**in all**	›	**lack 5**

Financing

Viborg County	DKK	128,000	
Danish EPA...............	DKK	166,000	
Other	DKK	4,000	
Thisted Municipality...	DKK	150,000	+ unemployment benefit recipients
Total	**DKK**	**448,000**	
	+ own staff + material + own planning		

Restoration of free passage at obstructions

Of the approx. 100 projects that the Danish Environmental Protection Agency supported financially over the period 1984-90, 66 concerned the removal of obstructions hindering the free passage of fish. The corresponding figures from 1992-93 also show a preponderance of funds being used to subsidize elimination of obstructions. In Århus County there is a clear tendency to move away from fish ladders and instead establish other solutions such as riffles and bypasses; these can be passed by all fish and invertebrates, and they blend more naturally in with the watercourse surroundings (15). A summary of restoration projects undertaken in Ribe County (Figure 6.8) (16) shows that by far the majority of projects concern the restoration of free passage for fish, both in county and municipal watercourses.

The work done in Ribe County gives a good idea of how much progress has been made with this and other forms of watercourse restoration (Figure 6.9): the 56 projects identified in Figure 6.9 involved the elimination of 41 obstructions in county watercourses and 67 obstructions in municipal watercourses, as well as the establishment of a large number of spawning grounds and the undertaking of a number of other restoration measures. Vejle County had also undertaken numerous projects by the end of 1992 (Figure 6.10). In Funen County, where there were once approx. 200 obstructions, the County had established passes at 122 of them by the end of 1993; they include 3 bypass streams, 19 fish ladders and 58 riffles, while 42 obstructions were simply demolished. In collaboration with its Municipalities, Nordjylland County has eliminated 44 obstructions over the period 1989-91, thereby opening approx. 100 km of watercourse to access by fish.

When prioritizing the work with obstructions, great weight is attached to how great and important a watercourse area the fish will gain access to. Thus access may be gained to large parts of the watercourse system (Figure 6.11). Such was the case when the entire Hjortvad Å stream system was opened (see page 126), and in Sønderjylland County the end is now in sight for the numerous obstructions in the county watercourses. The restoration of passage at the obstructions has been tackled systematically such that by the end of 1993, all the weirs in Arnå stream had been replaced by riffles (Figure 6.12) and by the end of 1994 all obstructions in the county watercourses should be gone, though with the possible exception of some obstructions that the county shares with Germany (see Figure 6.13). Nonetheless, there are still a number of obstructions remaining in the county in municipal and private watercourses.

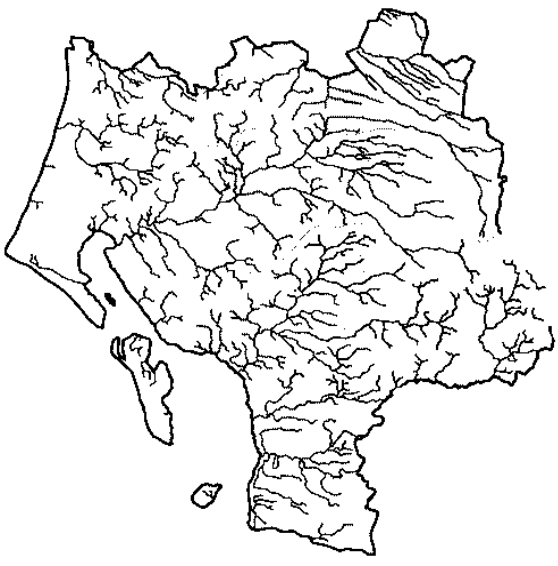


Figure 6.11 *Large areas of Ribe County are still closed to the free passage of fish. Adapted from (17).*

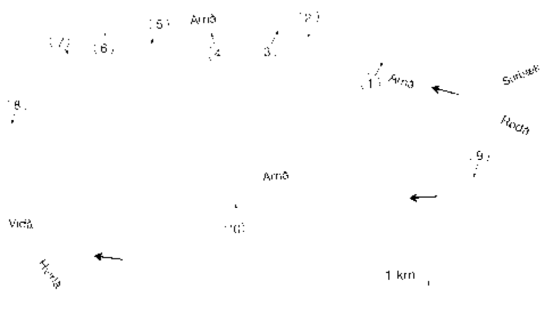


Figure 6.12 *Free passage has now been restored at 10 obstructions in Arnå stream. Adapted from (18).*

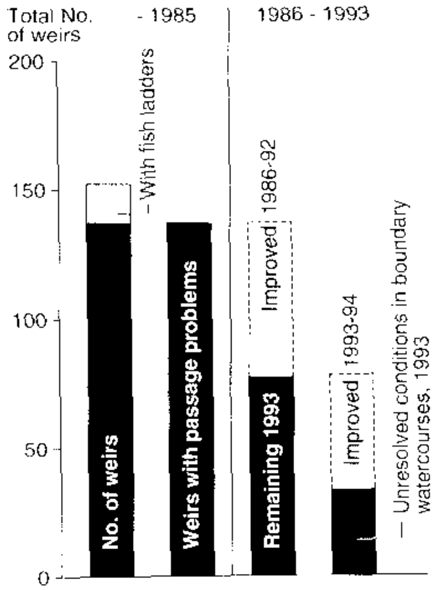


Figure 6.13 Status of obstructions in county watercourses in Sønderjylland County. Adapted from (18).

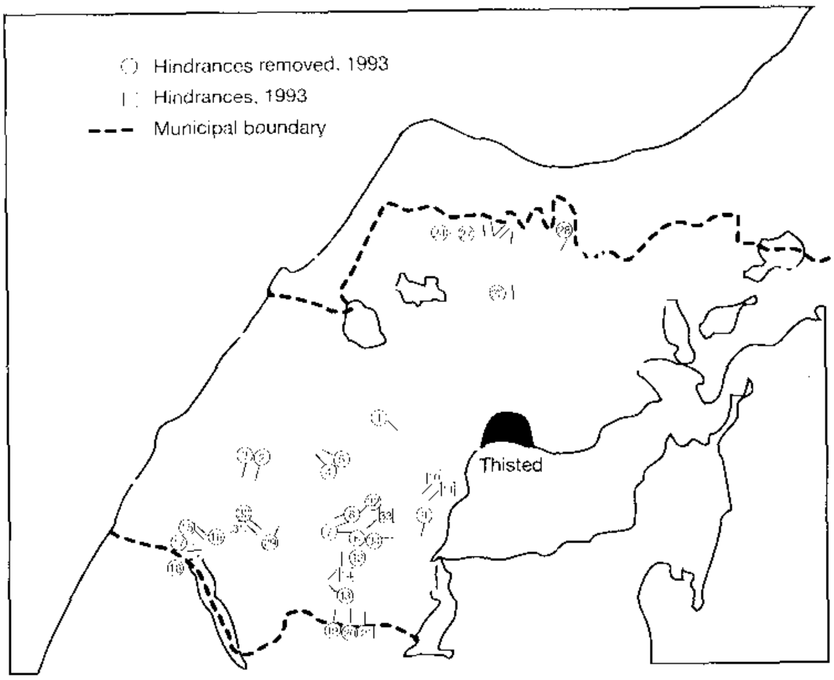


Figure 6.14 Status of obstructions in Thisted Municipality 1993.

In Viborg County, approx. 400 watercourse obstructions have been counted. As of autumn 1993, passage had been restored at 76 obstructions and was in the process of being restored at a further 39 (Tables 6.4 and 6.5). A good example from Viborg County is Thisted Municipality, where only 6 of 34 obstructions remain (Figure 6.14; Table 6.6). Those that do remain are serious obstructions that will be expensive to remove.

What do the restoration measures cost?

