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Collaborative project (large-scale integrating project)

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REstoring rivers FOR effective catchment Management

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Summary

This is part 2 of deliverable 5.3 Restoration practises, climate and land use change and flood protection. It presents case studies on flood protection, navigation, hydropower i.e. important topics where trade-off and search for synergy with river restoration is required. For flood protection both technical and nature-based examples are given.

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1. Introduction

This document accompanies D5.3 Effects of climate and land use changes on river ecosystems and restoration practices and overviews a number of 'good' restoration case study examples of synergies for both nature and non-nature based restoration solutions. Nature-based restoration means working with natural processes, including managing flood risk by restoring and emulating processes for the natural regulating function of catchments, rivers and floodplains (see REFORM D5.3 Effects of climate and land use changes on river ecosystems and restoration practices for further information). Over the past decade, it has been recognized that controlling rivers through hard engineering activities may be counter-productive in the long term and that more natural flood defence/protection measures may offer the best return in terms of societal benefits from flood control and ecological opportunities for lateral connectivity. In this context, the terms "natural flood defence" or "natural flood management" are often used when a specific set of measures reduce flood risk and improve natural floodplain functioning at the same time (Blackwell & Maltby 2006; WWF a, b. without year). These preventative flood reduction measures aim to reduce flooding probability and minimise the potential damage. A variety of natural flood defence measures have been applied in projects across Europe and specific techniques are described in D5.3 Table 4 & 5. Section 2.1 of this document overviews a number of nature based restoration case study examples.

Likewise for navigation there is a search for solutions how to balance navigability with naturalness. In particular large rivers have normalised for their width and depth to support navigation year-round and passing ships impact shore zones through water displacement and waves. The case studies presented focus in particular on protecting shore zones.

Working with natural processes is a best practise approach to river restoration, but when balancing societal and ecological needs, it is not always practical or feasible. For example, connecting a flood plain to reduce the impact of flood water in an urban area is not a realistic option and traditional hard defences may be needed. Furthermore, hard engineered solutions are still required in many areas of synergistic river restoration, for example, fish passes incorporated in to hydropower design and construction will improve fish migration pathways over barriers, whilst society still gains from hydropower production. This leads to a 'win-win' scenario and the cost of the restoration measure can often be subsidised by the sector, in this case the hydropower sector.

In summary, nature based solutions for sustainable river restoration should be the primary approach where possible, but it is imperative to acknowledge the need for hard engineered solutions in many instances. Section 2.2 of this document overviews a number of non-nature based restoration case study examples that include synergistic approaches between societal and ecological needs.

2. Nature based restoration case studies

2.1 Natural flood defence measures

2.1.1 Increased retention: Glendey Demonstration Site

Techniques demonstrated
The following techniques were applied:

- Tree planting on the hill slopes and down the gully;
- Removal of tree debris from the water course;
- Creation of meanders through the wetland;
- Blocking of artificial drains and planting of tree barriers across the wetland.

The problem
Past land use changes have included clear felling of the plantation forest, removal of the gully woodland, introduction of tree debris to the watercourse from the clear fell, loss of natural tree debris in the channel and artificial drainage of the wetland. These changes have affected the run-off characteristics of the hill slopes, increased run-off and erosion down the gully, increased flow rates in the watercourse and degraded the wetland.

Objectives
The objectives were to retain water in the soil or surface water during peak flow, which will decrease water levels during peak flows, and increased water levels during low river flow.

Project description
The Glendey demonstration site is in the upper River Devon catchment and covers an area of 0.0175 km^2 within a catchment of 2 km^2. The site includes an area of plantation forest, a gully woodland, a river channel with large woody debris and an upland wetland. Restoration of the wetland was considered in two stages firstly by blocking of the drains combined with the restoration of woodlands over the site (Figure 1).

Project success & lessons learnt
Restoration of the wetland has had a major effect on flood flows (Figure 2). The effects are most significant for the smaller events. However, even in a large flood event the blocking of the drains slows down the speed of the water and the restoration of the woodland reduced the peak flow and increased the volume of water stored.

For the largest event (estimated to have a return period of 1 in 25 years):

- The peak outflow was reduced by over 11% after the drains were blocked and the woodland restored;
- The mean velocity in the main channel was reduced by over 70% after the drains were blocked;
- The area flooded at the time of the peak increased by over 5%;
- The volume of water stored over the site increased by over 46% with the drains blocked and trees planted.

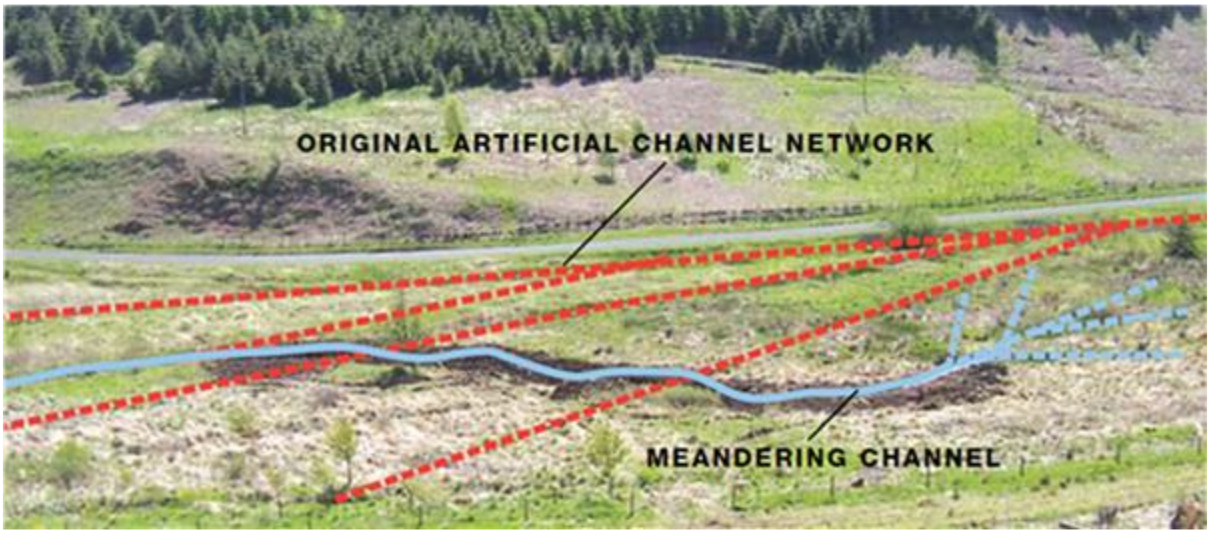


Figure 1. Diagram of the wetland showing the artificial drains which were blocked and the meandering channel which was constructed

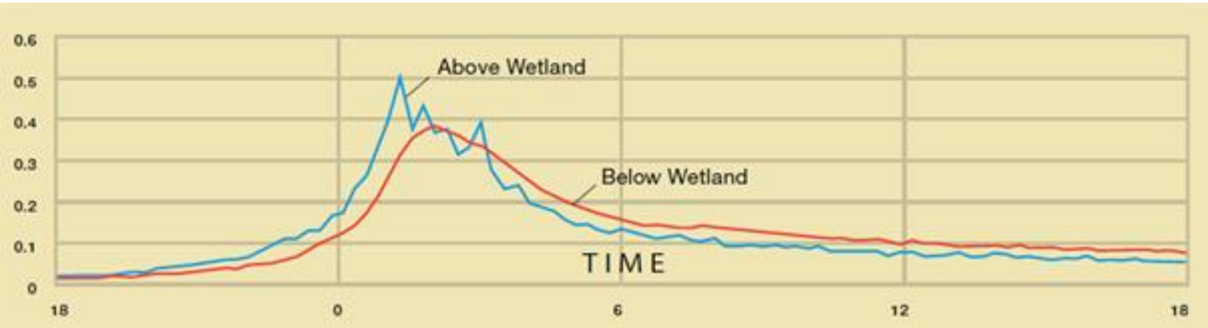


Figure 2. River flow data collected from the stations above and below the Glendey demonstration site. The blue line indicates the flow through an unrestored wetland. The red line shows how a restored wetland smooth's the flow and temporary stores water.

For the Glendey demonstration site, a hydrological model was used to simulate the effects of managing large woody debris in the gully. The model was run with the channel having no woody debris and then with debris across the channel at 30 m spacing down the channel. This simulated the situation where the large woody debris spans the channel with the branches touching the channel bed allowing low flows to pass under the debris but flood flows to be partially blocked. Results (Figure 3) showed that the water depths at the peak flow immediately upstream of the debris increased from 22 cm to 31 cm after tree debris was placed in the channel and at the base of the gully the water depths in the channel decreased by 2.9 cm. In addition, the velocity of the water decreased from 3.01 m/s at the top of the gully to 2.03 m/s at the base of the gully.

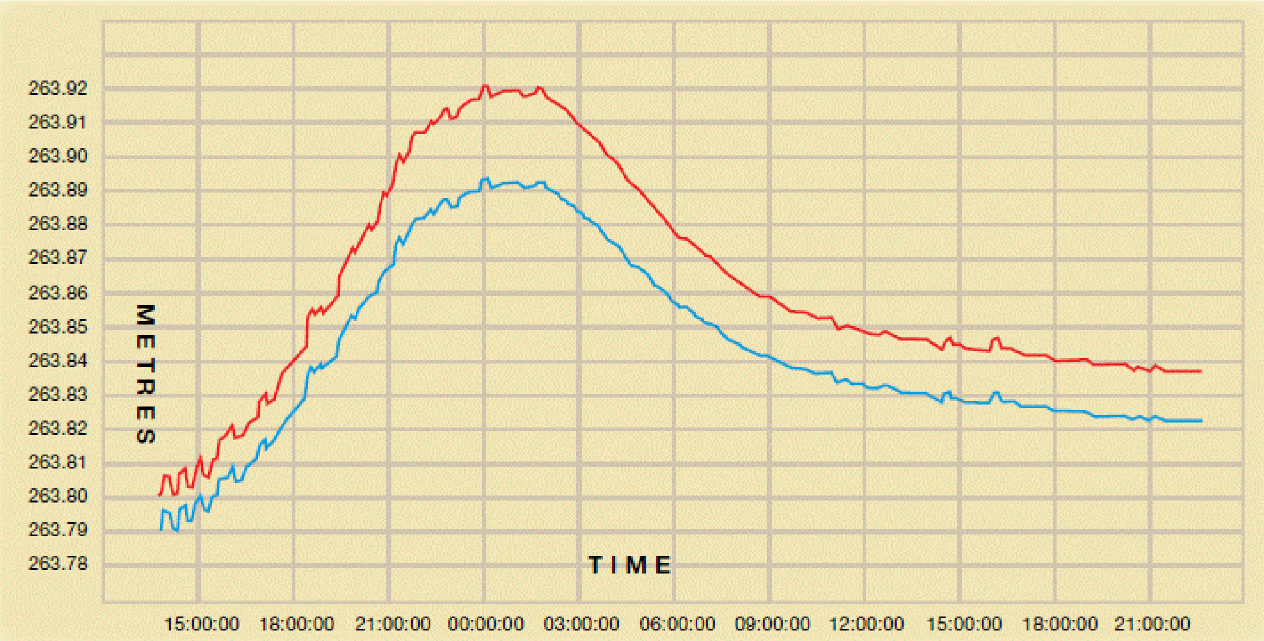


Figure 3. Time series of water level in the channel before (blue) and after (red) tree debris was placed into the channel

2.1.2 Skjern: re-meandering of river course

Techniques demonstrated

To restore the Skjern, the following measures were carried out:

- Rectify poor physical conditions and re-establish its natural self-purification capacity by;
- Re-meandering the river over a stretch of 20 km;
- Restore 2200 ha of the river valley;
- Improve biological diversity over 1600 ha by re-introducing grazing;
- Introduce appropriate management and land use in the Skjern valley.

The problem

An expansive marshland used to surround the mouth of the river Skjern harbouring a mixture of wetland habitats: meadows, reed-swamps, meandering watercourses, fens and shallow lakes. But in the 1960s, a relentless campaign of land reclamation and river channelization was carried out aiming to turn wet meadows into arable land. Meandering watercourses were then straightened out and dikes were constructed to prevent flooding. Pumping stations and drainage systems were also installed to lower the groundwater level to suit agricultural production. The reclamation had obviously a large negative effect on the wild flora and fauna by damaging the floodplain habitats and affecting the water quality (especially through nutrients inputs), thus resulting to species disappearance (e.g. Atlantic salmon and bittern) but also to agricultural revenues decrease since the land was not up to sustaining such intensive activities (e.g. soil collapse and water pollution). Fisheries were also concerned by the water quality degradation which led to fish resources decline.

Objectives

The objectives were to restore the nutrient retention capacity of the river and its valley, to restore the valuable wetlands and to promote fishery and to increase the recreational and tourist values of the project area.

Project description

A broad range of measures were implemented along the Skjern River through different “sub-projects”. The restoration work of the areas of conservation value for the NATURA 2000 network was undertaken under the LIFE Nature project - Restoration of habitats and wildlife of the Skjern River (LIFE00 NAT/DK/007116) – while the preparation of the new land use plan for the area was funded through a previous LIFE Environment project. The restoration work carried out between 1999 and 2003 is outlined below and illustrated in Figure 4.

- The lower 19 km of the channelled river were turned into a 26-km meandering course. Dikes were removed and more than 40 km of new meandering watercourses were dug in the 2200 ha natural area. The main target was then to widen the water courses since the natural process of a straight river course to change to a winding course would take too long. Furthermore, the old canalized river stretches were filled up and the pumping stations were removed or disconnected. The meandering plan followed as much as possible the old meanders as mapped in the 19th century.

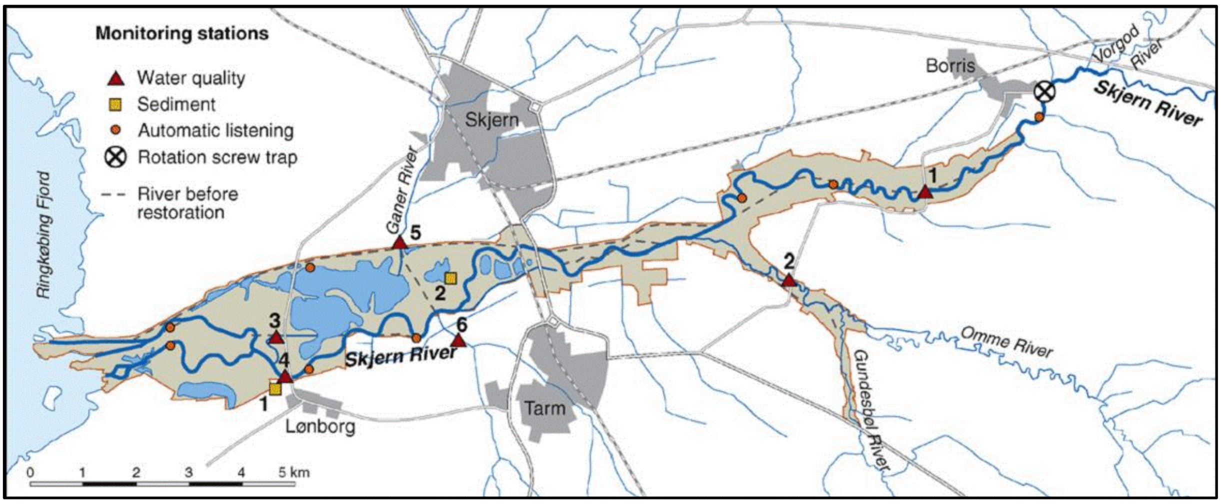


Figure 4. Map of the river Skjern. The dashed line represents the highly straightened river course before restoration.

- Re-establishment of the contact between the river and riparian areas by permitting periodic floods on land within the project area.
- Transfer of 1550 ha of arable land to extensive grazing. Only ¾ of the grassland establishments planned was accomplished by the end of the project. The measures implemented led to an increase of wetland and shallow lake areas instead of grasslands.
- The river has been laid out with several outflows to the Fjord, which, in time, will create a delta of approximately 220 ha.
- Creation of a lake of approximately 160 ha to store water and reduce water nutrients contents.

