Summary

The large lowland rivers are probably the ecosystems in Europe that have suffered most from human impacts during the last 100 years. The hydrological and geomorphological characteristics of European rivers have changed due to the construction of hydropower plants, regulation work for navigation purposes, land reclamation projects and large-scale flood control measures. To improve the ecological values of rivers various measures have been proposed but this thesis focuses on the (re)opening of secondary channels. In this thesis six man-made secondary channels will be compared for their characteristics, monitoring and results.
“Plan Doorstroming”, “Gameren”, “Opijnen” and “Beneden-Leeuwen” are the secondary channels along the Rhine. “Plan Doorstroming” arose due to the digging of the Nieuwe Merwede and was dammed. Due to this the river influence disappeared, when in 1970 the open connection to the sea was closed too, also the tidal influence disappeared. The main goal of the re-opening was the reintroduction of (river-)hydrodynamics. “Gameren” consists of three secondary channels. Two high water channels, designed to flow 100 and 265 days per year and a permanent flowing secondary channel. The goal of the opening was to bring back natural processes. “Opijnen” flows behind a training wall, which was built in favour of shipping. It flows 318 days per year and its goal was the development of spawning, shelter, foraging and growing areas for riverine fishes. “Beneden-Leeuwen” is integrated in a plan, which is a consequence of the WWF’s ‘Living Rivers’. It enters via a deep sand pit the floodplain, where it branches off into three channels to an oxbow lake and then back into the Rhine. It flows 349 days per year and its goal was the development of lotic habitats in the floodplain that used to exist in the main channel.
The secondary channels along the Danube are (from its mouth): Vén Duna and “Regelsbrunn”. The Vén Duna is a former river branch, which was opened again in 1998. The main goal was to bring back flowing conditions. “Regelsbrunn” is a backwater system along the upper course of the Danube, in Austria. The main goal of the restoration of “Regelsbrunn” was to increase the upstream surface connection with the river and the connectivity within the side channel to reduce retention time.
Every secondary channel in this comparison has its own characteristics. One difference is caused by topographical location. Four secondary channels are located along the Dutch Rhine and two secondary channels along the Danube. “Plan Doorstroming” is located in the freshwater tidal region while the Danube near “Regelsbrunn” is classified as a mountain stream. The other secondary channels are all located along comparable river stretches. The secondary channels are different in morphology. The secondary channels along the Danube are all several kilometres long while the Dutch channels are shorter. Also the depths and shores differ. “Opijnen” is an example of a shallow secondary channel with gentle slopes and on the other hand the Vén Duna is an example of a deep channel with steep slopes. Another difference is the difference of monitoring programmes. There are no results of the monitoring of “Regelsbrunn” yet, but the initial situation was monitored very well. “Gameren”, “Opijnen” and “Beneden-Leeuwen” are all monitored in an accurate way. The monitoring of “Plan Doorstroming” and the Vén Duna was not always done in such an accurate, standardised way. In all secondary channels the rheophilic (fish and macro-invertebrate) community increased immediately after the opening.
A secondary channel should be connected most of the time and should be located at a free-flowing river stretch so there will always be flowing conditions present. It should have different habitat types to attract as many species as possible. Morphological processes should be allowed but to a certain extent.

Acknowledgements

Aan het eind van mijn stage, die door allerlei onvoorziene problemen wat langer duurde dan verwacht, wil ik enkele mensen bedanken die mij op de een of andere manier geholpen hebben. Ten eerste mijn begeleiders bij het RIZA: Tom Buijse en Luc Jans. Met name Tom, als mijn "algemene begeleider", heeft mij erg veel geholpen, niet alleen met "stagedingen" (dat was immers zijn taak) maar vooral ook op andere gebieden (meerijden naar Arnhem/Lelystad, interesse als ik het weer eens "op mijn heupen/ribben/knieën had" enz.). Daarnaast wil ik iedereen bedanken die me geholpen heeft, bijvoorbeeld door tijd vrij te maken voor een gesprek over de nevengeulen: Frank Kok, Henk Kraaijeveld, Max Schropp en Jennie Simons.
Naast een periode in Nederland bestond mijn stage ook uit een buitenlands deel, om ter plekke de nevengeulen te bekijken. Zo'n twee maanden verbleef ik in Hongarije en aansluitend ben ik één week in Oostenrijk geweest.
2 hónap budapesti tartózkodásom után elmondhatom, hogy Budapest egy nagyon szép város egy gyönyörű országban, különös nyelvvel. A nyelvi nehézségekből adódó problémák ellenére is kellemes időt tölthettem Magyarországon.
Köszönetet szeretnék mondani mindazoknak, akik a két hónapos tartózkodásom alatt segítségemre voltak. Mindenek előtt köszönettel tartozom Csányi Béla konzulensemnek, aki elfoglaltságai ellenére is érdekes helyek bemutatásával gazdagította tudásomat. (További sok sikert munkádhoz és jó egészséget neked és családodnak!). Köszönet illeti továbbá: Bakonyi Pétert, Sziebert Jánost, Zsuffa Istvánt, Lányi Esztert és mindenkit, aki a VITUKI Rt.-ben töltött gyakorlatom alatt időt szakított rám és hasznos információkkal segítette munkámat. Végül köszönöm Kaszonyi Pált-nak a football mérkőzés jegyeket.
Niet alleen stage-technisch was het een nuttige tijd, ook voor mezelf was het een speciale tijd en bij deze wil ik de mensen die contact met me hielden bedanken en dan met name Esther, tevens voor E.H.B.E. (Eerste Hulp Bij Excel), Ajvun Keys en ons pap en mam. Zij maakten de lange reis naar Boedapest om met eigen ogen te aanschouwen onder wat voor omstandigheden ik daar leefde.
For my stay in Austria, I would like to thank the following persons. First of all Walter Reckendorfer (Department of Limnology, University of Vienna) for being my supervisor during my stay in Vienna and for showing me the places to be for good music (El Vez in "Szene"!). Furthermore, I would like to thank the following persons for their co-operation during the interviews and field trip: prof. Fritz Schiemer (director of the Institute of Zoology, University of Vienna), Sabine Plodek (WWF Austria) and Irene Zweimueller (University of Vienna).