There is no clear indication whether gentle maintenance is cheaper or more expensive than traditional practices. In some places it is more expensive, while in others it is cheaper - just as examples in the book show. It is obvious that if considerably less dredging is to be undertaken than previously, then there is money to be saved (see page 86, for example). The same applies if weed clearance is no longer to be undertaken in a watercourse as for example in Bygholm Å stream in Vejle County. However, if weed clearance has to be undertaken more frequently than before (when it was only necessary to clear on one or two fixed occasions), then costs may be greater. Nevertheless, in relation to the improvements bestowed on watercourses by gentle maintenance, the additional expenses are completely insignificant in comparison to the expenditure on the treatment of sewage. Voer Å stream is also an example of the fact that gentle weed clearance provides much more improvement per unit cost than do actual restoration measures (page 46).

As is apparent from this chapter, it can be somewhat expensive to re-expose culverted watercourses and remeander channelized watercourses, as it can be to remove large obstructions.

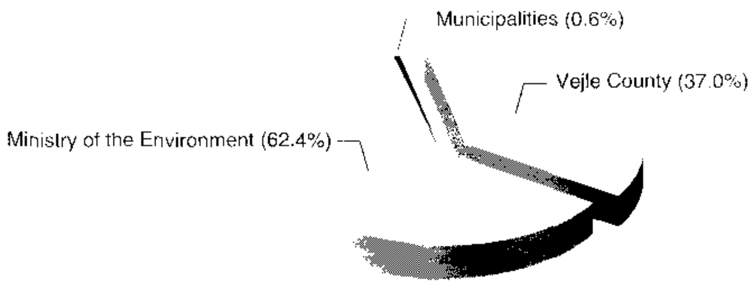


Figure 6.15 *Apportionment of restoration expenses in Vejle County 1986-92. The total expenditure was DKK 9 million. Adapted from (19).*

In order to encourage restoration work, the Watercourse Act opened the way for such projects to be subsidized. The support was given to cover additional expenses associated with the projects, i.e. material, additional manpower and additional expenses incurred by the watercourse authority's own personnel. In the beginning, 75% of admissible expenses were generally subsidized. A clear precondition was that the project should benefit watercourse quality. In recent years the subsidies have been reduced in order to be able to support a greater number of projects. Thus when replacing a weir with a riffle, the support given by the Danish Environmental Protection Agency will typically amount to 30%, while that for re-exposing culverted sections or remeandering channelized reaches can be 40%. This reflects the fact that higher priority is given to projects with wider environmental value than to projects primarily of benefit to fishing interests. In those cases where support is also provided from other sources, e.g. the Nature Restoration Fund, support from the Danish Environmental Protection Agency can be even lower (15%, for example).

The watercourse authorities must cover the remaining costs. As an example, cost apportionment and subsidy rules for Vejle County are shown in Figure 6.15 and Table 6.7.

Table 6.7 *Restoration project subsidy rules for Vejle County.*

Major obstacles:

Established before 19.07.1988: ....100% subsidy

Established after 19.07.1988:
- no right of passage stipulated in ruling...50% subsidy
- right of passage stipulated in ruling........25% subsidy

Repairing inefficient fish ladders ....100% subsidy

Minor obstacles:

The watercourse authority itself takes care of minor obstacles, usually with the advice and guidance of the county authorities

In step with growing experience in watercourse restoration at both county and municipal level, costs have in many cases fallen. The lesson has been learned that simple restoration measures are often all that is needed. The current attitude is usually to aim for as much "environment" as possible for the money. A good example of this attitude from Viborg County is given in Box 6.1.

Box 6.1 *Experience from Viborg County concerning the re-establishment of fish passages and spawning grounds. Adapted from (13).*

Economy

Under the motto "as many passages as possible for the money" deliberate attempts are made to hold project planning expenses at as low a level as possible, particularly with small projects. The "project" has therefore often been no more than a hand-drawn sketch on an A4 sheet of paper based on a few on-site measurements that is handed to those who are to carry out the work.

It has only been necessary to prepare real project plans with detailed measurements, drawings, etc., in the case of large projects that are important from the drainage or financial point of view, and for those projects for which subsidies have to be sought from other sources.

When planning expenses are kept at such a low level there is obviously a risk that problems may subsequently arise with insufficient drainage upstream of the riffle, thus resulting in complaints from landowners. Another risk is that one might select material of too small a size, with the result that the riffle is destroyed by exceptionally high discharge.

However, of the 76 projects that have so far been undertaken in Viborg County, such problems have only arisen twice! In both cases the problems could be rectified by a minor adjustment of the riffles, and at a cost significantly lower than that of a set of super architect-designed project plans that might have prevented the problems from arising. Expressed in another way: The stones can in most cases be dug up and replaced at least 10 times for the price of detailed architect-designed project plans. Hence, except for very large projects, such plans must therefore be considered superfluous.

Follow-up studies

With the passage restoration projects so far undertaken, only very limited resources have been available to study the upstream and downstream fish population prior to and following removal of the obstruction. However, as the establishment of riffles with a gradient of approx. 10‰ has been tried and tested at numerous places in Denmark, it is quite certain that such riffles actually provide sufficient passage and additional studies are therefore not necessary in every case. Nevertheless, fish population studies will still be undertaken in connection with some projects in order to directly demonstrate the development of the fish population.

Do the watercourses improve?

Chapter 2 presents examples demonstrating that gentle maintenance and other environmentally sound treatment of watercourses have a beneficial impact on the flora and fauna. It would be useful if one could evaluate what impact these endeavours (together with those to combat pollution) have had on Danish watercourses.

Nordjylland County has found the trout population to satisfactory at 80 stations in some Vendsyssel watercourses; at 61 of these stations this development was considered to be primarily attributable to the gentle maintenance now practised in these watercourses. At a further 84 stations the trout population was unsatisfactory, in 48 cases this being blamed on hard-handed maintenance (20).

Ribe County published an appraisal of fish population development in its watercourses in 1993 (17). This showed that over the last decade there had been a marked improvement in the trout population of the 990 km of watercourse in the county designated as "salmonid waters". Thus while at the beginning of the 80's the trout population was only satisfactory in 30% of the watercourses, and there were no trout at all in 40%, by the beginning of the 90's the trout population was satisfactory in 51% of the watercourses (Figure 6.16).