In order to undertake those restoration works, land had to be bought along the Skjern River. At some places, managers were actually faced with local opposition; some landowners wanted to keep their land in the valley. Discussions finally led to agreements but the government had to raise the compensation rates for the loss of land and/or production. It should be noted that the restoration project took twelve years from 1987 before any measures were undertaken because of debate, information work, scientific and technical surveys, land acquisitions, land allocations, legislation, planning and collation of environmental information.

Project successes

Hydromorphology

The water levels of surface water and ground water increased within the project area, but no changes have occurred outside of the area. The restoration also led to a less regular cross sectional profile in the river with larger depth variations and a smaller slope of the riverbanks. The river width and the water depths have generally decreased and the water velocity increased. As a consequence, mud deposits in the river have been reduced and the dominating bottom substrate is sand, but also the occurrence of gravel and stones has increased.

Water quality
The nutrient load was reduced by more than 200 tonnes of nitrogen per hectare a year. Returning to the natural functioning, the restored wetlands are now able to clean the water before it is discharged into the bay. However, the expected results weren't totally met since nutrient retention was still only around 10% at the project end.

Ecology
Following the restoration work, some ecological improvements were observed along the Skjern River. The restoration of the physical conditions of the river led to a more diverse range of habitats for the river fauna and vegetation, both within the river itself and on the riverbanks. The main outcomes are:

- Important changes in the plant species took place between 2000 and 2003 in the river valley. Domestic, cultivated grasses and typical weeds in cultivated fields were replaced by species typical for natural wetlands, or even water plants.
- The number of salmon returning from the sea to Skjern River to spawn has increased over the last 20 years, from about 100 to 1000 salmon annually. The increased number of spawning salmon was primarily caused by stocking of juvenile salmon but highlights the re-establishment of river continuity and water quality.
- In 1999-2000, otter faeces and footprints were found at 12 out of 19 sites visited. In 2003-2004, the corresponding findings were made at 18 out of 20 sites. It is concluded that there is a marked increase in the occurrence of otter in the entire project area and a permanent population
- The restoration improved both the breeding possibilities and the general survival possibilities of the amphibians common toad, natter jack toad, common frog and moor frog. The improvements were due to the creation of the many shallow ponds and flooded areas surrounded by non-cultivated land.
- The number of species of breeding water birds increased from 7-9 species in 2000 to 31 species in 2003 (Johannes Back Rasmussen 2005).
- The restoration has turned the project area into an extremely important feeding and roosting site for migratory birds especially dabbling ducks during their autumn migration. More than 105 new species of birds have been registered.

Nevertheless, natural processes take a long period of time before being restored; hence, the 2003 monitoring results above don't reflect the future ecological conditions and further improvements are expected in the near future since the ecosystem hasn't reached yet its equilibrium. Therefore some ecosystems components did not showed real improvements in 2003 but the expectation is that:

- The vegetation coverage was reduced after the restoration, because the plant communities had not yet colonized the shallow river bank zones. Nevertheless, new species were observed in 2003 such as: Branched bur-reed (*Sparganium emersum*), common waterweed (*Elodea canadensis*) but also water plantain which is very rare.
- The Danish Stream Fauna Index value was 7 both before the restoration (2000) and after the restoration (2003) which means that the invertebrates had rapidly colonized the new river reaches.

- Sea lampreys were found at 75% of the investigated locations both before and after the restoration even though a weir was removed.

Besides some ecological improvement, the restoration also led to unwanted impacts hampering others species. Therefore, management plans should be adjusted continuously to consider such conflicting interests. Some examples from the restored area are given below:

- The creation of Hestholm Lake has increased the number of dabbling ducks, grebe and pike, but led to an increase in salmon smolt mortality due to increased predation from herons and cormorants.
- Grazing by cattle or sheep is a precondition for the formation of typical meadow vegetation and birds attached to this habitat, but at the same time it excluded high vegetation and thereby the animals that occupy this habitat.
- Grazing near the shores of lakes, ponds and streams prevents the establishment of natural reed belt vegetation and the grazing increases the nutrient loading to the water bodies, but some birds occupying meadows benefitted from the naked mudflats created by the grazing animals.

Additional information

Social-economic factors

The Skjern river restoration project was led by the Danish National Forest and Nature Agency in partnership with the National Environmental Research Institute (NERI), which was in charge of the monitoring. Before launching the project, the Danish government established an advisory council with representatives from local and national authorities and NGOs which assessed the different restoration possibilities. The restoration project was actually under consideration for 12 years due to concerns about the environmental impacts of the drainage scheme and negotiations with private stakeholders. Farmers, fishermen, etc. were thus involved in the project design in order to adapt the measures according to their requests. This interaction led to the publication of a project proposal and an Environmental Impact Assessment in 1997 which included public ideas and proposals: the Parliament Act on Restoration of Skjern River.

Communication

Besides restoration work, recreational activities were also targeted through the development of “green tourism”. Therefore, recreational facilities were established in the project area such as 17.4 km of trails and 3 observation towers aiming to find the balance between protecting the natural area and allowing people to enjoy it. Furthermore, the Danish Forest and Nature Agency published hiking guides, booklets, folders, organized meetings with the public and two nature centres opened in 2006. So far, the site has attracted an increased number of visitors and by the end of the project the beneficiary estimated that 350,000-400,000 people had visited the site.

2.1.3 Water retention: Polder Altenheim

Techniques demonstrated

To improve the water retention capacity of the Upper Rhine while retaining a natural flooding frequency, two polders (Altenheim II and Altenheim I) are connected to the main river by a controlled inlet.

The problem

The Upper Rhine suffers from hydrological regime modifications by artificial barriers upstream and downstream of Polder Altenheim. These barriers, along with channelization and embankments were built to control flooding of settlements in the floodplains of the Upper Rhine and for generating hydropower. The weirs now have a negative effect on the flood protection, since they impound the river blocking the discharge during high water events.

Objectives

The global objectives were two sided. First, the projects initial goal was to restore the flood water retention capacity of the Upper Rhine to pre-weir conditions. Later, the restoration of typical Rhine floodplain nature in Polder Altenheim was added as global objective.

Project description

Polder Altenheim is a 520 ha floodplain in the Upper Rhine (Rhine km 278 till 284) near the village of Altenheim (Figure 5). The floodplain has functioned as a controlled water retention area since 1987. Later, ecological flooding was introduced to restore the floodplain nature. It is now one of the oldest natural flood protection projects in Europe.

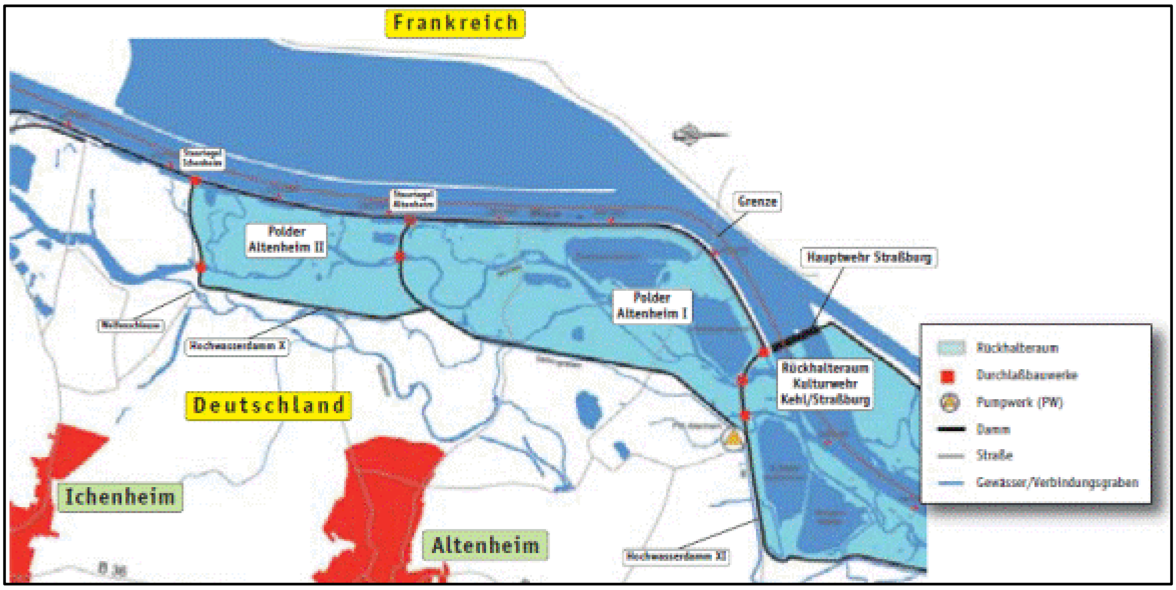


Figure 5. Map of Polder Altenheim (taken from Siepe 2006).

To improve the water retention capacity while retaining a natural flooding frequency, two polders (Altenheim II and Altenheim I) are connected to the main river by a controlled inlet. These inlets are designed to flood parts of the polders 65 days per year. When there is a higher discharge of once per 10 years, the polders will automatically flood to increase the retention capacity of the river. The outlet of Polder Altenheim I is connected to the retention area, Kulturwehr Kehl/Straßburg. In the polder, the dynamics caused by the ecological flooding are allowed to shape the habitats.

Project successes and lessons learnt

The response of the ecology was positive. The ecological flooding resulted in an increase in reed vegetation, floodplain forest and other characteristic species of floodplains. Typical mammal species of the floodplain also increased in the zones which were affected by ecological flooding, like the harvest mouse (*Micromys minutus*) which inhabits reed marches and the common shrew (*Sorex araneus*) and the wood mouse (*Apodemus sylvat)* that live in the alder forests. The number of typical floodplain bird species also benefited from the ecological flooding. For example, the number of breeding pairs of common kingfisher (*Alcedo atthis*) increased from 4 breeding pairs in 1988 to 9 breeding pairs in 1996. Amphibians also increased in numbers between the start of Polder Altenheim as retention area in 1988 and the last monitoring event in 1996. The European tree frog (*Hyla arborea*), a species on the Red List in Germany and a characteristic floodplain species, increased rapidly in numbers from a few individuals to 28 calling males in 1996. In 1998, the numbers increased to 100 calling males. The percentage of rheophilic fish species, dace (*Leuciscus leuciscus*), stoneloach (*Barbatula barbatula*) and chub (*Leuciscus cephalus*) increased from a maximum of 5% in 1993 to 10 to 15% in 1996. The macro-invertebrates showed a positive response to the measures. The population size increased and habitats were recolonized. The ecological flooding had no negative effect on the areas outside of the floodplain and the water retention during high discharges function well. The effects on other land uses are not described in the monitoring report.

2.1.4 Water retention: Grote Noordwaard

Techniques demonstrated

To improve the water retention capacity of the river Boven-Merwede, a large polder was selected to serve as a flood retention area during river peak flow. The following measures were carried out:

- Lowering of embankments;
- Breaking down of farms on flood prone locations in retention polders, and building of new houses at higher mounds, which will not be flooded during river peak flows;
- Creation of intertidal creeks in retention polders, which serve as a nature reserve areas.

The problem

To reduce the risk for flooding to acceptable levels, the water level at Gorinchem has to be reduced by 30 cm during river peak flow. The Grote Noordwaard (Figure 6) was selected to serve as a flood retention area in the 'Room for the River' programme, a national initiative to adapt the current flood defence structure to future climate change. In this project, agricultural land is given back to the river to improve the discharge during flooding and the nature is allowed to develop.

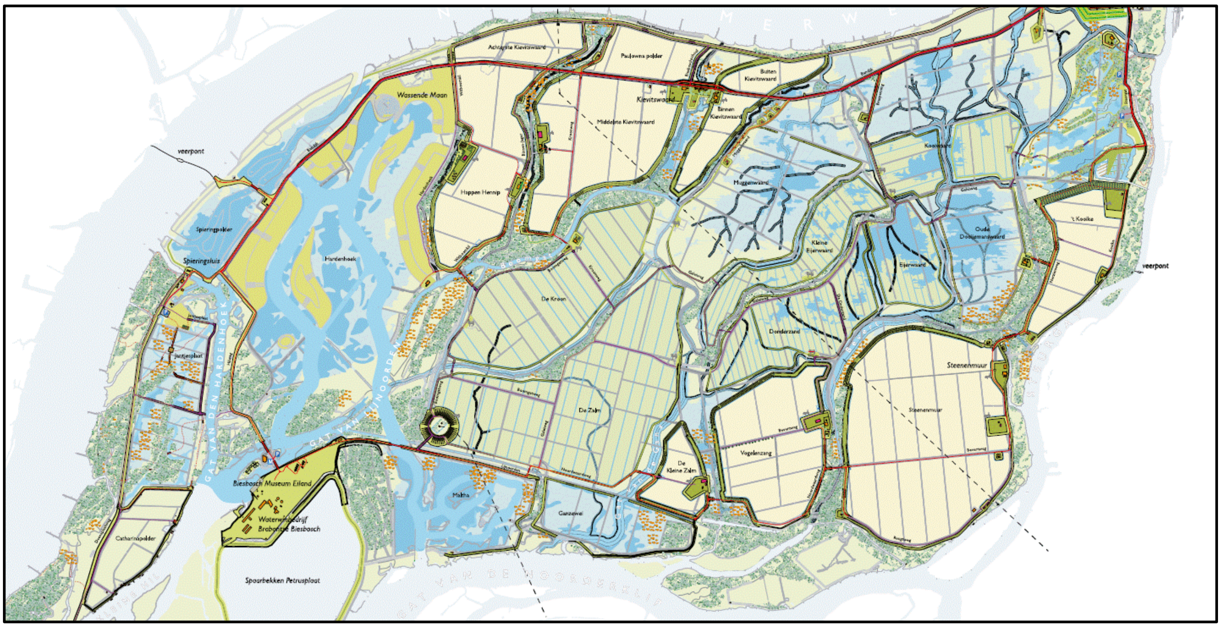


Figure 6. Map of the Noordwaard in the Biesbosch area

Global objectives

The project has two global objectives, namely:

- Create more intertidal nature that is connected to the existing Natura 2000 area Biesbosch;
- Decrease normative high water level at Gorinchem with 30 cm and keep local houses protected.

The project only has a specific objective for flood protection. The normative high water level at Gorinchem has to be reduced with 30 cm.

Project description
The Grote Noordwaard is part of the Biesbosch (Figure). The Biesbosch has a turbulent history, with many changes by man, water and nature. The area used to be an estuary, but in the Middle Ages it was converted to a large polder for agriculture. The Saint-Elizabeth flood in 1421 turned the polder into a large lake. Later, natural processes developed the Biesbosch again into an estuary. In the 1885, the Nieuwe Merwede was constructed to regulate the discharge in the area and in the 20th Century, the entire Biesbosch was again a polder but with large parts of the original creeks remaining. Since the 1990s development has given parts of the area back to nature and it is now an important nature and recreation area. The influence of the tides strongly decreased with the construction of the Deltaworks, but the Biesbosch still has a high ecological value. The Grote Noordwaard has a large network of creeks caused by the flow dynamics and sediment transport by the tides.

The embankments of a large number of polders have been lowered to create an area which will flood during winter. Two clusters of small polders remain protected by high embankments. Houses outside the new dike rings were adapted to cope with flooding. Historical creeks were restored, but in some cases were closed off to prevent recreational use. Nature is allowed to develop, but only on the edges of the discharge zone. The rest of the zone remains empty with grasslands that can be used for grazing in summer. Recreation is concentrated in two zones on the west and east side of the area to reduce recreational pressure in the discharge area and the creeks.

Project success & lessons learnt
The measures of this project are still in progress, and will be finished in 2016. No information about pre-restoration monitoring could be found in the project documents. The only specified success criterion for this project is a reduction of the normative high water level at Gorinchem by 30 cm. No specific targets are set for ecology.

It is expected that the measures will have a positive effect on the ecological value of the Grote Noordwaard and the Biesbosch as well as improvement of the flood protection. There are more possibilities for recreation, but the concentration of these activities will not disturb the local communities in the polder clusters. Agriculture will lose a large share of land in the Grote Noordwaard - a reduction from 1750 to 600 ha. To maintain the livelihoods of the farmers, sustainable small scale recreational side activities are allowed.