CONTENTS

1 Introduction

Human actions have had large effects on nature the last century. The global loss of biodiversity is widely accepted as a major problem (Tockner & Ward, 1999). The large lowland rivers are probably the ecosystems in Europe that have suffered most from human impacts during the last 100 years (Reimer, 1991). Although the water quality has improved since the 1960's (Grift *et al.*, 200a) ecological improvement is stagnating, indicating that restoration measures must not consider water quality improvements alone (van den Brink *et al.*, 1996). The hydrological and geomorphological characteristics of European rivers have changed dramatically since 1850 (Petts, 1989). They have been greatly impacted by the construction of hydropower plants, regulation work for navigation purposes, land reclamation projects, large-scale flood control measures (Tockner *et al.*, 1999a; Schiemer, 1995) and water pollution (Muhar *et al.*, 1995). River regulation and damming resulted in a straightening and enforcement of one main channel. This increased flow velocity, deepened the river bed and increased bedload erosion in the river itself, reduced the exchange conditions between the river and backwaters and reduced alluvial habitat types (Heiler *et al.*, 1995).
In 1980 the *River Continuum Concept* (RCC) was developed to describe the functioning of the river ecosystem (Vannote *et al*, 1980). The concept regards a river as a continuous gradient from headwaters to the mouth. But a river consists of more than just a main stream (Amoros *et al*, 1987) and the Flood Pulse Concept (Junk *et al.*, 1989) was developed. The FPC states that the most important feature of a lowland river is the flood pulse, which connects the river to its floodplains (Johnson *et al.*, 1995). In large alluvial rivers, water bodies of the floodplain are of vital importance (Amoros & Roux, 1988). Floodplains are areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or ground water (Junk *et al.*, 1989). Habitat diversity, species diversity, and diversity of processes are much higher in the floodplain than in the main channel (Junk, 1999). Floodplains in temperate zones have undergone severe modifications during the last century (Junk, 1999) and river regulation led to a drastic shift in composition of floodplain habitat types and successional stages accompanied by a decline in diversity (Schiemer *et al.*, 1999). The production of large alluvial rivers is strongly correlated to the connectivity of their different water bodies (Amoros & Roux, 1988) and habitat diversity, species diversity, and diversity of processes is much higher in the floodplain than in the main channel. Nowadays, the floodplain is regarded as an essential component of the system without which production is drastically reduced and community composition and energy pathways are radically changed (Bayley, 1991). And they are considered to be areas of high biological diversity, refuges for many rare animal species, area of high recreational value, important filtering corridors for inputs from the uplands, reservoirs for drinking water, water retention areas during floods, etc. (Junk, 1999). Therefore, the floodplain should be a critical element in all river restoration (Adams & Perrow, 1999) and the floodplain must be considered together with the river as one unit, the river-floodplain system (Junk, 1999).
Ecological rehabilitation calls for the return of ecotopes that were prevalent in centuries past, when there was a close interaction between the hydrodynamics of the river and the highly productive floodplain (Schropp & Bakker, 1998). To improve the ecological values of our rivers and to bring back some of the lost riverine landscapes various measures have been proposed. Examples of these measures are excavation of clay in the floodplains, widening of the river, re-opening of old secondary channels or excavation of new ones, removal of so-called summer dikes, construction of environment-friendly bank-protections and a different vegetation management in the floodplains which will allow for the growth of riverine forests (Barneveld *et al.*, 1993).

This thesis focuses on the (re)opening of secondary channels. Secondary channels are channels that pass through the floodplains and are linked to the main channel (Cals *et al.*, 1998). By opening secondary channels, favourable circumstances can be created for aquatic and shore vegetation, habitats can be restored for characteristic macro-invertebrates and fish species. Besides, secondary channels are important for many birds as feeding and/or mating area (Duel *et al.*, 1994). Another reason to focus on secondary channels is that the most endangered fish guild of large river systems is the rheophilic species (Schiemer, 2000). They are endangered due to the drastic reduction of free-flowing sections and lack of longitudinal exchange possibilities (Tockner *et al*, 1998; Schiemer, 1999). Secondary channels are supposed to offer living conditions for riverine organisms – conditions that are no longer present in the summer bed of the river and can make a valuable contribution to the ecological rehabilitation of Dutch rivers (Schropp & Bakker, 1998). In this thesis six secondary channels will be compared. Four of them are situated along the Rhine in the Netherlands. The other two are situated along the Danube, one in Austria and one in Hungary. The reason why these secondary channels in particular were compared is because they all are first examples of man-made secondary channels. Man-made means in this case, that none of the six secondary channels were formed by natural processes. On the one side because the secondary channel was totally excavated or on the other side because an old river branch was reconnected to the river by man. The secondary channels will be compared for their characteristics (design, size, main channel), monitoring and research programmes, and consequences of the opening of the secondary channel. The comparison is made on the base of literature studies, interviews with people involved in the various projects (Appendix A) and field visits. This included a two-month period in Hungary and Austria. In Hungary I stayed eight weeks in Budapest at VITUKI, in Austria I stayed one week in Vienna at the university.