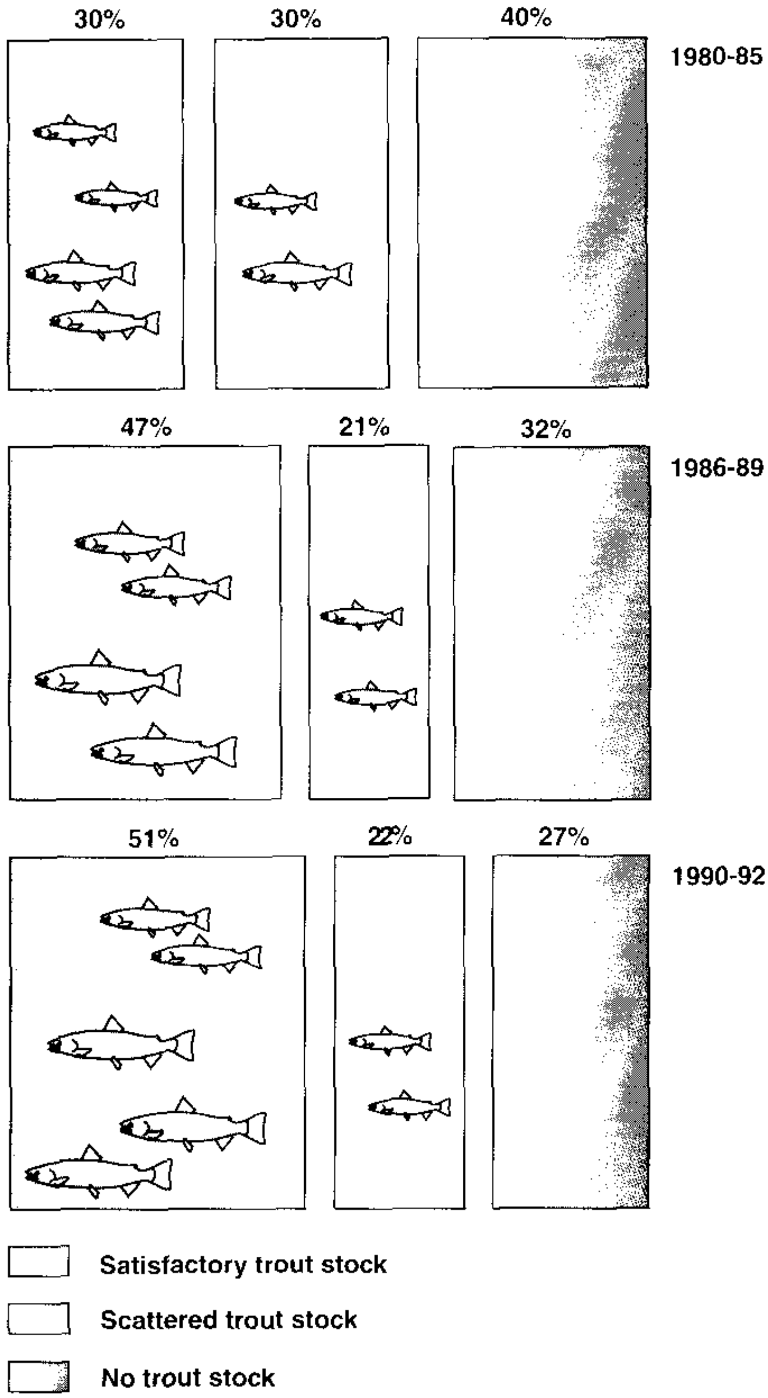


Figure 6.16 *Improvement in the trout population in Ribe County. Adapted from (17).*

Improvement in the fish population is not only attributable to stocking. Figure 6.17 shows that the majority of grayling in Vejen Å stream are small. The natural population disappeared in the 60's. Stocking of the stream with grayling has since been undertaken on several occasions, the last time being in 1989. However, examination of the population in 1992 revealed numerous yearlings, thus indicating that a natural population of grayling was starting to re-establish in the stream. They are born in the watercourse as part of a natural population, just as is also the case with the trout population in a tributary of the river Kongeå (Figure 3.15).

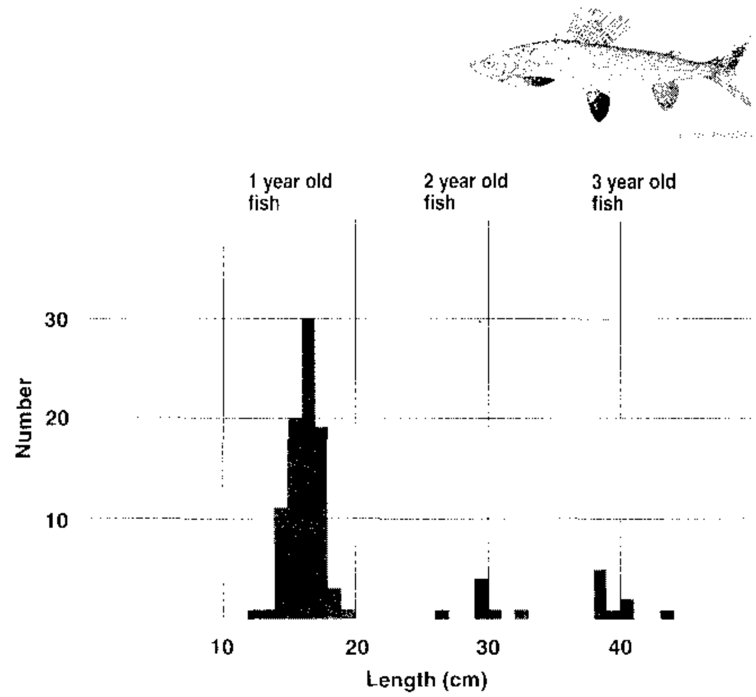


Figure 6.17 A natural population of grayling has now re-established in Vejen Å stream. Further stocking of grayling is no longer necessary there. Adapted from (17).

Do the watercourses become cleaner?

Many conditions have to be in order before good watercourse quality can be attained. Efforts to ensure cleaner water in the watercourses have a common denominator in all watercourses: The watercourses must not be polluted, although the degree of pollution, i.e. the watercourse class (see page 32), can vary slightly depending on the designated objective. The main aim is to ensure that no watercourse exceeds pollution class II-III and that the majority of watercourses are in class I or II.

In Vejle County, analysis has been undertaken of the trend at 1,215 watercourse sampling stations that have been regularly monitored since 1970 (21). The stations were evaluated according to pollution class (I-IV). At 29% of the stations conditions have improved by at least one whole "class", while at

3% they have deteriorated by at least one half class. Those stations that "only" improved by half a class were not counted as having improved. Figure 6.18, which covers the period 1987-1991, reveals that conditions have improved during that time.

There are fewer polluted reaches of class III, and a greater number of "clean" reaches, i.e. class I and II reaches. Most reaches are class II and II-III, with an increase in II-III and a decrease in II.

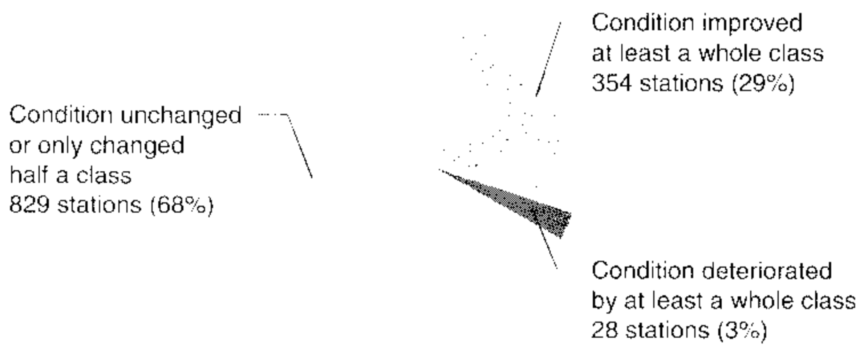


Figure 6.18 *The quality of many watercourse reaches has improved in Vejle County. Adapted from (21).*