2.1.5 River re-meandering: Avon Hale and Avon Seven Hatches

Techniques demonstrated

The specific objectives are focused on hydro-morphology, habitat, fish and macrophytes and macro-invertebrates. The following techniques were demonstrated:

1) Modify the operation of the Seven Hatches sluices, reducing height by an average of 0.15 m, thus increasing ecological connectivity between reaches and improving upstream habitat quality.
2) Restore the historic bed level and increase the heterogeneity of bed morphology in previously dredged reaches by the reclamation and re-introduction of excavated gravel/stone bed material.
3) Narrow over wide channels where necessary, in order to re-establish a sinuous channel of appropriate cross-sectional area with respect to present day hydrographs.
4) Increase the amount of large woody debris in the channel in order to increase both the availability of this habitat type and morphological diversity of the channel.
5) Break out and remove the tractor bridge footings and replace with a single span bridge. To remove the impounding effect of the structure.
6) Enhance the availability and quality of habitat for SAC species and habitats, in particular:

- Bullhead (*Cottus gobio*) (increased diversity of hard bed, particularly pools during winter and riffle/fast glides during summer and increased large woody debris for, particularly, juveniles);
- Brook lamprey (*Lampetra planeri*) (increased availability of well sorted, fine sediment in shaded, marginal areas with large woody debris for ammocoetes and gravel/sand dominated shallows <40 cm deep for spawning adults);
- Salmon parr (*Salmo salar*) (increased availability of coarse substrate, with overhead cover and woody debris lodged in the channel);
- Desmoulin's whorl snail (*Vertigo moulinsiana*) in the marginal zone of the channel;
- The Ranunculus community as a result of increased heterogeneity in velocity and bed morphology.

The specific objectives of the two locations are similar, but objective 1 and 5 are for Seven Hatches only.

The problem

At location Seven Hatches, the impoundments caused by the sluices, the footing of the railway bridge and the footing of the tractor bridge have resulted in siltation due to slower flows. In combination with the historical dredging, this has led to a loss of hard bed structures, over widening of the channel and the creation of raised floodplains. The hydrological connectivity with the floodplain has been lost and the grazing pressure of livestock has damaged riparian vegetation structures and caused erosion at some sites. At the location of Hale, the river is fast flowing with little flow variability within the channel. Historical land drainage works by dredging has made the channel too wide and deep with deposited spoil on the right and left banks. The hydrological connection with the floodplain was lost. The floodplains were used as grazing areas for cattle and sheep, slowing the development of a vegetation community which could facilitate a stable narrowing of the channel. In addition, the submerged macrophyte diversity is poor with a few dominating species.

Objectives

The global objective of the STREAM demonstration project is to restore the River Avon Special Area of Conservation (SAC) and Special Site of Scientific Interest (SSSI) to favourable conditions while addressing wider biodiversity issues outside the protected areas. Another important objective is increasing public awareness for the importance of the river and valley as natural heritage by improving public access.

For ecology however, no targets were quantified. In the original bidding document a value for the minimal increase in spawning habitat was given, but the exact value is not known. There was also a target for increasing hydro-morphological diversity, but no exact value was given. No other clear qualitative or quantitative success criteria for other hydro-morphological, biological or flood protection targets were defined for the project.

Similarly, no targets were given for changes in the hydrograph as a result of the restoration measures.

Project description

The Seven Hatches restoration site was divided in 7 reaches (Figure 7). No measures were planned for reach 1 and 7. In reach 2, 4 and 6, deflectors are installed to narrow the channel. The deflector in reach 2 will be based on a D-shaped outlined with wooden stakes and then filled with brushwood. In reach 4, the deflector is made with large woody debris and in reach 6, tree deflectors are constructed. Next to the deflectors, gravels are also imported in reach 4 and trees are removed. It was planned to re-grade existing banks, but this was later cancelled due to the limited machine access and minimal effect on the hydrology. Fences are used to prevent grazing of the banks by livestock. Native trees are planted to compensate for the removal of unsuitable tree species. It was planned to replace the tractor bridge, but this was later cancelled due to limited effect on the hydrology. It was planned to lower the sluices at Seven Hatches (reach 3) with an average of 0.15 meters, but this was later cancelled to protect salmon habitat upstream and fear for flooding problems in the Witton area.

Location Hale was divided in 7 reaches. No measures were planned for reach 1 and reach 7. At two locations (Reach 2 and 4) 30-40 m spawning riffles were created using existing and imported gravels. The existing gravels are used to create a stable crest. Gravels are placed on top and below the crest of the riffle to provide a suitable depth for spawning. In two reaches (Reach 4 and 6) upstream current deflectors were constructed to create a varying flow and to narrow the channel. These deflectors are made of large tree limbs set at angles between 30° and 60° and are 12-15 m in length. The tree limbs are secured to prevent washing away. Woody debris is added at all reaches (except reach 1 and 7). In reach 2, native trees were planted to serve as future source of woody debris. Temporary fencing is placed to protect the trees from graving by livestock. In the other reaches, trees were coppiced or pollarded to get woody debris in the stream. In reach 5, the woody debris was used to install a tree kicker.

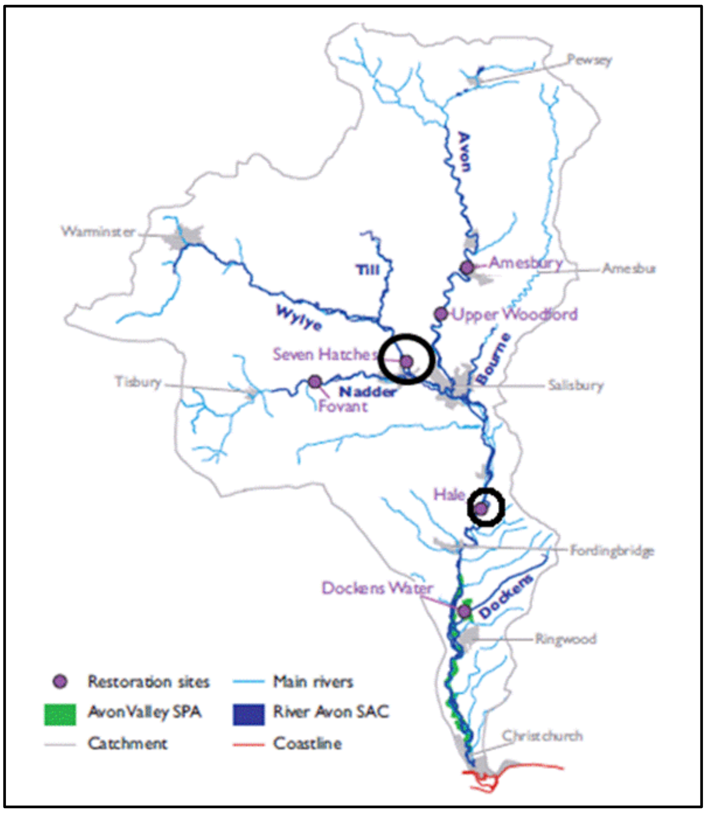


Figure 7. Hampshire Avon catchment with location Seven Hatches and Hale (taken from Demonstrating STrategic REstoration And Management of the River Avon SAC).

Project success & lessons learnt

The physical channel form was significantly changed by the measures. The depth decreased where the bed of the channel had been raised. However, the higher water level in 2008 minimized the decrease in water depth even at the riffles. Also the change in velocity was minimal due to the higher discharge in 2008 compared to 2006. There was however more coarse material and less coverage of silt.

The response of the river system to the measures at location Hale was varied. The vegetation structure and species diversity appears to be similar to the pre-monitoring. Water crowfoot (*Ranunculus penicillatus*) occurs intermittently along the channel. No other macrophytes are found in the post-monitoring. In the pre-monitoring, horned pondweed (*Zannichellia palustris*) was present in the river. Fish, macro-invertebrates and phytoplankton were not surveyed, so the effect of the restoration measures on these biological quality indicators is not known. However, occasional observations indicate that Barble has been spawning on the.

At the start of the last meander bend, a deep pool was observed. Upwelling was observed at two locations. It should be noted that the discharge and water levels were high and this could have obscured localised diversity created by the restoration measures. The two areas of upwelling can be related to the large riffle upstream of the first upwelling area and the woody debris deflectors within the second upwelling area.

Due to the high water level during the post-monitoring, the influence of the restoration measures on the patterns of sediment deposition in the channel bed could not be assessed. Bank erosion at meander bends is reduced due to increased marginal vegetation and local exclusion of livestock by through fencing.

In Seven Hatches, a total of 58 macrophyte taxa were recorded during the assessment of 5 transects. No invasive species were found and only one negative indicator Fennel pondweed was found. The key species brook water-crowfoot and hemlock water dropwort were only minimally present with less than 5% coverage. The most dominant species were Reed sweet grass and branched bur-reed with both species taking 10% of the coverage.

Compared to the pre-restoration state, the reach has less brook water-crowfoot and a strong increase in the negative indicator Fennel pondweed. A fewer number of taxa were observed and a reduced number of species were recorded as covering more than 5% of the channel. It was concluded that temporary disturbance caused by the construction of the measures could be the cause of this decrease. The installation of fences did increase marginal vegetation growth at some cross sections.

The fish survey 11 species of fish were caught in 2008 compared to 10 in 2006. There was a large increase in salmon, trout and bullhead, but a decrease in lamprey and minnow. The higher flow conditions in 2008 could be the reason why there was more bullhead and salmon, who prefer swift flowing water, and lamprey and minnow, who prefer more shallow water.

The physical biotopes observed in 2008 were the same as in 2006, with the exception of the created riffles. The riffles had an impact on the sediment regime, with more localized areas of sediment deposition and transport. The exclusion of livestock also decreased the input of fine sediment and an increase in sediment trapping margin vegetation.

2.1.6 Creation of side channels along the Rhine

Techniques demonstrated
The following natural flood defense measures have been applied (Figure 8):

- construction of three side channels in 1996 – 1999, viz. a permanent flowing side channel of 2 km, a 1 km channel flowing for approximately 265 days/year, and a channel flowing for approximately 100 days/year;
- rehabilitation of riparian vegetation by planting willows, which transformed sandy beaches to softwood forest. Additionally, the grazing intensity by cattle has been decreased.

Figure 8. Aerial photograph of the secondary side channels near Gameren along the River Rhine in The Netherlands.

The problem
For flood safety, there was a need to increase the discharge capacity of the river Rhine, because it is expected that the maximum discharge of this river will increase during the next decades.

From ecological point of view, there has been a strong loss of specific riverine habitats, especially shallow river beds with slowly flowing water. In addition, there are abrupt transitions between aquatic and terrestrial habitats, and a loss of hydromorphological continuity between the main channel and side waters.

Objective

- ecological restoration of side channels along the Rhine

Project description

In the period 1995-1999 three secondary channels were excavated in the Gamerensche Waard along the river Waal (the main side branch of the river Rhine). Regarding the dimensions, these channels are unique for Dutch rivers. These channels are dug out partly from former agricultural grassland and partly they exists of connected former sand and clay extraction pits. The three secondary channels vary with regard to location (inside and outside the summer embankment), length (0.5-2 km), width, depth (0-20 m), discharge (1-3%) and the like. Just one of the channels is flowing permanently; the other two contain flowing water in respectively 4 and 11 months a year.

Project success and lessons learnt

Changes in hydrology

The monitoring period (1996-2002) was characterized by relatively high river discharges. Therefore the secondary channels were connected to the stream flow more frequently than planned. The total discharge of the three secondary channels is about 2% of the average river discharge. The maximum flow velocity in the secondary channels appeared at narrows; the strongest turbulences just downstream of those narrows. With low river discharges, a large influence of navigation on the flow velocity was visible in the channels; this led sometimes to a turnover of the flow direction. The discharge capacity of the Waal with high floods was not lowered significantly by the sedimentation in the secondary channels. The vegetation development led to only a minimal decrease of the discharge capacity of the river.

Changes in morphology

The predicted sedimentation in the main channel parallel to the Gamerensche Waard did indeed occur, but it appeared difficult to prove because of the interference with slowly passing sand waves/dunes on the bottom of the Waal. The sedimentation resulting from the construction of the secondary channels was of the same order as the measurement uncertainty and the autonomous developments in the riverbed. Roughly no large morphological changes were measured in the secondary channels of the Gamerensche Waard. The erosion- and sedimentation rates in the first years after construction were larger than in the later years. Locally some clear (bank) erosion and sedimentation were recognized. It is expected that the former sand extraction pit will be filled up to the level of the rest of the channel around the year 2050 (net sedimentation rate is about 0.05 to 0.11 m/year).

Soil quality and ecological risks

The bed soil in the secondary channels consists mainly of sand (in the former sand extraction a mixture of silt and sand). The soil quality of the secondary channels has improved during the monitoring period (sedimentation of clean sand). Although the concentrations of toxic substances in the bottom are so high that negative ecological effects can be expected, the determined risks are not so high that these can block the ecological recovery seriously. These risks are gradually decreasing because the sediment becomes more and more sandy and this means also cleaner. There are no possibilities for (a cost-effective) extraction of the sediment due to the heterogeneous composition. Distribution of the sediment to other places in the river system is possible due to the tolerable quality of the sediment.

Response of the vegetation

The abundance of trees and bushes in the Gamerensche Waard is still limited because of the imperfect germination and establishment conditions: on the islands because of the dense grass cover and on the banks of the channels because of the large water level fluctuations. With regard to the floristic com-position, hardly any target species, Red-list species or protected species were found in or near the secondary channels. In spite of this, the floristic quality of the muddy banks of the channels is (very) good, but not exceptional in comparison with other nature developments projects along the river Waal. In the biggest secondary channel in the Gamerensche Waard some small fields with aquatic vegetation were found in 2002 (Myriophyllum spicatum and Potamogeton pectinatus).

Response of macro-invertebrates

In the secondary channels of the Gamerensche Waard about 75% of the recently recorded species of the river Rhine occurs. The species diversity of the secondary channels is much higher than in the groyne fields of the main channel. In the slow flowing parts of the secondary channels significantly less exotic species occur than in the main river bed. From the 46 (macroinvertebrate) target species, only 3 species were discovered in the secondary channels of the Gamerensche Waard. The absence of other target species can largely be attributed to the lacking of some specific habitats e.g. gravel, woody debris and aquatic vegetation. Those chironomid species that are characteristic for stable sandy flats re-colonised the area quite fast. The sediment type, the water depth, the flow velocity, the morphodynamics, the organic matter content and the soil chemistry together determine the species composition of the macroinvertebrate community. All these factors are mutually strong dependent on each other; evident relations are difficult to prove. The highest species diversity occurs on silt or vegetation in shallow, slow flowing water with a limited erosion or sedimentation. These factors seem to be of a larger influence on the macroinvertebrate composition than the degree of soil pollution.

Response of fish

In the secondary channels of the Gamerensche Waard various reophilic fish species (preference for flowing water) were found, including five target species (*Barbus barbus Leuciscus cephalus, Chondrostoma nasus, Leuciscus idus and Lampetra fluviatilis*). For these reophilic fish the secondary channels function mainly as a growing up area during their earliest stages of life. Later on they migrate to the main channel. The most rheophilic fish enters the secondary channels passively by means of larval drift.

Lessons learnt

Problems for navigation were not detected in spite of the slight sedimentation in the main channel, which is a result of the construction of the secondary channels. The sedimentation as a result of the secondary channels interferes with other large-scale 'autonomous' processes. Consequently one should always bear in mind the temporal fluctuations in bed level. Inland navigation was not hindered by (cross) currents at the in- or outlet of the channels. The increase of the river discharge capacity resulting from the construction of secondary channels was annulled for a small part (± 15%) by the sedimentation in the bed of the channels and by the bush encroachment elsewhere in the

Gamerensche Waard. At this moment dredging or digging the secondary channels in order to maintain the flowing character of the channels is not needed. At one location local bank erosion required intervention to prevent safety problems. Because of the large variation of water types, the secondary channels in the Gamerensche Waard offer suitable habitats for a wide range of species. However, concerning the species composition according to the intended nature target type, it is clear that the secondary channels are not yet complete. The secondary channels in the Gamerensche Waard remained largely at their original location, although locally distinct (bank) erosion appeared. Regular visual inspection of the banks of secondary channels is and will be necessary in future. A slight improvement of the soil quality occurred, because the new sediments in the secondary channels consist mainly of (clean) sand. The sand (transport) turned out to be a much more outstanding factor than the silt (transport). A deep extraction pit as part of a secondary channel functions as a sediment catch indeed, but it does not seem to be necessary at all to prevent filling up with sand.