2 Rhine

2.1 General

The Rhine starts in Switzerland and ends after 1320 km in the North Sea (Fig. 2.1). The Rhine basin area is 185,000 km^2, making it the fourth largest river in Europe. With more than 54 million inhabitants and 10% of the world's chemical industry, the Rhine catchment area is the most densely populated and industrialised river basin in Western Europe (Cals *et al.*, 1998). Its basin lies in Switzerland, Germany, France, the Netherlands, Belgium, Luxembourg, Austria, Liechtenstein and Italy. The Rhine can be divided into five sections: (1) Alpine Rhine (Alpenrhein), from the beginning to Basle, (2) Upper Rhine (Oberrhein), from Basle to Bingen, (3) Middle Rhine (Mittelrhein), from Bingen to Bonn, (4) Lower Rhine (Niederrhein), from Bonn to the Netherlands, and (5) Delta Rhine, from the German-Dutch border to the North Sea.

Figure 2.1. The Rhine. (source: Microsoft Encarta Online Encyclopedia 2001)

The Rhine in the Netherlands (Fig. 2.2) is a meandering sand-bed lowland river with a low slope (10^{-4}) and an embanked floodplain (Schoor *et al.*, 1999). The mean stream velocity varies from 0.5 m/s to 1.5 m/s and the mean discharge is 2,300 m^3/s (Middelkoop & van Haselen, 1999). In summer the river is mainly fed by melt water from the Alps, while in winter the main contributions come from the tributaries in Germany. High water periods usually occur in winter. The discharge is less prone to fluctuations than that of other European rivers of comparable dimensions because river reaches have different hydrological characteristics (Cals *et al.*, 1998). The Rhine branches off in the Netherlands into the "Waal" and the "Pannerdens kanaal" which on its turn splits into "Neder-Rijn" and "IJssel". Most of the water, 2/3 at high discharges, flows through the Waal. The Waal is free flowing and winding. At Gorinchem it changes into the wide "Merwede".

Figure 2.2 . The Rhine in the Netherlands with the position of the secondary channels.

Up until the mid-nineteenth century, rivers were allowed to flow and meander more or less naturally and the banks at some locations eroded while sandbars were formed at other places. As a result, the rivers and their floodplains developed into quite a diverse landscape (Schoor & Sorber, 1999). Today, river channels have been straightened for shipping traffic, dams have been constructed for flood control and hydroelectric power generation, most floodplains are separated from the rivers by dikes, and flooding is inhibited, because the floodplains are used for agriculture, construction of cities, roads, railways and other purposes (Junk, 1999). These factors have led to a great loss of characteristic river ecotopes, such as shallow (flowing) water, islands, unprotected banks, floodplain forest and floodplain grasslands (Simons *et al.*, in prep.). Due to this development the ecological situation in the Rhine, as in many other rivers deteriorated. For instance, the fish community changed into a less diverse, eurytopic community (Grift *et al.*, 2000b).
In the 1960s-1970s the water quality in the Rhine was very poor and oxygen levels were extremely low (Van den Brink *et al.*, 1996). As a result of the Rhine Action Plan the water quality of the river Rhine has improved considerably (Barneveld *et al.*, 1993). The Rhine Action Plan was established in 1987 as a reaction on the Sandoz fire in 1986 when heavily polluted fire-extinguishing water flew into the Rhine. It was the first time that a major transboundary river was considered for an action programme at international level with a specific ecological goal defined as the return of higher trophic level species (Cals *et al.*, 1998). At this moment the water quality of the Rhine is considered no longer the main bottleneck for ecological recovery. Ecological rehabilitation also calls for the return of ecotopes that were prevalent in centuries past, when there was a close interaction between the hydrodynamics of the river and the highly productive floodplain (Schropp & Bakker, 1998). The government is actively stimulating the rehabilitation plans for our rivers (Bureau Stroming en Grontmij Gelderland, 1996).
The Rhine has a variety of functions. The main water uses in the Rhine basin are public water supply, agriculture, industry (process water), cooling of power plants and navigation (Garritsen *et al.*, 2000) and it is used intensively for transport of water and

sediment, drinking water, recreation, and urbanisation (Cals *et al.*, 1998). In the summer, river water is let into channels to maintain surface water levels, while in the western Netherlands river water is used to 'rinse' the polders and thereby prevent salinization (Middelkoop & van Haselen, 1999).

2.2 Secondary channels

All Dutch secondary channels reviewed in this report (Table 2.1) are situated along the Waal and Merwede.

Table 2.1. Characteristics of the investigated secondary channels.

	Doorstroming	**Gameren** *	**Opijnen**	**Beneden-Leeuwen**
River stretch	Nieuwe Merwede	Waal	Waal	Waal
Position (kmr)	977.0 - 978.4	936.375 - 938.875	929.430 – 930.370	908
Opening	1992	1996, 1996, 1999	1994	1997
Flowing (days/year)	365	265 / 100 / 365	318	349
Height threshold (m NAP)	+0.45	+0.95 / +2.04 / -	+0.5	+3.0
Stream velocity (m/s)	?	?	0.1 - 0.5	0.1 - 0.3
Maximum discharge (%)	?	3.0	1.2	0.5
Length (km)	2.5 **	1.0; 0.5; 2.0	1.2	2.5
Depth (m)	Var.		0 – 1.0*** / 1.5****	0.5 - 1.5*** / 1.5 ****

* "G265", "G100", "G365" respectively
** length of the two main channels
*** at lowest discharge (Simons *et al.*, 2000)
**** in the flowing channel at moderate water level (Grift *et al.*, 2000a; 2000b)

2.2.1 Plan Doorstroming

General

"Plan Doorstroming" (Fig. 2.3) is situated in the "Dordtse Biesbosch". The "Dordtse Biesbosch" is part of the National Park "de Biesbosch". The Biesbosch was formed after the Sint Elizabeth flood in 1421. The flood created an inland sea of about 40,000 ha. In this inland sea a lot of sand and silt was deposited. The sedimentation also occurred in the Beneden Merwede making it less deep and thus an obstacle for shipping. Due to higher flood risks by this sedimentation the Nieuwe Merwede was dug, this was finished around 1885 (Paalvast, 2000). The "Brabantse", "Sliedrechtse" and "Dordtse Biesbosch" were separated from each other by the Nieuwe Merwede. Another result of the digging was that the tidal influence increased (Directie Zuid-Holland, 1992).

