River Restoration in Denmark

Fladså, Sydsjælland

River Storå
River Odense at Dalum
River Odense at Broby
River Gudenå
River Aarhus
River Gryde
River Vegen
River Vejle
River Almind
River Sneum
River Skensved
River Herredsbæk
River Donse
River Usserød
River Damvad
River Lemming
River Varde
River Halkær
River Odense
River Gels
River Krogbæk
River Bruså
River Tryggevælde
River Sønderå

24 examples

STORSTRØM COUNTY

River Restoration in Denmark – 24 examples

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24 examples

Storstrøm County
2006

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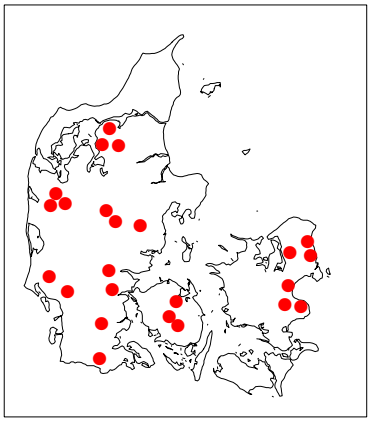


Foreword

We are presently mid in a reform of Danish municipal and county administrative structure. With the disbanding of the counties and the establishment of the new regions, many administrative tasks are being reassigned. Responsibility for our rivers (and lakes) has previously been shared between the counties and the municipalities. Henceforth, though, responsibility for rivers will lie with the new, larger municipalities. With this role comes responsibility for ensuring the many uses to which rivers are put – they must serve as conduits to transport water away from the arable land, forests and towns, but they also have to serve as habitats for a diverse flora and fauna.

In former times the only interest was in ensuring drainage. This resulted in rivers that were devoid of life. Nowadays rivers have to serve many purposes, though, thereby entailing a built-in conflict of interest. If life is to be present in the rivers, the water has to be clean, there has to be plenty of it and the physical conditions have to be good. As the rivers of the past were polluted, physically monotonous and affected by water abstraction, the task of re-creating rivers with a versatile flora and fauna is enormous. Much progress has been made, though. We have managed to reduce pollution and bring water abstraction and water consumption under control, and we have changed the way that rivers are maintained.

In Denmark we have built up considerable knowledge and experience about how to improve the physical condition of rivers. It is important that this knowledge and experience are not lost, but can instead be passed on to the new municipal authorities.

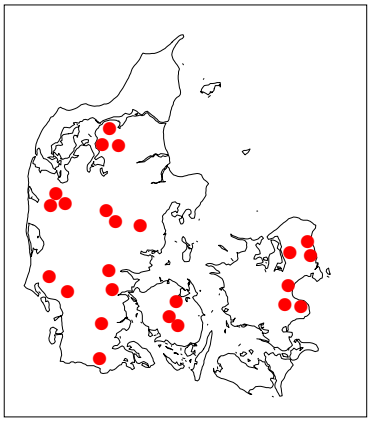
It is thus with great pleasure that I am able to introduce this collection of Danish river restoration projects. It has been assembled collaboratively by the various county officials responsible for river restoration. Hence there are examples from all over the country. We in Storstrøm County have edited and published the collection on behalf of our colleagues from all the counties. A large number of people have supported this publication, either by providing the examples or by providing financial support. We thank all those concerned.

It is my hope that this collection of examples will serve as a source of pleasure and inspiration for all those who will work with river restoration in the future.

November 2006

By Otto Jensen
Chairman
Committee for Technical and Environmental Affairs
Storstrøm County


VOLVO



Editor's foreword

By Søren Madsen
and Paul Debois
Storstrøm County

The aim of this book is to collate and share the experience with river restoration gained in the Danish Counties over the past many years. The idea for this book was spawned by a 3-day excursion to 22 river restoration projects arranged by the Professional Association of County Environmental Officers, DAVID. We presented the idea during the excursion, and it transpired that there was great interest in seeing the collection of examples published.

The present collection of river restoration projects has been collated, edited and published Storstrøm County. This was only possible because many people have been willing to contribute with their knowledge of the projects and their desire to disseminate this knowledge. We thank the many authors. The book is published by Storstrøm County with financial support from

Ringkjøbing County
Ribe County
Aarhus County
Vejle County
Vestsjælland County
Roskilde County
Frederiksborg County
Fyn County
Nordjylland County
Danish Forest and Nature Agency

It is our hope that the book will focus attention on river restoration as one of the means of improving the value of rivers as habitats for a diverse flora and fauna. It is also our hope that the collection of examples will help promote understanding of the fact that river restoration has to be seen as part of a holistic solution in which other habitat types and landscape, cultural history and drainage interests also have to be taken into account.

The experience reported here mainly derives from the county environmental authorities. One of the main aims of the collection of examples is to pass on our experience to the new authorities that will arise from the present reform of Danish municipal and county administrative structure. A further aim is to contribute Danish experience to the European network for river restoration that is comprised by the European Centre for River Restoration.

We hope that this collection of examples will be widely disseminated, both in book form and on relevant websites, and that it will serve as a source of help and inspiration in future work on river restoration.

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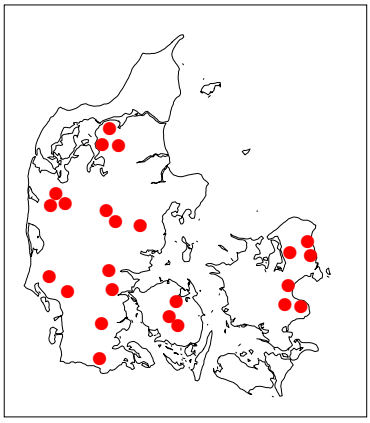
River Krogbæk

River Fladså

River Varde



Introduction

By Paul Debois
Storstrøm County

The days when rivers were solely used as canals for drainage and the transport of wastewater are long gone. Danish legislators and the population are becoming increasingly aware of the natural, landscape and recreational value of our rivers, and Denmark has entered into a number of binding international agreements.

For many years the Danish Regional Plans have stipulated quality objectives for most rivers. The coming river basin management plans and Natura 2000 plans will set a new standard for the quality of our rivers. If the Danish rivers are to meet environmental objectives and quality standards, it will be necessary to rectify the sins of the past.

Holistic solutions to the problems are needed. This book focuses attention on the physical side of the solutions that may prove necessary.

The physical quality of rivers has long attracted attention in Denmark. Former practices such as river regulation, channelization, culverting and the establishment of weirs have decisively altered the physical determinants of river quality. Experience shows that we can come a long way by changing river maintenance methods. That is not always sufficient, however. In many cases it will be necessary to change the rivers' physical characteristics. When the Watercourse Act was revised in 1982, the possibility to restore the physical characteristics of rivers was introduced.

Awareness of the decisive significance that physical characteristics have for life in the rivers has led to a longstanding tradition for river restoration in Denmark. Contributions have come from many different sides, but the main actors have been the Counties. It is therefore sensible to collate the considerable experience gained by the county authorities over the years so that this can be exchanged with and disseminated to other actors, both present and future.

The book is not a textbook in hydraulics, river biology or other relevant disciplines. Such books have been written by others. This book rather comprises a collection of examples intended to focus attention on river restoration in order to ensure the quality of our watercourses and serve as a source of inspiration to others as to how to solve various problems. The examples rarely involve ideal situations for which it is possible to propose ideal solutions, but rather just "the art of the possible". Precipitation, geology, landscape factors, land use and degree of urbanization differ considerably from region to region. Thus our aim has not been to describe projects with a high scientific profile, but rather a number of very diverse examples of problems and solutions pertaining to both large and small rivers. The examples encompass everything from restoration in the open countryside in places where there is an abundance of water and no runoff problems, to restoration in densely built-up areas with numerous physical barriers and considerable variation in runoff. Thus

the focus has been on the variety of the problems and the possible solutions.

The examples in the book also reflect the development that has taken place in the projects. The earliest projects were restricted to the establishment of fish ladders at the physical obstructions constructed in the rivers over the years. The fish ladders were followed by various forms of fish passes such as bypass riffles, etc. The next generation of projects opened up culverted rivers and improved the physical environment in the riverbed. In recent years the focus has been on re-meandering rivers in order to restore river dynamics. The earlier focus on the river as a single element has been replaced by a holistic understanding of the interplay between the rivers and their surroundings.

Several new projects reflect acknowledgement of the fact that some of the earliest projects did not live up to expectations. There can be several reasons for this. For example, the projects could have represented the solution that it was possible to implement – as seen in the light of existing knowledge and the understanding pertaining among the decision makers and legislators involved. Thus some of the examples concern previously restored river reaches or project areas that have been redesigned and re-restored based on new knowledge and new possibilities. There are also examples of reinterpretation of “old doctrines” and “rules of thumb”.

The individual chapters have been written by the county officials responsible for the projects. There are 24 examples of county projects. Each chapter follows the same template. We have focussed on describing the problem, the solution and the experience gained from the selected projects.

In 1996, the National Environmental Research Institute published “River Restoration – Danish experiences and examples” available on the Institutes website at the following link: http://www2.dmu.dk/1_viden/2_Publikationer/3_Ovrige/rapporter/river_restoration_uk_1-2.pdf. The examples in that collection were also written by the county officials responsible for the projects. Even though considerable knowledge and experience have since been accumulated, the examples can still serve as a source of inspiration. Many of the problems addressed still apply today. The new collection of examples is intended as a continuation of the first report, but with the focus on newer restoration measures.

Many of the examples in this book derive from a 3-day excursion held on 25–27 May 2005 to 22 restoration projects dispersed throughout Denmark. The excursion was arranged by the Professional Association of County Environmental Officers, DAVID (now MINA) – see the back inside cover. The authors of the various chapters either participated in the excursion or were project demonstrators.

The national perspective
The current reform of Danish county and municipal administrative structure transfers responsibility for rivers to the new, larger municipalities. One of the aims of this collection of examples is therefore to present the experience gained by the Counties so that it can serve as inspiration and guidance for the new municipalities and other actors involved in river restoration.

The international perspective
For many years Denmark has been one of the leaders in developing and focussing attention on river restoration. An international conference on river restoration was held in the Danish town of Silkeborg in 1996 (River Restoration 1996 – The Physical Dimension) under the auspices of the European Centre for River Restoration. Prior to and for a few years following the conference the National Environmental Research Institute in its role as the Danish National Centre did a good job of collecting and disseminating experience with river restoration at the national level. Little has happened on this front since then, however.

Members of the Professional Association of County Environmental Officers, DAVID, have been exchanging experience on river restoration since before the Silkeborg Conference. It is some of this experience that we now wish to disseminate to a wider audience. The conference in Silkeborg was followed up by one in Holland in 2000 and another in Croatia in 2004. The Croatian conference showed that the European Centre for River Restoration (ECRR), which now has its secretariat in Holland, is still functioning well. In this context, though, Danish efforts of the river restoration front are virtually invisible. This is undoubtedly because the level of activity at the Danish National Centre is extremely limited. This is really a pity, because we have much to offer. In view of this, and so that we can contribute to the common pool of knowledge being exchanged within the ECRR, the present collection of examples has been published in English as well as in Danish.

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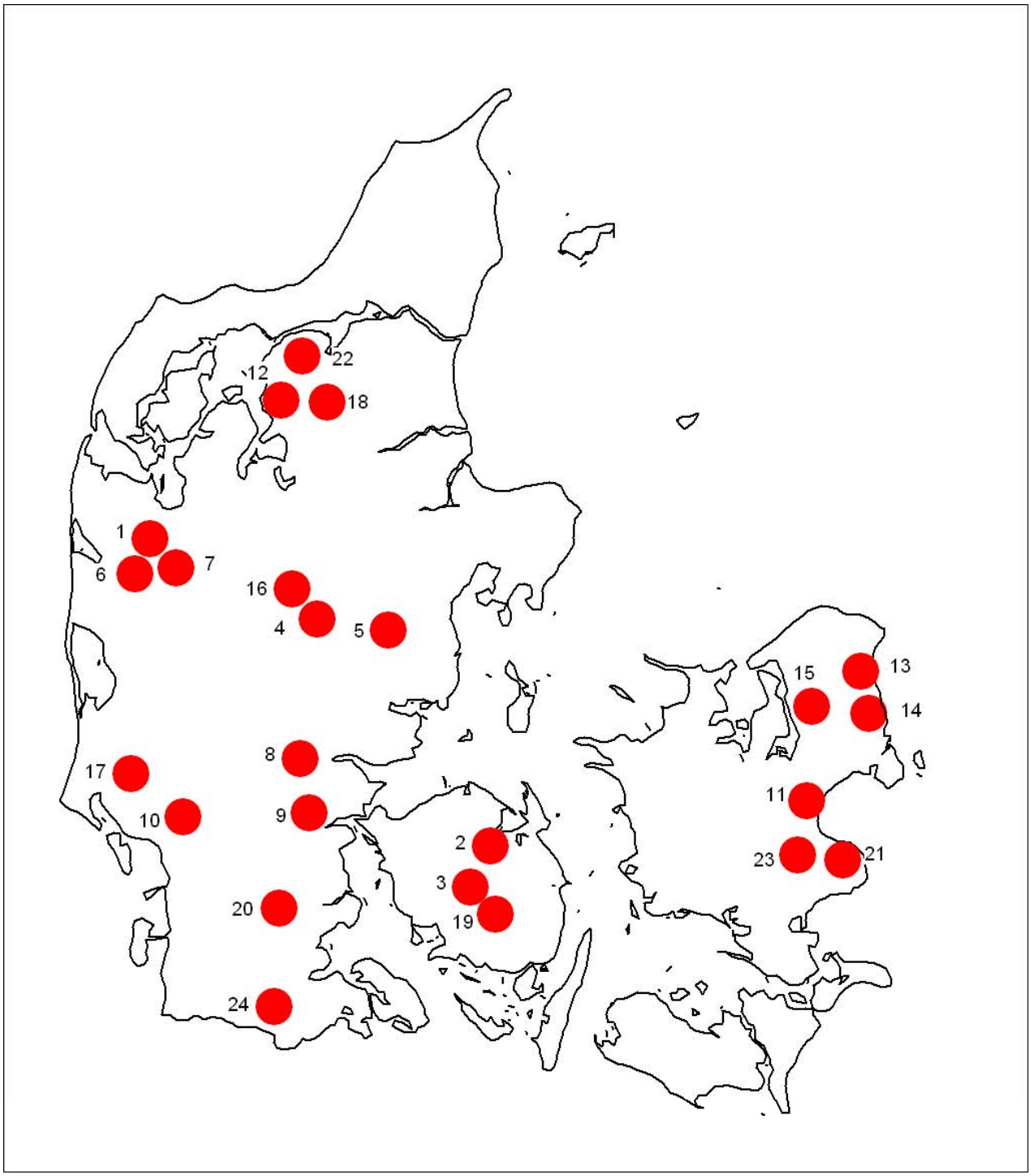
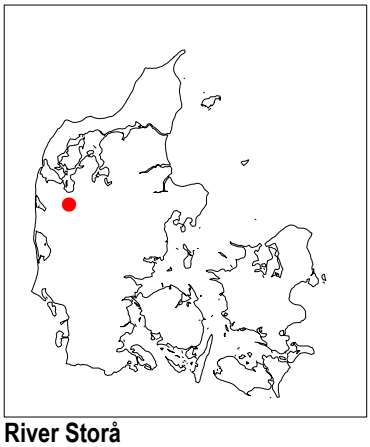


Map showing the location of the 24 project sites

Example No. 1

The river Storå at Holstebro hydroelectric power station



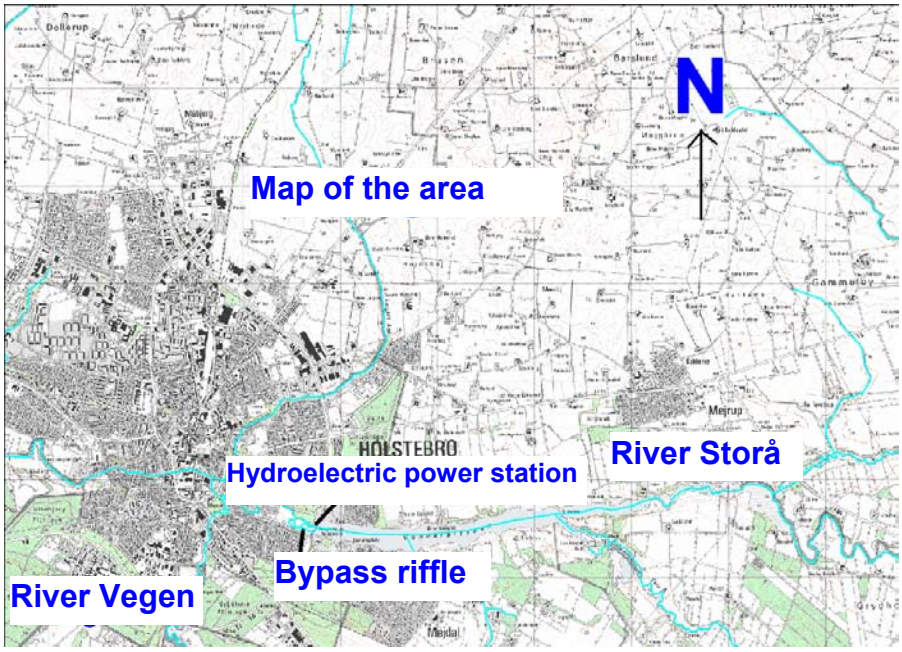
River Storå

By Per Søby Jensen
Ringkjøbing County

Description of the area

In 1942, a hydroelectric power station was built at Holstebro. The river Storå was dammed to provide electricity for the town's population. However, this hindered the free migration of fish to the upper two thirds of the watercourses in the Storå river system. It is true that a fish ladder was installed at the power station when it was built, but its effect was very limited despite subsequent alterations.

The dam completely prevented the passage of lavaret, a salmonid fish that migrates up the river Storå in great numbers to spawn. It was clear that the lavaret were unable to traverse the old fish ladder. When the lavaret migrated up the river Storå in November–December in an attempt to reach their spawning grounds, great shoals of them accumulated just below the power plant.



Map of the area

Aim of the project

Due to the poor success of the fish ladder, Ringkjøbing County decided to improve conditions for the passage of fish past the power station. By establishing a bypass riffle around the station it should be possible for virtually all species of fish to pass the obstruction.

The aim of the project was thus to ensure free passage for fish to the upper two thirds of the watercourses in the Storå river system.

Implementation of the project

The new fish passage was designed as a 655 m stone riffle that evens out a 5-m difference in elevation (see the figure). This would

ensure a sufficiently low water velocity that all fish species can migrate past the power station.

The riffle contained six pools for the fish to rest in, and spawning gravel was laid out in some reaches so that it could also serve as a spawning and nursery ground for the fish. In addition, a screen was established immediately downstream of the turbine outlet.

Design of the bypass riffle at Holstebro hydroelectric power station

Effect studies performed in connection with the project
After construction of the riffle a working group was established to regularly follow the functioning of the riffle and determine the need for any necessary changes in water flow and design. The working group consisted of representatives of Holstebro Municipality, Ringkjøbing County and the former Danish Institute for Inland Fishery Research.

The working group initiated investigations aimed at determining whether or not the bypass riffle was used and by what species, and in particular to what extent passage of fish was dependent on water flow in the bypass riffle. The effect of the spawning gravel that had been laid out was also investigated.

From the results of these investigations it can be concluded that the bypass riffle is indeed being used and can be traversed by all the species of fish that inhabit the Storå river system.

Moreover, based on the relatively large catches of a number of species, including 4,695 lavaret, it can be concluded that all fish wishing to migrate upstream are able to locate and use the riffle. A

precondition, though, is that water flow in the riffle varies periodically in accordance with the requirements of the individual species.

Optimal water flow for fish passes			
1,000 l/s	**400 l/s**	**Flow not decisive**	**Unknown**
Perch	Gudgeon	Bream	Rainbow trout
Pike	Roach	Dace	River lamprey
Salmon		Eel	Sea lamprey
Seatrout		Flounder	Tench
Steelhead		Greyling	Trout
		Lavaret	
		Ruffe	

It was also shown that salmon and greyling successfully spawned in the gravel beds laid out in the riffle, although it was not possible to determine the magnitude of this.

Spawning ground in the uppermost reach of the bypass riffle. In the background can be viewed the hydroelectric power station and its lake.

Experience gained through the project

The new way the riffle is operated with varying water flow allows for both the water flow requirements of the individual species and changes in the species' migratory patterns as a result of migratory conditions in the river Storå.

It can be concluded that the screen downstream of the turbine outlet plays a major role in enabling the seatrout, lavaret, salmon and steelheads to find the riffle. The distance between the bars in the screen should not exceed 20 mm.

It is noteworthy that high water flow and operation of the sluice, which appear to completely or partially mask the attraction flow from the riffle, do not have any negative impact upon the passage conditions (see the photograph below).

Aerial photograph of the hydroelectric power station during a situation with high flow through the sluice and turbine

Future plans for altering passage conditions at the hydroelectric power station
In connection with the 2004 national management plan for salmon, Ringkjøbing County was requested to draw up plans for new restoration measures in the river Storå that would improve conditions for salmon.

The County thus established a working group charged among other things with drawing up proposals aimed at improving passage conditions for fish and other fauna at Holstebro hydroelectric power station.

Scenario 1: *Ensuring/optimizing the downstream migration of smolts through the hydroelectric dam.*
The project entails establishing a permanent sheet-piling wall parallel with the northern or southern bank of the hydroelectric dam to ensure that the downstream migrating smolts are kept in a sort of watercourse corridor alongside one of the banks of the hydroelectric lake.

The costs are moderate, and will probably amount to approx. DKK 2–5 million. The project will be difficult, but is technically feasible.

Project data:
Project leader: Ringkjøbing County
Project design: DDH
Project year: 1989
Total costs: DKK 1.3 million
Financing:
Danish EPA – DKK 800,000
Ringkjøbing County – DKK 250,000
Holstebro Municipality – DKK 250,000.

River data:
Catchment: 725 km^2
Runoff:
Mean – 8,900 l/s
Max – 30,600 l/s
Min – 2,500 l/s
Quality objective:
Downstream – B1 (salmonid spawning and nursery waters)
Upstream – A (waters of special scientific interest)

Restoration data:
Length: 655 m
Height difference: 5.3 m
Bed slope in riffle: 10‰
Bed slope in spawning grounds: 4‰
No. of spawning grounds: 3 of 20 m
No. of pools: 6
Culvert under road: 29 m
Bed width in riffle: 2.75 m
Stone substrate: 1,025 m^3
No. of boulders for current shelters: 980
Spawning gravel: 50 m^3

The perspectives of the measure will be enhanced smolt descent in the Storå river system.

Scenario 2: *Optimization of the existing bypass around the hydroelectric power station or alternatively the establishment of a new fish pass*

The project entails augmenting the water flow capacity of the existing bypass riffle by approximately two-fold, i.e. to approx. 3,000 l/s or, alternatively, establishing a completely new riffle that can contain virtually the whole of the river Storå's water flow.

The costs will be moderate, probably approx. DKK 1–5 million depending on the solution selected. Both project proposals are technically feasible.

The perspectives of the measure will probably be enhanced migration of fish to the upper reaches of the Storå river system and eventually greater smolt descent in the Storå river system.

Project publications
Jørgensen, J., 1992: Fiskepassage ved Holstebro Vandkraftværk (Fish pass at Holstebro Hydroelectric Power station) – Report prepared for Ringkjøbing County by the Institute for Inland Fisheries Research.

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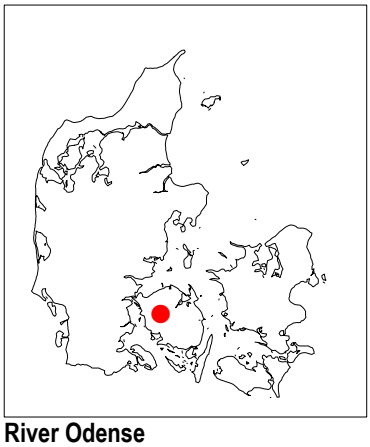
Example No. 2

River Odense – fish pass at Dalum Paper Mill



River Odense

By Peter Hyldegaard
Fyn County

Odense river basin

Description of the area

Dalum Paper Mill is located in the southern part of the river Odense, 16.4 km from its outlet in Odense Fjord. The present dam was constructed in the 1940s. Dalum monastery previously had a dam at the site.