2.1.7 Floodplain excavation: Grensmaas (Border Maas)

Techniques demonstrated

In this project, the following techniques were applied:

- large scale excavation of floodplains by means of gravel extraction;
- widening of main channel;
- construction of secondary side channels.

The problem

The Grensmaas is a rain-fed gravel river and is a heavily regulated lowland braided gravel-bed river. The river is strongly normalised and minor embankment have been made along the river, facilitating intensive agriculture in the floodplains (Figure 9). As a result, the gradient of high and low dynamic areas with gravel islands and side channels disappeared due to normalization. The river was locked, incising the main channel by erosion of the river bed and aggrading the floodplains. The result was a uniform main channel and the disappearance of gravel banks. Moreover, (deep) gravel extraction was carried out in the main channel, enhancing river incision even more. Additionally, weirs were constructed, which are always in operation, except during peak discharges.

Figure 9. Floodplain excavation at Grensmaas.

Objective

The objective of this project was to combine three goals: gravel extraction, nature development and flood defence.

Project description

To restore the dynamic character of the river, a cooperation between the Dutch Water Authority (Rijkswaterstaat), a nature protection organisation (Natuurmonumenten) and the local gravel mining company (L'Ortye) was initiated. The dykes were lowered to allow more inundation of the floodplain. At the same time the gravel mining company started to lower the area by shallow mining of the gravel in the floodplain. This was done in such a way that a slow rising gradient was created in the landscape; the area being lowest near the river slowly rising. The main advantage was that part of this project could be carried out by making arrangements with a gravel mining company in such a way that both the company and the ecological state of the area benefited. Since the Grensmaas is the border between The Netherlands and Belgium, similar plans for the Belgium side of the river were made.

Project success & lessons learnt

Hydromorphology

The river's hydrology has been affected in such a manner that it now has more space to flow into its floodplains. At the same time the high water channel was made to limit small peak discharges of the river, this to protect adjacent areas from flooding. As sensible as this is, it in fact limits the natural hydrology of the river somewhat.

The river has room to freely erode and deposit its sediment again. This has led to the formation of an island in the channel. The rising gradient of the floodplain has led to a gradient in flooding frequency which in turn is reflected in the flora of the site. Especially the rapid and the whirling pools nearby are great examples of morphological freedom of the river.

Aquatic environment

There has been a study into some indicative species of macrophytes in the area. It was shown that the site is home to a number of rare and characteristic species. Most of these occurred in the rapid, and are characteristic species for high flow velocities. Prior to the project a study was carried out which identified much of the same macrophytes, however it should be noted that the study was carried out in a year with very favourable conditions for macrophytes. All in all it is difficult to say with certainty if the macrophytes have been positively affected by the measure. In the worst case scenario they have remained the same, whereas in the best case they have developed well.

No studies were carried out for macroinvertebrates and fish.

Terrestrial environment

The terrestrial flora of the area shows a remarkable diversity in species. This diversity is much higher than it was prior to the project. As such it can be stated that the creation of a more diverse landscape has led to a more diverse floral composition. At the same time it should be noted that as succession progresses some rare species may well disappear and also the diversity may decline.

For birds, there has been a distinct change in the species composition in comparison to the composition prior to the project. The bird species have shifted towards a more characteristic composition for a river valley landscape.

The insects have been positively affected by the project. Both butterflies and dragonflies show an increase in rare species. The butterflies seem to be increasing still.

Lessons learnt

In the Dutch Common Meuse project, there is a pressure to maximise gravel extraction in order to cover the costs of the project, which should be budgetary neutral (Peters et al. 2011). Not all gravel should be replaced as gravel is necessary in order to sustain the existence of dynamic gravel banks which can be subject to ecological development and hydro-morphological processes. In the first plan "Future for a gravel bed river", shallow gravel extraction was innovatively coupled to nature development (Helmer 1991). In later plan versions gravel extraction became more optimized (Peters et al. 2011 - Figure 10). The quantity of gravel extraction jeopardises the nature development potential and inflicts the spatial quality. As a consequence, the locations Itteren, Geulle aan de Maas, Nattenhoven and Koeweide the intended ecological quality will not be achieved and on the locations Meers, and Bosscherveld concessions are done with regard to the desired spatial quality. Moreover, it is argued that due to the scale of the measures main channel widening and lowering of the aggraded floodplain too much gravel is extracted in balancing the spatial composition of the river-floodplain landscape. Furthermore it is argued there are too few high gravel environments created (Peters et al. 2011). In this sense, there is a real risk that the quantity of gravel extraction, which increased from 35 megaton originally to 53 megatons, meant for attaining the other project objectives flood protection and nature development became the most prominent goal at the expense of nature development.

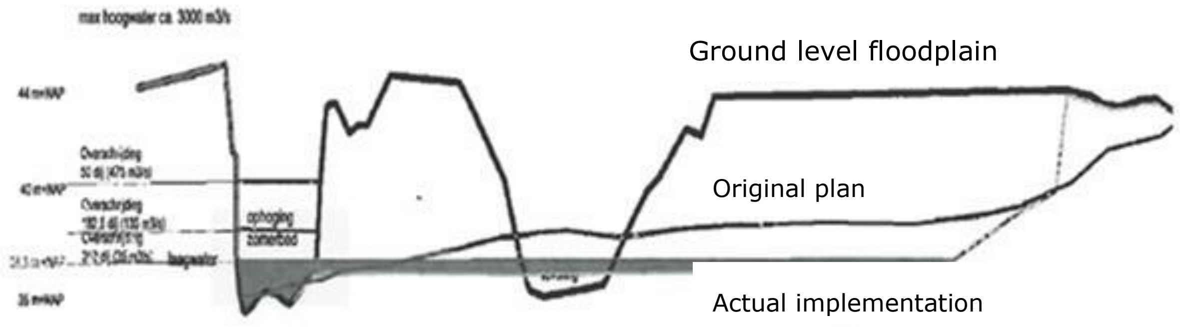


Figure 10. Comparison between the plan Green for gravel (original plan) and VKA 2003 (actual implementation) for the location Itteren at the Dutch site of Grensmaas (Peters et al. 2011).

In Belgium, the project goals were less inflictive and with the measures lowering of the riparian zone and of the aggraded floodplain, the creation of side channels and re-organization of gravel pits by the excavation of soil, the first locations with a good baseline for nature development have been created. Due to the absence of gravel extraction, and a good workmanship, the Belgium locations contain at present more dynamic gravel banks were characteristic species for such habitats may colonise and populate. Hence, project goals can be achieved by excavation of soil. However, in the Netherlands, caution should be paid to achieving all project goals instead of only gravel extraction and flood protection on the expense of nature development.

2.1.8 Lower Danube and Danube Delta

Techniques demonstrated

- Floodplain reconnection
- Wetland creation
- Off-line flood storage area

The Danube River is the second largest European river and world's most international river basin with a length of 2857 km and a catchment size of 801,463 km^2. At its end, the Lower Danube, including Danube Delta covers 27% of the total basin catchment (Figure 11, Table 1).

Figure 11. The Lower Danube within the Danube basin.

Table 1. General characteristics of the Lower Danube and Delta.

Characteristics	Lower Danube	Danube Delta
Catchment area (km2)	218 387	4 560
Mean catchment elevation (m)	355	9
Length (km)	942.5	Chilia arm: 84 Sulina arm: 77 Sf. Gheorghe arm: 81
Slope (m km $^{-1}$)	Km 942-863: 0.07 Km 863-375: 0.05 Km 375-100: 0.04	Sulina arm: 0.02-0.04 Chlia arm: <0.02 Sf. Gheorghe arm: <0.02
Average discharge (m^3 s $^{-1}$)	5960	6500
Geology	siliceous	siliceous, organic
Altitude (m)	Km 942-863: 100-200 Km 863-375: 5-70 Km375-100: 5	<5

The problem
An area of 473 556 ha from the area of the Lower Danube Floodplain – Romanian sector (out of 573 440 ha) have been embanked for agriculture, mainly during 1960-1965 (Figure 12). The ratio between river length (km) and floodplain area (ha) of the Lower Danube was reduced from 1:612 to 1:118 (Bacalbasa 1989).

The ecological effects:

- desertification of land and increasing salinization of soils;
- 4D connectivity interruption (longitudinal, lateral, vertical, temporal);
- loss of habitat for wetland species;
- changes in the structure and composition of vegetation;
- landscape fragmentation and disruption of fish circulation from / into the river to / from the lacustrine basins (where they had optimal breeding conditions and led to change of fish specific spectrum and dramatically declining of fisheries with high economic value , in particular Carp - due to the loss areas with shallow water suitable for spawning and feeding juveniles);
- loss of organic matter through mineralization;
- eliminating retention function through stopping of filtering role of sediment and nutrients which entering with flood water;

- The water level of the Lower Danube section increased as average with 0.6-0.8 m at high flow (13 000-15 000 m^3/s) and discharge increased at high water levels with 5% comparing to previous values, associated with increased flood risk (Bondar 1977). Other extreme increased water levels at peak floods are 0.4-0.9 m at Gruia and Cernavoda stations, and 1.55-1.60 m at Harsova stations.

Motivated by dramatic climate change in recent decades and especially increased frequency of extreme events, more efforts on developing models and scenarios of climate change were made, especially those related to land use change and flooding affecting local communities/regions, because Romania has been very affected by the devastating floods in the past decade. In 2005 and 2006 there were widespread flooding catastrophic, affecting over 1.5 million people (93 deaths) and destroyed a significant part of the infrastructure. The damage caused by floods in 2005 and 2006 were estimated at over 2 billion euros. The recent floods in Lower Danube Floodplain, Romanian Sector (2006, 2010) have shown weaknesses in both the techniques of flood protection and response capacity after flood.

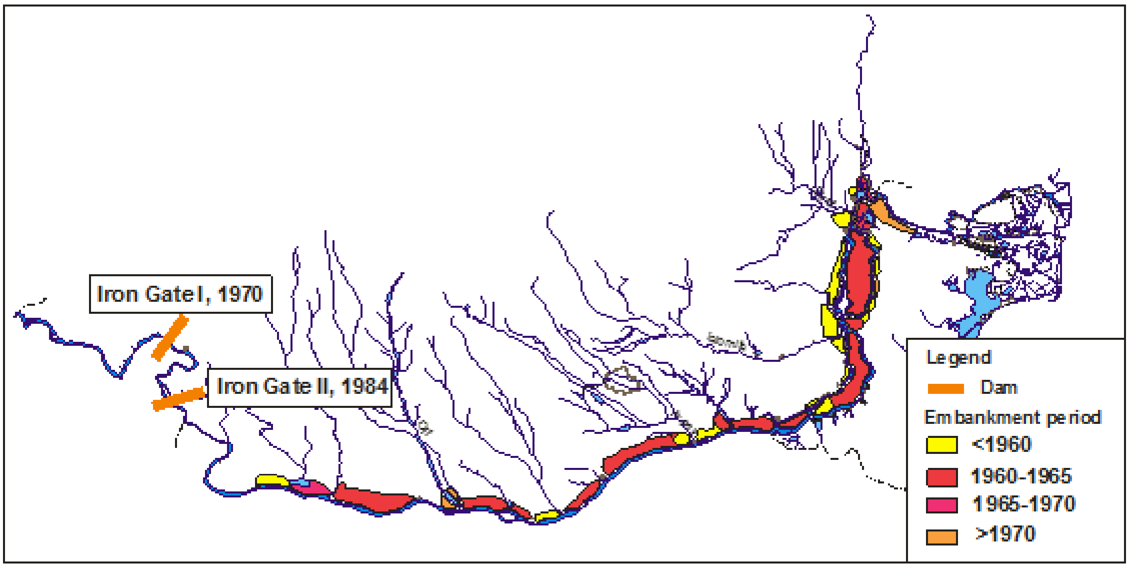


Figure 12. Hystorical hydromorphological chages in the Lower Danube section.

The human interventions are consequences of different land-use policies, which changed the pristine feature (Hartley, 1887) (Figure 13a).

In the end of the 19th century, measures were taken to improve the navigability of the middle arm of the delta, without major impact on the other delta's functions. Between 1903-1960, in so called "capture fishery period", new channels have been built or the older natural ones have been enlarged to activate water circulation inside the delta, aiming to improve fish production function.

A more intensive campaign of hydrotechnics works has been undertaken between 1960-1970, so called "reed period", in order to increase reed production and to facilitate reed harvesting and transport to cellulose factory. Besides the channels, the first large areas have been embanked to regulate and optimize the water level, as a key factor for the reed beds development.

The "fish culture period", between 1971-1980, followed by the "agriculture period", mostly between 1983-1989, altered the network of water courses. The embankments increased from 24 000 ha to 97 000 ha and have cut off from the Danube river pulse system and the total length of canals in the Romanian delta increased from 1 743 km to 3 496 km (Gastescu et al. 1983). As a result of development of a huge canals net, the water discharge from Danube river to delta wetlands increased from 167 m3/s before 1 900 to 309 m3/s during 1921-1950 and 620 m3/s during 1980-1989 (Bondar 1994) (Figure 13b).

The Danube Delta was declared a Biosphere Reserve in 1991 and the conservation of natural values and recovering of wetlands functions became priority objectives. A restoration programme of damaged ecosystems started in 1993 as a new period in the Danube Delta history (Figure 13c). It was designated as Natura 2000 site as well.

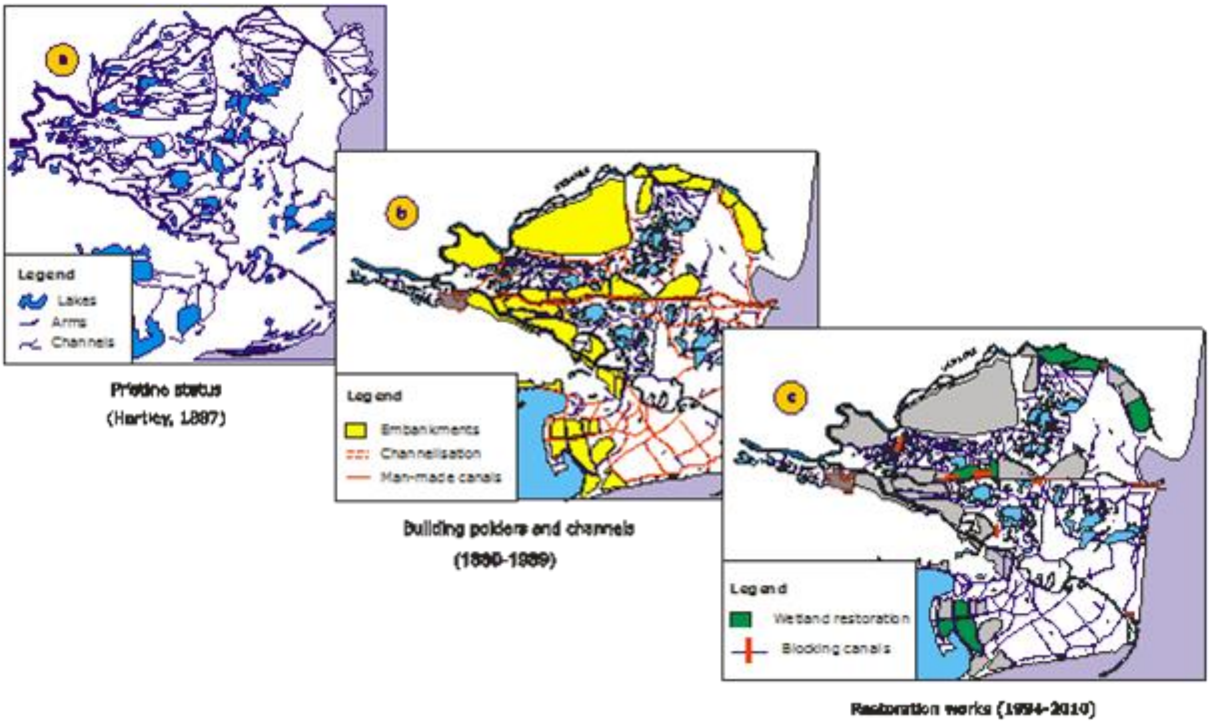


Figure 13. Historical land use change in the Danube Delta.