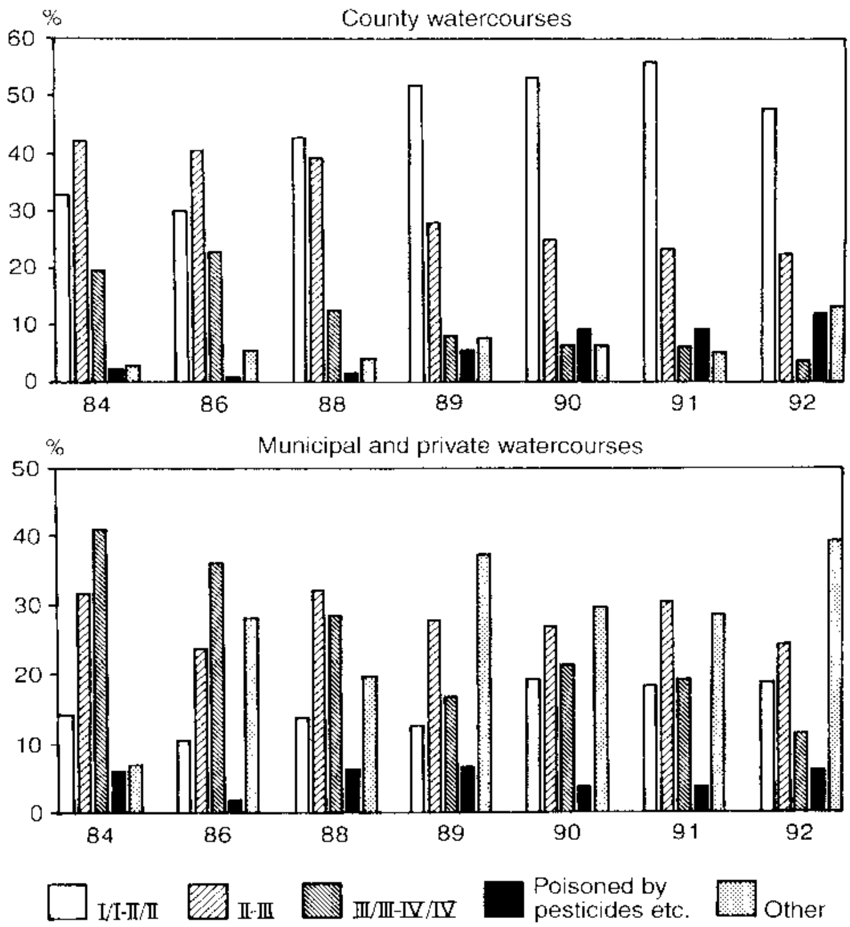


Figure 6.19 *County watercourses have become much cleaner on Funen. However, there are still problems with the smaller watercourses, as well as incidents of pesticide poisoning. Adapted from (22).*

A similar positive development has also been observed in Funen County. There has been a very clear improvement in the *pollutional state of the 550 km of county watercourse (Figure 6.19)*. Thus the percentage "clean", i.e. class I, I-II and II watercourses has increased from approx. 30% in 1984 to approx. 50 % in 1992, while that of polluted watercourses in class III and worse has decreased from approx. 20% in 1984 to approx. 5% in 1992. The picture is not quite so rosy for the 790 km of smaller municipal watercourse, however. Thus although there are more clean and fewer polluted watercourses, there is also a large "grey zone", where watercourses are neither particularly clean nor particularly polluted.

The problem watercourses in Funen and Vejle Counties resemble each other in that most are small with a weak current and uniform physical conditions. Their poor condition is due to a combination of pollution from small sewage outfalls, particularly *septic tanks, and the poor ability of the watercourses* to metabolize the pollutants. Vejle County closely examined this problem in three municipalities (Table 1.1, p. 28). It was found that pollution from septic tanks and suchlike was the cause of the problems in about a quarter of the watercourses, while poor physical conditions was the cause in about half of the watercourses. The physical conditions and pollutional state of a watercourse go hand in hand, maintenance being one of the factors determining a watercourse's quality class.

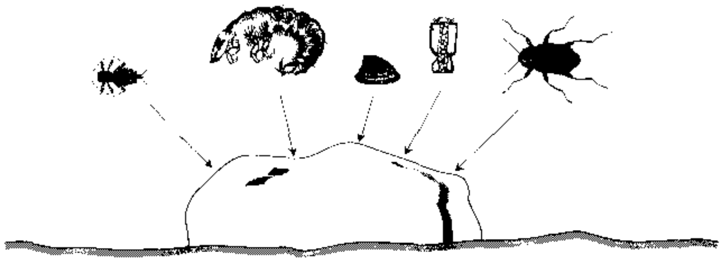


Figure 6.20 *Stone beds in watercourses provide a habitat for many clean-water macroinvertebrates.*

Better habitats - better "classes"

In order to determine a watercourse's "quality class", one investigates what macroinvertebrates inhabit it, as explained on page 32. The so-called clean-water macroinvertebrates can only live where the water is clean and richly oxygenated. That is not all that is needed, however, since the macroinvertebrates also have to have somewhere to live. Many "clean-water macroinvertebrates" live on stones (Figure 6.20). If these stones are covered with sand or ochre, or have been dredged out of the watercourse, then the watercourse will be devoid of these macroinvertebrates - regardless of how clean the water is. The watercourse will therefore be judged as belonging to a poorer class than the quality of the water alone would suppose. An example of this is Tvede Å stream (Table 4.5).

When stone beds replaced sand beds the number of clean-water macroinvertebrates increased. The watercourse was then rated in a higher class. There are several similar examples from watercourses in Århus County (23). A better bed with habitats for the clean-water macroinvertebrates shown in Figure 6.20 has "upgraded" watercourses from class II-III to II, and in some cases even to I-II. This has meant that some watercourses can now satisfy their quality objectives.

A watercourse with many different habitats will, as a rule, be rated in a higher class than a watercourse with uniform physical conditions, even if the two watercourses are equally clean. A watercourse offering a large variety of habitats with stones, weed borders, gravel, etc., will be inhabited by many different macroinvertebrates and as such, will be rated in a high quality class. In contrast, a watercourse with a bed comprised only of sand and having uniform coverage with plants such as bur reed will only be inhabited by a few species of macroinvertebrates, although they may be present in large numbers; as such it will be rated in a lower class.

A current channel provides a habitat for several clean-water macroinvertebrates, partly on the gravel bed where the current is strong, and partly within the weed borders. The watercourse will thus be assessed a higher quality class.

Vejle County has investigated the watercourses in Juelsminde Municipality (24). The watercourses were rated both as regards pollution class (I-IV) and physical condition, the latter being rated using the same scale as used to evaluate the suitability of a watercourse for trout (Table 3.1, page 95). This scale ranges from 0 in watercourses with the most uniform physical conditions, to 5 in watercourses with the best physical conditions.

The most polluted watercourses are nearly always those in which physical conditions are poorest (Figure 6.21). The County concluded that a number of the watercourses would undoubtedly move up into a higher class if their physical condition were improved. This could be achieved by gentle maintenance, which is much cheaper than further sewage treatment. However, it should once again be emphasized that