Dalum Paper Mill presently abstracts water from the river Odense for use in the production of recycled paper and for cooling the mill's power station.

A counterflow pass had previously been built at the dam. The present pass was built in 1994.

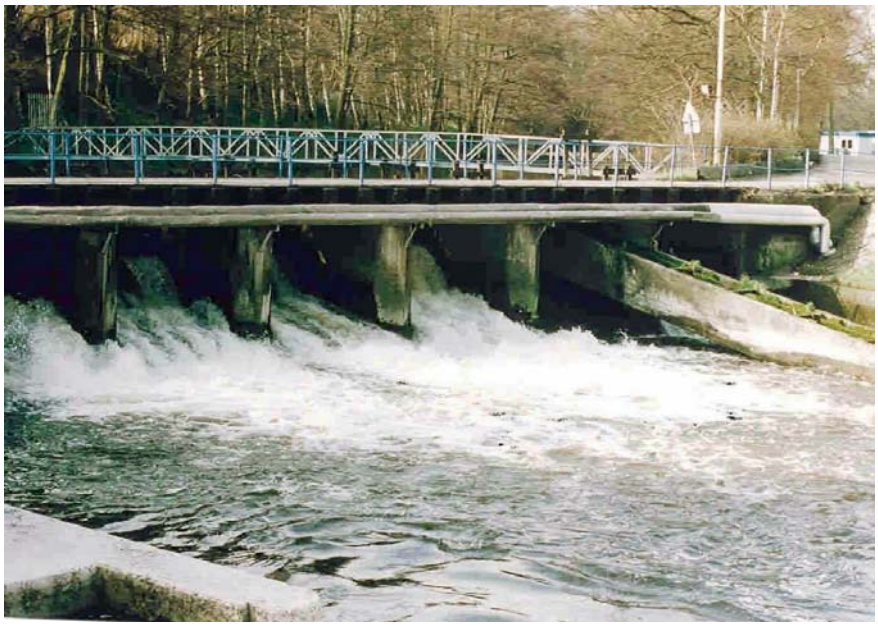
Aim of the project

The aim of the project was to create free passage past the dam for fish and other fauna, including poor swimmers and poor jumpers.

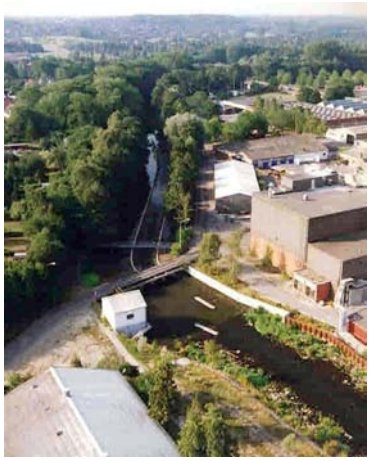
In carrying out the project. greatest possible consideration was paid to the factory infrastructure around the pass and to paper production, which had to continue undisturbed during the construction phase.

Description of the project

The difference in river level across the dam was almost 3 metres prior to carrying out the project.



The dam prior to establishment of the fish pass



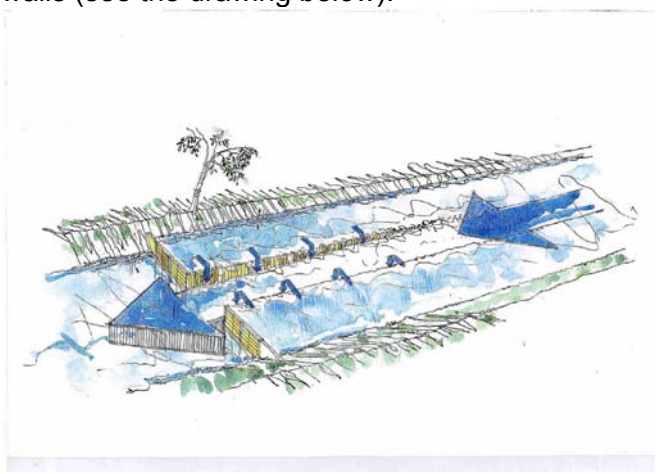
The project consists of a 150 m long and 5 m wide riffle upstream of the dam and a 200 m long riffle built across the full width of the river downstream of the dam. The slope across the riffle is 10‰.

The upstream riffle is located between two retaining walls in the middle of the river Odense. This solution was chosen so as to ensure an unchanged soil water content under the paper mill buildings, which are built in the actual river valley.

Dalum Paper Mill continues to abstract the same amount of water from the river Odense, and the maximum water level at the dam has not been changed by the project.

When water flow in the river Odense is low, all the water flows through the upstream end of the riffle (see the drawing above).

When the water flow in the river Odense increases, a greater and greater proportion of the water will start to spill over the retaining walls (see the drawing below).



When the water flow is highest it is necessary to permit free flow through the sluice in the dam.

Project data:
Project leader: Fyn County
Project design: COWI
Project year: 1994
Total costs: DKK 6.1 million
Financing: Fyn County and Danish EPA

River data:
Catchment: 510 km^2
Runoff:
Median minimum – 0.7 m^3/s
10 yr maximum – 28 m^3/s.
Quality objective: B1 (salmonid spawning and nursery waters)

Restoration data:
Length: 350 m
Width: 5 m and 30 m
Slope: 10‰
Stones laid out for erosion protection

The advantages of this type of pass are as follows:

- A high and very constant river level is assured upstream of the pass
- The original dam is preserved
- The water table in the area and under the mill is preserved unchanged
- The pass does not require supervision and cleaning
- The pass is virtually maintenance-free
- The pass considerably reduces the work entailed in operating the dam
- The pass ensures that the whole of the water channel under the bridge can be used to transport water such that the total discharge capacity is not reduced
- As water only runs through the riffle most of the time, attraction flow conditions downstream are good.

The riffle during medium water flow

Experience gained through the project

The pass is based on the same principles as used in the pass in the river Odense at Ejby Mølle (1993) and Brobyværk (2002). The pass has functioned to the full satisfaction of both Dalum Paper Mill and Fyn County.

Since 2000 Fyn County has had an electronic fish counter installed in the upstream part of the pass at Dalum Paper Mill. The results show that the upstream migration increased from approx. 600 seatrout in 2000 to approx. 1,025 in 2004. Relative to the size of the river Odense the number of seatrout that migrate up the river is still too low, but it can be concluded that the pass at Dalum Paper Mill meets expectations. The reason why too few seatrout migrate up the river Odense must be sought elsewhere.

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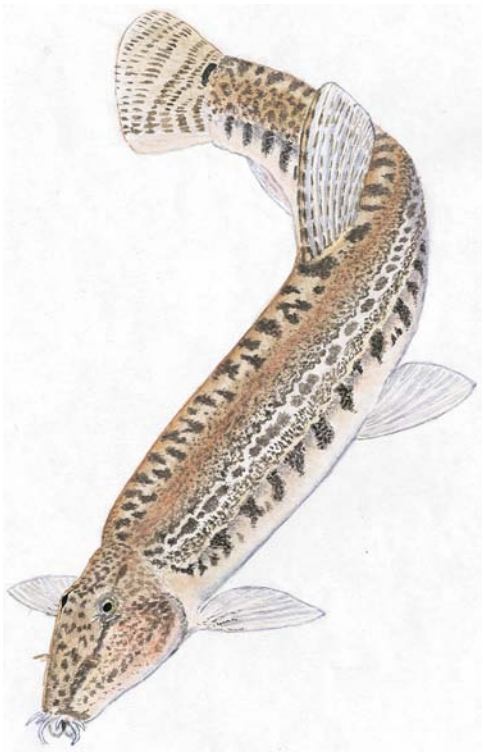

Spined loach
Cobitis taenia

Example No. 3

Fish pass in the river Odense at Brobyværk

River Odense

By Peter Hyldegaard
Fyn County

Description of the area
Brobyværk is located 40 km from the mouth of the river Odense in Odense Fjord. Here a milldam obstructs the passage of fish to upstream reaches of the river Odense.

The pass was opened in September 2002 after 8 years of preparation, including the three years that it took the agricultural commission to decide upon financial compensation for the mill owner.

Fish pass at Brobyværk

Aim of the project
To ensure free passage for fish to the upper reaches of the river Odense.

Description of the project
The project encompasses a 200 m long reach of the river Odense. The pass has been established in the main course as an approx. 5 m wide stone riffle with a slope of 10‰. The riffle follows the right side of the river upstream of the weir and the sluice bridge. On the Holmen side the riffle is bordered by a sloping grass- and stone-covered bank and on the other side by a retaining wall separating it from the remainder of the river.

In connection with the project the old weir has been replaced with a new weir. In addition, fish fry sluices have been established in the weirs at the sluice bridge and the water mill.

Project data:
Project leader: Fyn County
Project year: 2002
Total costs: DKK 3.3 million

River data:
Catchment: 228 km^2
Runoff:
Max – 27,000 l/s.
Min – 520 l/s

Restoration data:
Slope: 10‰
Length 200 m

For aesthetic reasons the visible side of the retaining wall facing the riffle has been clad with stones. The left side of the river Odense towards the inn has not been changed.

Mean water flow

A new maximum river level applicable all year round has been set at 23.06 m above Danish Zero Level (DZL). The minimum river level applicable all year round has been set at 22.70 m above DZL. The upper edge of the retaining wall is 22.8 m above DZL.

During low flow situations in the river Odense the riffle is always allocated a minimum water flow of 520 l/s. The maximum water flow in the river Odense at Brobyværk is 27,000 l/s.

High water flow

Experience gained through the project

As early as 2003–2004, approximately 400 seatrout passed through the fish counter under the bridge. Their average size was 65 cm. The largest seatrout recorded was 87 cm long. The river system upstream of Brobyværk consists of 60 km of county watercourse and approx. 230 km of municipal/private watercourse. This project is one of the many in Fyn county that have together opened up free passage to 430 km out of the 575 km of county watercourse in Fyn county.

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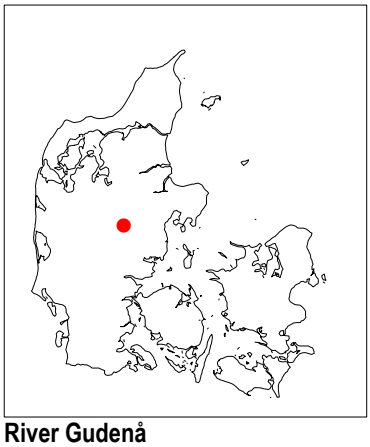
Example No. 4

The largest riffle in the river Gudenå – the fish pass at Silkeborg Paper Mill



River Gudenå

By Ole Helgren
Aarhus County

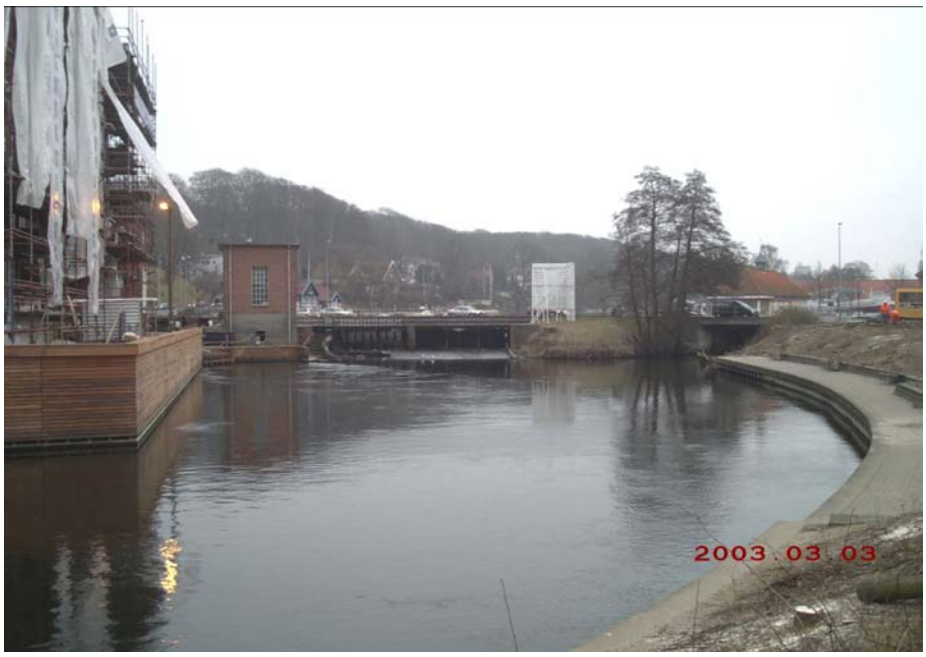
The river Remstrup (river Gudenå) in Silkeborg prior to closure of the paper mill

Description of the area
Upon decree by King Christian XIII the Drewsen brothers were granted the right to dam the river Gudenå (river Remstrup) and harness the water to drive a paper mill in 1846. This was the beginning of the town of Silkeborg. The present weir was built around 1875.

Around 1930 the mill wheels were replaced by a turbine, and in connection with alteration of the weir a primitive fish ladder was established.

In 1990, in response to the recommendation of the Gudenå Committee that “free passage be ensured in the main course of the river Gudenå”, Aarhus County approved the establishment of a fish pass at the paper mill to replace the old fish ladder.

The paper mill ceased operations in 2000, and the buildings have now been converted to a new town district with a hotel, cultural centre, homes and businesses. The physical conditions for the construction of a fish pass in the river Remstrup are complicated: Both the river and the paper mill lie squeezed in the middle of the town, and the upstream river level has to be kept constant in order to ensure passage for the steamboat Hjejlen and the more than 1,000 other local boats, as well as to ensure unchanged conditions around the foundations of the many houses built alongside the river. Downstream of the pass the river level varies by up to 1.5 m together with that of lake Langsø. In addition, the main sluice has to handle the dense summer traffic of 5–10,000 small pleasure boats.



The weir before establishment of the fish pass

The riffle on a winter's day

Purpose of the project

After many different proposals for the project the breakthrough came in summer 2002 when Aarhus County entered into an agreement to overtake the dam rights. This meant that it was now possible to establish a fish pass in the form of a stone riffle utilizing the whole of the water flow in the river Gudenå.

This is the absolute best solution for the fauna and concomitantly preserves and supports the harbour and river environments in the centre of Silkeborg, something that was a clear precondition for both the municipal and county councils.

Description of the project

The main technical challenge posed by the project was not the size of the stone riffle, but to control the river level. In designing the project a weir construction was therefore developed with weir gates built into the bottom of the riffle inlet. A combination of a fixed opening and three 10-m long variable weir gates enables the river level and hence the water level in the harbour to be maintained with a variation of only a few cm at water flows ranging from approx. 5 m^3/s to approx. 36 m^3/s. In designing the construction, considerable consideration was given to operational reliability and handling during extreme conditions.

The navigation channel alongside the riffle

The new weir and the fish pass viewed from downstream

Project data:
Project leader: Aarhus County
Project design: DDH
Contractor: MTHøjgaard
Project year: 2003
Total costs: DKK 14 million
- Danish Forest and Nature Agency – DKK 3.5
- Angling License Fund – DKK 0.4 million
- Aarhus County – DKK 10 million

River data:
Catchment: 1,000 km^2
Runoff:
- Max – 37,000l/s
- Min – 5,300 l/s
- Mid – 14000 l/s

Quality objective: B3 (cyprinid waters)

Restoration data:
River level: 20.97 m above DZL
Vsp downstream: From 18.55 m to 20.15 m above DZL
Riffle length: 85 m
Current channel length: 170 m
Width: From 50 m upstream to 18 m downstream
Slope:
- Direct fall – 22‰:
- Current channel – 11‰

Stone laid out: 10,000 tonnes
Earth excavated: 4,000 tonnes
3 weir gates each weighing approx. 50 tonnes
65 tonnes of sheet piling
10 tonnes of tropical timber (azobe)
1,000 m^2 of flagstones and steps

The actual fish pass is constructed as a stone riffle with a meandering double profile and a small slope. This allows for a large number of pools, a minimum depth of 0.6 m in the current channel and low flow rates irrespective of the magnitude of water flow.

Pleasure boats are led via the main sluice through a new navigation canal established parallel to the riffle to a fairway marked out in the river downstream of the riffle.

The project was designed in the second half of 2002, and construction work was carried out during the period March–September 2003. The project is a good example of how county nature management funds and other funds can be used to carry out major projects under the auspices of the County.

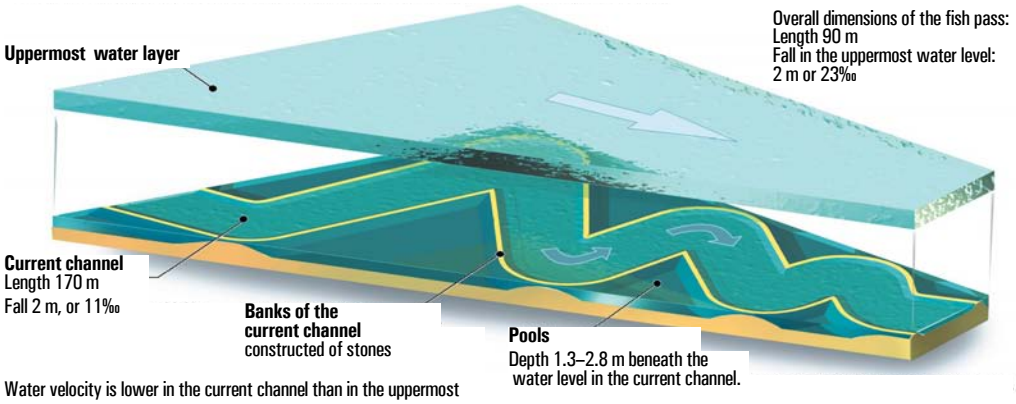
The river Gudenå has a very diverse fauna encompassing the species that are characteristic of large rivers and in which caddis flies and mayflies are richly represented. Twenty-four different species of fish have been recorded, the majority of which are coarse fish.

The weir gates are made of stainless steel, the riffle is built up of large stones, the restraining wall alongside the navigation channel is made of sheet iron piling that has subsequently been clad with certified tropical timber.

The new promenade and associated plateaus and steps are made of concrete, flagstones and natural stone.

Fish pass with current channel

The fish pass at Silkeborg is designed with a current channel that reduces the water velocity. The water in the current channel meanders through the fish pass and consequently takes a longer route through the fish pass than the water in the uppermost layer. The fall across the current channel is therefore less than in the fish pass as a whole.



Water velocity is lower in the current channel than in the uppermost layer of the fish pass. This enables poorly swimming fish such as carp and other coarse fish to work their way up through the pass. Pools have been established in the areas alongside the current channel where the fish can rest on their way up through the pass

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Example No. 5

The river Aarhus – the fish pass at Tarskov Mill

River Aarhus

By Ole Helgren
Aarhus County

Description of the area

The river Aarhus is approx. 25 km long and falls approx. 50 m with variable slope over its course. These physical conditions have led to the establishment of a total of seven weirs and associated mills.

The mills have long passed into history and over the period 1990–2000, Aarhus County established fish passes at each of the obstructions. With the exception of Tarskov Mill, all the passes were constructed as stone riffles that received all the flow through the river.

At Tarskov mill a bypass riffle had been established that could only transport the river's mean water flow, and it soon transpired that this riffle did not function nearly as well as the other passes.

Aim of the project

As Tarskov Mill is located lowest in the river Aarhus, the poor conditions for passage at the weir meant that the good environmental conditions upstream of the mill could not be fully exploited. The river Aarhus carries considerable quantities of material, especially in winter. As the river ran through the millpond, this transport, which largely consisted of sand, resulted in the pond silting up almost completely. Consequently the river cut an almost random course through the sediment, which made it difficult to localize the entrance to the bypass riffle. In agreement with the mill owner, Aarhus County therefore decided to replace the bypass riffle with a stone riffle able to accommodate all the river water.

As the buildings at Tarskov Mill are worthy of preservation and as the interplay with the millpond is of great architectural value, it was decided to construct a new river bed (stone riffle) as a separate part of the millpond. The project thus encompassed to main elements: Re-establishment of the millpond and construction of a new stone riffle in part of the millpond.

After removal of the weir

.

Before removal of the weir

Project data:
Project leader: Aarhus County
Project design: DDH
Contractor: Magnus Frisch A/S
Project year: 2004
Total costs: DKK 1.4 million
Aarhus County – DKK 1.35 million
Angling License Fund – DKK 50,000

River data:
Water flow:
Min – 150 l/s
Max – 4,300 l/s.
Area, millpond: 4,000 m^2
River level, millpond: 11.06 m above DZL

Restoration data:
Riffle length: 300 m
Riffle width: 4–5 m
Current channel width: 1 m
Current channel depth: 0.3 m
Riffle slope: current channel: 8–10‰
Directly across the lower part 18‰
Quality objective: B2 (salmonid waters)

The millpond with the stone riffle running alongside the trees

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Description of the project

The approximately 4,000 m^2 millpond was dredged to an average depth of approx. 1.5 m, and a 130 m long retaining wall with its upper edge equivalent to the water level in the millpond was built to separate the river from the millpond. The retaining wall was made of concrete elements that were subsequently clad with larch wood.

This construction was chosen as it is economical on space and used materials that match both the adjoining buildings and the strict geometry of the millpond.

The millpond is supplied with an average of 50 l/s via an intake from the river whereafter the water is led to the original millstream. The impression of a mill environment is thus preserved.

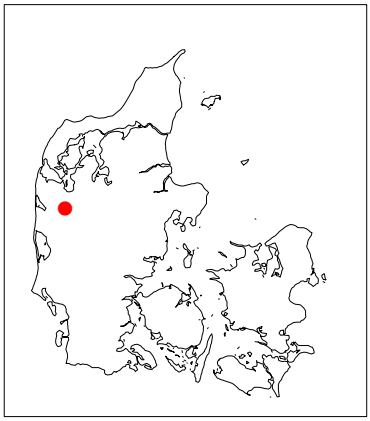
The millpond and the upper segment of the new stone riffle

The approx. 2.5 m height difference is evened out by an approx. 300 m long stone riffle constructed as two different but contiguous segments. The upper segment of the riffle is approx. 200 m long with a slope of approx. 8‰. This runs between the retaining wall and the original bank of the millpond and is 4 m wide with a 1 m wide gently meandering current channel in its bed. The lower segment of the riffle consists of a very compact and extremely meandering stone riffle with a slope of approx. 18‰ and a current channel slope of approx. 10‰.

The lower segment of the new stone riffle

Example No. 6

Fish pass at Gryde Fish Farm in the river Gryde in Holstebro Municipality

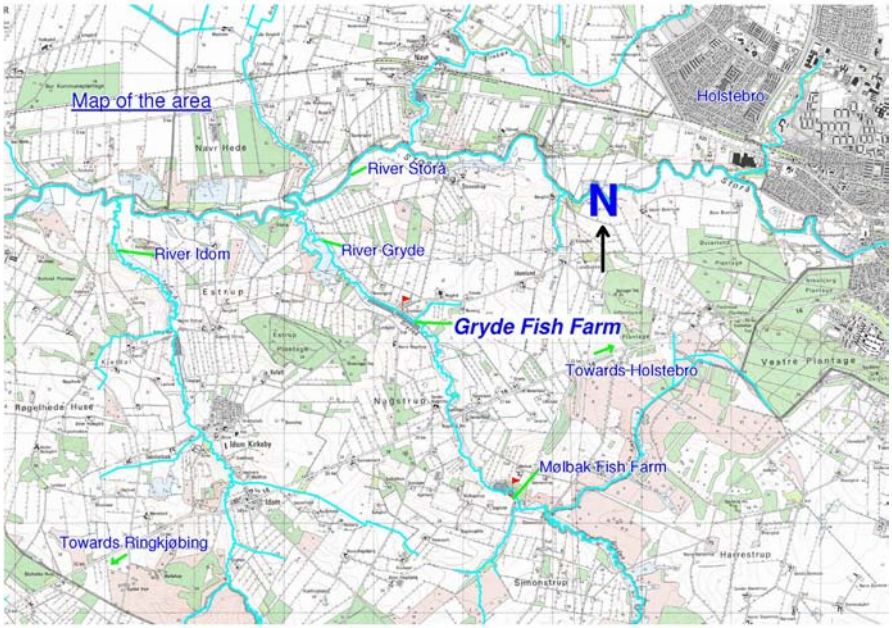


River Gryde

By Per Søby Jensen
Ringkjøbing County

Description of the area

The river Gryde, which is a minor tributary of the river Storå, arises a few kilometres south of Nørre Felding, whereafter it runs in a northerly direction to join the river Storå northeast of the town of Idom Kirkeby. Gryde Fish Farm, which uses water from the river Gryde in its production, is located on the river 6–7 km west of Holstebro (see the map below).