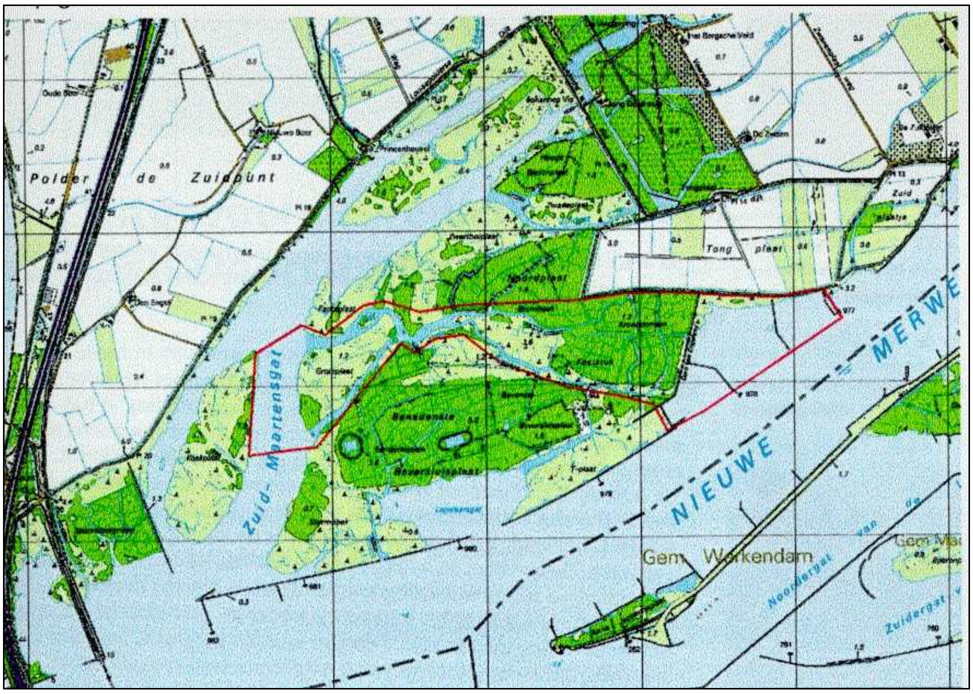


Figure 2.3. “Plan Doorstroming” (source: Paalvast, 2000).

The plan area includes three groin fields and the area behind the “Dam van Engeland” (the dam east of the area) until Zuid-Maartensgat. The area arose by silting of the main channel through the plan area after the construction of the “Dam van Engeland” (Paalvast, 2000). The “Dam van Engeland” was built in 1862 to prevent the ground, which originated from digging the Nieuwe Merwede, flew back into the river (pers. comm. Kraaijeveld). A system of creeks developed. To supply the river with enough water, the upstream gullies were dammed (Paalvast, 2000). By damming the gullies the river influence disappeared making the gullies tidal channels (Paalvast, 2000). In 1970 the open connection to the sea was closed and the tide disappeared in the Biesbosch. Because both the river and the tidal influence disappeared, sedimentation took place in the creeks.

Nowadays, the area consists of shallow open water with reed between the groins of the Nieuwe Merwede and Zuid-Maartensgat. Between the “Dam van Engeland” and Zuid-Maartensgat one finds (mostly bolted) holms and reed marshes which are intersected by a complex system of creeks (Paalvast, 2000). The complex system of creeks is dominated by two main channels which are both ca. 2.5 km long (pers. comm. Kraaijeveld). The system is flowing over the flood ways in the “Dam van Engeland” when the water level of the Nieuwe Merwede is above +0.45 m NAP. The mean low and high water level is according to Kraaijeveld (pers. comm.) respectively +0.40 m NAP and +0.69 m NAP at Deeneplaat. The “Dienstkring Merwede” (1996) however states that the mean low and high water is respectively +0.20 m NAP and +0.60 m NAP. However, in both cases the area is flushed two times a day (Fig. 2.4).

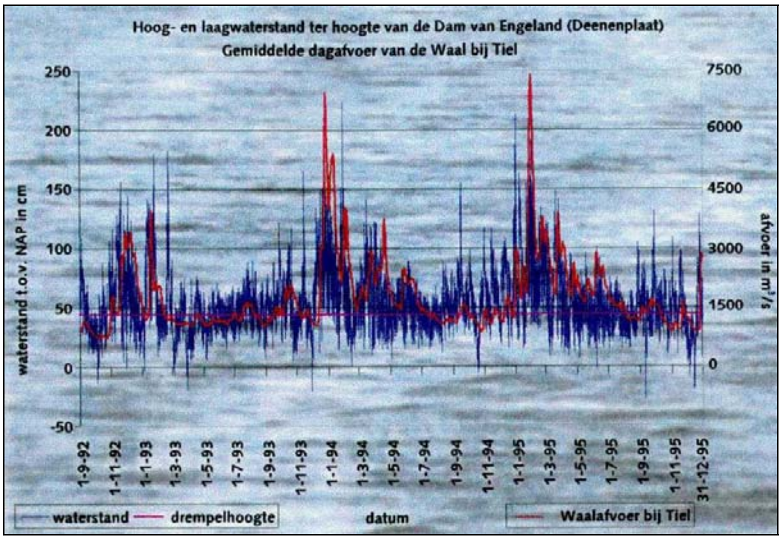


Figure 2.4. The water level and river discharge, 1992-1995. The blue graph (left y-axis) represents the water level, the straight red line is the threshold of the inflow (cm NAP). The red graph (right y-axis) represents the discharge of the Waal at Tiel (m^3/s) (source: Paalvast, 2000).