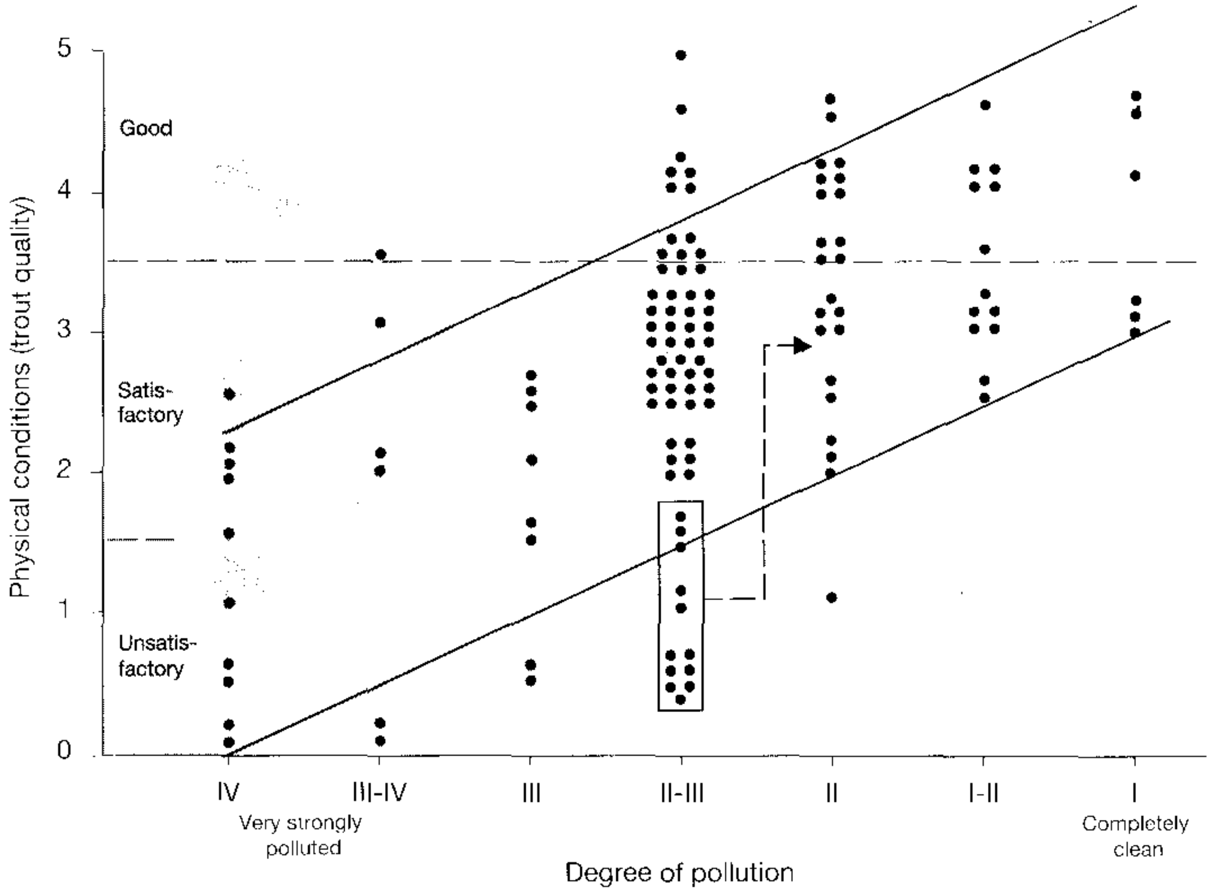


Figure 6.21 *In Juelsminde Municipality many of the polluted watercourses also have the poorest physical conditions. The watercourses enclosed in the box would undoubtedly be "upgraded" to a higher class if they were maintained more gently. Adapted from (24).*

gentle maintenance alone cannot replace sewage treatment or solve the problem of pollution from septic tanks.

Hard-handed maintenance is undoubtedly an important reason why watercourses remain in unsatisfactory quality classes despite considerable effort to deal with pollution. This is reflected by an investigation that Ribe County undertook of watercourses in four of its municipalities (Figure 6.22) (25). The watercourses in all four municipalities had been maintained in a hard-handed manner for many years. After the introduction of environmentally sound maintenance practices in two of the municipalities (C and D), there was a considerable improvement in the watercourses' quality, especially in municipality C. That the effect was not as marked in municipality D may be because many of the watercourses there are so troubled by ochre that their quality class cannot be determined. However, as described on page 87, gentle maintenance can also alleviate that problem.

In the other two municipalities the environmental condition of the majority of the watercourses is still poor despite considerable effort having also been made there to reduce pollution. One of the reasons could be that watercourse maintenance in these municipalities is still undertaken in the traditional manner.

Watercourse "self-purification"

It is not just better living conditions for macroinvertebrates that can upgrade watercourses to a higher class. Water also becomes cleaner in watercourses in which physical conditions are good. Such watercourses are self-purifying and can metabolize and neutralize the organic compounds with which they are polluted. The stones and vegetation in the watercourses are covered with a thin biological film (often referred to as a biofilm) comprised of an enormous number of bacteria and microorganisms. These absorb and metabolize pollutants from the water, which thereby becomes cleaner. They are the same type of microorganisms that are employed in sewage treatment plants. However, they are unable to deal with the phosphorus in sewage.

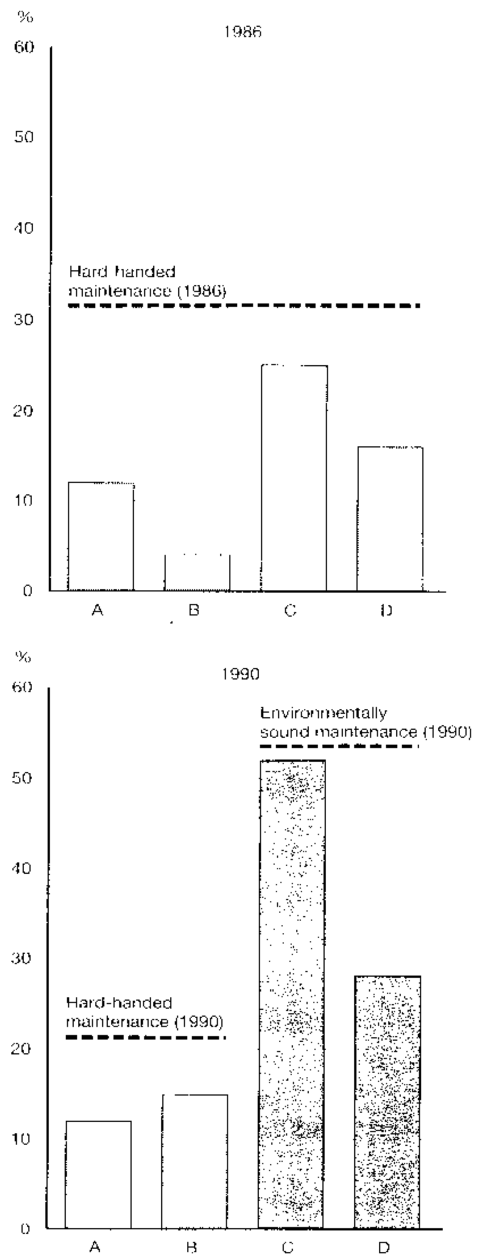


Figure 6.22 *The percentage of watercourses in four municipalities that were clean enough to meet their quality objectives in 1986 and 1990. The two municipalities where watercourse quality has improved the most (C and D) have introduced gentle weed clearance. This might explain part of the improvement.*

The biofilm consumes oxygen when purifying the water. When the watercourse has a brisk current which swirls around weed borders and stones a constant supply of oxygen enters the water from the atmosphere, both day and night. Oxygen is also produced by the aquatic plants, but only during the day when there is sufficient light.

If on the other hand a watercourse is lazily flowing, oxygen deficiency can arise and the self-purification process will come to a halt. Thus when hard-handed maintenance removes the stones and weed borders from a watercourse, it also removes the self-purifying biofilm and decreases reaeration capacity. As a consequence, even a slight amount of pollution will have a noticeable impact on the watercourse.