Map of the area

The decision to construct a new stone riffle and thereby improve passage conditions for fish at Gryde Fish Farm weir was spurred by a number of factors.

The former fish ladder that was built into the original weir at Gryde Fish Farm was probably only passable by the largest and strongest salmonids (trout), and there was therefore a real need to improve the possibilities for upstream migration at the fish farm weir. In earlier electrofishing studies only a few seatrout and salmon were caught upstream of Gryde Fish Farm.

A further factor was that the river Gryde is virtually unregulated with a good slope and fine physical conditions and could be utilized by migratory fish to a much greater extent than at present.

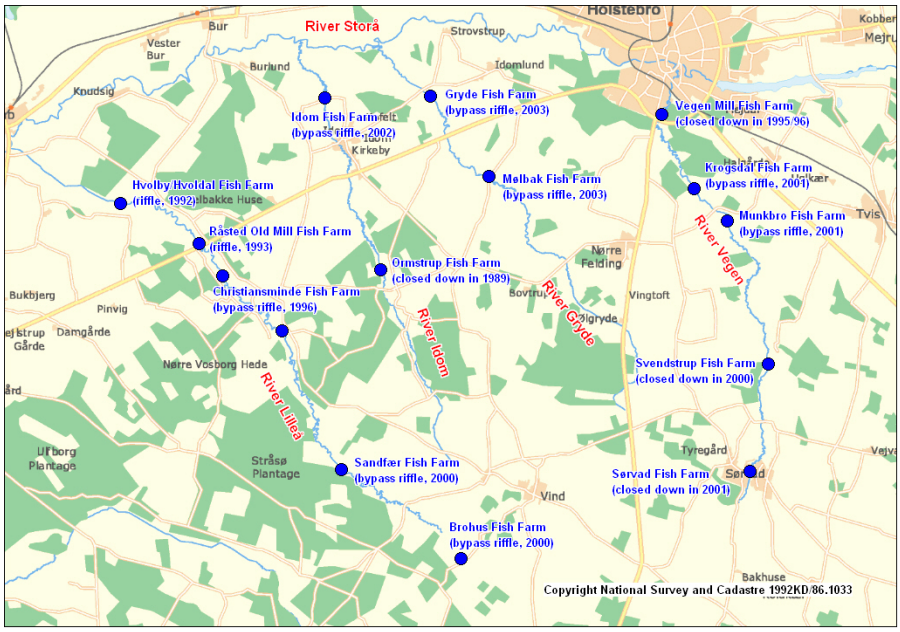
Aim of the project

The aim of the project was among other things to fulfil the quality objectives stipulated for the river in the Regional Plan. The objective

for the section downstream of Gryde Fish Farm is B1, i.e. salmonid spawning and nursery waters. The Regional Plan requires that all

obstructions making the passage of fish difficult or impossible should be rendered passable in all rivers with quality objectives A, B1, B2 and B3.

In recent years, Ringkjøbing County has worked intensively to ensure free passage in the river Gryde and generally in the whole of the Storå river system (see the map below).

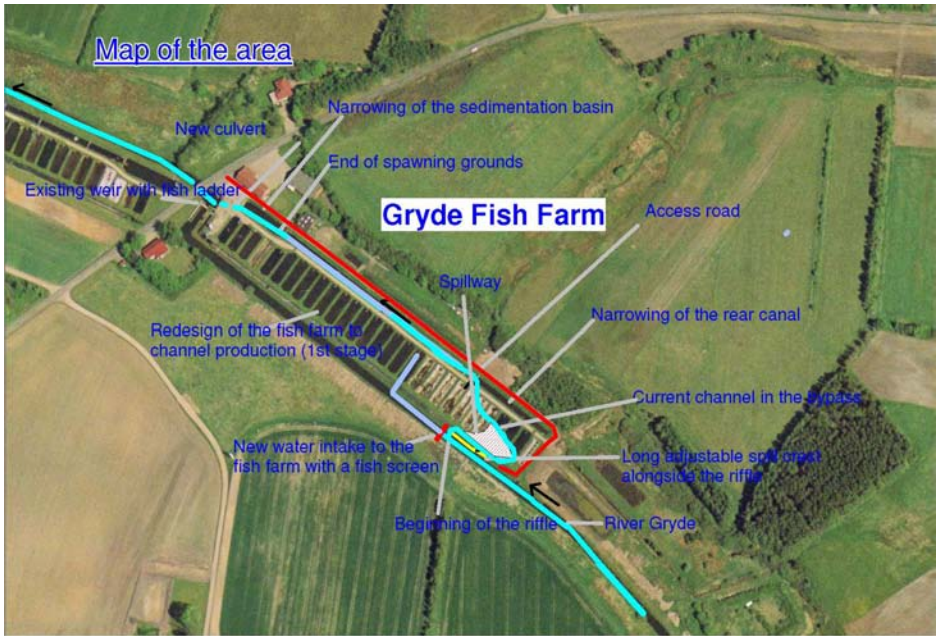


The lower part of the Storå river system showing the obstructions to fish passage that have been restored over the period 1992–2003

Following restoration of the former obstructions in the river Gryde at Gryde Fish Farm and Mølbak Fish Farm located further upstream the fish in the river can now move freely in the main course of the river over an approx. 20 km long reach from its source to its confluence with the river Storå.

Description of the project
Instead of establishing a traditional bypass riffle at the old main weir – a solution used by Ringkjøbing County at a number of other similar obstructions – it was decided to use an alternative solution involving relocation of the weir upstream to a new large fish pass with a high water flow capacity.

The new, approx. 120 m long fish pass was established east and north of the fish farm's new weir (see the aerial photograph below).



Design of the new fish pass at Gryde Fish Farm

The new riffle ends in the fish farm's former rear canal, which has subsequently been converted to a new segment of the river Gryde with six new spawning grounds and large boulders for the fish to rest behind.

From the converted rear canal the water is led via a large new pipe directly out behind the fish farm's former main weir, which is connected to the lower section of the river Gryde.

The new bypass riffle receives water flow corresponding to at minimum 50% of the summer water flow (median minimum water flow) and is designed to be able to carry the whole of the river Gryde's maximum water flow.

The high transport capacity of the riffle is largely attributable to the weir's approx. 25 m long spill crest and the extremely wide spillway in the uppermost section of the riffle (see the photograph below of the new fish pass).

The newly established fish pass at Gryde Fish Farm

Project data:
Project leader: Ringkjøbing County
Project design: Ringkjøbing County
Project year: 2003
Total costs: DKK 500,000
Financing: The Directorate for Food, Fisheries and Agri Business provided DKK 47,000

River data:
Catchment: 45.8 km^2
Runoff:
Max – 4,000 l/s
Min – 300 l/s
Mean – 950 l/s
Quality objective: B1 (salmonid spawning and nursery waters) both upstream and downstream of the fish farm

Restoration data:
Riffle length: 120 m
Height difference evened out: approx: 1.5 m
Riffle width: 7–25 m
Riffle slope: 10‰
Stone laid out: approx. 600 m^3
Gravel laid out: approx. 140 m^3 – 60 running metres of spawning ground

Changes to outflow conditions at Gryde Fish Farm

In order to optimize the possibilities for fish to migrate upstream a minor alteration was made to the existing fish farm outlet aimed at masking the fish farm's former false attraction flow.

Before this alteration the water flowing through the outlet from the fish farm reached right over to the opposite bank of the river with great force. After establishment of an approximately 4-fold wider outlet the false attraction flow does not even reach to the centre of the river (see photographs below).

Prior to alteration of the fish farm's outlet

After alteration of the fish farm's outlet

Experience gained through the project

Electrofishing studies performed in the new riffle shortly after its inauguration in 2003 (see the photograph below) revealed the presence of many fish of different sizes. During winter 2005/06, a larger fish migration study will be carried out focusing on seatrout, salmon, lavaret, etc.

Ringkjøbing County conducting electrofishing in the bypass riffle in connection with inauguration of the project

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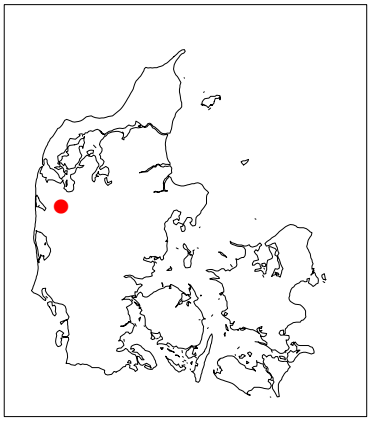
Example No. 7

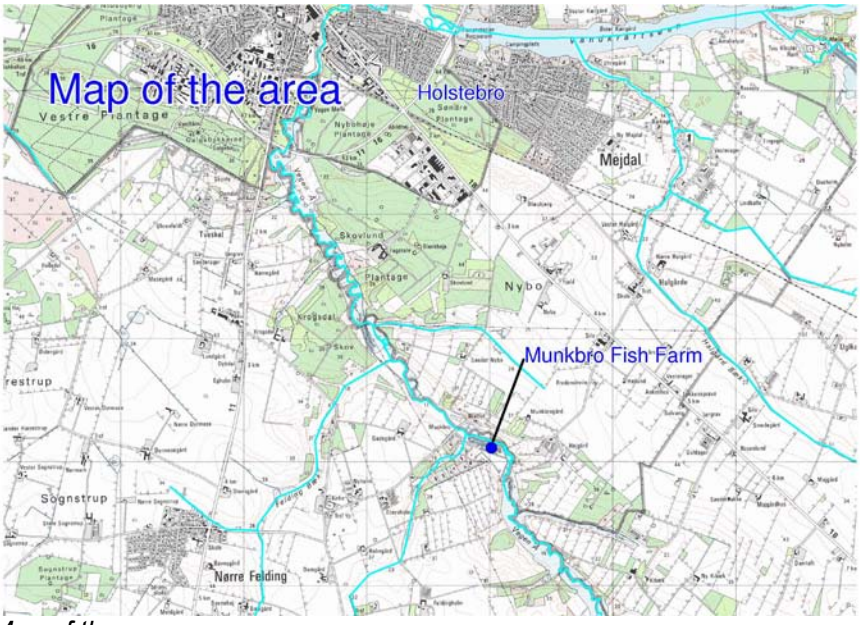
Fish pass at Munkbro Fish Farm in the river Vegen in Holstebro Municipality



River Vegen

By Per Søby Jensen
Ringkjøbing County

Description of the area
The river Vegen is a medium-sized river that runs into the river Storå in the centre of the town of Holstebro just below the hydroelectric dam. The river Vegen arises south of the town of Sørvad, whereafter it runs in a northerly direction to join the river Storå. Munkbro Fish Farm is located on the river around 5 km south of Holstebro.



Map of the area

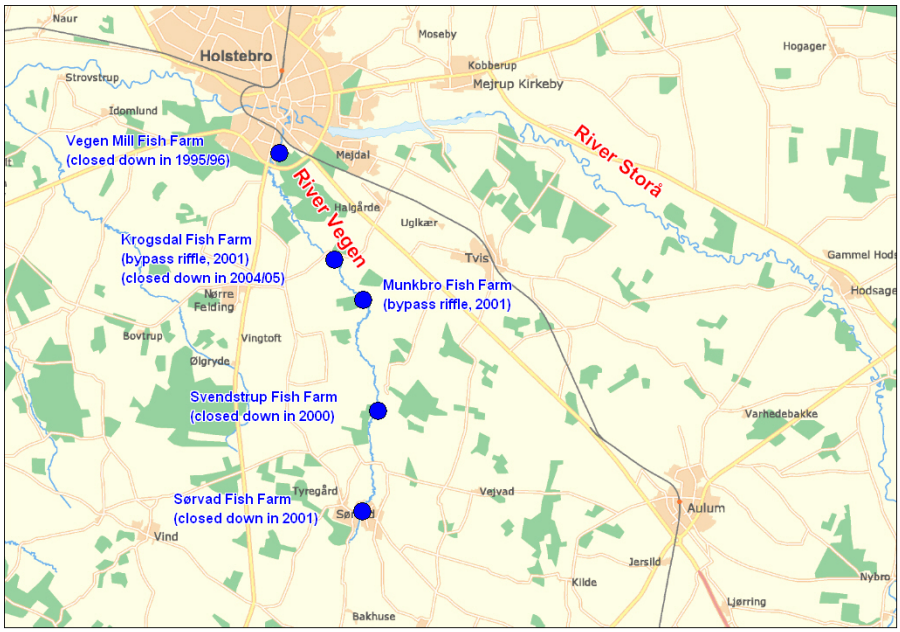
The decision to construct a new stone riffle and thereby improve passage conditions for fish at Munkbro Fish Farm weir was spurred by a number of factors.

The former fish ladder built into the weir at Munkbro Fish Farm was probably only passable by the largest and strongest salmonids (trout), and there was therefore a real need to improve the possibilities for upstream migration at the fish farm weir.

Further factors were that the river Vegen is virtually unregulated with a good slope and fine physical conditions, and that the Vegen river system is virtually free of ochre pollution.

Aim of the project
The aim of the project was among other things to fulfil the quality objective stipulated for the river Vegen in the Regional Plan. The objective for the reaches of the river upstream and downstream of Munkbro Fish Farm is B2, i.e. salmonid waters. The Regional Plan requires that obstructions making the passage of fish difficult or impossible should be rendered passable in all rivers with quality objectives A, B1, B2 and B3.

In recent years, Ringkjøbing County has worked intensively to ensure free passage in the whole of the Vegen river system, where Munkbro Fish Farm is the last of the five fish farms that were previously located on the river Vegen



Fish passes that have been established in the Vegen river system over the period 1992–2005

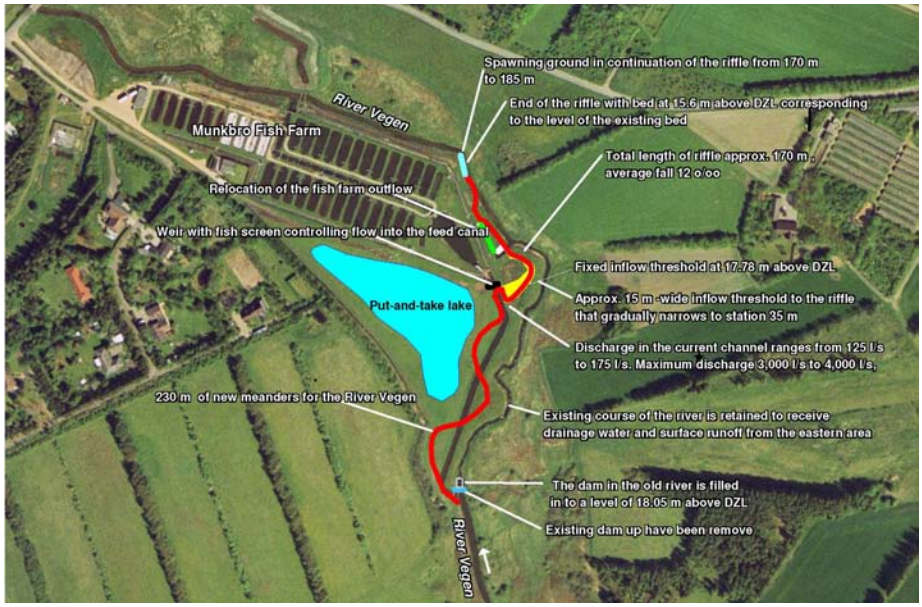
Following restoration of the many obstructions in the river Vegen the fish in the river can now move freely in the main course of the river over a 20–25 km long reach from its source to its confluence with the river Storå.

The work on closing down the fish farms and establishing the new fish passes in the main course of the river Vegen cost a total of approx. DKK 5 million. The project was carried out through constructive cooperation between Trehøje Municipality, Holstebro Municipality and Ringkjøbing County.

Description of the project
Instead of establishing a traditional bypass riffle at the old main weir – a solution used by Ringkjøbing County at a number of other obstructions – it was decided to use an alternative solution involving relocation of the weir downstream to the fish farm.

In connection with relocation of the weir a new larger fish pass was established able to conduct large volumes of water.

The new, approx. 170 m long fish pass was established as shown in the aerial photograph below.



Design of the new fish pass at Munkbro Fish Farm

The reach of the river Vegen from the former main weir and down to the Munkbro Fish Farm's new main weir has subsequently been remeandered and relocated in over the fish farm's former feed canal.

As a result of the relocation of the weir the approx. 500 m long "dead" reach of the river Vegen from the old fish farm's former water intake to the outfall has been reduced considerably.

The new riffle has been led down past the fish farm's new water outlet, which has also been relocated in connection with the project. Approximately 20 m of spawning ground has been laid out in continuation of the riffle.

The new fish pass at Munkbro Fish Farm in the river Vegen

The new fish pass receives water flow corresponding to at minimum 50% of the summer water flow (median minimum water flow) the whole year round and is designed to be able to conduct the whole of the river Vegen's maximum water flow (i.e. all the free water).

The high transport capacity of the riffle is largely attributable to the long spill crest (approx. 15 m) and the wide overflow pool in the uppermost section of the riffle.

Alternative fish screen at Munkbro Fish Farm
A new feature at Munkbro Fish Farm is the establishment of a means of screening out the wild fish from entering with the river water flowing into the farm. The new screening system, which is a sort of "reverse biodrum", is intended to ensure favourable downstream passage for invertebrates and fish larger than 3 mm in size.

Munkbro Fish Farm's new 3-mm screened river water intake screen designed to ensure optimal downstream passage of smolts, etc. The view is from the river looking upstream. The water for the fish farm is drawn from the side of the biodrum screen.

Project data:
Project leader: Ringkjøbing County
Project design: Ringkjøbing County
Project year: 2001/02
Total costs: DKK 500,000

River data:
Catchment: 57.2 km^2
Runoff:
Max – 4,500 l/s
Min – 350 l/s
Mean – 1,150 l/s
Quality objective: B2 (salmonid waters) upstream and downstream of the fish farm

Restoration data:
Riffle length: 170 m
Height difference evened out: approx: 1.5 m
Riffle width: 3–12 m
Riffle slope: 12‰
Stone laid out: approx. 500 m^3
Gravel laid out: approx. 20 m^3

Experience gained through the project

The preliminary results of the study carried out of descending trout and salmon smolts showed that the fish screen on the river water intake functioned virtually flawlessly. Of the 500 smolts released upstream of the fish farm, none were caught inside the fish farm. See the photograph below of trapping studies in the feed canal.

Fish traps in the intake to the fish farm. The biodrum screen can be seen on the right, and the riffle in the background

Electrofishing studies carried out in the main course of the river Vegen after completion of the new fish pass revealed the presence of seatrout right up to Sørvad. Lavaret and flounder – species that were previously unable to pass the old fish ladders in the weirs – were detected far up in the river system. During winter 2005/06 a larger fish migration study will be carried out focusing on seatrout, salmon, lavaret, etc.

Fish species that Ringkjøbing County have caught in the river Vegen during subsequent electrofishing studies

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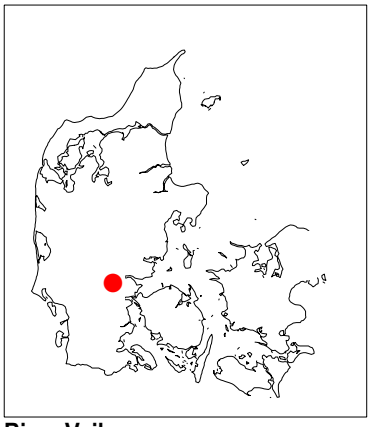
Example No. 8

Fish pass at Vingsted Fish Farm in the river Vejle

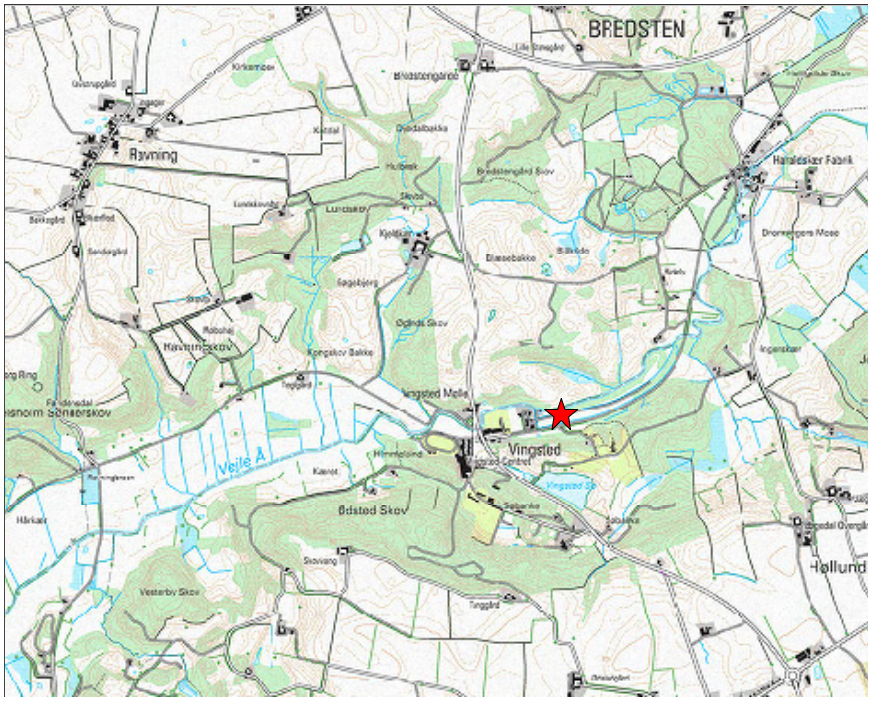


River Vejle

By Tony Bygballe
Vejle County

Description of the area

Vingsted Fish Farm lies on the main road between Ødsted and Bredsten. The entrance is near the Vingsted Centre approx. 15 km west of Vejle.



Map of the area

Vingsted Mill held the rights to dam the water in the river Vejle. In connection with a regulation project in which funds were not available to purchase the dam the latter was sold to a fish farmer who established Vingsted Fish Farm in the 1950s.

At that time the fish farm was the largest in the river Vejle with a feed quota of 200 tonnes.

Aim of the project

The aim of the project was to improve the possibilities for migratory fish in the river Vejle to pass the fish farm. The weir contained a counter-current fish ladder but the fish had difficulty in finding it because the attraction flow from the main water stream lay some distance from the entrance to the fish ladder.

Description of the project

Vejle County has entered into an agreement with the fish farm that the weir height is to be reduced by 0.7 m. A long spill crest has been established perpendicular to the river. In order that the new profile can contain the full water flow the river has been made 4 m wider.

Quite a few canoes navigate the reach. In order that they can sail through and to ensure that the fish pass remains open during low water flow a 4 m wide current channel has been established with a permanent water depth of at least 0.5 m.

In order to equalize the last 1 m of the fall at the weir a 100-m long riffle with a slope of 10‰ has been established.

The weir and fish ladder after the river level had been lowered

The riverbed has been raised downstream of the weir. The water intake to the fish farm's feed canal is now regulated so as to ensure a constant water flow, with the remainder of the water being led through the fish pass.

The current channel

Project data:
Project leader: Vejle County
Project design: Vejle County
Project year: 2002
Total costs: DKK 1.6 million
Angling License Fund – DKK 40,000
Vejle County – DKK 1.56 million

River data:
Catchment: 190 km^2
Runoff:
Max – 15,000 l/s,
Min – 2,200 l/s
Mean – 4,000 l/s
Quality objective: B2 (salmonid waters)

Restoration data:
Riffle length: 100 m
Riffle width: 8 - 12 m
Slope: 10‰
Stone laid out: 700 m^3
Gravel laid out: 100 m^3

The current channel and overflow basin.

Experience gained through the project

The project has been successful. Seatrout no longer congregate at the weir. Canoes easily navigate the reach. After the river level has been lowered by 0.7 m, a really good 500 m long stretch of river has developed. The selected extension of the profile is more than adequate since no problems have arisen upstream of the weir during periods of high runoff.