Objectives

The objectives are:

Floodplain reconnection in the Lower Danube and wetland creation (restoration) in the Danube Delta as integrated win-win solutions for river restoration, flood mitigation and wetland protection.

Project Description

Lower Danube floodplain reconnection

The work was based on the Lower Danube and Delta hydraulic models, modelling with an average accuracy of 4%. Hydrological scenarios were run for representative hydrologic years: 2003 lowest, 2004 average levels and 2006 for maximum levels. The Hydraulic Modelling integrates the Danube modelling 1D between dykes with the 2D modelling of flooding areas (Deltares/Sobek 2.11.002c coupled with 2D Overland). In the Lower Danube, upstream the delta, a project designed and launched in 2008 to assist the Romanian Government in planning long-term strategy to achieve the objectives of the Water Framework Directive and the effective implementation of tasks of prevention, protection and mitigation of floods, set in the Framework Directive on flood Risk Management.

Based on flood risk maps, two hydrological scenarios were made:

<u>First scenario</u>: wetland restoration/creation of 15.9% of embanked areas by 3D reconnection (lateral and temporal). The effect on water levels at peak flows were assessed (Figure 14, Figure 15).

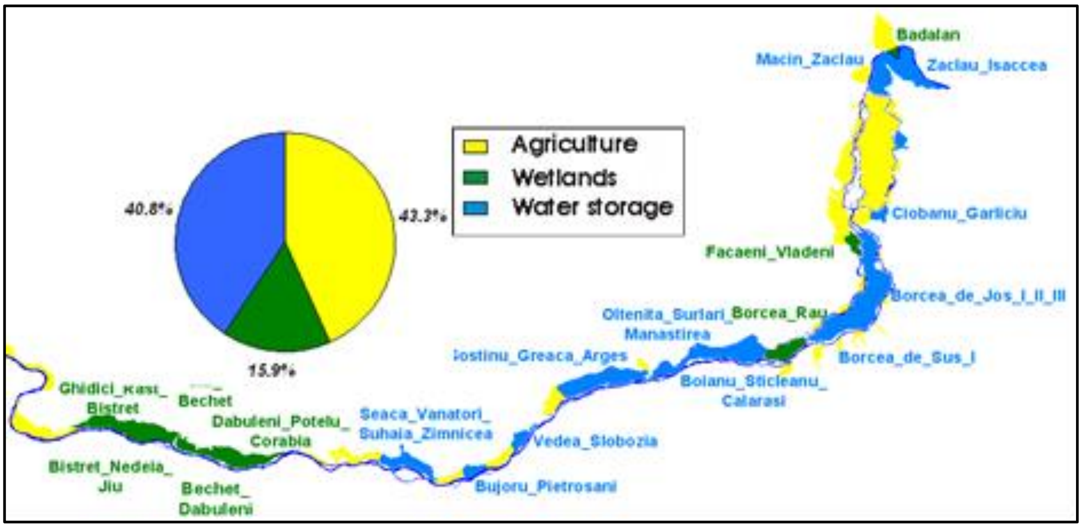


Figure 14. The land use re-designation used for scenarios.

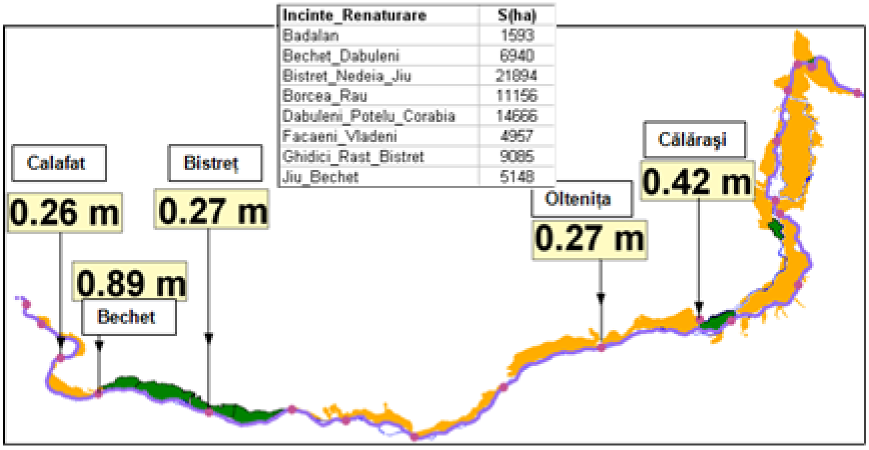


Figure 15. The effect of the first scenario on the peak flows. The values indicate the decrease of water levels in some Danube river section.

Second scenario: mixed solution: permanent wetlands (15.9%) and designation of another 40.8% of embanked areas for water storage at peak flows (Figure 16, Figure 17). The effect on water levels at peak flows were assessed for this scenario as well (Figure 16, Figure 17).

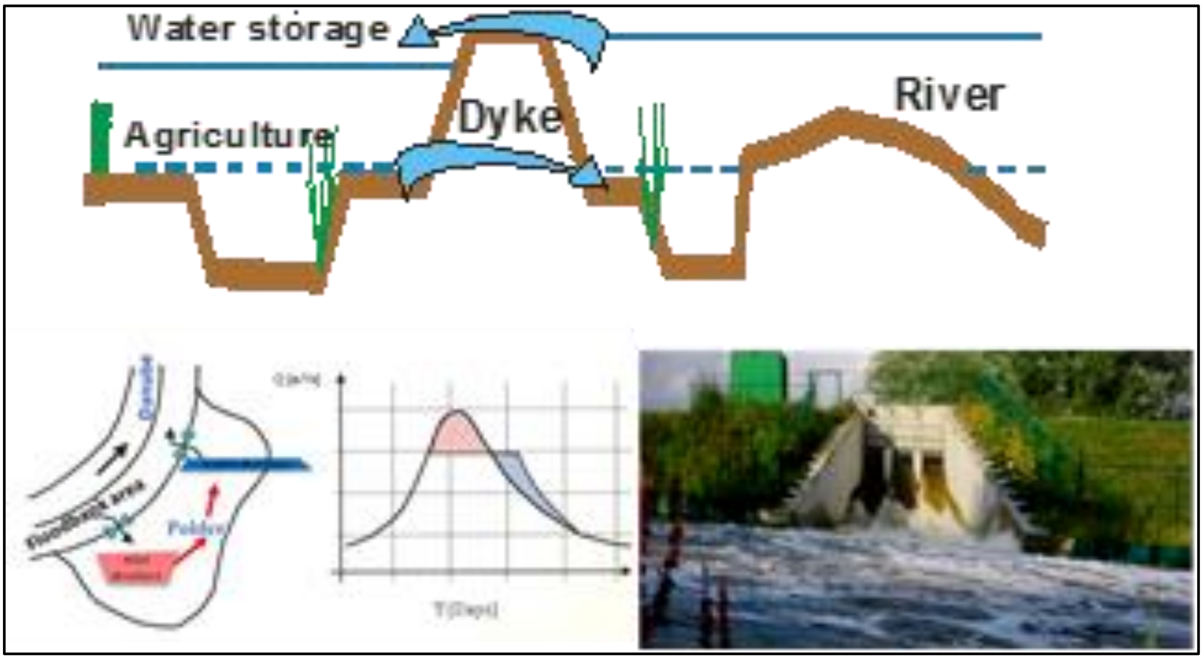
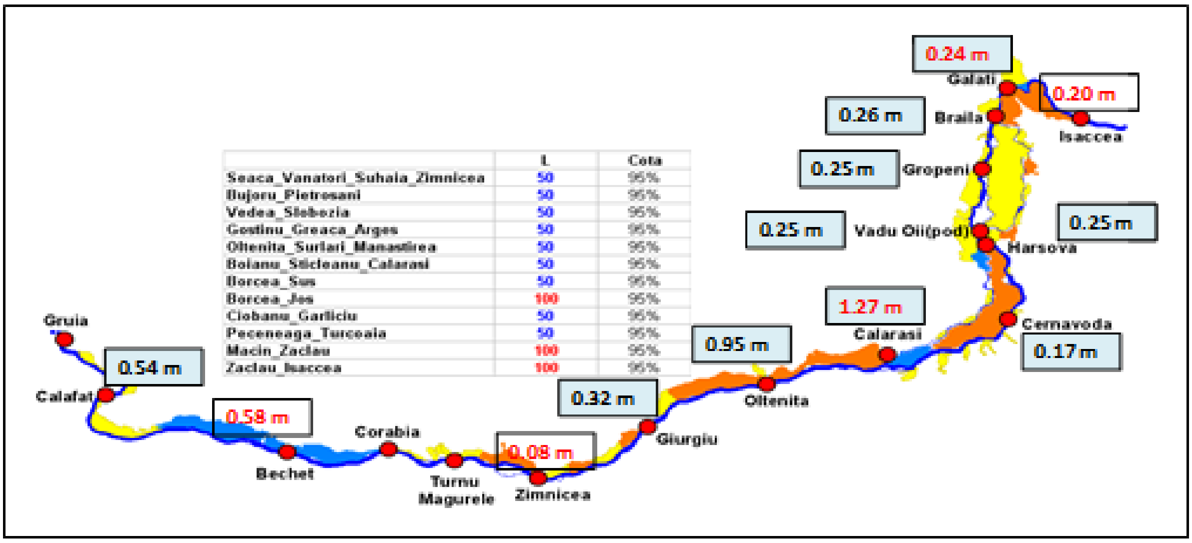


Figure 16. The concept of alternative (mixt) scenario.



	L	Cota
Seaca_Vanatori_Suhaia_Zimnicea	50	95%
Bujoru_Pietrosani	50	95%
Vedea_Slobozia	50	95%
Gostinu_Greaca_Arges	50	95%
Oltenita_Surlari_Manastirea	50	95%
Boianu_Sticleanu_Calarasi	50	95%
Borcea_Sus	50	95%
Borcea_Jos	100	95%
Ciobanu_Garliciu	50	95%
Peceneaga_Turcoaia	50	95%
Macin_Zaclau	100	95%
Zaclau_Isaccea	100	95%

Figure 17. The effect of the second scenario on the peak flows. The values indicate the decrease of water levels in some Danube river section.

Danube Delta

An area of 15 000 ha were reverted to wetlands in the Danube Delta by 2014 as a first phase of a large scale restoration programme in the area (Figure 18).

The pre-conditions have been favourable for restoration. The hydrologic regime of the Danube is not changed significantly (Bondar, 1994). The embankments subject to restoration have not been achieved long time ago and the land elevation has not been increased as happened commonly in other

Figure 18. Implemented projects in the Danube Delta.

Project success and lessons learned

Modelling win-win scenarios for land use policy associated with flood risk mitigation in the Lower Danube floodplain proved to be an useful tool for an integrated multisectoral spatial planning, despite of a fully consent between river restoration needs and social-economic development. Whereas floodplain restoration is the only sustainable way to reduce the flood risks and losses in the climate change prospective, some long term visions on agriculture development still count on floodplain arable land.

The post-project monitoring results in the Delta showed positive effects on biota, valuable habitats for flora and fauna have been restored. Irreversible man made changes and functional ecosystem integrity proved to be challenges for restoration technical solutions. The restoration actions should take into account and adapted to the existing hydro-morphological pre-conditions. The sedimentation processes within the areas close to the river projects in the Danube Delta are usually altered due to surrounding dykes. The separate water inlets and outlets connections with river proved to be unsustainable due to periodically maintenance dredging works. Downstream reversible inlet/outlet connections are recommended. It should be mentioned that the natural hydrological regime in the case of some implemented projects in the Danube Delta could not be fully restored due to surrounding dykes or land fragmentation.

Other Benefits

Contribution to implementation of the Danube Green Corridor project (www.wwf.panda.org; www.icpdr.org).

2.2 *Navigation case studies*

2.2.1 The River Waal, The Netherlands

Location:
The Rhine branch River Waal near Tiel (the Netherlands; LAT 51.868803°; LON 5.424834°).
Construction period: 2014 – 2015.

Problem & ecological deficiency:
The 'Room for the River' programme is the Dutch water management response following the flood events in the large river Rhine in 1993 and 1995. The programme not only aims to enlarge the flood protection level anticipating more extreme flood and drought events in the future (Design discharges rising from 15,000 to 16,000 $m^3.s^{-1}$), but is also meant to improve environmental quality and support other ecosystem services. Instead of further heightening of the major embankments a suite of different measures have been or are at present implemented to create more discharge capacity (Figure 19). The programme comprises over 30 projects with a choice of measures suited to the local requirements (Figure 20). All measures have been ex ante evaluated for their contribution to lower water levels during flood events and have been negotiated with a wide range of stakeholders (municipalities, farmers, citizens, recreational fisheries, environmental NGO's, navigation sector etc;). Once the contours of the programme were known measures have been fine-tuned through local consultation. Furthermore the programme has been adapted over time as long as it did cause delays or raised the budget e.g. to benefit WFD objectives and transport capacity or by embracing local initiatives (http://www.ruimtevoorderivier.nl/english/). One of the adaptations is a pilot with a training bund instead of lowering groynes to improve navigability and ecology in the shore zones.

Measures:
<u>Parallel training bunds</u>
All measures have been evaluated to which extent they can contribute to achieving other objectives such as navigation and WFD. Measure #2 (lowering of groynes) was one of the measures chosen for the River Waal, which is the largest branch discharging on average 2/3 of the total Rhine discharge. This measure has, however, very little additional benefits besides lowering water levels. The conclusion has triggered the initiative for a pilot with parallel training bunds (Figure 21), which is presently constructed (2014 – 2015). Over a 10 km long stretch – 7 km on the left bank and 3 km on the right bank both on the inner curves – groynes are removed from the main channel and replaced by training bunds. The bunds separate the main channel into two channels: one of 230 m wide for commercial navigation and of 90 m wide for recreational purposes. The openings in the bunds serve to control the discharge through both channels and can be adjusted (adaptive management) in case undesired discharge distribution, sedimentation or erosion occurs. The training bund aims to support the multifunctionality of the River Rhine and mitigate the impact of both flood and drought events: reduced water levels during floods and improved navigability during low Rhine discharges.

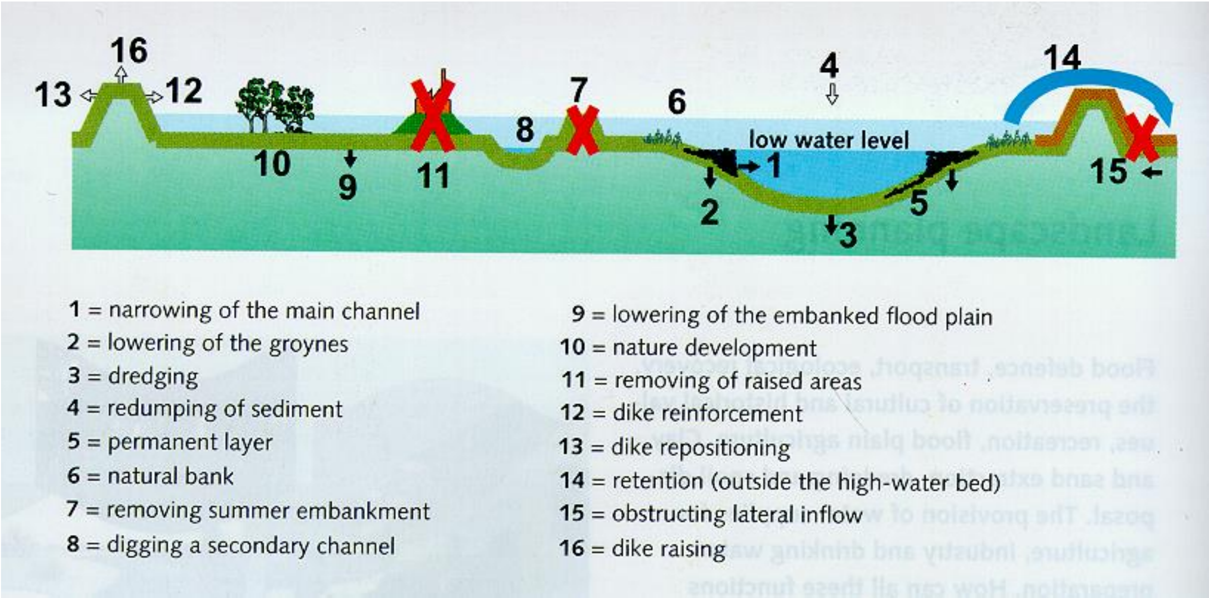


Figure 19. The suite of 'Room for River' measures (after Middelkoop and van Haselen 1999).