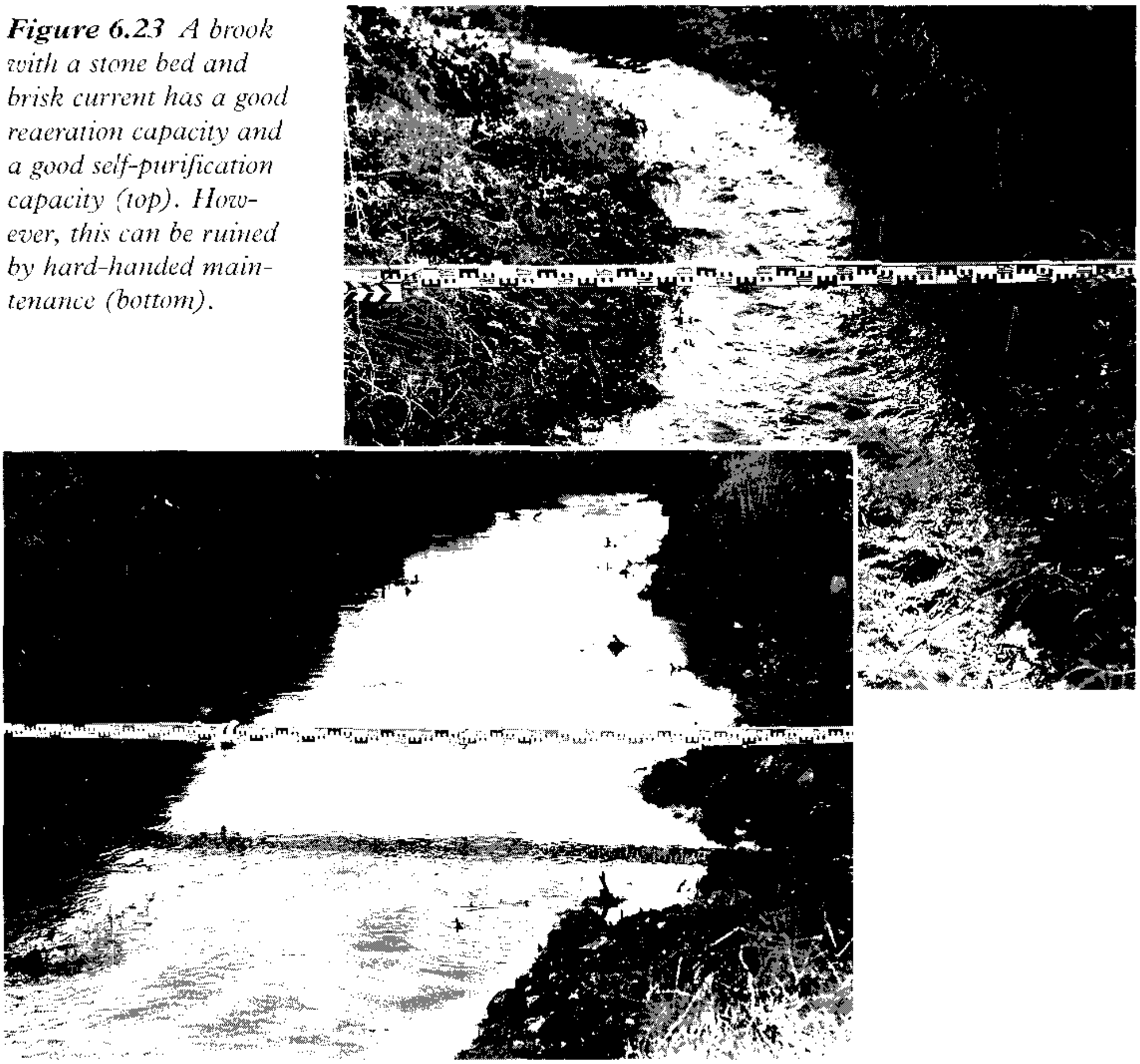


Figure 6.23 *A brook with a stone bed and brisk current has a good reaeration capacity and a good self-purification capacity (top). However, this can be ruined by hard-handed maintenance (bottom).*

The improvements in watercourse physical conditions that accompany gentle maintenance and watercourse restoration measures can therefore help to ensure the good quality of the water.

This book provides many examples of the considerable amount of work being done throughout the country to improve our watercourses. While there is still much to be done, there is increasing local political will to get on with gentle maintenance and restoration measures. This growing interest is undoubtedly coupled to the fact that visible results are rapidly obtained in the form of more pleasant watercourses containing more fish. Even more important, though, is the improvement in the ability of the watercourses to metabolize pollutants. Watercourse maintenance and restoration measures are not only of significance for the watercourses themselves, but also for the entire aquatic environment.

Figure 6.24 *The stream and adjacent meadows are being united once again. Photograph by Sønderjylland County*

7. Conclusion

Our surroundings have always been undergoing transformation. Nature adapts to changes in climatic and geological conditions and, not least, to the impact of human activity. As can be read from the "fen books", i.e. the remains of plants in fen sediments, man was already well on the way to changing the watercourses' surroundings in Denmark in the early Iron Age. One can "read" that our early ancestors exploited the agriculture. The meadows and watercourses were in fact the actual source of early agriculture, a role that they preserved right up to the middle of the present century. There was water there, and in the water there were nutrients for the crops. It was not only in the valleys of the Nile and Euphrates that man benefitted from flooding.

Exploitation of the watercourses changed them. They were dammed so that flooding could be controlled. More than a thousand years ago watercourses were regulated in order to drive mills. In Viking times the harbours were located far inland, where the ships were better protected than on the coast; an example is Ravningbroen bridge on the river Vejle Å.

Thousands of kilometres of ditches were built to drain the fields (1). At the end of the 18th century large canal systems were built to irrigate meadows in western Jutland. Canals were also built to exploit the water's energy, an example being the canals at Ansager Å and Holme Å streams, which supply energy to Karlsgårdeværket power station. In other parts of the country canals were built for transportation purposes. An example is Torpe canal on the river Suså.

If one excludes the innumerable mill dams that have prevented the free migration of salmonid fish through the watercourses for a millennium or more, the most marked change in the watercourses is the pollution and channelization to which they have been subjected during the present century.

Times have changed, however. We are now able to prevent pollution, and the results are starting to become apparent, as discussed in Chapter 6. We have also learnt that good drainage and good natural conditions are not necessarily incompatible. Examples are given in Chapter 2. Moreover, we have learnt that it is possible to create good fish passes.

However, it is not just a question of new insight. Times have also changed in other ways. Thus technology has also had an impact within agriculture, it now being possible to produce more than is sufficient using a smaller and smaller area. There is no longer the same need for exploiting marginal land. The low meadows alongside the watercourses are losing their value as agricultural land. Their time has past.

Time is running out for meadows in more ways than one. One of the conditions for their intensive exploitation was that they had to be drained. In those meadows lying on peat - approx. 200,000 ha - the earth overlying the drains is disappearing. The dry soil is being decomposed by bacteria and it is compressed by the heavy farm machinery. In the course of a few decades the drains will be too near the surface to be able to keep the soil dry enough for crops to thrive (Figure 7.1).

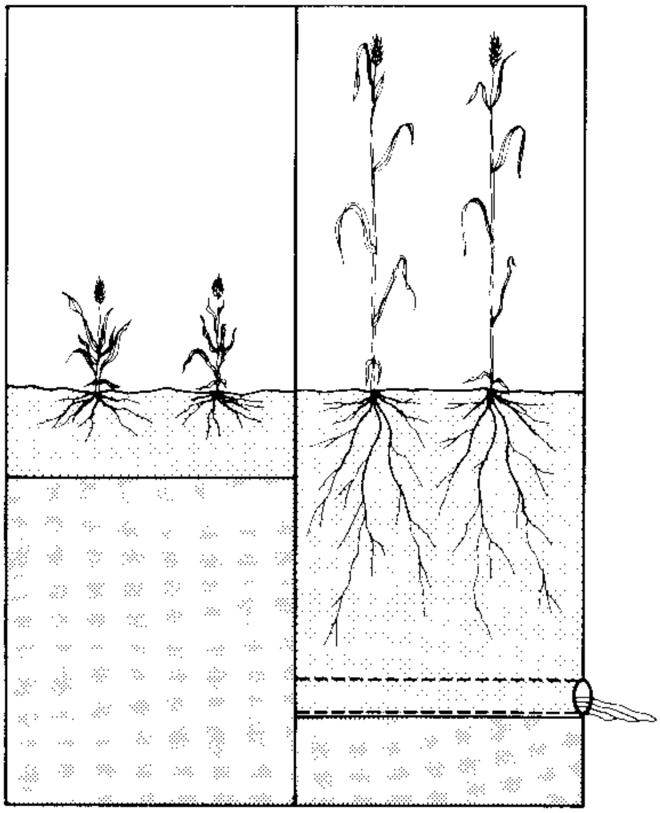


Figure 7.1 *In a wet field the roots of crops do not develop well.*

Meadows revert to a natural state

In the times when it was economical to cultivate low-lying meadows, the drains were usually re-laid when they came to lie too near the surface. At the same time the watercourse beds were lowered or drainage water was pumped up. However, with current developments in farm prices it is no longer economical to renew the drains. Meadows with old drains will therefore gradually revert to their natural state. Figure 7.2 summarizes the age of drains in Ribe County (2). Many of them are starting to reach an age at which they no longer function.