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Example No. 9

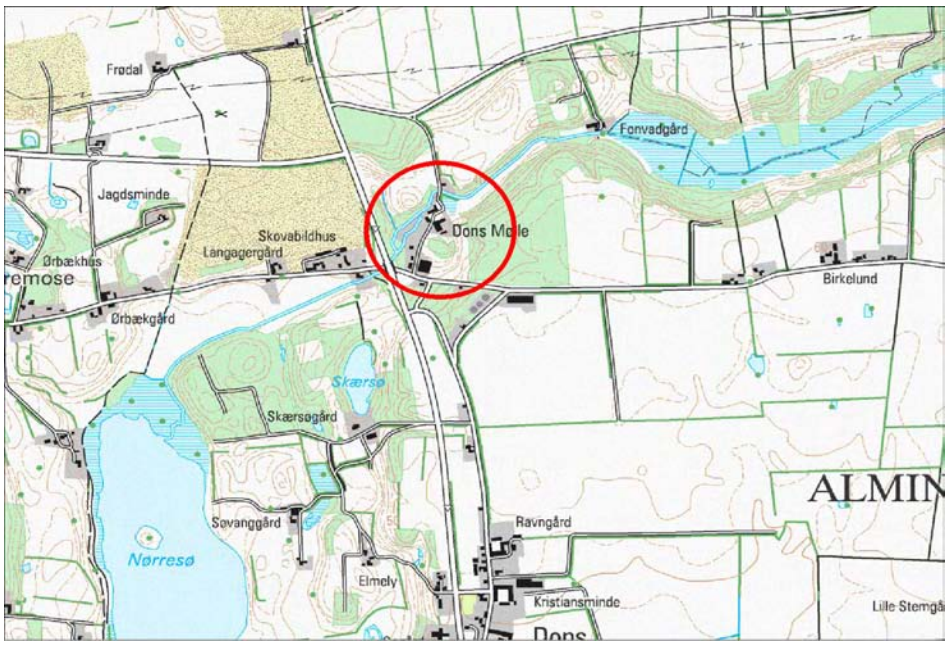
Fish pass at Dons Mill in the river Almind

River Almind

By Tony Bygballe
Vejle County

Description of the area

Dons Mill is located in Kolding Municipality, 1.3 km upstream of where the river Almind runs into lake Nørresø (see the map below).



Map of the area

Aim of the project

The quality objective set for the river Almind in the Regional Plan is B1, i.e. salmonid spawning and nursery waters. One of the conditions for fulfilment of this objective is that there has to be free passage along the river. The aim of the project was to create free passage to 4.1 km of river designated as salmonid spawning and nursery waters.

Former weir

Description of the project

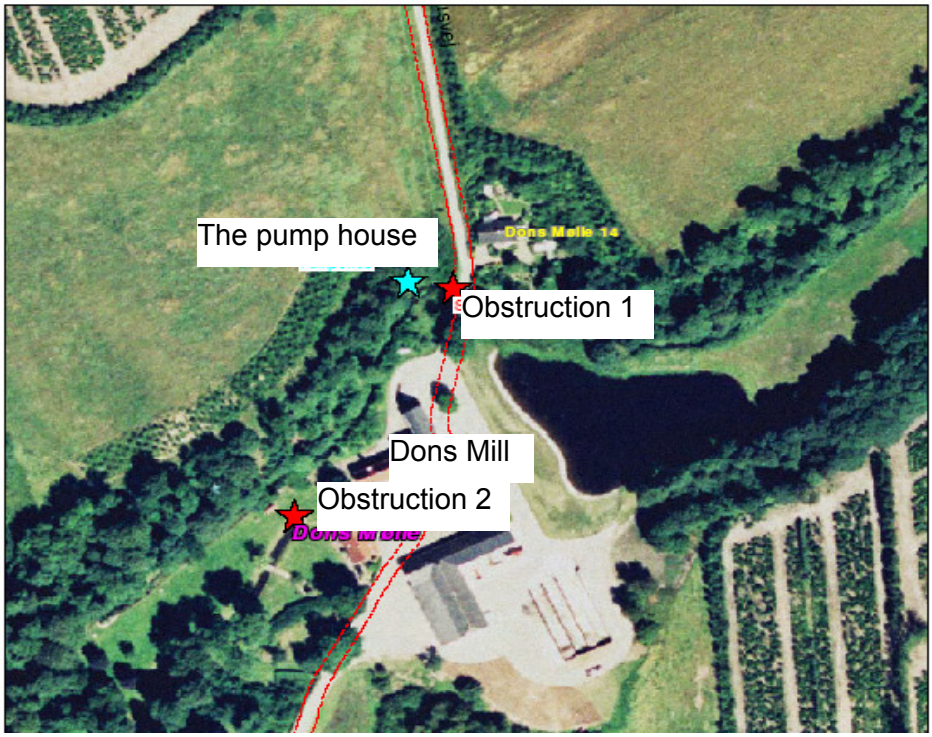
There were two obstructions in the river Almind at Dons Mill.

One obstruction (Obstruction 1) was near the road, where the water falls approx. 0.5 m. Downstream of the weir there were numerous large stones that hindered the fish in jumping up into the current.

The other obstruction (Obstruction 2) lay approx. 115 m downstream of the first obstruction. Here the river divided into two branches. One branch ran through the garden in an approx. 20 m long culvert. The fall across this culvert was 0.35 m, and the water fell approx. 0.5 m at the outlet. If migratory fish chose this branch they had no possibility to progress further. If they took the other branch they could get past the first obstruction, but 115 m later would reach the next obstruction, which they were unable to pass.

Newly established stone riffle

The pump house lay 20 m downstream of the weir at the same level as the water in the river. From the pump house a pipe traversed the river at a height of approx. 30 cm above the river level. In order to create passage it was necessary to raise the riverbed downstream of the weir. This brought the pump house below the water level in the new river profile. The pump obtains water from a well located 50 m northwest of the pump house.



In order to ensure free passage the following measures were taken:

Obstruction 1
The riverbed was raised to ensure that flow under the bridge was not interrupted by a fall. The bed was raised approx. 60 cm downstream of the bridge. The fall was equalized over a distance of 50 m. The river was made with a width of 1.5 m varying between 1.2 and 1.8 m and given a slope of 20‰. Just below the bridge the width of the river was widened to 5 m along a 6 m long segment.

The pump house was relocated into the field approx. 40 m northwest of its previous location. A new pump house was built with a wooden housing that can be removed to allow the pump to be repaired. The existing pipes were connected to the new pump house.

Project data:
Project leader: Vejle County
Project year: 2004

Restoration data
Slope: 10‰
Riffle length: 115 m

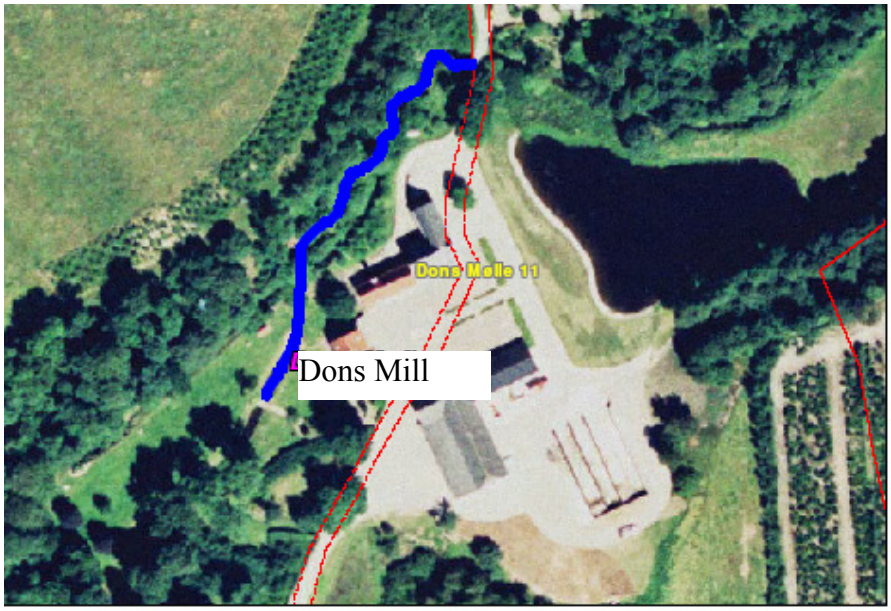
All woody vegetation between the river and the mill building was removed. The area down to the river was regulated so that the terrain sloped gently after the trees had been removed.

Obstruction 2
The 0.85 m fall was evened out over two segments. Firstly the riverbed was lowered 0.5 m just before the river divided, and secondly the remaining 0.35 m was evened out by establishing a riffle running from the point where the river subdivides down to the river in the garden. One of the branches was kept as an overflow channel to which the water can be led during periods of high runoff so that not all the water flow has to pass through the garden. A pipe was inserted through the weir to ensure that this branch was continually fed with a small amount of water.

The riffle was established with a slope of 10‰ and a width of between 1.2 and 1.8 m. The banks were given a slope of 22‰ in a flat construction.

The bridge in the garden was removed and replaced by two bridges. With both obstructions it will not be necessary to establish an eel pass in the future.

The location of the new riffle is shown on the map below.



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Example No. 10

Improving a steep rifle in the river Sneum at Størsbøl

River Sneum

By Allan R. Jensen
Ribe County

Description of the area

The river Sneum is one of the six large rivers that drain into the Wadden Sea. The steep riffle was located at Størsbøl where the river is 8–9 m wide with a flow of approx. 1,000 l/s and an annual maximum flow of 10–15,000 l/s. The biological quality of the water is generally good, rated 5–6 or higher on the Danish Stream Fauna Index.

Much of the central part of the river follows a naturally meandering course, whereas the lower part is regulated. The latter part is located within the special area of conservation for the houting and is included in the joint EU application by Ribe and Sønderjylland Counties and the Danish Forest and Nature Agency for funding of a wetland stretching from the riffle and approx. 5 km downstream. Among other things the EU project aims to create spawning and nursery grounds for the houting and the salmon by raising the river level and establishing gravel spawning grounds.

Map of the area

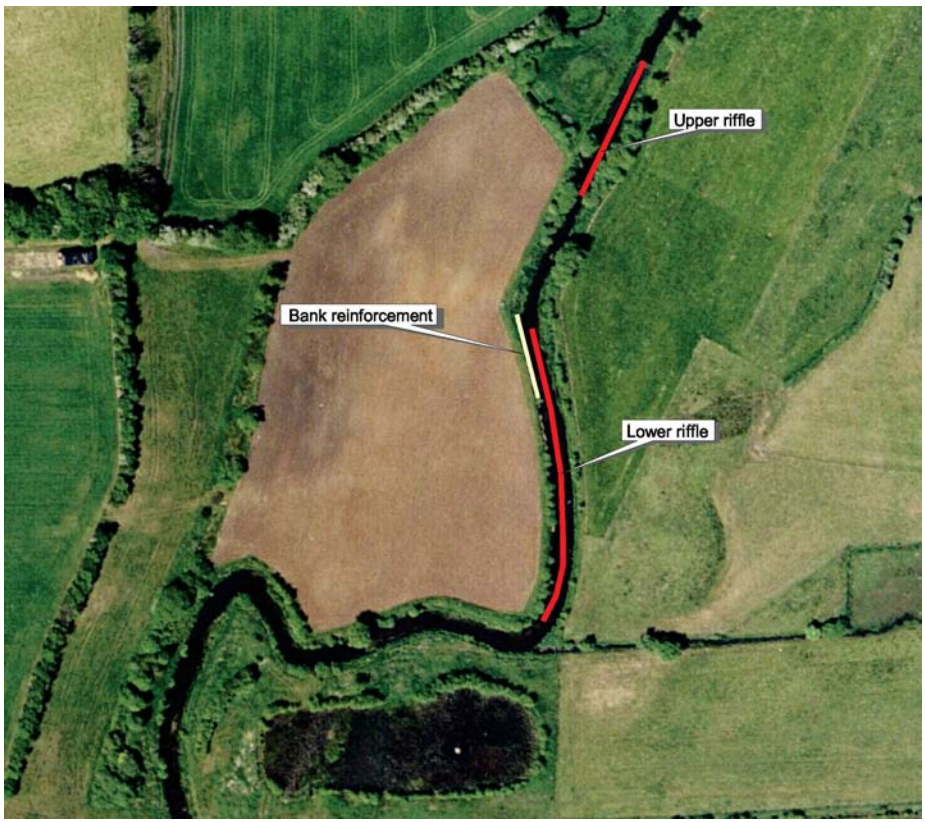
In connection with regulation of the river Sneum in 1955 the difference in elevation between the regulated and the unregulated upstream segments of the river became so great that a double fall was established with a combined drop of about 1.5 m.

Aim of the project

Some 15 years ago the double fall was converted to a stone riffle to improve passage conditions for houting. In connection with this, a short reach of the river downstream of the new riffle was re-meandered and the riverbed was raised. The stone riffle was constructed in a manner typical for that time, with two short riffles with a slope of 10‰ and 15‰ and the whole structure protected with large boulders.

The riffle functioned reasonably in accordance with the intention as passage conditions for trout and salmon improved considerably. Unfortunately, though, only very few houting were seen upstream of the riffle, and the large congregation of houting at the downstream end of the riffle clearly indicated that they were unable to pass the steep slope.

In order to enhance spawning possibilities for seatrout a 2x10-m stretch of spawning gravel was laid out downstream of the riffle. The spawning gravel was used regularly by the large fish during the first two years, but was thereafter dispersed by the current. After some years erosion damage started to appear in the bed and banks downstream of the boulders, thereby leading to sand migration and dissatisfied landowners.



After a few years the riffle sanded up completely, and even the steep part of the riffle turned into a hard sandy bed densely vegetated with water crowfoot and branched bur-reed.

Description of the project
In order to meet the requirement for effective fish passage and optimal spawning grounds for seatrout and salmon the riffle was rebuilt to its present form in 2003. The total length of the new riffle is approx. 220 m, and it consists of two segments separated by a deep section. The deep section arose by the erosion of the bed and banks of the old riffle. The erosion pool was preserved as it offered the advantage that the riffle could be divided into two segments with a naturally deep resting pool between them.

The short segment of the riffle upstream of the erosion pool was lined with approx. 60 m^3 spawning gravel to reduce the slope from approx. 10‰ to 5–6‰. The downstream and longest segment of the riffle is approx. 110 m long and made of spawning gravel with a slope of 4–5‰. To protect the spawning gravel, three 2–3 m wide transverse bands of boulders were laid across the river, one at the beginning of the riffle, one in the middle and one at the end. These are effective in ensuring that the current cannot catch hold of the gravel and cause it to move.

Experience gained through the project
We have now established several riffles in large rivers using this method. One of the great advantages of only giving the riffles a slope of 5‰ is that erosion damage to the banks is avoided, and it is therefore normally unnecessary to protect them. In addition, these riffles are well suited as spawning grounds for large salmonids (seatrout and salmon).

It has been necessary to provide some protection to the west bank, however, due to the severe erosion damage caused by the old riffle. A single layer of boulders has been pressed into the bank, which was

Project data:
Project leader: Ribe County
Project design: Ribe County
Project year: 2003
Total costs: DKK 200,000
Financing: Ribe County and State subsidies

River data:
Catchment: 220 km^2
Runoff:
Max – 15,000 l/s
Min – 1,000 l/s,
Quality objective: B2 (salmonid waters)

Restoration data:
Riffle length: 220 m
Riffle width: Bed 8–9 m
Slope: Approx. 5‰
Stone laid out: 40 m^3

thereafter planted with bank vegetation so that the boulders could not be seen.

Today, three years after its establishment, the riffle appears completely natural without any signs that it is starting to sand up. The water depth varies from 30 to 80 cm, and the current over the stone bed is strong. The riffle is vegetated with water crowfoot, starwort and greater water parsnip, and only very little branched bur-reed, which is the dominant plant species at other locations in the river Sneum. One landowner has reported that he has seen large spawning seatrout and salmon on the riffle each winter for the last couple of years. Very recent studies conducted in September 2006 revealed a salmon fry density of approx. 100 fry/100 m^2 as well as a few trout fry. On this basis it is concluded that the salmon population on the riffle is optimal. Corresponding studies performed on the old riffle in 1997 before restoration revealed a total lack of salmon and trout fry and only very few larger trout.

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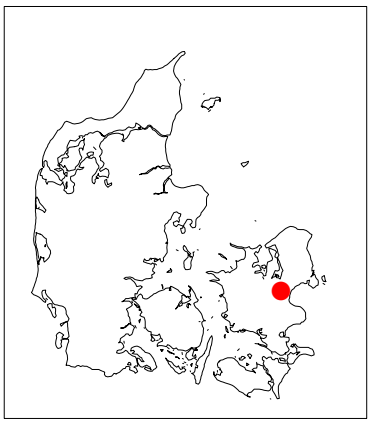
Example No. 11 Rehabilitation of the river Skensved



River Skensved

By Anne-Marie G. Kristensen
Roskilde County

Description of the area

The river Skensved is a small, approx. 14 km long river that arises east of Viby Sjælland and runs into Køge Bay at Jersie Beach. The upper part of the river is a municipal watercourse, while the reach from Rubjerg to its mouth is a county watercourse administered by Roskilde County.

The quality objective set in the Regional Plan for the reach of the river Skensved upstream of Navrbjerg Bridge is B1, i.e. salmonid spawning and nursery waters, while that set for the downstream reach is B2, i.e. salmonid waters. The requirements stipulated in the 2005 Regional Plan for meeting these quality objective are a biological quality of fauna class 5 on the Danish Stream Fauna Index and a median minimum water flow in the lower part of the river Skensved of at least 15 l/s. According to the Regional Plan the restoration of the river Skensved encompassing the laying out of stones and spawning gravel and the planting of shade-giving trees and bushes is necessary if the river is to meet its quality objectives.

As is the case in many other rivers in eastern Denmark, water flow in the river Skensved is affected by water abstraction, with very low water flow in the summer. In order to supplement flow in the summer, groundwater has been pumped into the upper part of the river from a well at Åbakkegård since 1986. The pump, which supplies 8–9 l/s, starts up when water flow at Åvad (at Lille Skensved) decreases to below 29 l/s.

Map of the area

In the part of the river Skensved that is administered by Roskilde County there are reaches with a good slope and good physical conditions with shade-giving trees. There are also long reaches with a relatively wide profile, though, either due to the shading or to severe bank erosion, and as a consequence the water is very shallow during periods of low runoff.

Navrbjerg Bridge

Roskilde County started restoration work in the river Skensved in autumn 2004. In the first instance this encompassed narrowing of the current channel under the three bridges in order to improve passage conditions for fish and invertebrates. In addition, dry fauna passes were established under the bridges. At Rubjerg a steep riffle was converted to a longer riffle, and a sand trap was established downstream of a long reach that sloped 3–6‰.

Restoration continued in 2005 with the laying out of large stones and spawning gravel, narrowing of the current channel and the planting of trees.

Aim of the project

The aim of the project was to improve conditions for fish and invertebrates and thereby help promote attainment of the quality objectives for the river.

Sand trap

Railway bridge at Lille Skensved

The improvements are intended to enhance the variation in physical conditions, including ensuring a sufficiently high river level during periods of low runoff.

Description of the project

At Rubjerg the previously steep riffle has been converted to a longer riffle with a double profile and a narrow current channel. The length of the riffle has thereby been increased from approx. 20 m to 60 m and the slope has been reduced from approx. 30‰ to 10‰. In order to avoid the impact of the outflow from a 30-cm diameter pipe the fall was not used to make an even longer riffle.

Project data:
Project leader: Roskilde County
Project design: DDH and Roskilde County
Project year: 2004/05
Total costs: DKK 390,000
  Roskilde County – DKK 370,000
  Angling License Fund – DKK 20,000

River data:
Catchment: 38.5 km^2
Runoff
  Max – 2,900 l/s
  Min – 0 l/s
  Annual mean – 130 l/s
Quality objective: B1 (salmonid spawning and nursery waters) upstream of Navrbjerg Bridge; B2 (salmonid waters) downstream
Fauna class before and after restoration: 4–5 on Danish Stream Fauna Index (2003)

Restoration data
Riffle:
  Length – 60 m
  Width – 1 m
  Slope – approx. 10‰
  Stones laid out – approx. 20 m^3
  Gravel laid out – 14 m^3
Sand trap:
  Length – 54 m
  Width – 5 m (bed width)
  Stone laid out – approx. 15 m^3 (63–250 mm)
  Earth excavated – approx. 480 m^3
Double profile, railway bridge:
  Length – 9 m
  Width – 5.5 m
  Stone laid out – approx. 22 m^3 (63–300 mm)
  Gravel laid out – approx. 5 m^3
Double profile, Navrbjerg Bridge:
  Length – 8 m
  Width – 4 m
  Stone laid out – approx. 10 m^3 (63–300 mm)
  Gravel laid out – approx. 3 m^3
Double profile, motorway bridge:
  Length – 40 m
  Width – 5.5 m
  Stone laid out: approx. 78 m^3 (63–300 mm)
  Gravel laid out: approx. 4 m^3

Under the railway bridge and the Navrbjerg Bridge at Lille Skensved and under the motorway bridge at Jersie Mire the current channel in the river has been narrowed by constructing wet berms along the sides. The river level has thereby been raised by approx. 5–15 cm at summer mean flow. Under the railway bridge high berms have been built along both sides, where as they have only been built along one side of the river under the other two bridges. The berms have been constructed in such a way that they flood during median maximum water flow.

At Hvidlundsege an approx. 54 m long sand trap has been established that is approx. 1 m deeper than the previous riverbed and has a bed width of approx. 5 m corresponding to twice the width stipulated in the regulations governing the river. The soil excavated during construction of the sand trap was spread out on adjoining farmland.

Experience gained through the project
Specific studies to assess the effect of the restoration measures have not yet been carried out since completion of the project in 2005.


Motorway bridge at Jersie Mire

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Example No. 12

River Herredsbæk – minor re-meandering and improvement of fish passage

River Herredsbæk

By Ole Schwalbe Madsen
Nordjylland County

Description of the area

Herredsbæk Fish Farm lay on the river Herredsbæk in the Bjørnsholm river system. The reach of the river Herredsbæk encompassed by the project is administered by Løgstør Municipality (see the map of the area).

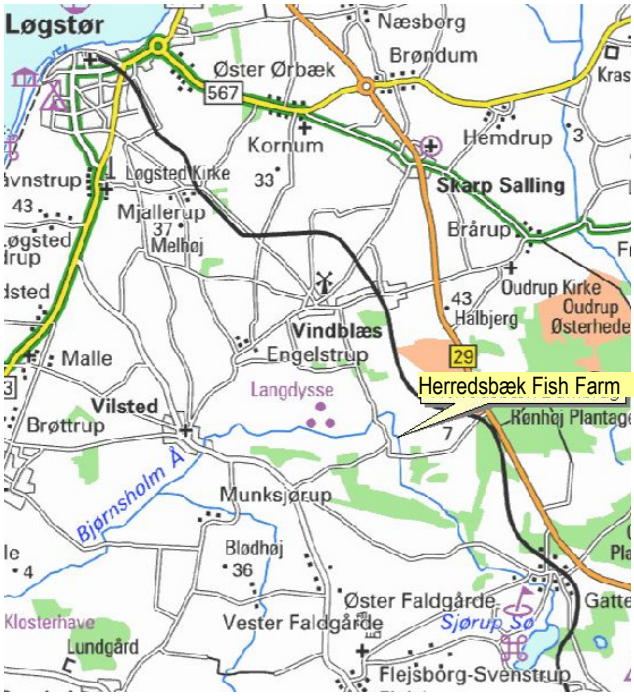
The fish farm was closed down in spring 2000. Until then it had been responsible for an approx. 560 m "dead" stretch of river where there would otherwise have been good possibilities for spawning. In the previously dead reach the river has been re-meandered within its own trajectory, and spawning gravel has been laid out.

Aim of the project

The aim of the project was to ensure free passage all year round to approx. 7 km of spawning and nursery grounds for salmonids and to improve the physical state of the river.