Figure 20. The Room for the River programme in the Netherlands encompasses more than 30 projects with different measures for flood protection and environmental quality (Source: www.ruimtevoorderivier.nl .

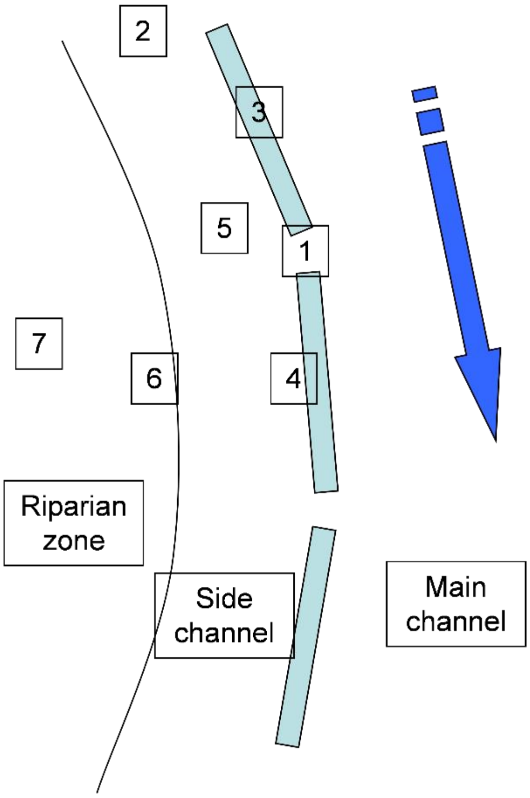
Figure 21. The yellow line demarks the 10 km stretch along the River Waal where the parallel training bund is constructed. A 7 km stretch on the left bank followed by a 3 km stretch on the right bank. Both situated on the inner curve (Source: www.rws.nl/kribverlagingwaal).

Expectations:
The foreseen benefits are the following:

- Flood protection: lowering water levels during flood events.
- Navigation: the River Waal has 165,000 passing ships per year. Safety will be increased by separating recreational and commercial navigation. Adjusting the discharge distribution between the two channels is expected to increase navigable depth during low discharges.
- Ecology: the main channel of the River Rhine in the Netherlands has incised by > 2m over the last two centuries. The training bund should reduce bed incision. The bunds protect the 90 m channel and shore line against ship-induced waves and water displacement arising from commercial navigation (recreational navigation will be speed-limited); the shoreline behind the bunds will develop into natural riparian zones.

Monitoring and research
Whether this innovative measure will meet the expectations is not yet known. On beforehand, modelling studies have fine-tuned the final design to regulate the discharge of water and sediments. Baseline data prior to implementation have been collected. A monitoring programme (2015 – 2018) will evaluate the functionality of the training bunds for flood protection, navigation and ecology. Two Ph.D. students as part of the STW

research programme Rivercare ("Towards self-sustaining multifunctional rivers") will investigate the hydraulics, morphodynamics and aquatic ecology in detail. The potential development are illustrated in Figure 22.



1. Dimension and in-between distance of the lateral openings (width, threshold, distance) control sediment exchange, lateral flows and sedimentation and erosion both in the side and main channel (navigability, discharge capacity)
2. The design of the upstream opening (width, threshold with or without vertical slot) controls the permanency and quantity of water flow in the side channel, the sediment transport (both suspended and bed-load) into the side channel and the riverbed incision in the main channel
3. Height and slope (inner, outer bend) of the LTD control impact of navigation on the side channel and riparian zone and …
4. Sedimentation on the inner bend transfers artificial rip-rap into natural substrate
5. Hydromorphological dynamics enlarge habitat diversity in the side channel (combinations of depth, water level fluctuations, flow velocity and substrate) and steer the colonization of aquatic vegetation and habitat suitability
6. Steep slopes on the riparian zone of the inner bend become more gentle with more extensive land-water transitions and support vegetation development
7. Land-use in the floodplains influence vegetation development in the riparian zone

Figure 22. Potential hydromorphological and ecological developments following the construction of the training bunds.

Figure 23. The parallel training bund. Top left: the training bund is situated on the inner curve. Top right: waves and water displacement caused by passing ships are strongly reduced behind the training bund. Bottom left: The riprap on the shore origins from the former groyne (Photos: Tom Buijse).

Figure 24. Impressions of the construction of the parallel training bund (March 2015; photos: Tom Buijse).

2.2.2 The Danube, East Vienna

(*Text in this section is taken from EC 2012b*)

Problem & ecological deficiency:
The Donau Auen National Park, east of Vienna in Austria, covers a total area of 100 km² and incorporates a 36 km reach of the Danube, all of which is in Natura 2000. It is one of the last major floodplain areas left in central Europe and is exceptionally rich in biodiversity. The former flooding regime of the Danube used to exhibit highly diverse water level fluctuations but this was altered many years ago when several kilometres of flood alleviation embankments and river regulation measures were put in place. The disconnection between the river and the floodplains and the alteration in flood duration and frequency resulted in the drying up of large areas of wetland.

In 2002 the Austrian Federal Ministry of Transport and via donau (the Austrian Waterways Authority) initiated an integrated expert process for an "Integrated River Engineering Project on the Danube East of Vienna" (IREP). The project aimed to balance the interests of inland navigation with the environmental needs of the Danube Floodplains National Park and the conservation objectives of the Natura 2000 site in particular.

The joint process started by looking at the state of the river. It concluded that this free-flowing section of the Danube downstream of Vienna has long been subject to river bed degradation (erosion of 2-3.5 cm/year), leading also to a lowering of the groundwater table. At the same time, insufficient fairway depths during low water periods and strongly varying fairway conditions were hindering the smooth passage of inland navigation. A chain of hydropower plants upstream of the project area, river regulation and bank protection measures had also reduced former morpho-dynamics in this river reach and floods had led to sedimentation of side channels and the inundation area.

The IREP planning process included the following steps:

- First, an Interdisciplinary Steering Group (ISG) consisting of well-known experts from the fields of hydraulic engineering, ecology, inland navigation and regional economy was established. The group analysed in detail several alternatives and some 11 different variants for developing the Danube section east of Vienna. The preferred alternatives were discussed intensively and improved on over several years.
- In parallel to these discussions, a wider stakeholder involvement process was carried out to discuss the interim results of the ISG. This process involved about 40 stakeholders representing NGOs, affected ministries, authorities, communities, the navigation sector, the national park and others. This resulted in proposals for modifying the scenarios which were then assessed and improved by the ISG and the planning team in an intense discussion process.

The environmental impact statement (incorporating the appropriate assessment under Article 6 of the Habitats Directive) was finalised, and accepted by the ISG in 2006. After a total planning period of some three years where both ecology and navigation experts were willing to find a compromise, an agreed set of measures was defined, aiming for a win-win situation for both ecology and navigation. The IREP was thus prepared to improve the navigability as well as to sustain river bank restoration and the lateral connectivity of river with national park side-arms.

Measures:
The measures leading to a significant improvement of ecology included:

- The granulometric bed improvement: an approximately 25 cm thick layer of 40 to 70 mm coarse gravel material will be added to the bed surface, focussed to pool reaches, to reduce bed load transport capacity and minimise bed degradation.
- River restoration for improving the ecological status consists of riverbank restoration (removal of bank protection at inner bends, allowance of side erosion), side-arm reconnection and the stop of river bed degradation.
- Optimisation of the existing low water regulation: east of Vienna, higher water levels during low flow conditions are a common goal for navigation and ecology. Higher water levels compensate for many years of river bed degradation and improve the reconnection of side-arms. The shape and arrangement of groynes are optimised under ecological criteria, reducing their total number and the length of engineering structures. At the same time the new shape will lead to more dynamics along the river bank.

The measures for the improvement of navigation were:

- optimization of the existing low water regulation to increase its effectiveness, to reduce sedimentation in groyne fields and to reduce maintenance efforts;
- dredging and defined refilling of material (leading to a sediment balance);
- the relocation of certain sections of the existing navigation channel in order to use deeper zones for navigation purposes; this measure also reduces the requirement for dredging;
- granulometric bed improvement; the reduced bedload transport also reduces the need for maintenance dredging.

Improvements:
The realisation of these innovative measures will be carefully monitored by an interdisciplinary team to measure their success. For details go to www.donau.bmvit.gv.at

2.2.3 Germanys, River Moselle

(*Text in this section is taken from EC 2012b*)

Problem: Simplified navigation channel with steep reinforced banks

Ecological deficiency: Steep reinforced banks restrict vegetation growth. Ship-waves provide inadequate habitats for macrozoobenthic organisms and fish.

Measure: Construction of a 700-m training wall parallel to the bank with connection to the river flow in 1993 (Figure 25).

Figure 25. Construction of a 700-m training wall parallel to the bank with connection to the river flow in 1993.

Improvements: Enhanced structural diversity, reduced impact of ship waves on bank. Wide and shallow water are behind training wall. Significant improvement of habitat conditions for numerous animal species and amphibious and aquatic vegetation. Ecological improvements were shown by the increase of fish due to the presence of habitat for different age stages of limnophilic species spawning on macrophytes such as carp and tench. The alluvial fan of the inflowing rivulet is a potential habitat for fry of rheophilic, species spawning on gravel that is better protected by the training wall against detrimental impacts of ship waves (Figure 26). Favourable conditions for the establishment of aquatic vegetation. Ecologically significantly improved habitat conditions regarding diversity and abundance against the steep, rip-rap banks of the Moselle in this impounded reach.

Figure 26. The alluvial fan of the inflowing rivulet, a potential habitat for fry of rheophilic, species spawning on gravel, protected by the training wall.

2.2.4 Germany, River Main

Problem: Bank reinforcement

Ecological deficiency: Decline of the macrozoobenthos community and of the bank vegetation through the construction works to facilitate navigation.

Measure: Establishment of shallow-water zones with connection to the River Main, succession zones, vegetation-free gravel and pebble areas as well as two bluffs on a former ploughland area of approximately 5 ha (Figure 27 & Figure 28).

Figure 27. Wetland habitat "Neuer Hafen", a short time after the measure in 1990.

Improvements:

- Improved physical-structural diversity.
- Reduced impact of ship waves on habitats of the water-land transition zone.
- Wide and shallow water areas offer favourable conditions for the establishment of aquatic vegetation.
- Enlargement of the amphibious zone and thus promotion of amphibious plants and animals.
- Diverse habitat structures (bluffs, vegetation-free areas, coppices, meadows, and tall forbs) offer favourable conditions for avifauna.
- High fish-ecological significance as habitat for different age stages of limnophilous species spawning on hydrophytes.
- Significantly higher ecological habitat value in terms of species diversity and abundance than rip-rap banks.

Figure 28. Aerial view of the harbour in 1990.

2.2.5 Flood-spillway Rees, Germany

(*Text in this section is taken from EC 2012b*)

Problem:
The Lower Rhine in Germany is heavily affected by river bed erosion; up to 2 cm/year is a maximum value in recent time. Decline of navigable water levels and subsequent effects on ecological and land-use functions are to be expected. Counteracting this impact is currently done by expensive river bed load supply and additional measures fixing the river bed technically.

The stretch of Rhine-km 833,5 to 839,0 – where the city of Rees is located – is at almost a 90o angle, which causes a bottleneck in river discharges. This in turn increases the risk of flooding. The wide left bank floodplain at present allows a multifunctional use i.e., farming, recreation, tourism and nature protection (Figure 29). The whole area is protected under Natura 2000 network.

Measures:
Considerations to counteract bed erosion have already been initiated in 1995 resulting in the adoption of the program to "minimise river bed erosion on the Lower Rhine" by the German Ministry of Transport in 1998. The main navigational targets: a) maintain navigable water levels, b) to reduce bed erosion and c) to minimize expensive bed load supply have been included in an integrated planning approach. But the project also aimed to be multifunctional and in particular a) relieve the city of Rees from danger of flood damage, b) enhance natural value within the area and c) integrate farming, recreation and tourism. These targets have been included in the early planning process by involving a stakeholder expert panel advancing their views and interests.

For achieving these multiple goals there was mutual consent to use the floodplain by increasing its portion in river discharge. The subsequent effect of lowered flow velocities in the river channel should then decrease the bottom shear stress finally leading to reduced bed erosion. Before any engineering work began, several alternatives of flood-spillway directions and of reshaping floodplain morphology were evaluated mainly from the ecological perspective (Figure 30).

After having selected an ecologically viable alternative that fulfilled at the same time the hydraulic targets and the nature targets, the actual construction design could begin. Because of the project's multiple targets it received additional funding from the Federal State of North-Rhine-Westphalia responsible for flood-control in that area.

The legal administration procedure was initiated including the Environmental Impact Assessment (EIA) and the appropriate assessment procedure under Article 6 of the Habitats Directive in relation to the Natura 2000 sites conservation objectives. The project was legally approved in 2008.

Figure 29. Aerial view of the Rhine floodplain at the city of Rees (*taken from EC 2012b).*

Figure 30. Five alternatives for the spillway and lowering the floodplain (*taken from EC 2012b).*

Improvements:
The construction works started in 2009 and should end in 2015. An extensive monitoring programme was launched at the same time this will not only monitor the effects of the measures being undertaken during the construction phase but also after the project has been completed.

All measures for ecological enhancement (e.g. designing a wet grassland, ecological revetment of spillway banks) and for compensation, if needed, are realised simultaneously to the technical construction itself.

Thanks to this integrated planning approach, a win-win-situation was created for both navigational and other stakeholder targets. Although primarily a navigation project the "Flood-spillway Rees" project produces added values for flood prevention, nature value, farming and recreation (More information:http://www.wsa-duisburg-rhein.wsv.de/Projekte/Flutmulde_Rees/index.html).

2.2.6 Modification of groynes at Elbe riverbanks (DE)

(*Text in this section is taken from EC 2012b*)

Problem & ecological deficiency:
More than 6900 groynes have been installed to stabilise the riverbed at mean water level and assure the navigability of the river Elbe (Figure 31). The fixing of the riverbed in this way however resulted in the severe loss of structural diversity along the river banks and the regular incline of the groynes induced a long term siltation process in the groyne fields leading to a loss in typical riverine habitats such as scours and gravel banks.

In parts of the middle Elbe river, where regulation measures were not properly maintained before German unification around 1500 groynes were fully or partially damaged and had therefore lost their hydrological function. It was decided to use this opportunity, as part of a waterway maintenance measure to test whether the groyne could be made more ecological. Two types of groynes were built: type I involved the construction of a v-shaped groyne inclined on the bank side and declined on the riverside. Type II involved an inclined groyne lowered by 1.20 m below mean water level on the riverbank side.

The monitoring results indicate that the new groyne designs have increased hydromorphological dynamics at the riverbanks which will in turn decrease the aggradation processes in the groyne fields. The improved structural diversity in the groyne field is also improving the condition for aquatic fauna, especially juvenile fish whilst having no negative consequences for navigation. Long term monitoring will determine the final ecological efficiency of these new designs. More information on: http://www.bafg.de

Figure 31. Creation of side channels along the Main (DE).