The main goal of “Plan Doorstroming” was the reintroduction of (river-) hydrodynamics (Paalvast, 2000). From this goal the following secondary goals can be derived (Paalvast, 2000):

- More aquatic vegetation on the river side of the “Dam van Engeland”
- Enlargement of the aquatic-terrestrial transition zone (ATTZ) on the river side of the “Dam van Engeland” and beside some creeks
- Local silt trap in rush fields
- Enlargement of the area with reed besides the creeks
- Enlargement of the area rushes
- A larger diversity of substrates in the creeks
- Less erosion of the shores of creeks
- More spawning fishes
- More water birds.

To reach these goals the following measures were taken (Fig. 2.5):

- In the “Dam van Engeland” two flood ways of 50 m long on + 0.45 m NAP were made so there would be a higher substrate diversity and an increase of spawning fish.
- The eastern groin of groin field B was raised over a length of 240 m. Also a training wall of 700 m was built. The goal of these actions was to create a lee where vegetation could develop. Also the groin fields should act as sedimentation basin enlarging the area of drying mud during low-tide, which should attract various water birds. To prevent transportation of the silt over the “Dam van Engeland” rush is planted in front of the flood ways.
- A part of the groin between A and B was removed to ensure an open connection, even at low water.
- 1500 m steep reed shores of creeks are lowered along the main channel through the plan area.
- To prevent in-flow of water at the west-side of the area during flood, the creek is shut off by three culverts at its mouth in “Zuid-Maartensgat”. Another culvert is shut off.

Figure 2.5. The measures taken to reach the goals. Translation of the legend, respectively: lowered reed shores, raised groin 240 m, removed groin part 80 m, floodway 50 m, training wall 700 m, dam with three culverts, closed culvert, dug end of creeks, rushes (source: Paalvast, 2000).

There were no constraints for the executing of the project, neither for the safety nor for shipping (at that place the Nieuwe Merwede is two km wide). The only constraint was that resting times for birds should be taken into account, no restoration work during the resting/breeding season of birds (pers. comm. Kraaijeveld).

Monitoring

The monitoring programme (Table 2.2) consists of physical, chemical and ecological parameters. The goal was to investigate whether the execution of the plan had the desired effects (Paalvast, 2000)

Table 2.2. The monitoring programme of the “Plan Doorstroming” (Paalvast, 2000)

	1991 1992	**1993**	**1994**	**1995**	**1996**	**1997**
Altitude pendicules creeks and altitude groin fields, “Lepelaarsgat” (m NAP)	+	+	-	+	-	+
Stream velocity	+	+	-	-	-	+
Silt content of the water (mg/l)	+	+	-	-	-	+
Underwater soil quality	+	+	-	-	-	+
Aquatic vegetation cover	+	+	+	+	-	+
Shore vegetation	+	+	+	+	-	+
Development of vegetation holm	+	+	+	+	-	+
Development plantation rushes	+	+	+	+	-	+
Development plantation reed shores	+	+	+	+	-	+
Development plantation reed training wall	+	+	+	+	-	+
Macro-invertebrates	+	+	-	-	-	+
Birds	+	+	+	+	+	+
Breeding birds	+	+	+	+	+	+
Juvenile fish	-	+	+	+	+	+

Results

The data collection and the results of the "Plan Doorstroming" are described extensively by Paalvast (2000). A short summary will be given here.
The monitoring programme was not, due to all sort of setbacks executed as planned. The altitude between the groins was not measured, neither were the measurements of stream velocity and aquatic vegetation (1997). Other parameters were measured but the situation before the opening was not known.
The main goal 'the reintroduction of (river-) hydrodynamics' was reached (Fig. 2.4). The following secondary goals were reached: 'enlargement of the ATTZ on the river side of the "Dam van Engeland" and beside some creeks', 'enlargement of the area reed marsh besides the creeks', 'a larger diversity of substrates in the creeks' and 'more water birds'. Not all goals were reached. The goals 'local silt trap in rush fields' and 'enlargement of the area rushes' were not reached due to grazing of water birds. For other goals it is not clear whether they were achieved. For instance for fish, there was an increase of the number of (rheophilic) species. The number of rheophilic species increased from five species before the re-opening to eight species after that. The following rheophlilic species were found: barb *Barbus barbus*, flounder *Platichthys flesus*, stickleback *Gasterosteus aculeatus*, spined loach *Cobitis taenia*, chub *Leuciscus cephalus*, bullhead *Cottus gobio*, gudgeon *Gobio gobio*, asp *Aspius aspius*, dace *Leuciscus leuciscus* and ide *Leuciscus idus*. The goal was to attract more spawning fish and it is not clear whether this happened. For the rheophilic species it is almost certain that they did not spawn in the area, because the conditions for them to spawn were not present. Macro-invertebrates were not sampled before the opening. So a comparison could not be made. However, the monitoring in 1997 showed a larger number of taxa and al larger number of individuals per m^2 than in 1993. None of these species was characteristic for a certain type of water.