Description of the project

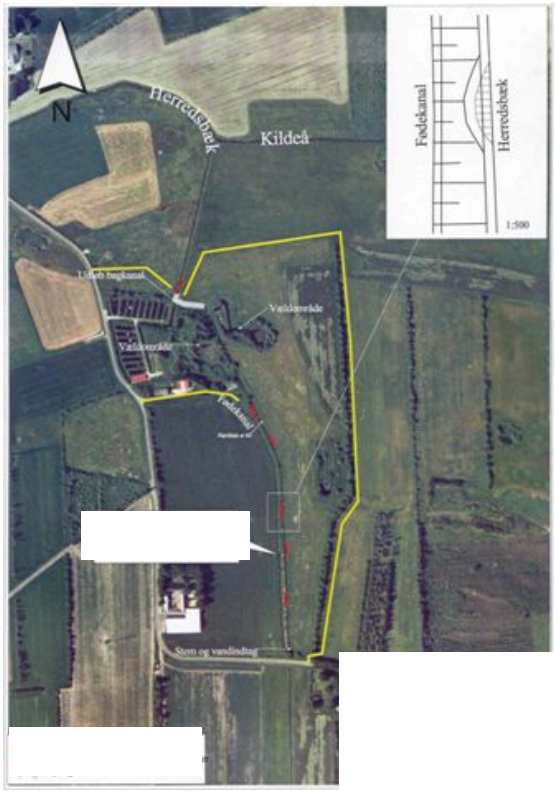
The fish farm, which had a feed quota of 43 tonnes per year, was closed down. The weir was removed, and the feed canal filled up with earth. A lake was established in the former fish ponds. The 560 m long dead reach of the river was restored with minor meanders in its own trajectory. In addition, spawning gravel was laid out, and steep banks were flattened (see the project drawings on the next page).



Map of the area

Experience gained through the project
Watercourses that are deep and have steep banks can be cheaply and effectively restored within their own trajectories by flattening the banks and constructing minor meanders/groups of boulders.

Impact assessment
An electrofishing study was carried out on a 100-m reach of the river upstream and downstream of the former fish farm and in the dead reach on 14 September 2000. Similar studies were not made before the restoration work, and comparison of trout density, etc. is therefore not possible.



The trout density per 100 m of river was as follows:

Downstream	Dead reach	Upstream
Fry – 65 Adults – 0	Fry – 30 Adults – 5	Fry –125 Adults – 0

The study was carried out immediately after the fish farm had been closed down. The results show rapid colonization of the dead reach, which had hitherto been completely devoid of water. It can be expected that the density of trout in the former dead reach has subsequently increased.

Project data:
Project leader: Nordjylland County
Project design: Nordjylland County
Project year: 2000
Total costs: DKK 623,000, comprised of DKK 192,000 for construction (DKK 66,000 excl. VAT for river restoration) and DKK 431,000 excl. VAT for compensation for closure of the fish farm
Financing: Nordjylland County, Angling License Fund and State Funding

River data:
Catchment: 15.62 km^2
Runoff:
Median minimum – 30 l/s upstream and 110 l/s downstream (many springs feed into the reach)
Annual mean – 110 l/s (upstream)
Median maximum – 490 l/s (upstream)
Quality objective: B1 (salmonid spawning and nursery waters)

Restoration data:
560 m dead river reach rehabilitated.
Gravel laid out: 74 m^3
Fish farm rehabilitated, and approx. 5,000 m^2 lake established.
Vegetation belts established alongside river.
Ponds established for amphibians.

The project has opened up for free passage past the fish farm, which previously comprised an almost complete obstruction. A seatrout study showed, though, that the population upstream of the former fish farm was very small. This finding is probably attributable to the fact that the study was performed immediately after the fish farm closed down. Previously it had been a rather uncertain survival strategy for trout upstream of the fish farm to become seatrout as very few of them ever returned to the upstream population. Today, though, a larger population of seatrout can be expected.

The reach downstream of the fish farm previously failed to meet the quality objective set for the river in the Regional Plan due to wastewater discharges from the fish farm. Loading from this source has now been removed, and it should therefore be possible for the reach to meet the quality objective now such as is the case with the upstream reach of the river Herredsbæk.

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Example No. 13

River Donse – daylighting of a culverted reach

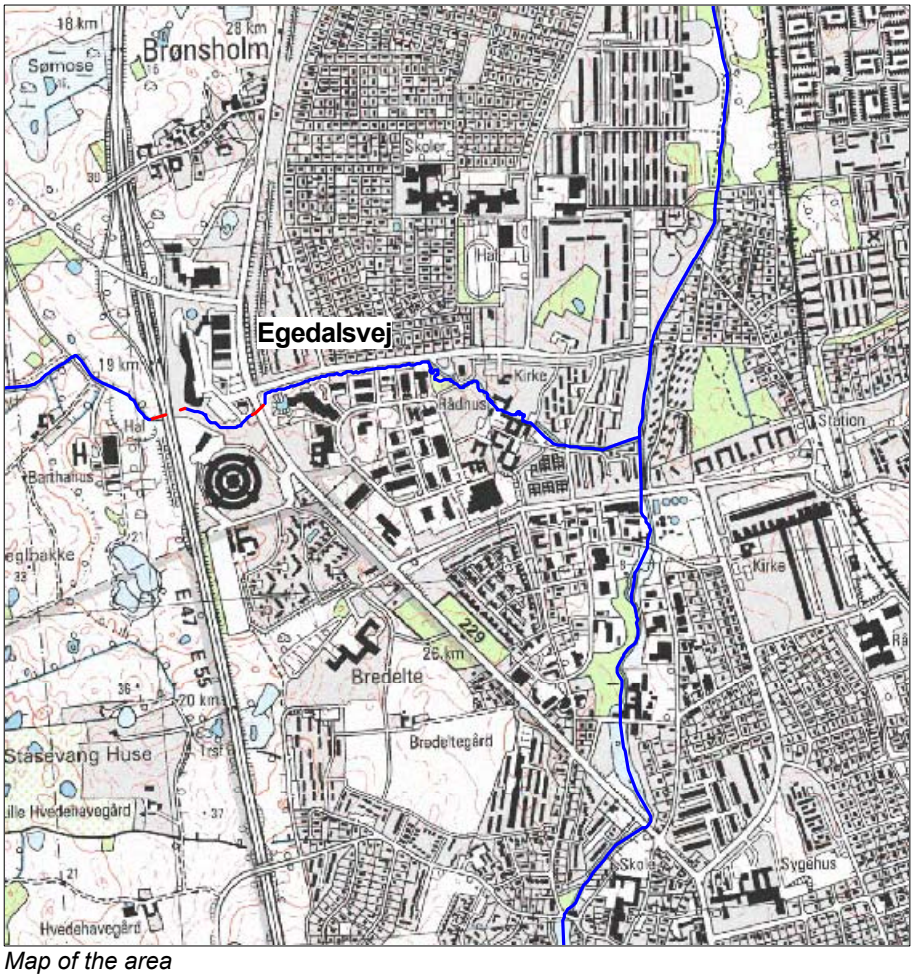
River Donse

By Berit L. Mogensen
Frederiksborg County

Description of the area

The quality objective stipulated for the river Donse in the Regional Plan is B1, i.e. salmonid spawning and nursery waters. Prior to the project, however, the river did not meet its quality objective due to low summer water flow, the poor physical conditions and the fact that three long reaches were culverted. The river Donse is part of the Nivå river system and due to its generally good slope has the potential to be the most valuable trout spawning area in the whole river system.

The river was regulated in the 1800s, and three reaches were culverted in the 1960s in connection with road construction and expansion of urban Kokkedal. The reach between the Helsingør motorway and the river's confluence with the river Usserød runs through a built-up area. The river Donse is culverted under the motorway and along Egedalsvej road. The two culverted reaches prevent trout from ascending from the sea (Nivå Bay) and up through the rivers Nivå and Usserød to the upstream reaches of the river.



Map of the area

Project data:
Project leader: Frederiksborg County
Project design: NIRAS
Project year: 2001
Total costs: DKK 2.7 million excl. VAT
Financing: Frederiksborg County

River data:
Quality objective: B1 (Salmonid spawning and nursery waters)

Restoration data:
Length: Approx. 500 m
Slope: 5‰

Aim of the project

The aim of the project was to open up the approx. 500 m culverted reach along Egedalsvej road in the town of Kokkedal and lay out stones and spawning gravel along the reach between the motorway and the confluence with the river Usserød.

Description of the project

The water level in the culvert under the motorway was raised by establishing a riffle. This reduced the water velocity and increased water depth, thereby enabling the fish to pass the motorway.

The culvert along Egedalsvej road was located 4–6 m below ground surface. Had the culverted reach been daylighted at its existing depth the river would have been far too low relative to ground surface. It was therefore decided to daylight the river well above the old culvert with the latter being used as a stormwater basin. Using this solution the trajectory ended up between 1.5 and 2 m below the surrounding terrain.

The slope of the river Donse is very high over that reach. Stones and gravel were therefore laid out along the whole reach, which now has the character of a bubbling brook.

Experience gained through the project

As early as the following season for the ascent of seatrout, several large fish were observed in the reach. In the spring, trout fry were observed, thus indicating that spawning had taken place. Seatrout were also observed upstream of the motorway, so the restoration measures must have had a beneficial effect.

Later, though, it transpired that sand migration in the river Donse is still too great, and that the spawning grounds had started to sand up. If this reach of the river is to function according to intention, it will be necessary to establish more sand traps.

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Example No. 14

River Usserød – modification of the outlet from lake Sjælsø and re-meandering

River Usserød

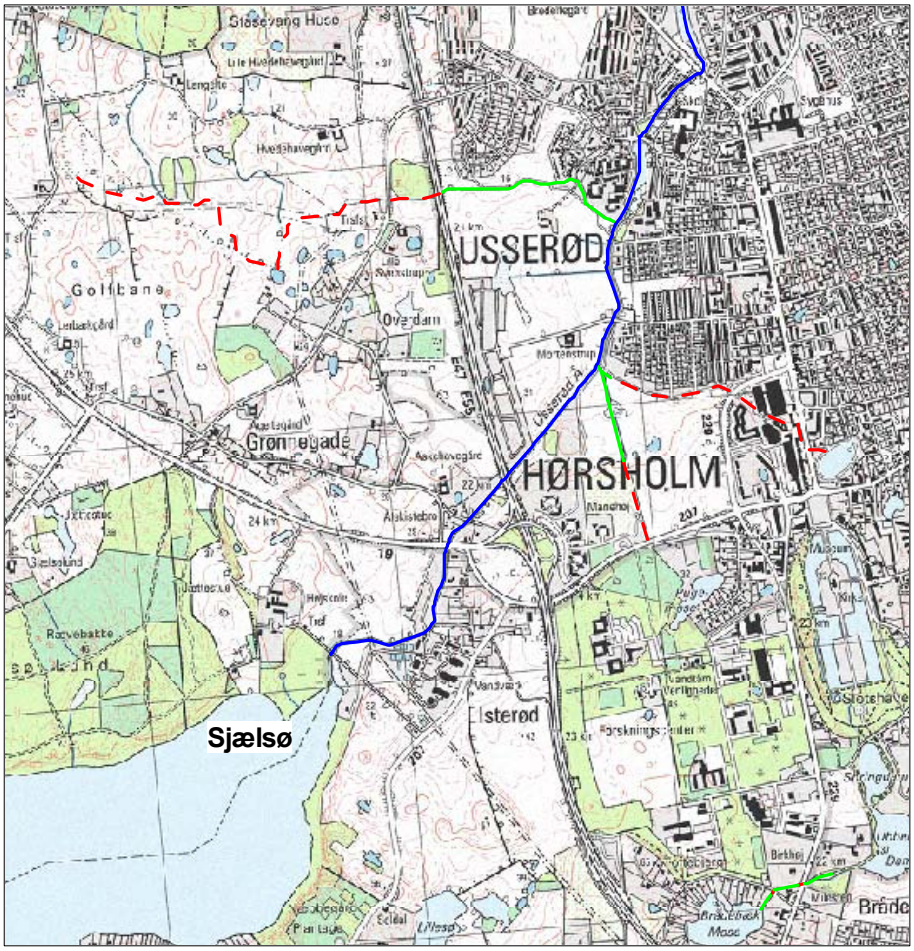
By Berit L. Mogensen
Frederiksborg County

Description of the area

The river Usserød is part of the Nivå river system. The quality objective for the first 5 km set in the Regional Plan is B3, i.e. cyprinid waters. The objective was not met, however, due to the input of wastewater and stormwater discharges, poor physical conditions and low summer water flow.

The river Usserød was straightened and deepened as early as the 19th Century in order to improve drainage of the riparian areas for agricultural purposes and for the operation of mills in the river.

The outlet from lake Sjælsø is dammed, and flow through the sluice gate was regulated out of consideration for the threat of flooding around the lake rather than the water flow needs of the river Usserød.



Project data:
Project leader: Frederiksborg County
Project design: Water Consult, NIRAS
Project year: 2002
Total costs: DKK 3.5 million excl. VAT
Financing: Frederiksborg County. Danish Forest and Nature Agency, Angling Licence Fund

River data:
Quality objective: B3 (cyprinid waters)

Restoration data:
Length: Approx. 3.5 km

Aim of the project

The aim of the project was to ensure higher summer water flow in the river Usserød by accumulating water in lake Sjælso during the winter for release to the river in the summer.

Description of the project

The outflow sluice from lake Sjælsø was converted from a manually operated sluice to a fully automatic sluice.

The reach of the river between the lake and Stampedam was re-meandered. Despite the fact that the river is designated as cyprinid waters, spawning grounds were laid out together with large stones intended to aerate the water as much as possible. Re-meandering of the reach proved to be more difficult than expected due to the many cables, pipes, etc. present in the ground near the river.

A further wish was to graze back the grass in part of the river valley after the riparian area had become wetter in the winter period. This wish has been met by the establishment of a cattle grazing association started upon private initiative that now ensures that the area is kept grazed back.

Experience gained through the project

The project has subsequently proven to live up to expectations. The dynamics of the river have changed considerably for the better, and several new plants and various invertebrates have colonized the river.

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Example No. 15

River Damvad – fish pass and re-meandering

River Damvad

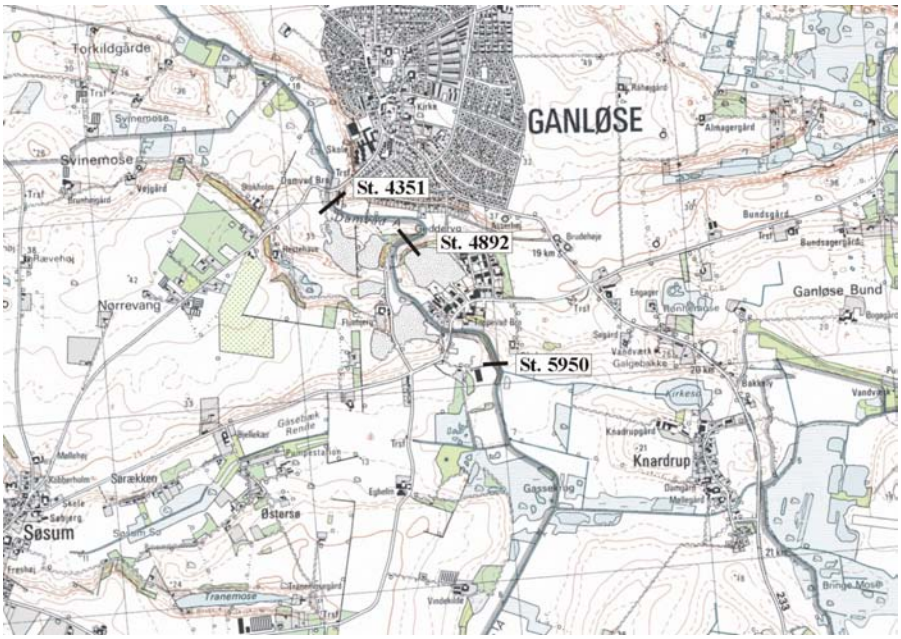
By Troels Karlog
Frederiksborg County

Description of the area

The river Damvad in Stenløse Municipality is a county watercourse administered by Frederiksborg County. The quality objective stipulated for the river in the Regional Plan is B1, i.e. salmonid spawning and nursery waters.

Before the project was carried out the reach downstream of Toppevad Bridge was characterized by a diverse macroinvertebrate fauna. Here the slope of the river was very steep and the profile alternated between very rapidly flowing riffles and calm pools. Upstream of the bridge the physical conditions well less good, and not optimal.

The river Damvad is the only part of the Værebro river system that has a satisfactory trout population. Before the project was carried out there was a pronounced fall across the culvert under the bridge. This hindered the ascent of trout and the passage of other fish and macroinvertebrates to the reach upstream of Toppevad Bridge.



The river Damvad at Toppevad, 1:25,000. The restoration project encompassed the reach between metre 4351 (upstream) and metre 5950 (downstream) of Toppevad Bridge.

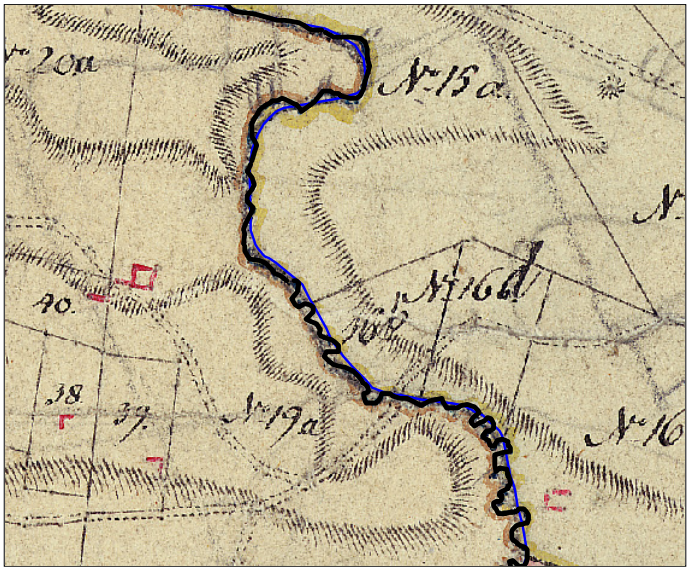
Immediately upstream of Toppevad Bridge there are a number of homes with gardens adjoining the river. Prior to the project these gardens often flooded during periods of high runoff in the river.

Aim of the project
The aim of the project was to improve conditions upstream of the culvert at Toppevad Bridge and to improve passage of fish and macroinvertebrates through the culvert. A further aim was to reduce the frequency and magnitude of flooding of residential properties located immediately upstream of Toppevad Bridge.

Description of the project
In autumn 2002 Stenløse Municipality and Frederiksborg County replaced the culvert under Toppevad Bridge with a 2.5 m diameter semicircular tunnel. When establishing the tunnel the steep slope of the previous culvert was evened out by lowering the riverbed in the upstream end of the tunnel.

The restoration project also encompassed a change in the official dimensions of the river (i.e. those stipulated in the regulations governing the river) over an approx. 1,300 m reach upstream of Toppevad Bridge and a 300 m reach downstream of the bridge.

The old river regulations stipulated that the slope of the reach upstream of Toppevad bridge should be 2.2–2.5‰. However, the actual slope prior to restoration was 3–6‰ over some short sections and 0.5–1‰ over others. The steeply sloping segments had the character of riffles with a bed consisting of stone and gravel, whereas sand dominated in the gently sloping segments. The regulation bed width was 60 cm, but the actual bed width was 90–130 cm and in some places as much as 200 cm. As the river maintenance was only carried out within the official bed width, a double profile had formed in long reaches consisting of a narrow and deep current channel meandering through the wide river profile.



Map of the river Damvad at Toppevad Bridge drawn in 1818. The river trajectory at that time is drawn in black and the present trajectory in blue. Illustration prepared by Mogens Lindhardtsen, Frederiksborg County.

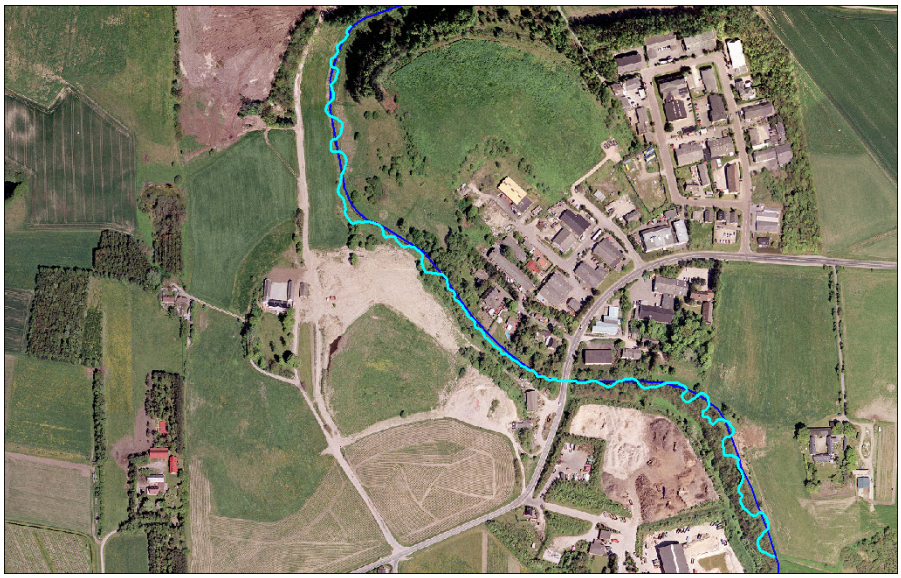
Project data:
Project leader: Frederiksborg County
Project design: Frederiksborg County and Water Consult
Project year: 2003
Total costs: DKK 800,000
Financing: Frederiksborg County, Danish Forest and Nature Agency and Angling Licence Fund

River data:
Catchment: approx. 20 km^2
Runoff:
Max – 462 l/s
Min – 25 l/s
Annual mean – 47 l/s
Quality objective: B1 (salmonid spawning and nursery waters)
Fauna class: 4 (Danish Stream Fauna Index)

Restoration data:
Length: 1,600 m
Width: 60 cm.
Slope: 3–6 ‰
Stone laid out: 30 m^3
Gravel laid out: 150 m^3

The majority of the reach is unshaded and with well-developed weed vegetation dominated by water parsnip in the actual river profile and by reed sweet-grass on the banks.
The main principle was to regulate the elevation of the riverbed so that the very steep fall in and near the former culvert under Toppevad Bridge could be utilized to create good sloping conditions across a long reach upstream of Toppevad Bridge.

As is apparent from the old map drawn in 1818, the river Damvad originally followed a clearly meandering course through the narrow river valley. In connection with the project a similar meandering course was constructed. It was not possible to re-establish the original meanders along the segment running along the residential gardens at Toppevad Bridge and the approx. 100-m segment downstream of the bridge due to the presence of buildings or because the terrain had been levelled.



The present course of the river Damvad is shown on this aerial photograph in dark blue together with the proposed new meandering course shown in light blue. Illustration prepared by Mogens Lindhardtsen, Frederiksborg County.

When the new profile was constructed the occasional 3–8 m long segment was dug more deeply to serve as resting pools for large fish. Likewise the occasional 3–6 m long riffle of gravel and stone was laid out to improve the spawning possibilities for trout and improve the macroinvertebrate fauna associated with a stony bottom. Finally, a number of individual boulders were laid out in the new profile.

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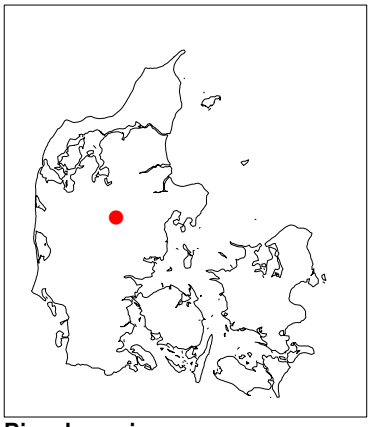
River trout

Example No. 16

River Lemming – restoration of the river and the river valley



River Lemming

By Ole Helgren
Aarhus County

Description of the area

The river Lemming is approx. 10 km long and arises at Kragelund north of Silkeborg and ends in the river Hinge between lake Hinge and lake Alling. The lowermost 5 km of the river has largely the character of natural watercourse and has been administered by Aarhus County since 1995. The quality objective stipulated for the river in the Regional Plan is B1, i.e. salmonid spawning and nursery waters.

Aim of the project

In connection with the establishment of the now closed Kjellerup railway line the river Lemming was regulated in 1918–20 and relocated to a new trajectory alongside the railway line from Sejling Brook to Lemming Bridge. Later (approx. 1950) the river was further regulated in connection with the establishment of weirs for three fish farms on the river. Aarhus County would like to give the river its meandering course back. The project was spurred by a landowner, who wanted to have the old meandering river back.

Map of the area

Description of the project

Aarhus County would like to re-meander the river, and as the rumour of this spread among the landowners the number of proposed meanders increased markedly. It was only possible to meet all their wishes if the weir at Lemming Fish Farm was removed.

Several landowners offered to make land and severed meanders available to the project free of charge. Two of the fish farms wished to give up their right to dam the river, and many landowners sought permission to clean out existing ponds or establish new ones. Within a short time the basis was thus established for a comprehensive restoration plan for the whole river.