The falling economic interest in low-lying meadows coincides with the increasing application of gentle watercourse maintenance practices. Irrespective of whether gentle maintenance influences drainage conditions, the new economic perspectives have made life easier for the river keeper (7).

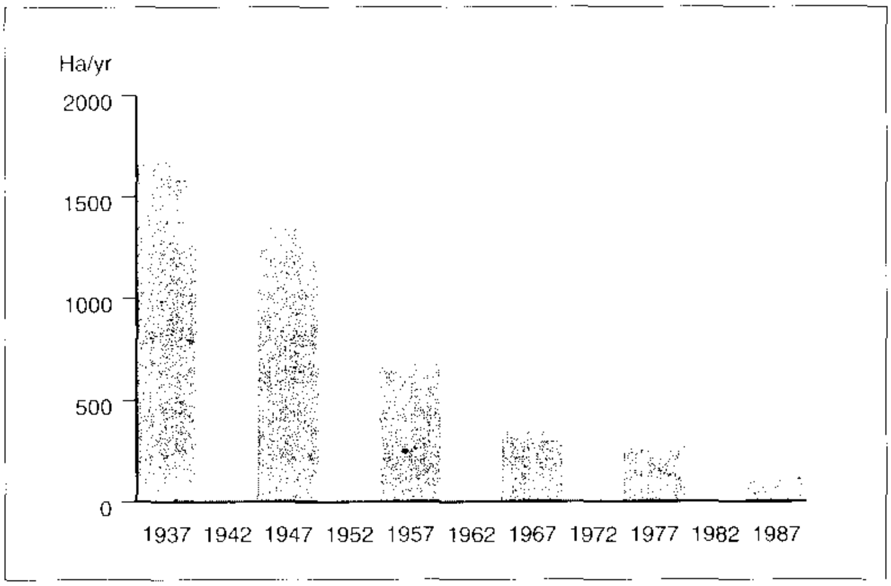


***Figure** 7.2 Many of the drains are now so old that they no longer function. The example shown is from Ribe County.*

Nature's treatment plant

Watercourses lead the water out to sea via lakes and fjords. They also transport the substances that cause marine oxygen depletion and fish kill. Technical solutions are available for some of the problems; for example, sewage effluents can be treated. However, there are many other sources of pollution, e.g. ochre from drained meadows and nitrogen from cultivated fields. Chapters 2 and 5 give examples of how ochre pollution can be curbed using relatively simple means. Nitrogen pollution can also be curbed, as in the long run can that by phosphorus.

Gentle maintenance practices, which are increasingly taking over, help to retain pollutants in the watercourses and their surroundings. Part of these substances is metabolized there, while the remainder is retained and hence does not reach the lakes and fjords until the seasons during which they cause no damage. The National Environmental Research Institute has been studying this for a number of years, among other places in Gjern Å stream (4): In spring and in summer 20-65% of the phosphorus and nitrogen is retained and so does not reach the lakes and fjords during summer, when it causes most damage. It is not until discharge increases in the autumn that the part which has not been metabolized is flushed downstream. If discharge is particularly great and the stream floods its banks, many of the substances end up in the meadows. Here they remain, eventually to be incorporated into the meadow vegetation and subsequently to form topsoil. This is how meadows arise.

However, even more happens in some of the meadows that revert to a natural state, namely the meadows based on peat, and which are so wet that the topsoil lacks oxygen. It is in these meadows that the nitrate that leaches from cultivated fields is removed by denitrification (Figure 7.3). Although the process has long been known (5), recent Danish studies have nevertheless shown that surprisingly large amounts of nitrogen can be removed in this way. Just how important it actually is for total nitrogen pollution in Denmark is unknown, but the total area of meadows having the appropriate characteristics is approx. 200,000 ha (6).

As an example, nitrogen removal in a meadow on Funen was measured to be 400-600 kg NO^3-N per ha per year (7). This is a considerable amount considering that runoff from cultivated land is approx. 20 kg NO^3-N per ha per year.

A very convincing result has been obtained in some meadows bordering a tributary of Gjern Å stream (8): A strip of meadow just 13 m wide adjacent to a cultivated field removes all the NO^3-N that leaches from the field.

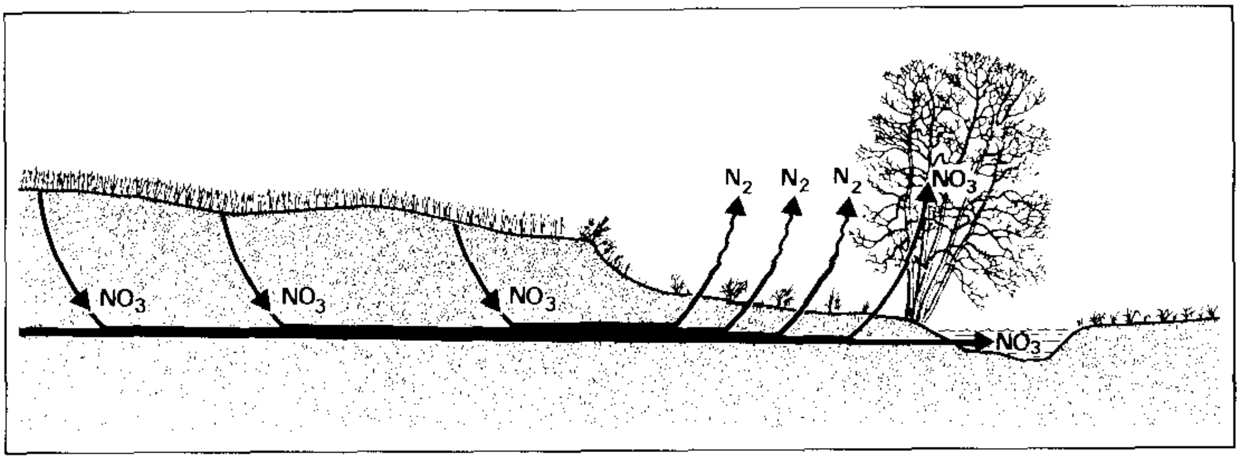


Figure 7.3 *Wet meadows remove nitrate by denitrification, the process whereby nitrate is converted to harmless nitrogen gas.*

The watercourse of the future

Irrespective of whether wet meadows can help in solving the problem of nitrogen loading of the aquatic environment, cessation of intensive cultivation of meadows in any case provides a number of environmental benefits.

One can maintain the watercourses in such a way that good natural conditions develop. Alternatively, one can maintain them in such a way as to provide good leisure activities such as angling. The two are not necessarily compatible. Wildly growing bank vegetation can pose a problem for anglers, yet be beneficial for the fauna of both the watercourse and the adjoining fields. Weed borders along the banks can make it difficult for an angler to land a fish, but can be of great value for the watercourse. A bank trampled down by cattle can be of value to many birds, yet provide little shelter for fish.

In some cases, one can refrain from maintaining watercourses altogether. This would benefit the larger watercourses, but in the case of many small watercourses would result in them becoming completely overgrown. They might become wide swampy areas where the water seeps away. If one wants to approximate natural conditions in the watercourses, i.e. have watercourses that are as far as possible "untouched by man", then some of them will come to look quite different from the watercourses we presently consider to be "natural". The latter are usually distinct and well-defined meandering watercourses. Some will perhaps become completely overgrown with weeds and the water will spread over the meadows. Some will perhaps end up with a braided course (Figure 1.7). One of the most natural watercourses in Denmark, Holme Å stream, probably takes its name from the many islets there were along its course, and which are typical for braided watercourses. This watercourse presently follows a well-defined meandering path, undoubtedly thanks to former maintenance practice.