Measures:
Along the river Main at km 151.96-152.53 the river channel was fixed by groynes and the former floodplain became elevated (winter and summer dikes) and transformed into agricultural land and sand and clay extraction pits. The specific riverine habitats and lateral hydromorphological connectivity was lost as a result.

Pursuant to the domestic nature conservation act, several compensatory measures were put in place which included:

a. Creation of three side channels in 1996-1999. A permanent channel of 2 km, a 1 km channel flowing approx. 265 day/year and a channel flowing approx. 100 days/year.
b. 200 m rehabilitation of riparian zones by planting willows and transforming sandy beaches to softwood forest.

This was accompanied by measures to decrease grazing intensity and by monitoring. The measure created dynamic riverine habitats typical for the river Rhine and the species associated with these habitats. There was a much improved diversity in flow conditions and inundation frequencies, erosion and sedimentation. This restored typical habitats provided valuable areas for rheophilic fish and macro-invertebrate species in particular (higher diversity than in groyne fields).

Improvements:
There were no negative effects on navigation other than minor sedimentation in the main channel at entrance of largest channel. The width of the floodplain is only several hundreds of meters compared to several kilometres in a natural state.

2.2.7 River Spree, Berlin

Problem:

River Spree is a lowland river flowing through the urban areas of Berlin, Germany. It is highly regulated, deepened and widened for both commercial and recreational navigation. At lock Charlottenburg situated 500 m upstream of the rehabilitation site 4667 and 14,432 commercial vessel respectively pleasure boat passages were counted in 2009.

Measures:

In the urban River Spree at 52°31’46.05’’N and 13°16’25.42’’E a shallow artificial bank structure, in the following rehabilitation site, was built as compensation measure for fairway enlargements in 2004. It was intended to create a shallow littoral area protected from vessel induced wave wash and currents according to Wolter et al. (2004). The measure had a total length of 264 m and was separated from the main channel by a sheet pile wall. Six trapezoidal openings of 11×5×1.5 m (upper × lower width × depth) towards the main channel structured seven wake-wash protected segments (Figure 32). The banks behind the sheet pile wall were protected with riprap. Next to the openings, shifted gabions have been placed perpendicular to the sheet pile wall to protect the shallow littoral from return currents parallel to the banks.

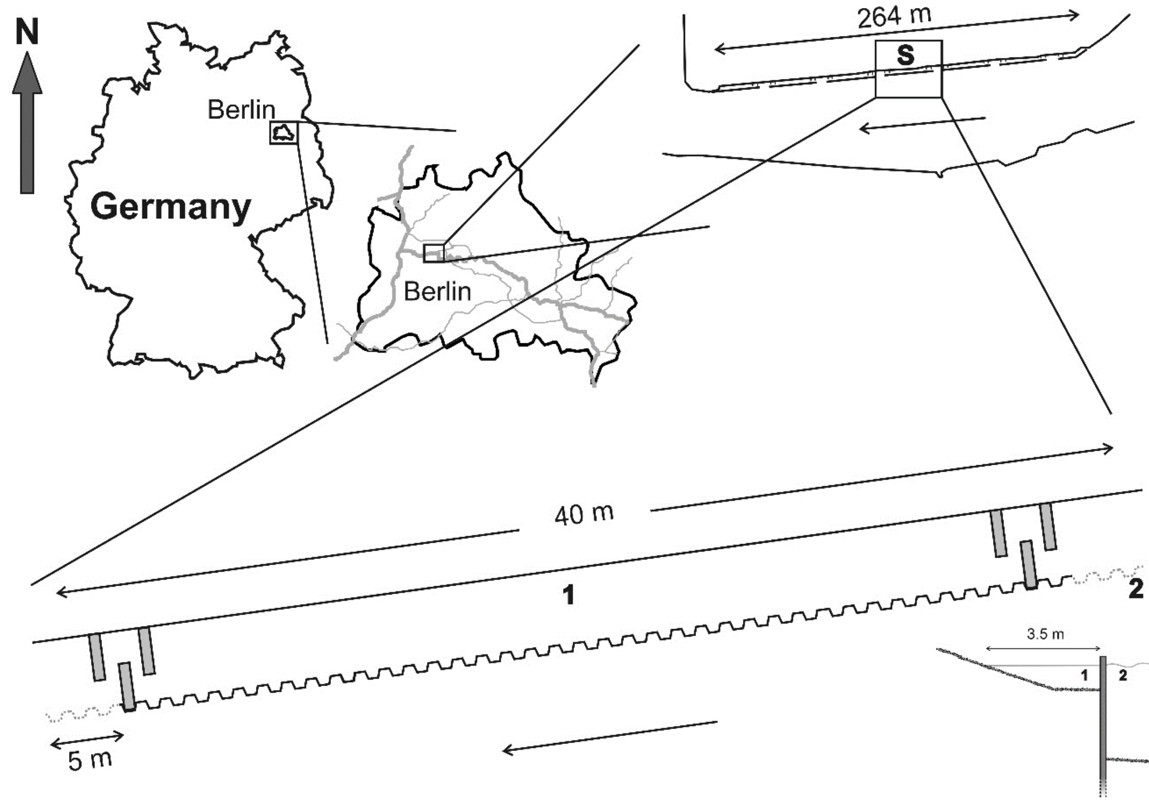


Figure 32. Location and structure of the rehabilitation site (R) in the urban part of River Spree, Berlin, Germany. Lower right: lateral view.

Improvements:
The ecological efficiency of the rehabilitation structure has been evaluated for fish in 2006 and for macrophytes, benthic invertebrates and fish in 2009. Details in Wolter (2010) and Weber et al. (2012).

As intended, the rehabilitated site provided suitable low flowing, wake-wash protected habitats for fragile aquatic organisms and small fish with lower swimming performance. This was indicated by significantly higher fish densities in the rehabilitation site (1565 fish/100 m) compared to the reference, a typical canal site (138.3 fish/100 m) (Wolter 2010). In addition, in the rehabilitation structure the amount of small juvenile fish was significantly higher as indicated by significantly smaller median fish length (Figure 33). Although the canal site and rehabilitated site were exposed to similar amounts and frequencies of navigation-induced flows and currents, many more – and smaller – fish were able to maintain habitats in the artificial shallow bank (Wolter 2010).

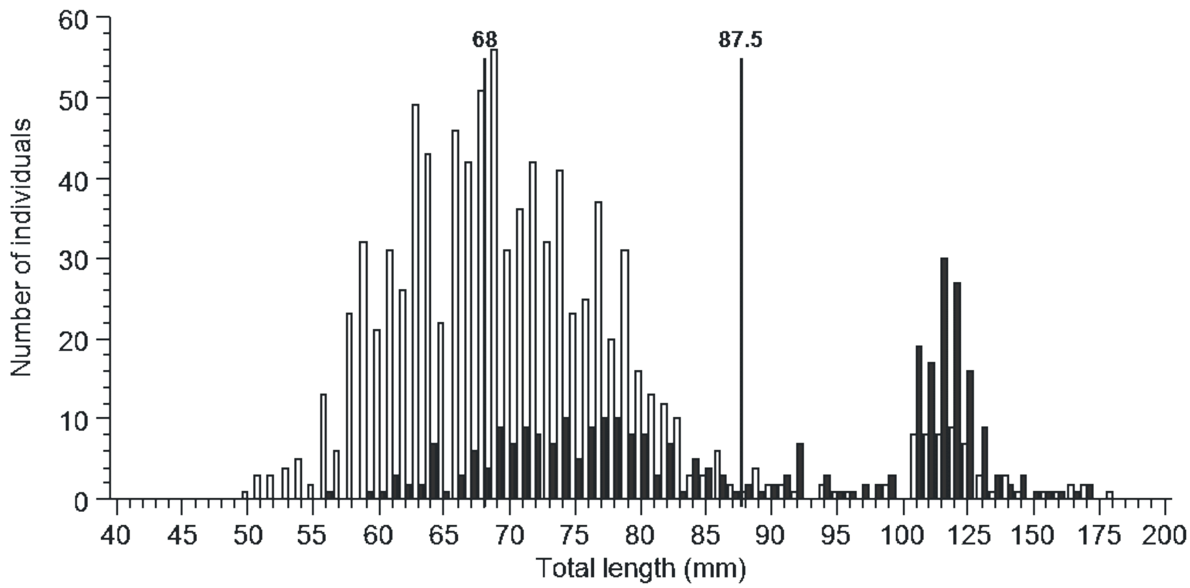


Figure 33. Length distributions of fish caught in the rehabilitation site (white bars) compared with a typical unprotected waterway site in the canal Charlottenburger Verbindungskanal (dark bars). Median length differed significantly (P < 0.01, Kruskal-Wallis H statistic).

Later on the positive effects on fish disappeared. The highly successful development of submerged and emerged plants in the rehabilitation structure added to the technical measures to reduce wave and current effects. As a result, the lateral exchange with the main channel was substantially reduced (Weber et al., in review) and the oxygen content in the structure significantly reduced (Figure 34, Sukhodolova et al., in review).

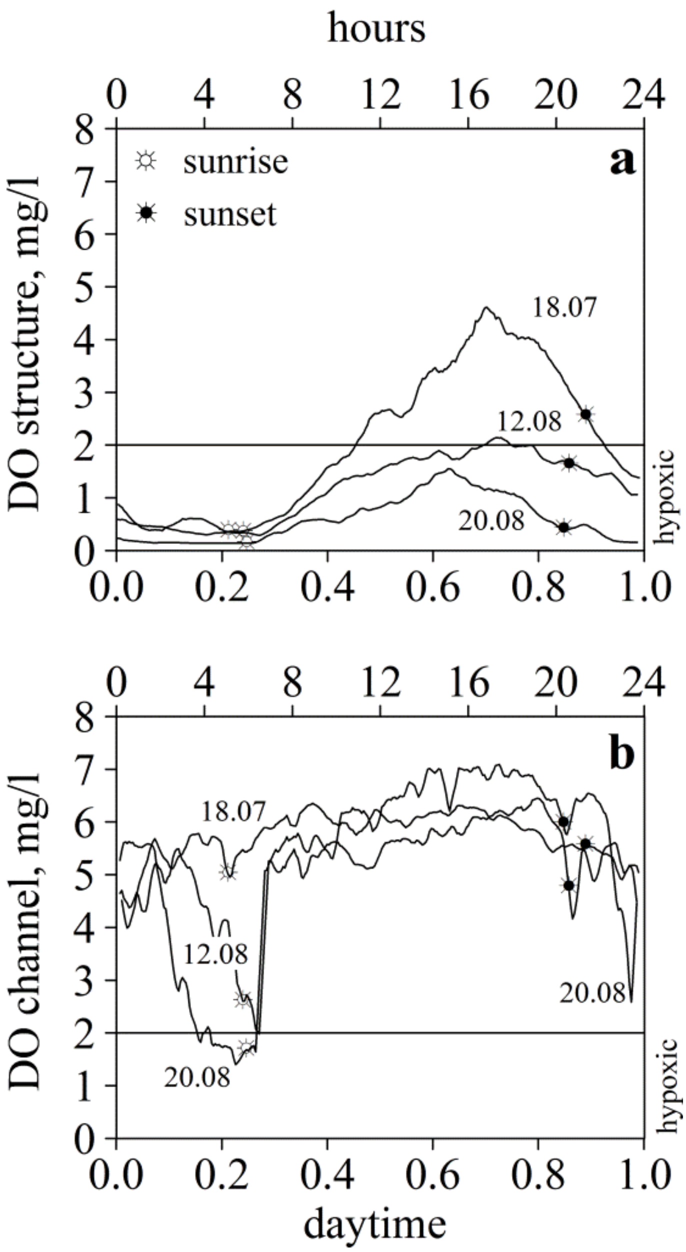


Figure 34. Change in the diurnal curves of DO (mg/l) from July to August in the rehabilitation structure and the main channel. Additionally the sunrise and sunset times are indicated and the threshold to hypoxia (DO < 2 mg/l). From Sukhodolova et al. (in review).

The improvement of aquatic macrophytes due to the rehabilitation structure was very pronounced. At the rehabilitation site the hydrophytes showed a clear increase in species number, quantity and diversity from 2004 to 2009. Using the German National assessment scheme for aquatic macrophytes Reference Index (RI), the rehabilitation site reached the "good" ecological status and even the "high" ecological status if the planted RI group C species *N. lutea* was excluded from the calculation (Weber et al. 2012). It must be questioned whether both, the RI and river type TN (medium-sized lowland rivers of northern Germany) sufficiently apply to the urban River Spree; however, nonetheless the results clearly show positive effects for macrophytes.

The succession of the macrophyte community is illustrated in Figure 35.

Figure 35. Rehabilitation structure in the urban River Spree in Spring 2005 (left) and Autumn 2011 (right).

The response of benthic invertebrates to this rehabilitation measure shows some changes but did not indicate substantial improvements of the ecological status. However, the invertebrates' diversity (# taxa) was significantly higher within the rehabilitation measure and both abundance and species numbers of non-native invertebrates were significantly lower there (Figure 36).

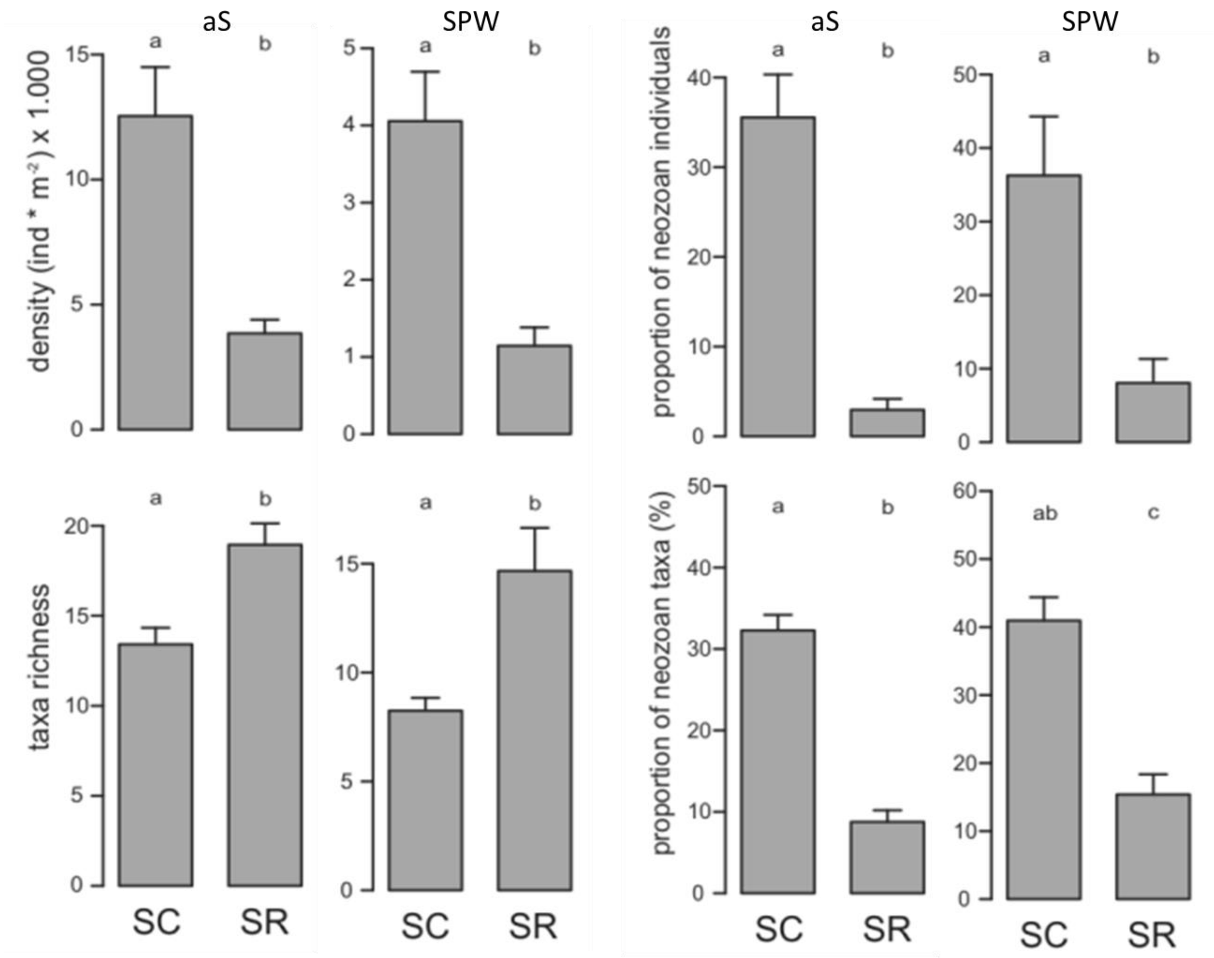


Figure 36. Average invertebrate (left) and neozoa (right) densities and taxa richness ± SE averaged over all available substrates (aS) and only sheet pile wall (SPW). SC= control site, SR= rehabilitation site.