2.2.2 Opijnen

General

In 1984 a training wall was built in the outside bend of the Waal at river km 930 near Opijnen to improve the conditions for the shipping. By this action the groin fields behind the training wall became isolated from the river. There were PVC-pipes of 20-30 cm diameter through the training wall for the refreshment of water and to make the migration of fish possible (Simons *et al.*, 2000) but they were placed too high to maintain a permanent connection to the river. In 1994 openings were made in the training wall and the groin fields were connected to the river again. As a result a ca. 1 km long system of connected groin fields with a high diversity of habitats was formed (Fig. 2.6). There is a relatively wide variety of flow velocities due to the alternation of narrow inflow openings in the groins and the gentle shores. Due to the gentle shores there is a zonation in the vegetation which is linked to the inundation time and frequency. The system is flowing for 318 days per year (Fig. 2.7) and has a maximal discharge of 1.2 % of the discharge of the Waal (Simons *et al.*, 2000).

Figure 2.6. “Opijnen” (picture from Jans).

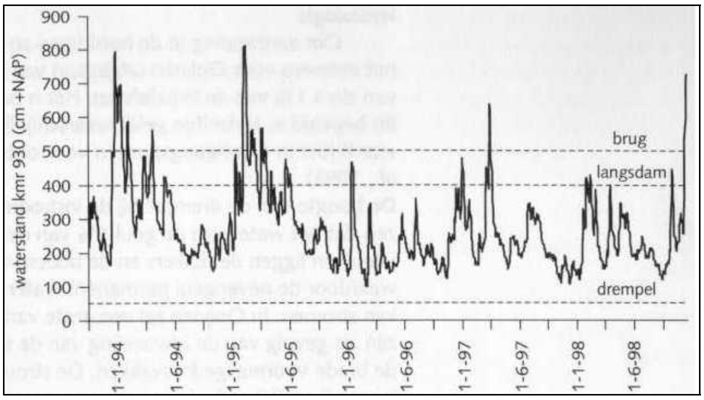


Figure 2.7. The water level at “Opijnen”. The upper dotted line indicates the height of the bridge at the outflow, the middle dotted line indicates the height of the training wall and the lower dotted line indicates the threshold (source: Simons *et al.*, 2000).

The main goal of this secondary channel is the development of spawning, shelter, foraging and growing areas for riverine fishes (Simons *et al.*, 2000). Secondary goals are to create (Simons, *et al.*, 2000):

- shelter, foraging and settlement areas for macro-invertebrates
- foraging place for birds, especially for water birds and stilts
- a diverse water and shore vegetation.

Monitoring

The goal of the monitoring programme was to determine (Table 2.3, Simons *et al.*, 2000):

- the discharge in the secondary channel in relation to the Waal's discharge and changes in time
- the composition and height of the bottom and shore of the main and secondary channel and the changes in time
- the function of this area for the fish and macro-invertebrate community
- the function of the secondary channel plus its shores for vegetation, bird community, dragonflies and grasshoppers
- the value of the area for amphibians.

Table 2.3. Monitoring programme "Opijnen" 1993-1998 (Simons *et al.*, 2000)

	1992	1993	1994	1995	1996	1997	1998	1999
Discharge and stream velocity	-	-	+	+	+	+	+	+
Water level Waal	-	+	+	+	+	+	+	-
Drilling	+	-	-	-	-	-	-	-
Soil composition	-	-	-	+	+	+	-	-
Morphology channel	-	-	-	+	+	+	-	+
Morphology summer bed	-	-	-	+	+	+	-	-
Composition macro-invertebrates	-	+	-	-	+	-	+	-
Composition fish	-	+	+	-	+	-	-	-
Growth and forage function fish	-	-	-	-	-	+	+	-
Aquatic vegetation	-	+	+	+	-	-	-	-
Terrestrial vegetation floodplain	-	-	-	+	-	-	-	-
Water birds	-	+	+	-	-	-	-	-
Breeding birds	-	-	+	+	+	+	+	-
Stilts	-	-	+	+	+	+	+	-
Species composition, propagation dragonflies	-	-	+	-	+	-	+	-
Species composition grasshoppers	-	-	+	-	+	-	+	-
Propagation, land biotopes amphibians	-	-	+	-	-	-	-	-

Results

The data collection and results are extensively described by Simons *et al.* (2000). Here a short summary is given.
Sedimentation and erosion took place to a limited extent in the secondary channel. The effects of sedimentation and erosion were smaller than expected due to the height of the threshold in the inflow opening and the location in the outer bend. A result of the morphological processes was that the bottom height in the channel itself raised and nowadays controls the through flow while at first the height of the threshold in the inflow opening used to regulate through flow.
No aquatic vegetation, except *Potamogeton pectinatus*, was found after the opening of the secondary channel. It was expected that there would be aquatic vegetation present in the secondary channel. The zonation of the vegetation on the gentle shores was a result of the water level. The shoreline vegetation developed well as expected, due to the gentle slopes.
The number of macro-invertebrates stayed more or less the same after the opening of the secondary channel but there was a shift in the species composition, macro-

invertebrates with a preference for stagnant water disappeared in favour of species with a preference for more dynamic circumstances (e.g. *Chironomus acutiventris*). The numbers and densities of rheophilic macro-invertebrates species have increased after the opening of the secondary channel. However, the species composition is still small and just a few rare or characteristic species were found. The increase in rheophilic species was mainly due to exotic species from the Ponto-Caspian region (e.g. *Corophium curvispinum*).
The diversity of fish species increased after the opening of “Opijnen”. All species that had been present before the connection to the Waal were still present thereafter. The density of juvenile fish is 100 times higher in "Opijnen” than in the groin fields of the main channel, and 10 times as much rheophilic juvenile fish were caught in “Opijnen”. The following rheophilic species were found in “Opijnen”: lampern *Lampetra fluviatilis*, bullhead, nase *Chondrostoma nasus*, barbel, dace, chub, gudgeon, ide, asp and spined loach. Although the number of rheophilic species increased immediately after opening, still the fish community was dominated by eurytopic species (e.g. bream *Abramis brama*). From June to September the number of rheophilic fish decreases.
The results for birds and amphibians are also listed by Simons *et al.* (2000).