If the meadows are left alone, they will also change from those we know today. They will become overgrown by willow and alder scrub that will obscure the watercourses. This type of meadow will be a good habitat for the marsh titmouse and other small birds. However, the lapwing and wading birds will disappear, as will the great variety of flowering plants found in meadows.

One has also the opportunity to decide what type of fish there shall be in the watercourses. Maintenance and restoration are of decisive importance with respect to whether watercourses will in future house a natural fish stock. The question is whether one is to promote a particular population (e.g. salmon) by stocking and perhaps even by removing fish such as pike and zander, which can threaten the salmon fry.

Once it was energy that was needed. Then it was water for irrigation. Now it is more their utilization for leisure activities that is in focus. In this case, however, the interests are legion, and they are the basis for just as intense conflicts as have always been associated with the usage of watercourses.

Now, when we are well on the way to restoring good natural and environmental conditions in Danish watercourses, it is high time that planning took into account the various demands currently made on our watercourses.

The far-sighted quality objectives laid down for our watercourses are discussed in Chapter 1. These have been of decisive value with respect to the achievements made. They set the course. However, the time is now ripe to draw up objectives for the mosaic of various uses to which the watercourses are now put, not least the leisure activities.

A key word in Danish environmental and nature protection is versatility. A versatile flora and fauna was high on the list of priorities when the Environmental Protection Act was being drawn up in the 1970s. Thus this is stated in the objects clause of the 1973 Act.

This versatility should also apply to the exploitation of the restored natural resources in and near the watercourses. There should be room for a multitude of different activities.

"Useful in the past. A pleasure in the future" is the inscription on a monument erected at the Taps Mølleå stream restoration project near Christiansfeld.

Let that be the book's closing sentiment.

Figure 7.4 *The future for watercourses should be versatile exploitation for leisure activities.*

Notes

Nearly all the information in this book is based on the practical work that has been undertaken with watercourses. Much of the information is to be found in reports and articles, but the majority is derived from personal contacts. The staff of the Counties, Municipalities and certain institutions have been exceedingly helpful.

The sources of the information are given below for each chapter, the numbers referring to those given in parentheses in the text. This is followed by a brief list of more general works on the topic. Because of the nature of this book, most of the sources referred to are written in the Danish language.

•

Chapter 1:

1: Leopold, L.B., 1994: A view of the river. Harvard Univ. Press.

2: Hansen, H.O. et al., 1992: Restoration of the source of the river Gudenå (in Danish). Vand & Miljø, 8, p 263.

3. Frandsen, S.B. et al., 1993: Cleaner watercourses in Vejle County (in Danish). Vand & Miljø, 10, p 123.

4: Danish Environmental Protection Agency, 1994: Registration of Danish watercourses 1992 (in Danish). In press.

5: Sønderjylland County, 1992: The aquatic environment in Sønderjylland County (in Danish).

6: Danish Land Development Service, 1976: Maintenance of municipal watercourses (in Danish).

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Abstract: The new Danish Watercourse Act entered into force in 1982. The Act made it possible to modify watercourse maintenance practice such that Danish watercourses could once again become good habitats for fish, plants and invertebrates. This book brings together a selection of the methods that the watercourse authorities have developed over the last 10 years to improve watercourse quality. The book examines gentle weed clearance and actual watercourse restoration measures, and presents an overview of the improvements that have taken place in Danish watercourses during that period.

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Resume:
I 1982 blev den nye vandløbslov vedtaget. Den gjorde det muligt at ændre vedligeholdelsen af vandløbene, så de igen kunne blive gode levesteder for fisk, planter og smådyr. I denne bog er samlet et udvalg af de metoder, vandløbsmyndighederne gennem de sidste 10 år har udviklet for at forbedre vandløbskvaliteten. Det handler om skånsom grødeskæring og egentlig vandløbsrestaurering, og der er lavet en status over de forbedringer, man har set i vandløbene i denne periode.

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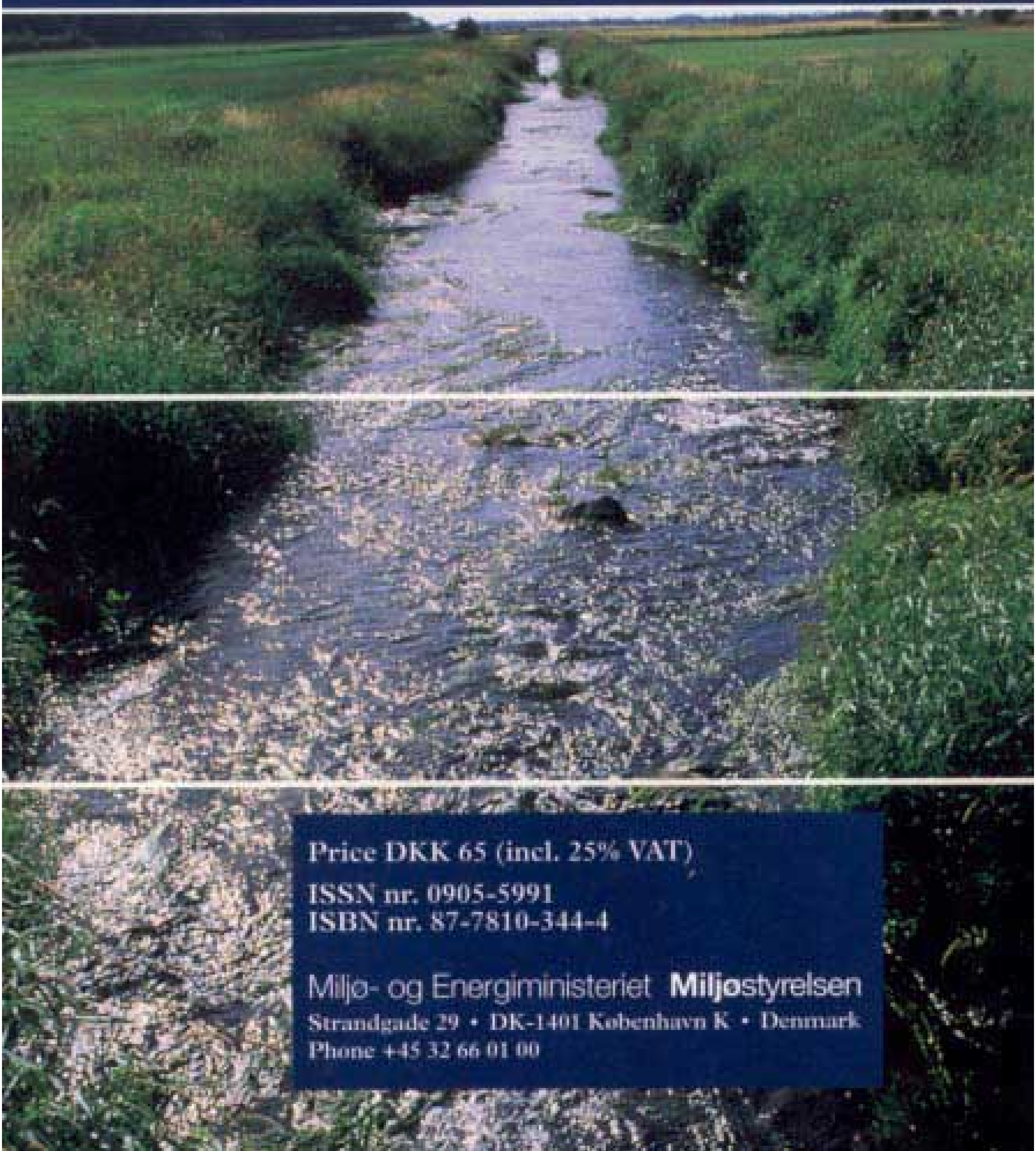

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