Project data:
Project leader: Aarhus County
Project design: Aarhus County
Project year: 1998
Total costs:
Construction (1998) – approx. DKK 500,000
Subsidy from the Danish Forest and . Nature Agency – DKK 140,000

River data:
Quality objective: B1 (salmonid spawning and nursery waters)

Restoration data:
Length: 5 km in all .

The overall restoration plan encompassed the following elements:

- Re-meandering of approx. 3 km of the river Lemming between Sejling Brook and Lemming Bridge
- The establishment of three new ponds
- Purchase of the damming rights at Lemming, Holm and Sletkær Fish Farms
- Removal of the weirs at the three fish farms and the establishment of riffles
- Restoration of the river valley at the former fish farms.

All the construction work was carried out over a two-month period in autumn 1998. The weir at Lemming Fish Farm was removed, and the fish farm site levelled out.

Between Sejling Brook and Lemming Bridge the river was partially restored to its original meandering course and now crosses the nature trail (the old railway embankment) four times. The straightened reach alongside the old railway line has been maintained, however, such that the water can distribute in both the old and the new course during the winter period. The weirs at Holm and Sletkjær Fish Farms have also been removed and the fish farms have been re-established as meadows and ponds

Experience gained through the project

As far as possible the lowermost 5 km of the river Lemming and the river valley have been restored to the state they were in before they were extensively regulated, and the river fauna now has unhindered passage along the whole of the river Lemming. In cooperation with the landowners, Silkeborg Municipality has restored long reaches of the river system upstream of the river Lemming. Via its confluence with the river Hinge the river Lemming is a very important part of the Gudenå river system. Once passage has been restored in the river Hinge at Allinggård there will be free access to the whole of the restored river Lemming.

A wish for three small meanders thus grew in the spring of 1998 to a comprehensive restoration plan for a whole river system and, during the subsequent half year, to the restoration of both the river Lemming and the river valley. The project was designed and carried out by Aarhus County. Subsequently, Silkeborg Municipality has established fords and cattle crossings and erected fences in agreement with the landowners.

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Example No. 17

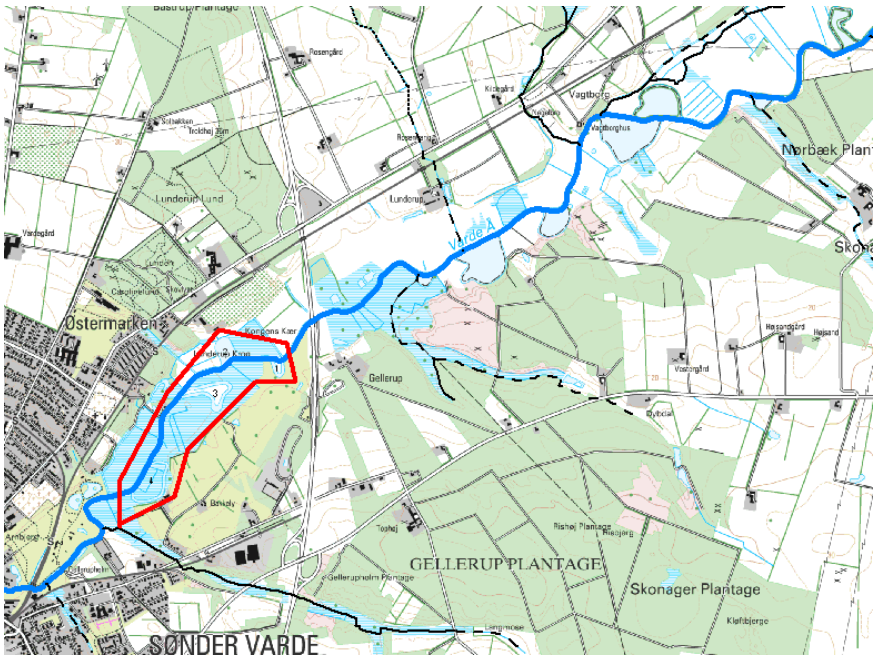
River Varde, Ribe County – re-meandering and laying out spawning grounds

River Varde

By Ove Kann
Ribe County

Description of the area

The project focussed on the lower part of the river Varde located on the eastern edge of the town of Varde approx. 17 km from the mouth of the river in the inner part of Ho Bay and approx. 6 km downstream of Karlsgårde Hydroelectric Power Station. The reach is surrounded by grazed or unused meadows.



Map of the area

The reach of the river Varde between Karlsgårde Hydroelectric Power Station and Varde was regulated in 1929 in order to increase the fall across the power station turbines. Thirteen meanders were severed during straightening, and the riverbed was lowered 0.5–1 m. The excavated material was laid out as embankments along the river rather than being placed in the severed meanders, most of which are consequently still visible in the terrain as more or less overgrown or swampy areas.

Before the re-meandering project was carried out in 1999/2000 the reach was a deeply lying canal (due to the embankments) of little value to the landscape or the environment. Boring – especially in view of its close proximity to the town and a recreational area (golf course) located just south of the project area.

The project was spurred by a DKK 1 million donation from the JL Fund given via the Danish Society for Nature Conservation for “a project centred around the Varde river”. In collaboration with the Society and Varde Municipality, and after considering several possible projects, it was decided to use the donation to re-meander a

1.4 km long reach of the river – a project that would double the length of the reach.

A steering committee was established with representatives of Ribe County, Varde Municipality and the Danish Society for Nature Conservation to prepare a budget and assign responsibility for the various tasks. The County dealt with the design of the project and administration of the construction work and, as the environmental authority, official processing of the project. Varde Municipality arranged the agreements with the affected landowners and the Society dealt with contact to the JL Fund.

The river contains the only population of freshwater pearl mussel in Denmark and hence is a protected habitat. The species was known to occur on a stone riffle approx. 3 km upstream of the project area. The question was whether it also occurred in the project reach. An underwater survey revealed that this was not the case, but that large, very old examples were present immediately downstream.

Aim of the project
The aim of the project was to enhance the landscape and environmental qualities of the river, including improving the river as salmonid spawning and nursery waterw.

Aerial photograph of the project area prior to re-meandering of the river Varde. The location of former meanders 1–4 is indicated.

Description of the project
The first task when designing the project was to determine where the bed of the river's original meanders lay, its character and the character of the material that had to be excavated. The task was performed during a long period of frost during which it was possible to

move around on the iced-over former meanders. Here approx. 50 profiles holes were bored through the ice in order to allow insertion of a long iron bar and a sampler to determine the location of the old solid bed and collect mud samples.

The profiles were used to design the new river. The initial design called for a cross-sectional area of approx. 45 m^2 corresponding to the river's upstream and downstream cross-sectional area so that the river would be large enough to accommodate high runoff levels of 30–40,000 l/s. The course to which the river was to be restored was indicated by the terrain, and the old banks were still visible. An upper width of 18–22 m was marked out on the terrain. The sloping banks were set to angle of 22° – 33° and the elevation of the bed relative to Danish Zero Level was set to 0 ±0.5 m (high bed elevation on the inner side of the bends and in the straight segments between bends, and low bed elevation on the outer side of the bends) In addition, earth calculations were made for each of the four meanders together with calculations of how much surplus earth the future sealed-off sections would be able to contain. The earth calculations were made using computer programmes for designing road projects. When using them for the river Varde project it was just necessary to "turn everything upside down."

The reason for the very imprecise description of the new river was that an air of humility soon arose regarding the river's power given the 4,000–40,000 l/s range in water flow through the river together with recognition of the fact that neither our knowledge nor our financial resources were sufficient to enable more precise and close calculation of stable profiles so as to be able to avoid both erosion and deposition. The project description therefore only ended up containing drawings of stylized profiles.

We nevertheless had to assess the drainage consequences of re-meandering the reach. This was done using the watercourse administration programme PROKA, in which the new river was designed. River level calculations showed that at mean runoff the river level would rise by 10–15 cm immediately upstream of the upper meander. The calculations proved to be correct.

The call for tenders for the project resulted in 17 tenders ranging from DKK 1.57 to 3.77 million. The cheapest tender was selected. Before the excavators started the operators were thoroughly instructed concerning the shape of the profiles in the bends and straight segments of naturally meandering rivers. The intention was to imprint on their retinas a picture of how they should shape the course of the river within the loosely defined framework. That was a great success, and because of it the task became even more exciting for the excavator operators.

Meanders 1 and 3 were opened up in 1999 at an inauguration ceremony in September. A couple of weeks later, as much precipitation fell over a 14-day period as would normally fall in 3–4 months. The flow in the river increased to 50,000 l/s, and the river

Project data:
Project leader: Ribe County
Project design: Ribe County
Project year: 1999/2000
Total costs: DKK 2 million
Financing:
JL Fund – DKK 1 million
Ribe County – DKK 600,000
Varde Municipality – DKK 200,000
Danish Society for Nature Conservation – DKK 100,000
Danish EPA – DKK 100,000

River data:
Catchment: 850 km^2
Runoff:
Max – 50,000 l/s
Min – 4,300 l/s
Mean – 12,500 l/s
Quality objective: B2 (salmonid waters)

Restoration data:
Length: Before 1,400 m, after 2,800 m
Width: Upper 18–22 m, bed 10–15 m
Slope: Approx. 0.1‰
Gravel laid out: 1,500 m^3
Earth excavated: 60,000 m^3

level increased 2.5 m! The whole of the river valley stood under 1–1.5 m of water. At the last minute the contractor just managed to save his machines and iron plates, etc. He also managed to line the bank of the entrance to meander 3 with stones and gravel. It was with great trepidation that we made the first inspection after the river level had fallen to near the "normal" level. It transpired, though, that all the banks – both old and new – had withstood the onslaught of the water.

The project was completed in 2000 with the opening of meanders 2 and 4 without further drama. In all, some 60,000 m^3 of earth and mud had been excavated, moved and deposited, 11 spawning grounds consisting of in all 1,500 m^3 of gravel had been established, and the banks in front of a single house on the edge of meander 3 had been protected with 600 m^3 of stones.

Aerial photograph of the river Varde after completion of re-meandering

Experience gained through the project
The re-meandering of the river Varde is very much appreciated by both the landowners and the local community as well as by other inhabitants of the county who are able to enjoy the result close-up when walking along the nature trail from Bække to Blåvand. Anglers report particularly good catches in the area. Canoeists now enjoy a completely different and exciting experience when navigating the re-meandered river.

No actual biological effect studies have been made, as these are rather difficult to carry out in the 1.5–2 m deep river. It is apparent, though, that the new course of the river is stable, even though the banks in the bends have not generally been protected.

The processes of designing the project and drawing up the call for tenders, the tender process and supervision of the construction work were carried out in close cooperation between the Ribe County roads division and aquatic environment division, a cooperation that proved most fruitful and which has continued in other similar projects.

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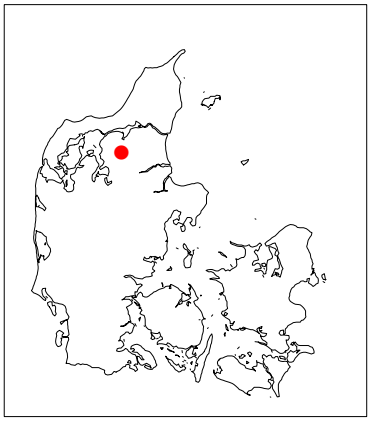
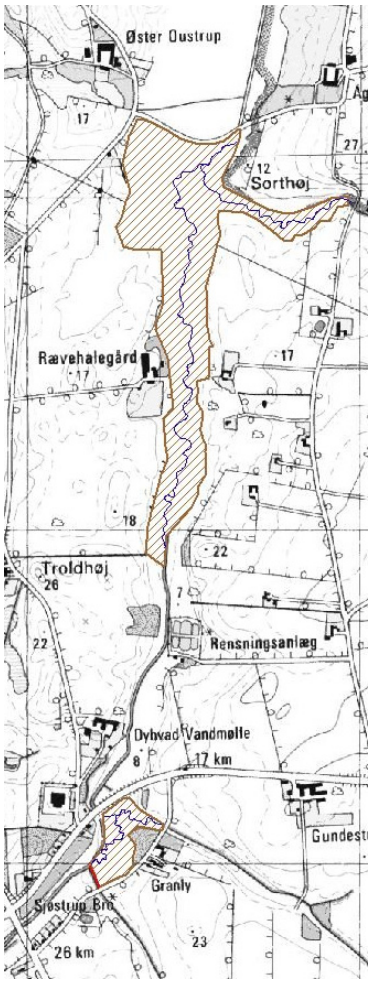
Example No. 18

Re-meandering and wetland project in the Halkær river valley at Års



River Halkær

By Ole Schwalbe Madsen
Nordjylland County



Map of the area

Description of the area
The Halkær river valley is a tunnel valley running north/south through western Himmerland. The project area is located in the upper narrow part of the river valley.

The river Halkær was already regulated for use in connection with a water mill as long as 200 years ago when the first maps were drawn. Since then the mill has been moved to a regulated reach at the bottom of the river valley.

Aim of the project
The aim of the project was to:
- Reduce leaching of nutrients and ochre by raising the water table in the river valley and thereby helping the agricultural sector fulfil the reduction targets stipulated in the Action Plan on the Aquatic Environment.
- Re-create valuable natural habitats such as meadows and wetlands and to improve the physical state of the river to the benefit of the flora and fauna
- Provide possibilities for public access to a path in part of the area.

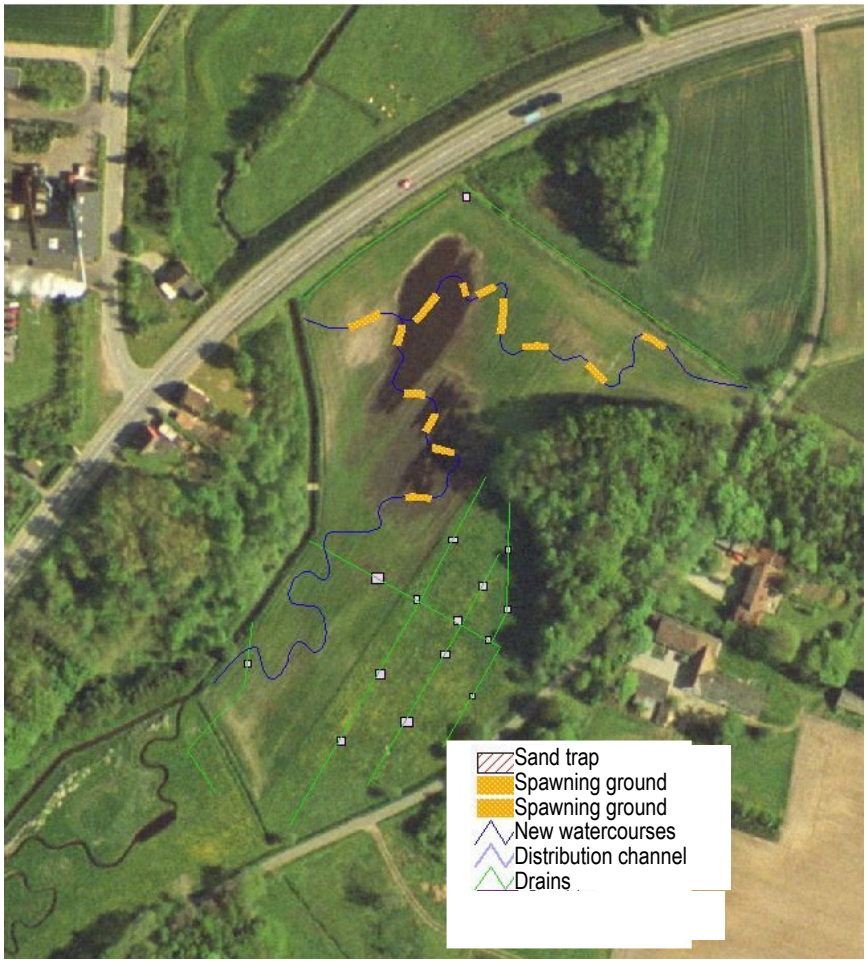
Description of the project
The re-meandering project was carried out in several stages. In 1999 an approx. 1 km long reach of the river Halkær near Aggersundvej road was re-meandered. One part of the area is owned by the Municipality, while the other part was undertaken in connection with an agreement on changed drainage made under the agri-environmental measures scheme.

In 2004 a wetland project was carried out around an adjoining reach and a longer reach located between the wastewater treatment plant and Ågårds Bridge.

The meanders during excavation

Two reaches of the river Halkær have been re-meandered. A reach upstream of Roldvej road and a reach running upstream from Ågårds Bridge towards the wastewater treatment plant. In addition, Herredsbæk brook has been given a new 2,020 m long meandering course and 655 m of the lower part of Sillevad brook has been re-meandered. Finally, Gundestrup brook was re-meandered downstream of Sjøstrup Bridge.

Spawning grounds were established in Herredsbæk brook upstream of Roldvej road and Ågårds Bridge, as well as in the lower part of Gundestrup brook and in Sillevad brook. The bed of the new river was raised relative to the existing bed, and the width was reduced relative to the existing width. Maintenance of the new river will be reduced in future, and flooding of the adjacent low-lying areas can be expected during periods of high runoff. The drains in the project area were sealed off to eliminate the drainage effect.



Project data:
Project leader: Nordjylland County
Project design: DDH and Nordjylland County
Project year: 1999 and 2004
Total costs:
Construction in 1999 – approx. DKK 350,000.
Construction in 2004 – DKK 850,000 + landowner compensation – DKK 750,000
Financing: Danish Forest and Nature Agency (wetlands) and Nordjylland County

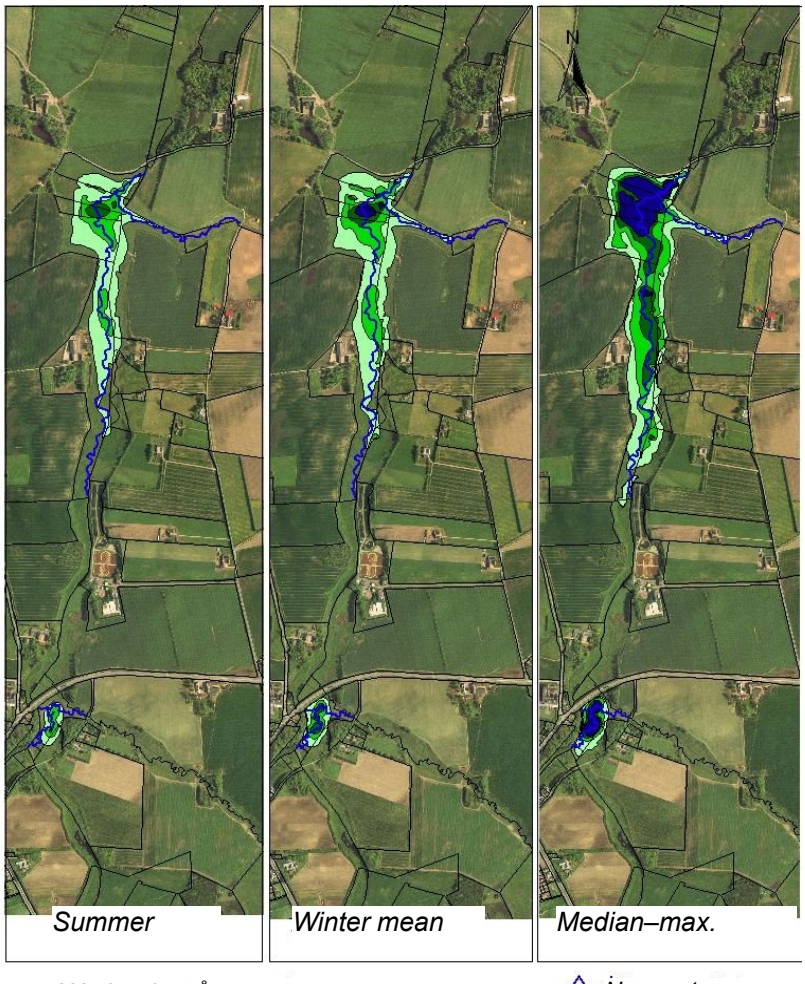
River data:
Catchment: 27 km^2
Runoff:
Max – 1,580 l/s
Min – 130 l/s
Mean – 330 l/s
Quality objective: B1/B2 (salmonid spawning and nursery waters/salmonid waters)
Pollution class before and after: II

Restoration data:
Length: 3 km in all + approx. 1 km tributary
Stone laid out: 57 m^3
Gravel laid out: 400 m^3
Earth excavated: 5,000 m^3
Slope: 0.4–2.9‰

Experience gained through the project

Immediately before the work started in 1999, electrofishing was performed in the whole of the 300 m long reach of the river Halkær downstream of Aggersundvej road that was destined for re-meandering. Ten fish were caught – 8 trout and 2 eels.

Electrofishing was repeated in August 2004 on 100 m of the re-meandered river. This time 585 trout ranging in size from 6 to 23 cm were caught, most of which were fry 6–10 cm in length. As trout stocking had not been carried out during the preceding years the fish must have derived from natural production. The population density was around 365 fish per 100 m^2. This is not only among the best-recorded population densities in northern Jutland, but also in Denmark.



Contact
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Freshwater mussel
Unio crassus

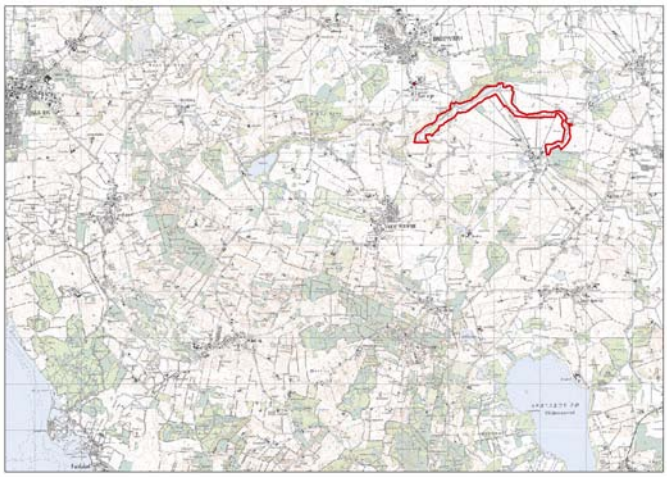
Example No. 19

River Odense – wetlands project and re-meandering

Tørringe brook and river Odense

By Lars Bangsgaard
Fyn County

Description of the area
The project area is located on mid Fyn upstream of Brobyværk at Søhule, approx. 46 km from the outlet of the river Odense in Seden Strand.



Map of the area

Over the periods 1944–46 and 1948–50 some 13.4 km of the river Odense upstream of Brobyværk, including parts of the Silke, Sallinge and Hågerup rivers and Tørringe brook, were regulated.

The regulation work was highly subsidized by public funds and often met protests from several of the landowners. After regulation this reach of the river Odense was 2.2 km shorter and lay up to 1.2 m deeper in the terrain. The regulated river was constructed with a bed width of between 5 and 9.5 m with a trapezoid profile, an even bed and fascines along both sides. The bed slope was 0.5–0.7‰, and the bank slope was 1:1.25. Approx. 205,000 m^3 of earth was excavated. .

In 2003 the bed of the river Odense lay up to 0.5 m deeper in the terrain than immediately after regulation and relative to the level stipulated in the regulations governing the river. The bed material, which predominantly consisted of sand, had not been excavated, but had been eroded away by the force of the river water.

Aim of the project

The main aim of the project was to re-create 78 ha of wetland with wet and dry meadows along the river Odense to help transform some of the nitrogen input to the aquatic environment from arable land. The project was carried out as part of Action Plan on the Aquatic Environment II. Subsidiary project aims were to:

1. Enhance the nature value of the riparian areas
2. Improve the conditions for fish, macroinvertebrates and plants in the river Odense through re-meandering and laying out of stones and gravel
3. Create a habitat for birds
4. Ensure that the river Odense can continue to drain the farmland in the catchment
5. Establish continuity between the existing natural habitats.

Description of the project

In 2003 a 3.6 km long section of the river Odense was re-meandered and thereby extended by approx. 1.2 km. At the same time its bed was raised to a level between that of the original river before regulation in the 1940s and that of the newly excavated riverbed immediately after regulation, a level of up to 1 m above that of the riverbed before the project started.

To even out the fall at the downstream end an approx. 185 m long stone riffle was established.

Wherever possible existing drains were led to the surface at new outlets within the project area. A field bridge was established over the river Odense to ensure a landowner access to substitute land.