2.2.3 Beneden-Leeuwen

General

In 1993 a plan was made for the development of nature in the floodplains near Beneden-Leeuwen. Due to the high waters in 1993 and 1995 the “Deltawet Grote Rivieren” came into effect and made it possible to combine dike improvement and nature development (Simons *et al.*, 2000). The secondary channel plan is integrated in a plan “A fan of channels” which is a concrete result of the WWF plan ‘Living Rivers’ (WWF,1993). The Living Rivers Initiative which sets out an agenda for the renewal of Europe’s rivers and floodplains aims to conserve and restore the functions and integrity of freshwater ecosystems for the benefit of all life (WWF, 1999). The plan encompasses the development of river nature in the floodplains near Beneden-Leeuwen and this goal is reached by clay excavation and storing polluted sediments in the deep sand pit (Bureau Stroming en Grontmij Gelderland, 1996).
“A fan of channels” forms a complex system of different water bodies (Fig. 2.8). First the water enters the floodplain via a deep sand pit. Then it crosses an access road through two culverts. These two culverts regulate the discharge to a maximum of ± 9 m^3/s until the water flows over the access road (Fig 2.9). After the culverts the channel splits into three channels to an oxbow lake and after that back into the river. One of the branches flows through a small willow forest. The system has a large number of habitats because the system consists of different types of water bodies and north and south of the secondary channel there are also clay pits. These clay pits are connected to the secondary channel when the water level is above +4.0 m NAP (south) and +6.5 - +7.0 m NAP (north). In spite of the number of habitats the shores are rather steep in the system (Simons *et al.*, 2000).

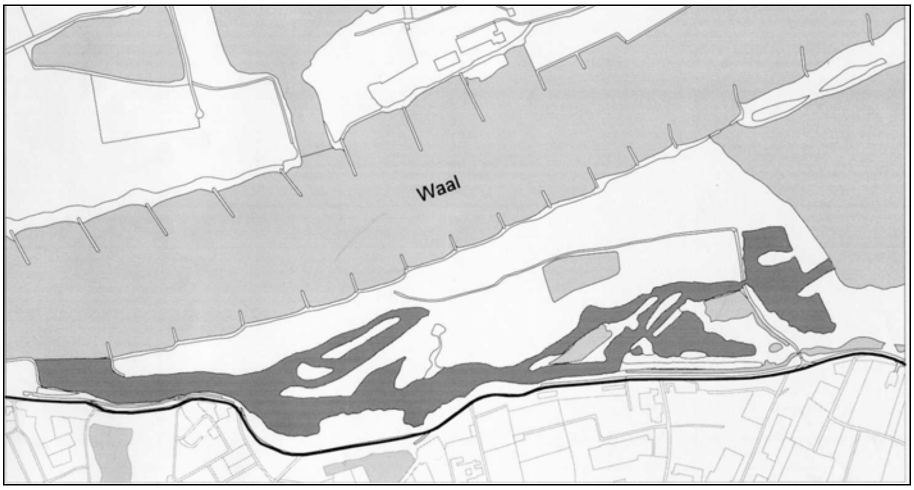


Figure 2.8. “Beneden-Leeuwen” (picture from Jans).

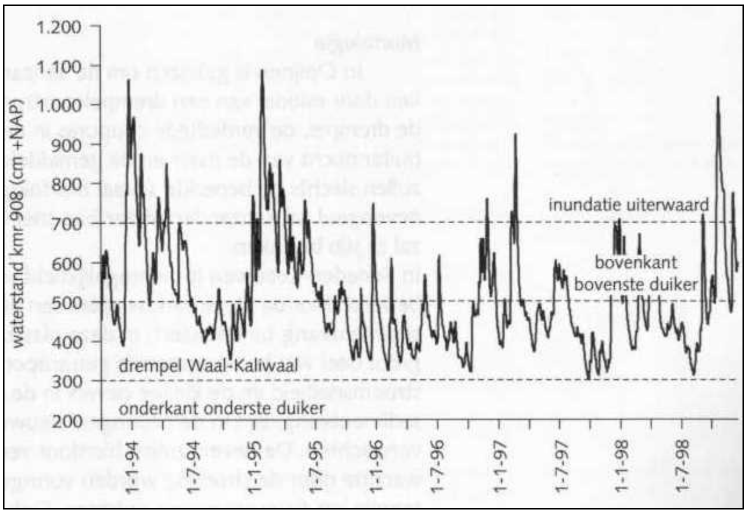


Figure 2.9. The water levels at “Beneden-Leeuwen”. The from top to bottom the dotted lines indicate respectively: inundation of the floodplain, top of upper culvert, threshold river-inflow, bottom of lowest culvert (source: Simons *et al.*, 2000).

The goal of the project is the development of lotic habitats in the floodplain that used to exist in the main channel. (Simons *et al.*,2000).

Monitoring

The goals of the monitoring programme of "Beneden-Leeuwen" (Table 2.4) were to determine (Simons *et al.*, 2000):

- the discharge in the secondary channel in relation to the discharge of the "Waal" and changes in time
- the composition and height of the bottom and shore of the main channel, the sand pit and the secondary channel and changes in time
- the function of the secondary channel for the fish and aquatic macro-invertebrates community in the secondary channel and the connected clay pits, oxbow lake and sand pit
- the function of the secondary channel plus shores in the floodplain for the vegetation, the bird community and the dragonflies in the area
- the value of the area for amphibians.