In summary, the technical wave breakers provided sufficient shelter to improve macrophyte growth, invertebrates' diversity, and juvenile fish density. This rehabilitation measure initiated a measurable recovery of hydrophytes achieving the environmental objectives of the WFD.

However, the accelerated flow protection by both artificial structures and recovering plants also accelerates isolation, sedimentation and rapid succession, followed by oxygen depletion and loss of functionality for juvenile fish within six years. Therefore, similar rehabilitation structures require maintenance and modifications to sustain the long-term performance of the rehabilitation site in mitigating navigation induced impacts. With increasing macrophyte growth and density the technical flow and wave protection should be removed or reduced. Natural vegetation will take over the flow protection while maintaining connectivity with the main channel.

2.2.8 Canal Oder-Havel-Kanal, Eberswalde

Problem & ecological deficiency:
The artificially constructed Oder-Havel-Kanal (OHK) is the central part of the 150 km long Havel-Oder-waterway (HOW) crossing the watersheds between the Rivers Havel (Elbe catchment) and Oder in the north-eastern lowlands of Germany. The OHK was firstly opened in 1620 and has existed in its present form since 1914. For more than two thirds of its length, the OHK is located above the surrounding land and therefore constructed as a special waterproof structure with a clay spalant. As a result, the OHK is 'unusually' straightened, 34 m wide, 3 m deep, with artificial embanked shorelines (95% rip rap and 3·8% sheet pile wall), steep bank slopes (mean 33%) and a negligible flow velocity (<0·05 m/s). In such waterways restricted in depth and width, the operation related physical forces from moving vessels are most pronounced (Söhngen et al. 2008). Accordingly, the juvenile fish recruitment is severely impaired (Arlinghaus et al. 2002) and the navigation-induced habitat bottleneck is especially high (Wolter & Arlinghaus 2003).

Measures:
In 2008 two waves and flow protected artificial shallows have been constructed to rehabilitate aquatic macrophytes and to provide littoral habitats for invertebrates and fish. The first structure is 204 m long and situated at canal-km 64 (52°51'25.13"N and 13°43'56.52"E) the second structure at canal-km 65 (52°51'11.63"N and 13°44'54.56"E) is 458 m long. Both structures are similarly constructed as parallel dam, built from gabiones, with 2 m wide and 0.4 m deep openings every 9 m (Figure 37 & Figure 38).

The littoral behind the parallel dam was partially filled up with a sand and gravel mixture to achieve a maximum depth of 1.2 m in the rehabilitation site.

Improvements:
Both rehabilitation sites have been evaluated for success for the first time in 2013 (Rauch 2014). The evaluation comprised the performance in lowering waves and currents as well as the ecological improvement of aquatic plants, juvenile, and adult fish.

Wave height was measured using pressure sensors, flow velocity using Acoustic Doppler Velocimeter (ADV). Measuring both variables during vessel passages in the openings of the parallel dam and close to the bank behind yielded the efficiency of the measure in lowering the physical forces in the littoral.

In total 21 vessels and pleasure boats of different sizes and with different speeds have passed by the site during measurements. For all, even the slowest vessels, there was a measurable effect of dampening the flow velocities and the wave height at the bank (Figure 39). Except vessel 19, that has passed at a speed and an angle that the incoming and reflected waves superimposed at the bank.

Figure 37. Artificial waves and current protected shallow littoral habitat as instream ecological rehabilitation measure constructed in the Canal Oder-Havel-Kanal, Germany.

Figure 38. Detail of the parallel dam formed from gabions with the regular openings.

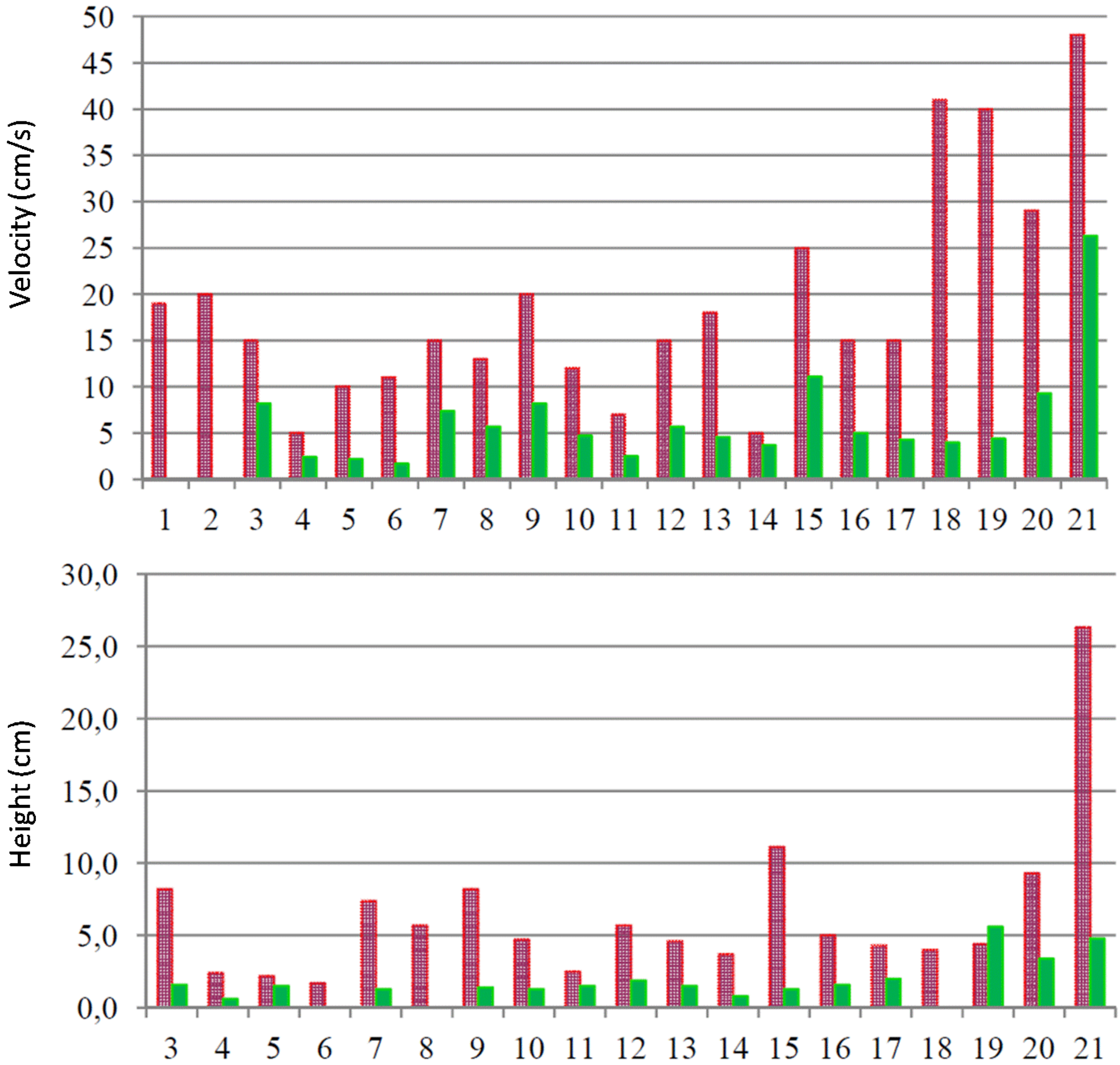


Figure 39. Flow velocity (above) and wave height (below) measured for 21 ship passages at the gabiones in the opening of the parallel dam (Magenta bars) and at the canal bank in the rehabilitation structure (green bars).

Except for the very fast vessel passage number 21, the incoming flow velocity was always reduced to values tolerable for juvenile fish and macrophytes below 10 cm/s at the bank.
Accordingly, there was an immense cover and diversity of submerged aquatic plants in the rehabilitation structure, including the fragile Starry stonewort *Nitellopsis obtusa*. The average cover of aquatic plants was significantly higher in the rehabilitation structures compared with the controls (Figure 40).

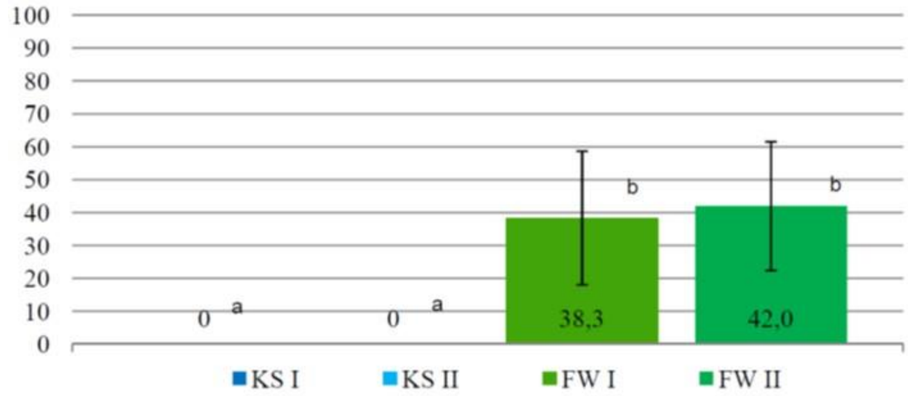


Figure 40. Cover (%) of submerged macrophytes in the control sites (KS) and rehabilitation structures (FW).

Similar significantly positive effects have been observed for juvenile and adult fish. Throughout the year 2013 significantly higher numbers of 0+ fish were found in the rehabilitation structures. The only exception was a single event of freshly hatched bleak *Alburnus alburnus* at the control site number 1 (Figure 41). However, it has to be noted that the natural fish spawning and recruitment is rather low in artificial canals (Arlinghaus et al. 2002).

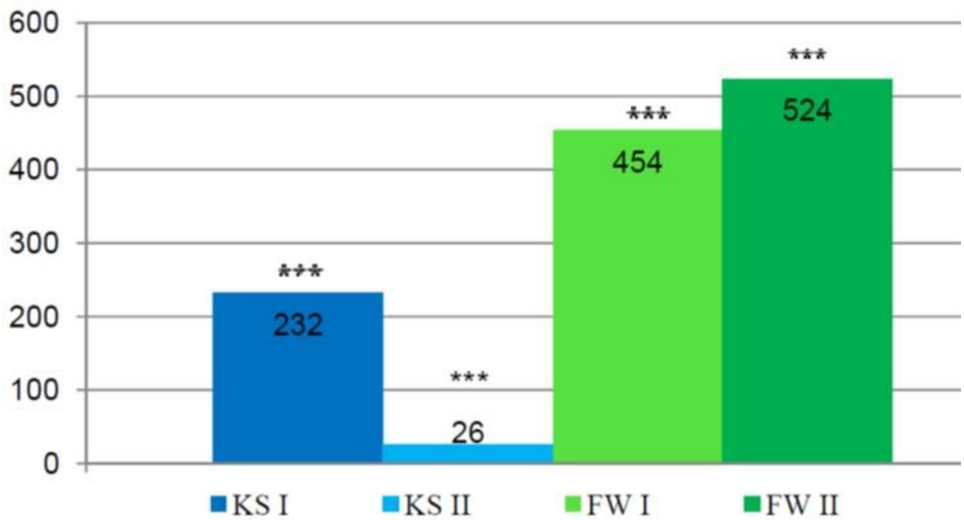


Figure 41. Number of 0+ juvenile fish caught at the two control sites (KS) and the two rehabilitation sites (FW) in 2013 (from Rauch 2014).

Last not least, also the density and diversity of adult fish was higher in the rehabilitation structure compared to the reference sites. Tench *Tinca tinca* and rudd *Scardinius erythrophthalmus* found preferred plant structures here. In the rehabilitation structure successful spawning and reproduction was detected for both species as well as for chub *Leuciscus cephalus* and bleak.

Five years after construction both rehabilitations sites supported a remarkable aquatic plants community and served as suitable nurseries for juvenile fish. The total extent of both sites is probably too low to increase to ecological assessment of the whole canal, but the potential of such measures for ecological improvement became evident.

Further, the parallel dam with its numerous openings enabled sufficient water exchange with the fairway well maintaining ecological functioning still five years after construction.

3. Non-nature based restoration case studies

3.1 *Hydropower case studies*

3.1.1 Demonstration Plant in the Kinzig River: Moveable hydroelectric power plant for ecological river improvements and fish migration reestablishment

Source: Life project
http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3075

Background:
Hydroelectric power accounts for 10% of the total EU electrical power production. Large dams have in the past been used to produce hydroelectric power but for environmental reasons such constructions are no longer tolerated in the EU. There are also a very large number of smaller hydro power weirs in the rivers of Europe, which were constructed to prevent erosion and are characterised by a low turbine head. The main drawbacks of these weirs is that the energy output is not economical and fish are unable to pass through the constructions, which as a consequence has reduced the number of fish and the diversity of species in European rivers.

Objectives:
The Moveable HEPP project aimed to demonstrate the potential of a movable hydroelectric power plant and prove that it can operate economically even at low turbine heads. Pilot actions were to be implemented in existing weirs and expected to create substantial ecological improvements. As an alternative to the existing hydroelectric power plants, the proposed moveable system was anticipated as offering a solution for **both economical power generation and a construction which allows fish to pass through.**

Results:
This project successfully proved that its new hydropower technology, known as 'Moveable HEPP', can operate effectively as a source of renewable energy in a manner which does not adversely hinder the natural ecosystem functions of river habitats.

Two test sites were used to introduce full-scale HEPP systems into existing river weirs. These included installing both a complete turbine plus generator at each site. The technology operated as planned with its moveable components being able to work at different heights. Water flowing through the HEPP generated power and water also flowed over and under the HEPP equipment to facilitate free movement of fish.

Studies on HEPP's potential ecological impacts showed no threat to fish populations. Fish were even able to swim through the turbine as it operates at a low rotation speed. No problems were recorded concerning flood problems since no risk of damming occurred by a build-up of debris around the HEPP plant. Tree parts and other floating matter simply moved over and past the HEPP plant as they flowed downstream. Gravel and other river bed matter were not affected by the HEPP and noise levels were considered low.

HEPP’s economic advantages are attributed to high efficiency, lack of frequency converter, combined turbine and generator on one single shaft, and use of a permanent magnet for the stator which saves the power for electric magnetisation. Furthermore, HEPP avoids costs involved in compensatory measures for managing flood risks or the transfer of river bed matter.

Calculations indicated that HEPP could create savings of 16% compared to a conventional plant, plus 11% higher returns (electricity sales) due to better efficiency. Combining these factors led the HEPP team to estimate that their technology could increase the ratio of ‘raw profit per investment sum’ by more than 40% (from 5.18% to 7.36%).

Strong demand has been shown in HEPP from the commercial sector and the project’s website offers interested parties a preview of how the technology works in practice via live webcams embedded in working versions of the HEPP technology.

The project has been awarded two prizes: the “NEO2010 - Innovationspreis der TechnologieRegion Karlsruhe” as well as the “Umwelttechnikpreis Baden-Württemberg“ (i.e. an environmental award for outstanding and innovative products in environmental technology: Hydro-Energie Roth won the first prize in the category Energy efficiency") in July 2011.

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