The project was based on voluntary agreements with the landowners in the project area. The landowners received compensation in the form of either a one-off payment, a subsidy under the agri-environmental measures scheme or substitute land. Following completion the whole project area remains in private hands.

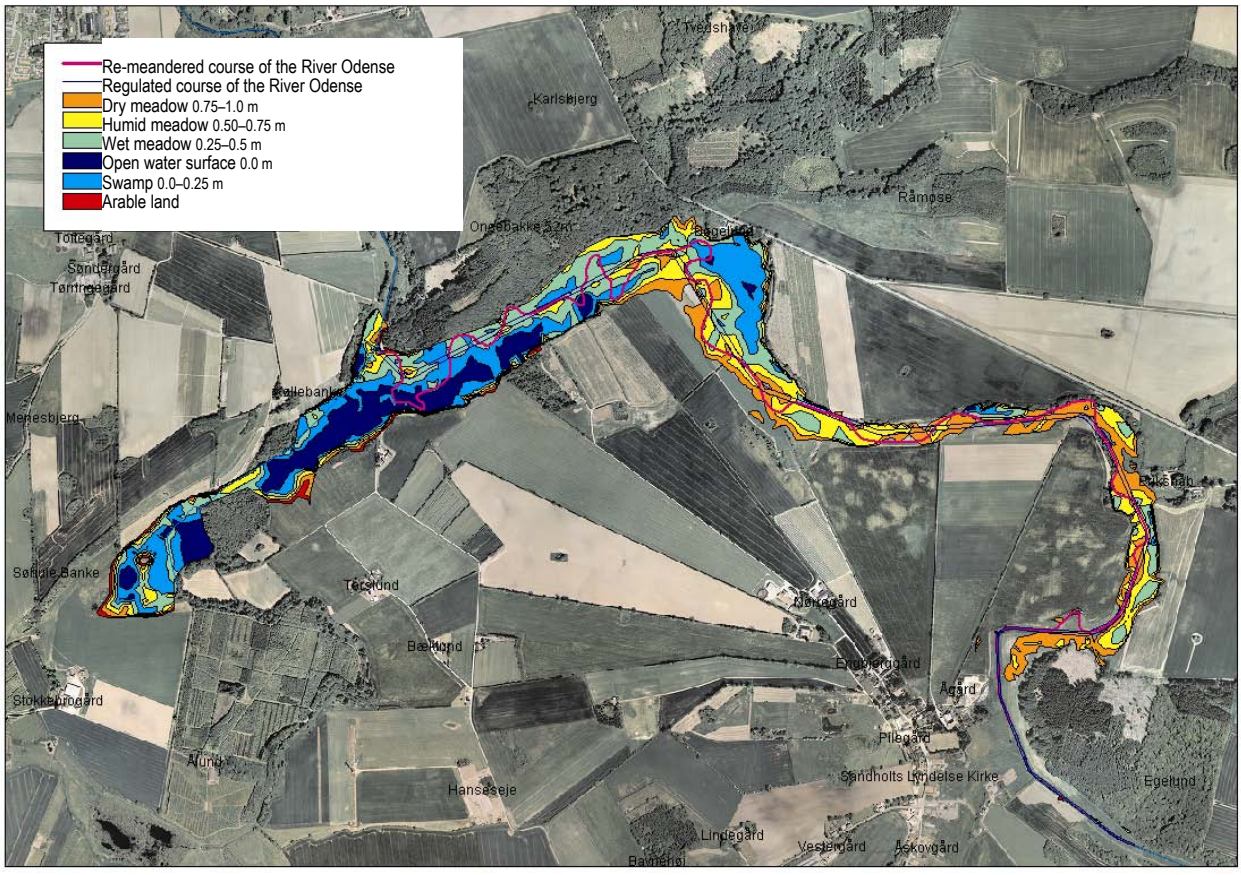
The establishment of spawning grounds in the river Odense has provided the trout with the possibility to spawn in the reaches in question, In winter 2003, spawning sea trout were observed in the new re-meandered reach.

The wetlands alongside the river Odense and Tørringe brook are expected to be able to remove approx. 18 tonnes of nitrogen from the aquatic environment each year.

By re-meandering the river Odense, re-creating the hydrological connection between the river and its riparian areas, laying out spawning gravel and subsequently cutting back on river maintenance it has been possible to considerably improve physical conditions in the river. This has created the basis for the establishment of a more diverse flora and fauna in the watercourses.

The river Odense has been designated a special area of conservation for several animal species and habitats pursuant to the Habitats Directive. The species in question include the spined loach, the river lamprey and the freshwater mussel *unio crassus.* The project aims to ensure favourable conservation status for these species and habitats.

Experience gained through the project
Wherever possible, re-meandering projects should include sufficient land around the new meanders to allow the river to cut a naturally meandering course in the river valley in the future. If that is not the case it will often be necessary to anchor the meanders with stone cladding to prevent the river meandering out into the cultivated fields.



Project data:
Project leader: Fyn County
Project design: COWI A/S
Project year: 2003
Construction costs: DKK 1.3 million (incl. DKK 310,000 for a new field bridge)
Pilot studies: DKK 150,000
Project design and supervision: DKK 410,000
Total costs: DKK 4.9 million
Fyn County – DKK 3.2 million
National Forest and Nature Agency –DKK 1.7 million

River data:
Catchment: 310 km^2 (approx. 10% of the total area of Fyn County)
Runoff:
Max – 18,400 l/s,
Median minimum – 400 l/s
Mean – 2,400 l/s
Pollution class before: 4–5 on the Danish Stream Fauna Index in 2003
Quality objective: B1 (Salmonid spawning and nursery waters)

Restoration data:
Meanders: 15
Length: 4.8 km
Bed width: 5 m
Bed slope: 0.4–0.5‰
Spawning grounds: 9, each 20 mlong
Stone and gravel laid out: 1,300 m^3
Earth excavated: 30,000 m^3
Drains relocated: 450 m
Bank slope: Varying between 1:1 on the outer side of the bends to 1:3 on the inner side

Immediately after re-meandering, considerable amounts of material migrated in the reach. In order to limit this sand migration several sections of the old regulated course were reused as sand traps as they had a wider profile and greater depth than that of the new course.

Re-enforcement mats were laid out on the outer side of the bends to prevent unnecessary erosion of the sides immediately after the construction work. The mats did not function as intended, however, as they were cut to pieces by the ice during the first winter following completion of construction work.

Flooding

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Example No. 20

The river Gels at Bevtoft – re-meandering and re-creation of wetlands

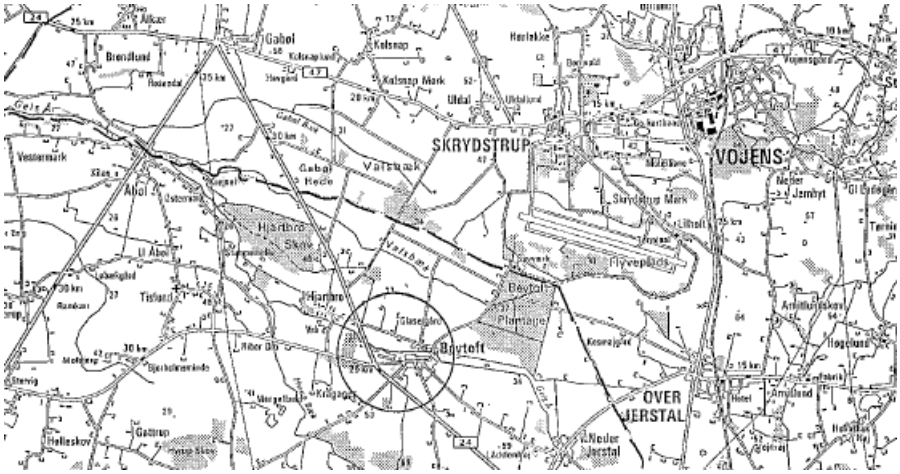
River Gels

By Ole Ottosen
Sønderjylland County

Description of the area

The river Gels is part of the Ribe river system and arises just a few kilometres from the east coast of southern Jutland. At Bevtoft the river Gels runs in a rather narrow river valley.

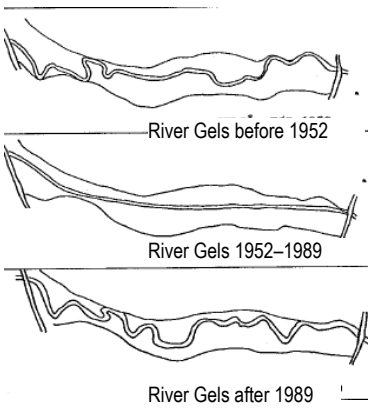
This reach of the river was straightened and regulated in 1952. Since then the land has settled and lost its value as good arable land. Thus the majority of it is now used for extensive grazing. Like many other regulated watercourses, the river Gels is affected by sand migration.



Map of the area

Aim of the project

The aim of the project was to convert the straight canal-like river to a beautiful meandering river, while concomitantly improving the physical conditions in the watercourse and thereby enhancing the habitat conditions for the plants, macroinvertebrates and fish. A further aim was to re-establish contact between the river and the adjoining meadows. The project was also of great recreational value, not least because of the area's proximity to the town.



Description of the project

The project was carried out in autumn 1989. It started at Bevtoft Mill, where a 60 cm high fall was levelled out. From the mill and alongside Bevtoft, a 1,340 m long straight section of river was restructured to a 1,850 m long meandering reach. In addition, 18 spawning grounds were laid out. In order to approach conditions in a natural river, deep pools were established in the meander bends and shallow riffles in the straight sections between bends. At the same time the river's profiles were reshaped with flat beds on the inner side of the meander bends and sloping beds on the outer side.

Project data:
Project leader: Sønderjylland County
Project design: Sønderjylland County
Project year: 1989
Total costs: DKK 1.3 million excl. VAT
Financing: Danish EPA, Danish Forest and Nature Agency, Alving Fund, Football Pools and Lottery Fund, Nørre- Rangstrup Municipality and Sønderjylland County

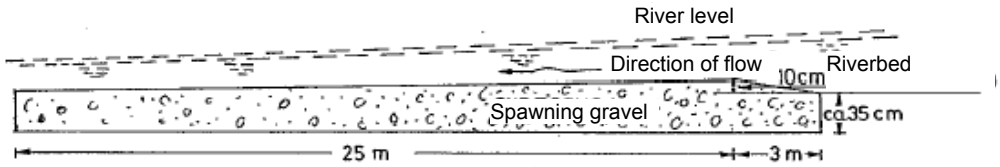
River data:
Catchment: 113 km^2
Runoff:
Max – 7,950 l/s
Min – 660 l/s
Mean – 1,490 l/s
Quality objective: B1 (salmonid spawning and nursery waters)
Pollution class:
Before – II (very slightly polluted)
After – II

Restoration data:
Length before/after: 1,340 m/1,850 m
Bed width: 5 m
River width: 7–8 m
Slope: 0.9‰
Stone laid out: 1,000 m^3
Gravel laid out: 750 m^3
Soil excavated: 15,000 m^3

Experience gained through the project

Nature rapidly healed the sores after the major intervention that a re-meandering project entails. Thus as early as the following year it was difficult to see that the river was newly dug.

During the first years after completion of the project the National Environmental Research Institute and Sønderjylland County performed a number of studies to determine the effects of the project. The environmental effects on the river and the associated riparian areas are described in Technical Report 110 published by the National Environmental Research Institute in 1994. Among other things the studies showed that aquatic plants and benthic invertebrates rapidly colonized the restored reach. Just one and a half years after completion of the work the flora and fauna in the restored reach were more diverse than that in an upstream reference reach. The recreational conditions in the area have also improved considerably, and the establishment of a footpath along a minor part of the restored reach ensures good public access.



Example of the design of a spawning ground in the river Gels at Bevtoft

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Example No. 21

River Krogbæk – re-meandering without set levels and maintenance

River Krogbæk

By Søren Madsen
Storstrøm County

Map of the area

Description of the area

In 1998 the river valley in the project area came in under the agri-environmental measures scheme for changes in drainage, and the drains in the area were sealed off. In connection with this we found some old maps showing that the river had previously followed a quite different course. From maps dated 1835, old aerial photographs and cadastral maps it can be seen that the river used to follow a very winding and irregular course that would have allowed for a very varied river. As the drains from the surrounding land had already been severed, the project would become more entire if the river was also re-meandered. In autumn 2001 we re-meandered the river Krogbæk in collaboration with the landowner.

Map from 1835. The straightened course of the river is indicated in blue

Aim of the project

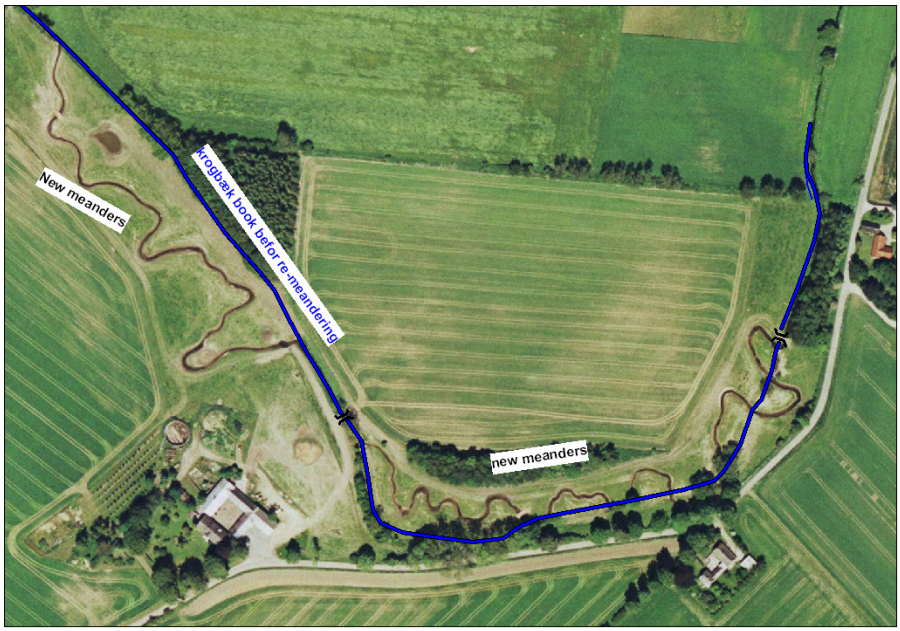
The aim of the project was to find the river's old meandering course and expose it, in part by using old maps and aerial photographs and in part by scraping away the topsoil in trenches in order to determine the former course of the river. The aim was to end up with a new course that was as close to the original course as possible as this would result in a river profile that would immediately be in balance with the hydrological conditions.

Description of the project

Approximately 6,000 m^3 of soil had to be excavated in the area. If it proved necessary, it was planned to establish a sand trap in the lower part of the project area. Additional stone and gravel were laid out in the riverbed where necessary. A shallow lake of approx. 500 m^3 was established. Additional cattle crossings were established where areas of the meadow became isolated by construction of the meanders. Free-standing alder trees were planted along the edge of the river's new course.

A 1.1 km long reach of the river was re-meandered, with the new course being approx. 300 m longer. Except for the first 200 m, no levels were set for the new course, the intention being to dig the new course in such a manner as to follow the old course as closely as possible and thereby avoid future watercourse maintenance.

Spawning gravel being laid out



Project map indicating the course after re-meandering. (Aerial photograph 2002)

Before and after

Experience gained through the project

It proved impossible to find the original course of the river by scraping away the topsoil to locate the bed as the river had wandered all over the river valley over the past couple of thousand years and all the soil in the valley had consequently been re-deposited. The course was therefore estimated based on the old maps.

In contrast, it proved to be extremely beneficial that the river was dug from the side and without predetermined levels having been set. The fact that the contractor digs from the side means that there will be greater variation in depth and width than if the river is dug backwards along the course. This can be seen on the figure below.

Digging from the side

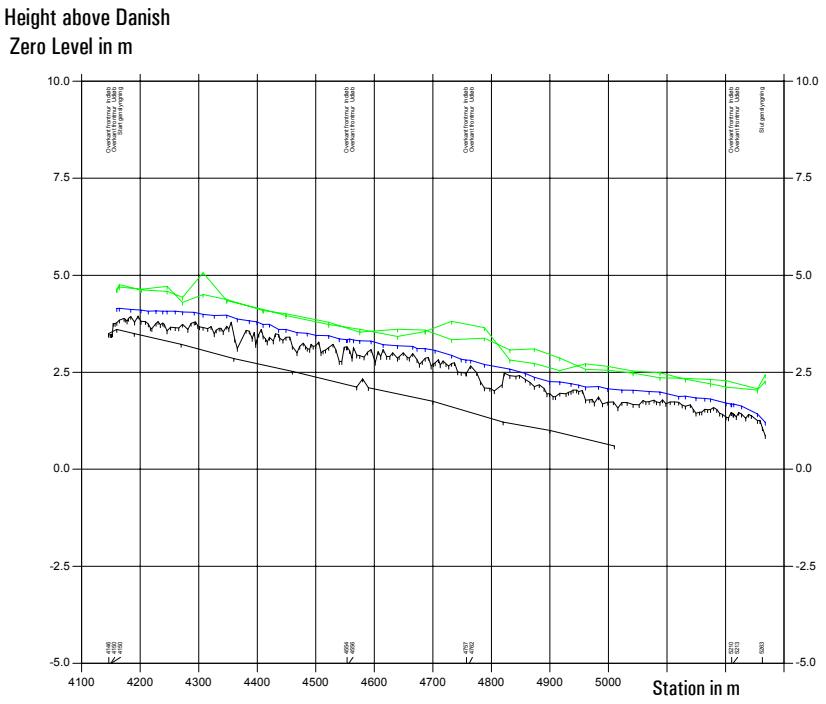


Figure showing the river valley in green, the river level in blue and measurements of the bed before and after digging the new course in 2001

Prior to restoration, stone samples were collected in the project reach and an upstream reach to determine the size of the spawning gravel. These stone samples were sieved on site. The variation was considerable, however, and it was necessary to collect at least 10–15 samples.

Determination of stone size

Project data
Project leader: Storstrøm County
Project design: Storstrøm County
Project year: 2001
Total costs: DKK 286,000
Financing: Storstrøm County with subsidies from Angling Licence Fund and Danish Forest and Nature Agency

River data
Catchment: 44 km^2
Runoff:
Max – 2,500–3,600 l/s in winter
Min – 20–30 l/s in summer
Quality objective: B1 (salmonid spawning and nursery waters)

River data.
Length: Before – 0.8 km, after – 1.1 km
Width: 1–3 m
Slope: 4–2‰
Gravel laid out: 120 m^3
Stone laid out: 3 m^3

The depth of the river proved to be just right as the river floods the valley once or twice a year. The spawning gravel only moves a little and hence is relatively stable.

In order to develop a good river we believe that it is important to leave the aquatic vegetation alone and not clear the weeds, thereby ensuring the best habitat conditions. This is relatively simple in the case of steeply sloping watercourses in eastern Denmark with low summer flow, but also necessary as the water level in the watercourses would otherwise be too low in the summer. So far the river has proven well able to maintain itself.

In order to ensure the cattle as easy access to the meadow as possible, two extra iron bridges were established. These had no foundations but had an approx. 4 m^2 iron plate welded on each end. The advantage of this method is that the bridge is easy to move with an excavator if the river changes course.

Welding the bridge. The bridge is moveable and only lies on the two plates seen beneath each end. After positioning the bridge surface is covered with 5 cm of soil.

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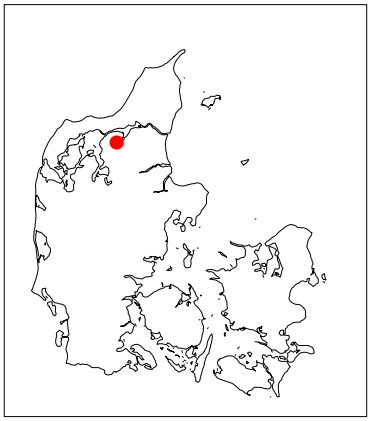
Example No. 22

Nature restoration at Bruså Mølle Fish Farm

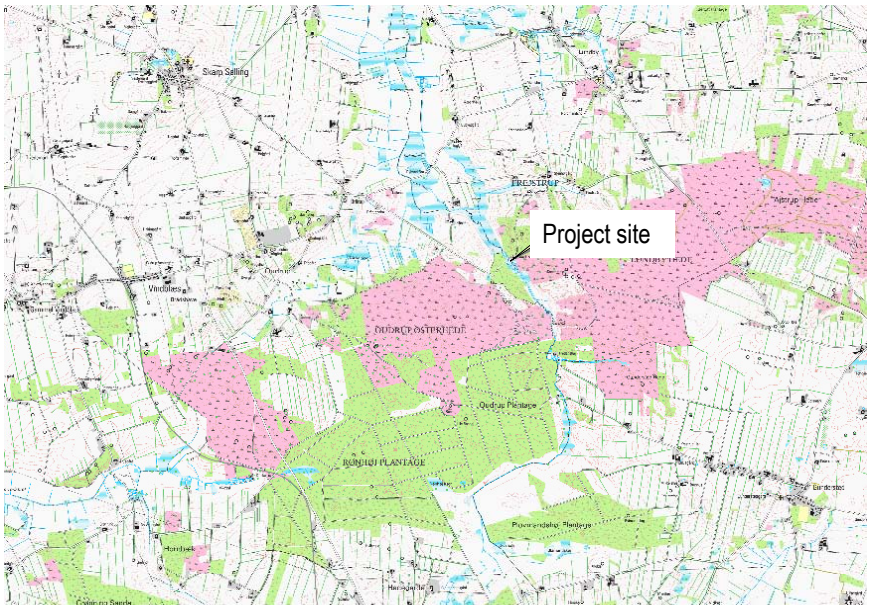


River Bruså

By Ole Schwalbe Madsen
Nordjylland County

Description of the area

Bruså Mølle Fish Farm is located in western Himmerland and borders up to the preservation area comprised by the western Himmerland heaths. The river Bruså runs into Limfjorden fjord via the river Dybvad.

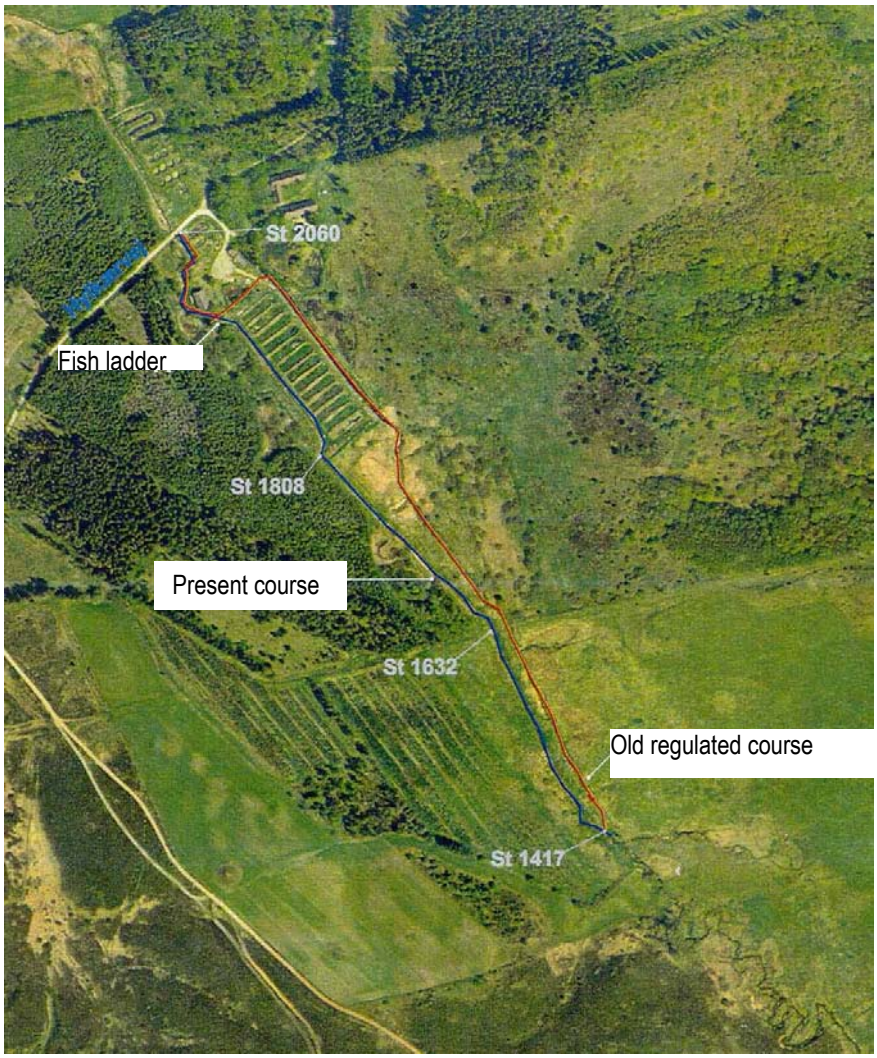


Map of the area

The fish farm was established in 1958 on the site of a former water mill. The mill had been built sometime between 1816 and 1880. A map dated 1880 shows the water mill and a major millpond. It can also be seen that most of the river in the project area had already been straightened at that time. In contrast, the 1816 map shows the original, highly meandering course of the river without watermill.

The original meandering course of the river Bruså drawn on an aerial photograph

In connection with establishment of the fish farm an approx. 1.6 m high weir was built and the river was redirected through a newly dug course that comprised the farm's feed canal. In 1990 a fish ladder was established at the weir. Due to the presence of the weir, the physical conditions of an approx. 500 m long reach of the river were very poor (low slope and canal-like form). Upstream of the project area there is still an approx. 1 km long reach of unregulated river that runs through heathland. The aerial photograph below shows the two straightened courses of the river Bruså – the present course and the location of the course before the fish farm was established – as well as the fish farm and the location of the weir/fish ladder.



Aerial photograph of the area

The aerial photograph above also shows a little of the meandering course of the river upstream of the project area (lower right corner). The old regulated course was dry except for the lowermost section, which served as the fish farm's rear canal. Between the two watercourses lay a large embankment of the earth dug from the present course. The border of the preservation area cuts across the river at the fish farm (St. 1808), the upper 1,808 m of the river thus being located in the preservation area. The earth embankment and

the two river courses appeared as ugly foreign elements in an otherwise very beautiful landscape.

The fish farm ceased operations in 2000. In connection with sale of the property the new owner wanted the area to undergo nature restoration and therefore contacted the county authorities. No compensation was paid for permanent closure of the fish farm.

No fish surveys were undertaken before the project started, but the reach appeared to be almost devoid of fish (only very few had to be moved!).

Aim of the project
The aim of the project was to restore the river to something as close to the original as possible. A further aim was to get the project area to merge naturally into the surrounding landscape in view of the fact that it bordered/lay within the preservation area comprised by the Himmerland heaths. Finally, the project also aimed to create spawning grounds for salmonids as there were only a few of them in the river system.

Description of the project
The fish farm site was levelled, and a new river was dug through the area. The fish ladder/weir was removed. The new reach merged with the existing course at the location of the former fish ladder but at an elevation corresponding to downstream reach. The two regulated reaches were filled up with earth. The new reach had the greatest slope, and a number of spawning grounds were established in it. The part of the fish farm site located downstream of Hylkærvej road (see the previous aerial photograph) was only levelled by the owner himself. Spawning grounds were established from the fish ladder to approx. 50 m downstream of Hylkærvej road.

Aerial photograph taken after re-meandering

Three years later

Part of the old river course upstream of the fish farm was reused as the physical conditions were good and the width was harmonic. The occasional new meander was dug in this reach. There was slightly less fall available over the upper reach and hence only a couple of spawning grounds were laid out. The whole of the regulated reach was filled up with earth. The new course of the river Bruså is shown in the aerial photograph above.

As the nature in the project area was already rich, this was taken into account in the project design. Among other things there were a number of old sedge tussocks.

When designing the new meanders we closely studied the natural meanders located upstream of the project area. Among other things we found out that the terrain along the inner side of the bends is generally much lower than on the outer side along a zone of up to 15 m wide. In contrast, the sides of both banks at river level were usually vertical. The principle of the new bends is shown in the photograph below.

Digging the new meanders

Considerable earthwork was needed to get the project area to merge into the surrounding landscape.

In accordance with the wishes of the landowner, a small lake was dug.

In continuation of the project an agreement was reached with the Municipality and the landowners upstream of the project area that weeds were no longer to be cut in the upstream natural reach. Within the project area itself it was agreed that there would be no requirement to keep the river clear of weeds. In addition to enhancing the number of species of aquatic plants and hiding places for fish, the cessation of weed clearance should also hinder sand migration as the river runs through sandy heathland.

Project data:
Project leader: Nordjylland County
Project design: Nordjylland County
Project year: 2003
Total cost: DKK 390,000 excl. VAT
Financing: Angling License Fund – DKK 15,000 subsidy

River data:
Catchment: 18 km²
Runoff:
Max – 900 l/s
Min – 85 l/s
Mean – 180 l/s
Quality objective: B1 (salmonid spawning and nursery waters)
Pollution class: Before – 6 on the Danish Stream Fauna Index. Class 7 is expected.

Restoration data:
Length: 950 m
Bed width: Varies from 1–2 m
Regulation width: 1 m
Bank slope: 1:1 (regulation value)
Stone laid out: Few
Gravel laid out: Approx. 90 m³
Earth excavated: From river approx. 3,000 m³; large amounts of earth moved in connection with renovation of the 5,000 m³ fish farm site
Slope: 1–7‰ (mean 2.5 ‰)

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Experience gained through the project

The project has lived up to expectations. It has received considerable praise from the local community. The design of the meanders and terrain appears “right”, and they seem quite natural.

No detailed plans were drawn up for the shape of the meanders. Instead we took the excavator operator out to study the meanders, and he regularly adjusted the river’s shape and course during the excavation work. This approach proved highly successful.

The photographs below show the fish farm and the embankment between the two rivers prior to restoration.

Prior to restoration

European crayfish
Astacus astacus

Example No. 23

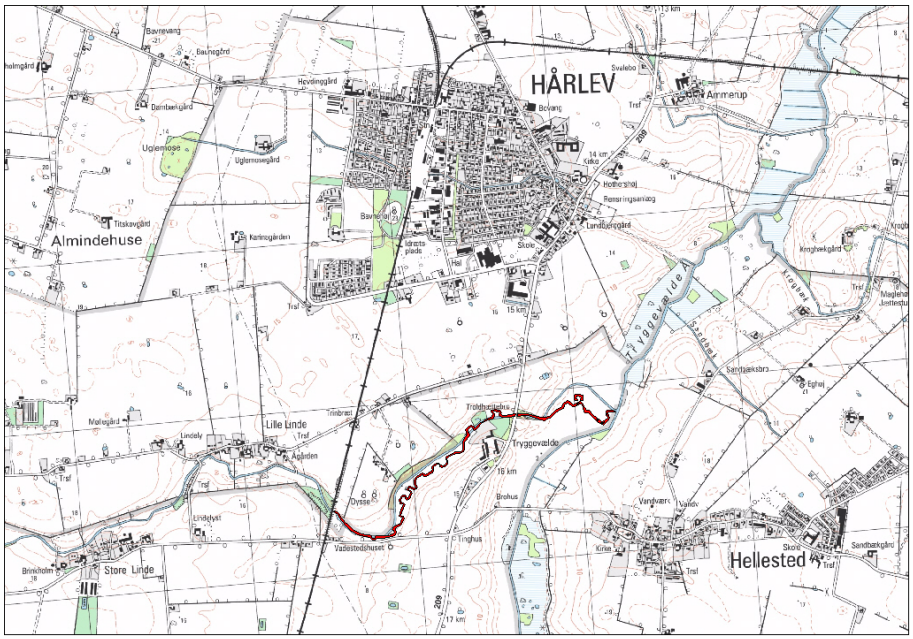
River Tryggevælde – a river valley project

River Tryggevælde

By Søren Madsen
Storstrøm County

Description of the area

The river Tryggevælde is located in eastern Zealand approx. 60 km south of Copenhagen. The river is one of the largest on Zealand. In areas where the river has been re-meandered, the river runs from a small, approx. 50 m wide river valley to a large 2–300 m wide river valley. As the wide river valley is situated at a lower elevation than the narrow river valley, the slope of the river Tryggevælde is high – up to 4‰.



Map of the area

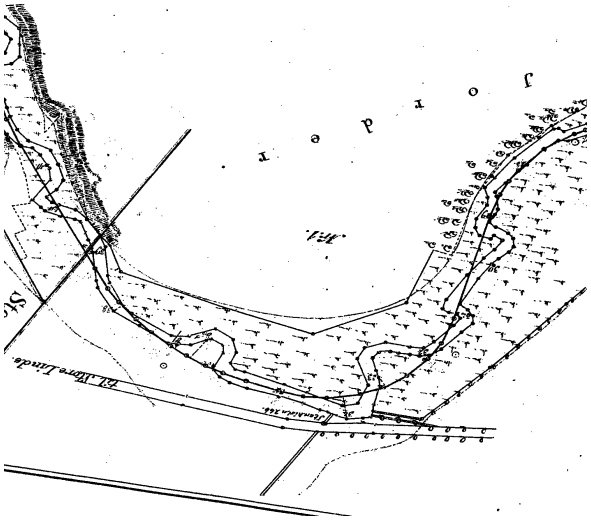
The river Tryggevælde is regulated over the whole of its 25 km long course. The river was initially regulated in the 1870s, but was further deepened in the 1950s. The river valley alongside this reach is under crop rotation except for a few small areas of woodland. Due to the intensive use of the river valley the river Tryggevælde is extremely channelizsed, and its bed lies 2–3.5 m below the bottom of the valley.

Aim of the project

The restoration of the river Tryggevælde to its natural course would considerably affect the whole river system. It would create better habitats and spawning conditions for trout, etc. In addition, a meandering river would give a very beautiful river valley.

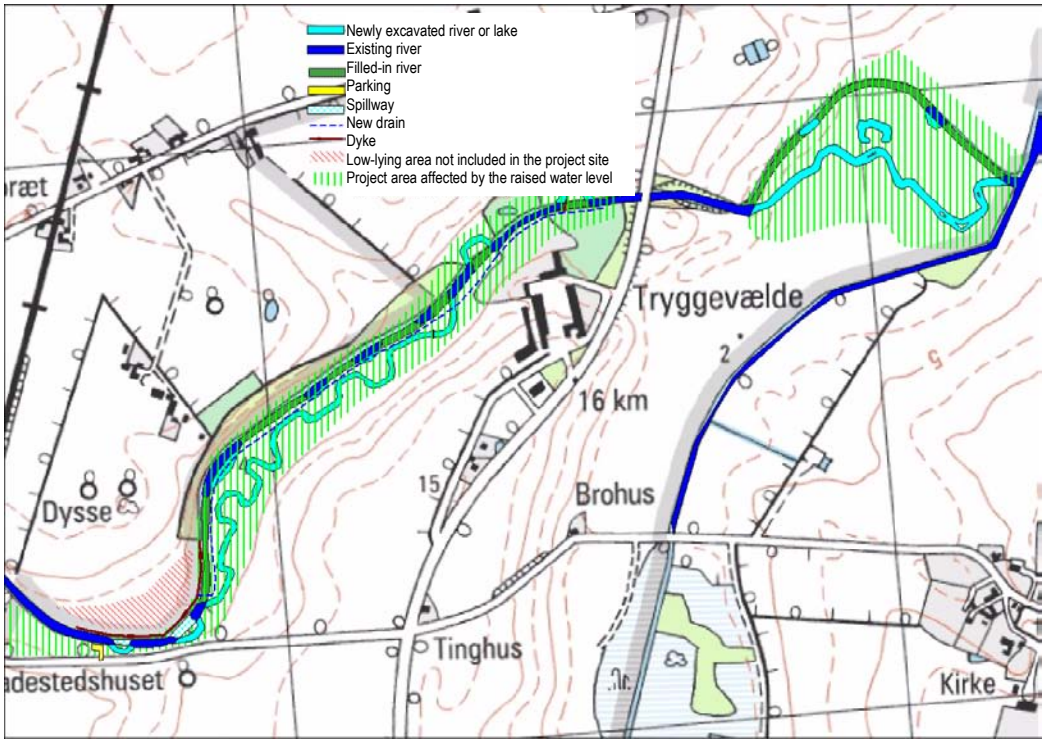
Description of the project

It was important to locate the river's old meanders through the use of old maps and aerial photographs. The intention was to dig as close to the original course as possible and thereby create a water profile that would be in balance with the hydrological conditions right from the outset. In our opinion the small size of the fish population was mainly due to the unsatisfactory physical conditions in the river.



Part of the survey of the river Tryggevælde undertaken in connection with its regulation in the 1870s

The re-meandering of the 2.7 km long reach of the river Tryggevælde is the largest nature restoration project of its kind in Storstrøm County. The project was planned in collaboration with the landowners and Køge Angling Association. Storstrøm County moved 12,000 m^3 of earth and laid out 350 m^3 of stone and gravel in the new meandering part of the river Tryggevælde. Restoring the river to a meandering course both improves spawning possibilities for trout and habitat conditions for other fish, macroinvertebrates and plants. In addition, restoration of the river Tryggevælde will have a beneficial effect on the whole river system in the area.



Project map

It is not just the river fauna that will benefit from the project, but also the local inhabitants. A new nature trail is being established alongside the new meandering reach of the river.

A new meander with a 3.5‰ slope

As a survey of the river Tryggevælde was carried out in 1870 in connection with the regulation work, it was easy to find the river's width and depth. It is noteworthy that the river was not very deep, the riverbed being positioned at an average only 50 cm below the terrain.

Some sections of the river were already regulated at the time of the 1870 survey so for these sections we just copied a meandering course located a few km upstream.

Experience gained through the project

We had good experience with digging the river with varying width and to position it high in the terrain (0.5 m under terrain level). Dynamic changes took place in the new river already the first year. In addition, the visual impression of the river is much better when the river bed lies high rather than when it lies 1–1.5 m below terrain level.

When we opened up the last meander we lacked stones to protect the bank at the old straightened channel. We therefore constructed a 30–40 cm high flat dyke on top of the filling material in the old river channel. As a consequence, the terrain there is higher than the surrounding terrain.

Project data:
Project leader: Storstrøm County
Project design: Storstrøm County
Project year: 2006
Total costs: DKK 1 million
  Storstrøm County
  Roskilde County
  Angling License Fund

River data:
Catchment: 130 km^2
Runoff:
  Max – 10,360 l/s
  Min – 20 l/s
  Mid – 849 l/s

Restoration data:
Length: 2.6 km
Width: 7–12 m
Slope:
  1.3 km with 1.2‰
  0.7 km with 3.5‰
  0.6 km with 0.6‰
Stone laid out: 150 m^3
Gravel laid out: 250 m^3

August 2006

No marked erosion occurred even though the river flooded its banks and despite the fact that the earth filling lies on the outer side of a sharp bend that slopes 3.5‰. This is undoubtedly a method that will be used in future as it is both relatively cheap and more natural. River banks that only consist of large stones are not natural in Danish rivers. The soil is ordinary moraine soil.

The bed was too uniform, though, as it was dug with the same slope. Spawning gravel will now be laid out on the bed of the river and the river will be deepened in the bends and in places where it has already begun to erode away at its bed.

Orfe spawning in the re-meandered river

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Example No. 24

River Sønderå – a river valley project

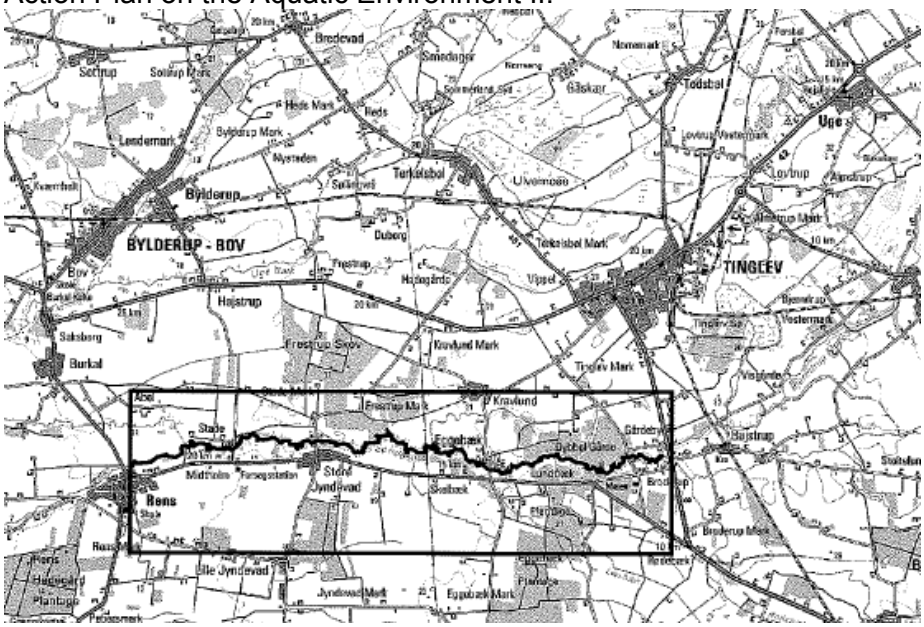
River Sønderå

By Ole Ottosen
Sønderjylland County

This river valley restoration project entailed curtailing maintenance of the river, re-meandering the straightened reaches, closing drainage ditches and re-establishing wet meadows.

Description of the area

The river Sønderå and its upstream tributaries (river Bjerndrup Mølleå, Almstrup Canal and river Gejl) form part of the Vidå river system. The project area is located south of Tinglev and encompasses a 24 km reach of river. The rivers lie within a 20 km area of river valley covering 300 ha. The project is directly connected to Tinglev Mire, which encompasses an area of approx. 250 km^2 that has been restored concomitantly with the river Sønderå project. The project was carried out over the period 2001-2003 as a project under Action Plan on the Aquatic Environment II.



Map of the area

Aim of the project

The aim of the project was:

- To create administrative possibilities to conserve and if possible improve the existing good environmental conditions and nature in the river and the river valley.
- To improve water quality in the river Sønderå and its upstream tributaries, among other means by reducing ochre pollution of the river.
- To ensure the continued existence of mosaics of wetlands and humid areas to the benefit of the flora and fauna – including birds.
- To enhance nitrogen turnover, primarily by severing drains and ditches, such that nitrogen-containing drainage water from higher-lying fields would filter down through the meadows.

- To prevent conflicts between agriculture and nature/environmental interests by settling future land use of the meadows in the river valley.

Description of the project

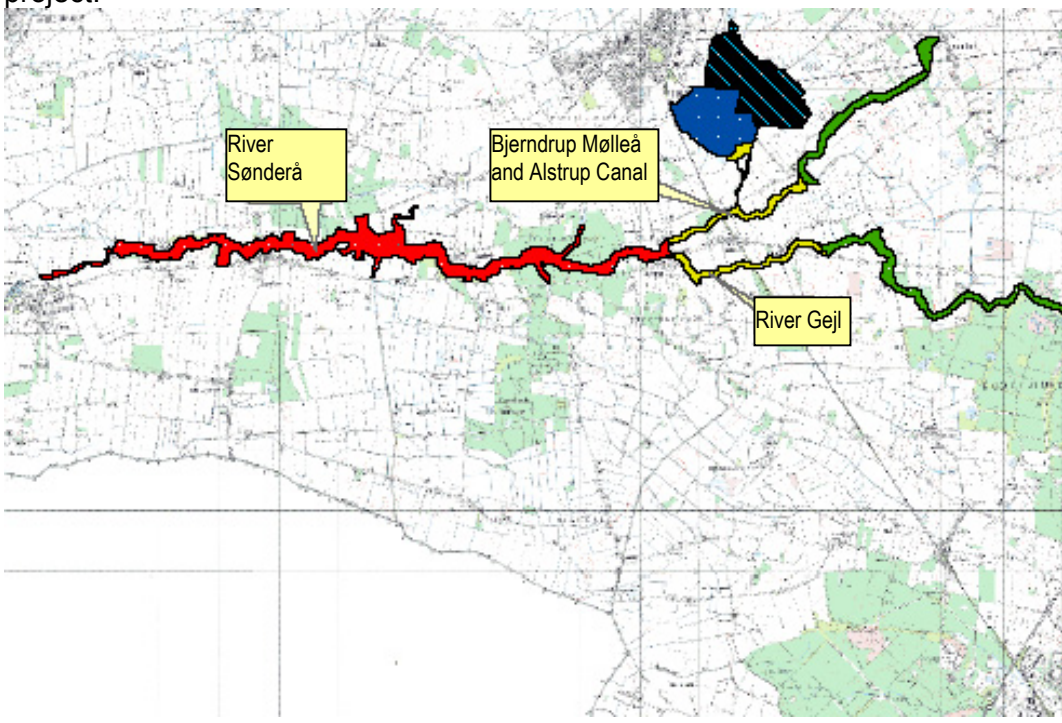
Measures in the river Sønderå
Maintenance of the river Sønderå will generally cease. The possibility will be retained, however, to carry out limited weed clearance in a current channel before 1 April in years in which much weed survives the winter. Future maintenance of the river Sønderå will be based on the maximum permitted river level at specific flow levels. Weed clearance will only be carried out if coupled measurements of river level and water flow show that the maximum permitted river levels are exceeded.

The discharge capacity stipulated for the river Sønderå in the river regulations has been changed corresponding to a narrowing of the bed width by 1 m.

In order to improve spawning possibilities for the various fish species, spawning gravel has been laid out in various parts of the river Sønderå.

Measures in the river valley
Drains from higher-lying areas have been changed so that they surface close to the edge of the river valley. Drains and ditches that drained the meadows have been sealed off at ground level. Any other drains subsequently detected in the river valley will also be sealed off.

A few ponds have also been established in connection with the project.



Project data:
Project leader: Sønderjylland County
Project design: Sønderjylland County
Project year: 2001/03
Total costs: DKK 4.7 million excl. VAT
Financing: Danish EPA, Danish Forest and Nature Agency and Sønderjylland County

River data:
Catchment: 260 km^2
Runoff:
Max – 8,000 l/s
Min – 800 l/s
Mean – 2,425 l/s
Quality objective:
B2 (salmonid waters) for the project reaches of the rivers Sønderå and Bjerndrup Mølleå
B1 (salmonid spawning and nursery waters) for the river Gejl and
B3 (cyprinid waters) for Almstrup Canal

Measures in the upstream tributaries (river Bjerndrup Mølleå, Almstrup Canal and river Gejl)

As part of the project, maintenance of Almstrup Canal and the Bjerndrup Mølleå and Gejl rivers has been modified by reducing weed clearance and by generally leaving the rivers to take care of themselves.

Maintenance of the reaches of Bjerndrup Mølleå and Gejl rivers located within the project area is now based on the minimum permitted water flow at specific river levels, and weed clearance is not normally undertaken. Weed clearance is only undertaken if the water flow drops below the minimum permitted levels, and in all events only in a current channel and before 1 May. Maintenance of the reach of Almstrup Canal located in the project area has been modified to current channel clearance before 1 July.

The discharge capacity stipulated for Almstrup Canal and the Bjerndrup Mølleå and Gejl rivers in the river regulations has been changed corresponding to a narrowing of the bed width by 1 m.

In order to improve spawning possibilities for the various fish species, spawning gravel has been laid out in the bed of the rivers at selected places at a level 10 cm above the bed elevation stipulated in the regulations governing these three rivers.

Drains from higher-lying areas have been changed so that they surface on the river valley slopes. Drains and ditches that drained the meadows have been sealed off in the ground.

A 375 m straightened reach of the river Bjerndrup Mølleå at Broderup has been restored to an approx. 570 m naturally meandering course. Moreover, an approx. 500 m straightened reach of the municipal river Volddalsgrøften has been re-meandered within the project area.

Two ponds have been established on the southern side of the river Gejl.

Experience gained through the project
Since the project is relatively new the experience gained has not yet been collated.

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Vandløbsrestaurering

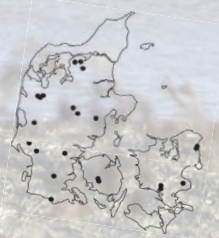
Flødå ved Hastved

Sneum Å
Varde Å
Skjern Å
Vegen Å
Grydeå
Storå
Bruså
Herredsbæk
Halkær Å
Lemming Å
Gudenå
Århus Å
Donse Å
Usserød Å
Krogbæk
Suså
Ellebæk
Odense Å
Tørringe Bæk
Sønder Å
Gels Å
Almind Å

Udgivet af Storstrøms Amt

Ekskursion til 22 vandløbsrestaureringsprojekter

den 25-27 maj 2005



DAVID

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