Table 2.4. Monitoring programme "Beneden-Leeuwen" 1993-1998 (Simons *et al.*, 2000)

	1993	1994	1995	1996	1997	1998
Discharge and stream velocity	-	-	-	+	+	+
Water level Waal	-	+	+	+	+	+
Water quality	-	-	-	+	+	-
Morphology channel	-	-	+	+	+	+
Morphology oxbow lake	-	+	-	-	-	-
Morphology sand pit	-	+	+	+	+	-
Morphology summer bed	-	+	+	+	+	-
Grain size distribution	-	-	+	-	-	-
Texture shore clay pit (at inflow)	-	-	-	+	+	-
Grain size distribution/organic	-	-	+	+	+	-
Composition macro-invertebrates	-	+	+	+	+	-
Composition fish	-	+	-	-	-	-
Growth and composition fish	-	-	+	-	-	-
Grow and forage function fish	-	-	-	-	+	+
Aquatic vegetation	+	-	+	-	-	-
Vegetation floodplain	-	-	+	-	-	-
Water birds	+	+	+	+	-	-
Breeding birds	-	+	+	-	+	-
Stilts	-	+	+	-	-	-
Composition, propagation dragonflies	-	+	+	-	+	-
Composition grasshoppers	-	+	-	-	-	-
Migration, propagation, land biotopes amphibinas	-	+	-	-	-	-

Results

The results and the way they were obtained are extensively described by Simons *et al.* (2000). Here a short summary is given.

Little sedimentation and erosion took place in "Beneden-Leeuwen" due to the sand pit at the beginning of the secondary channel system, which acts as a sediment trap. Behind the two culverts there was some erosion. The eroded material is deposited further in the secondary channel.

No aquatic vegetation was present in the secondary channel. There was some vegetation in the isolated clay pits and pools north of the secondary channel. Softwood and floodplain forest was pre sent near the secondary channel and clay pits. Due to the steep shores the chances for vegetation development on the ATTZ were small.

There were more macro-invertebrates species found in "Beneden-Leeuwen" than in

“Opijnen”, due to the large variety of water bodies in “Beneden-Leeuwen”. However, the number of rheophilic species is almost the same as in “Opijnen”. Flood events seemed to be more important for the rheophilic macro-invertebrates than the opening of the secondary channel. Macro-invertebrates species could reach the secondary channel during those events but could not maintain themselves afterwards. The variety of species was largest in the oxbow lake, pools and clay pits, due to the variety of hydrological circumstances there.
The number of (rheophilic) fish species increased after the opening of the secondary channel. “Beneden-Leeuwen” was compared to “Opijnen” of less importance for juvenile rheophilic species. This was probably due to smaller area with lotic conditions and the lack of gentle slopes, in “Opijnen” there is always shallow flowing water present and deep water in reach. “Beneden-Leeuwen” did not play an important role for older rheophilic fish species. The following rheophilic species were found in “Beneden-Leeuwen”: bullhead, nase, barbel, dace, chub, gudgeon, ide and asp. Like in “Opijnen” eurytopic species (bleak *Alburnus alburnus*) dominate the fish community.
The results for birds and amphibians are also listed by Simons *et al.* (2000).

2.2.4 Gameren

General

The secondary channels near Gameren are situated where the Rhine transits from the free flowing, meandering Waal into the wide, straight Merwede (Jans *et al.*, 2000). At low river discharges there is already some measurable tidal influence (Van Wijngaarden, 1998; Schropp *et al.*, 2001), which is however insignificant compared to the river hydrodynamics. The system consists of three channels (Fig. 2.10). Two dynamic high water channels in the summer bed (“G265” and “G100”) and a permanent flowing secondary channel (“G365”) between the summer and winter dike. The numbers in the name of the various channels refer to the number of days the channel was designed to be connected to the river.

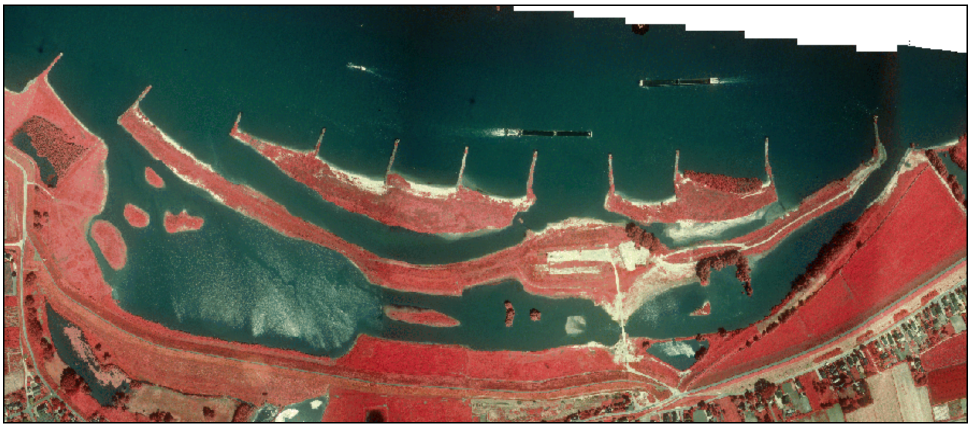


Figure 2.10. “Gameren” (false colour aerial photo, June 2000).

The two high water channels in the summer bed are smaller and flow only part of the year (Fig. 2.11). “G365” flows whole year and shows a wide variety in depths and width because it consists of an shallow oxbow lake which is connected to a deep sand pit. This sand pit functions as a sediment trap. “G365” was at first downstream connected and in 1998 the regulatory work halfway, connecting the oxbow lake was made. In 1999 then, an upstream connection to the Waal was made. The sand obtained from digging the inflow opening was put in the deeper parts of the channel (east of the access road). This was done because of two reasons, a) because of licenses, no soil should leave the area, and b) because of the desire for more gentle shores (Jans *et al.*, 2000). Just before the regulatory work, on the left shore, there is an isolated pond.

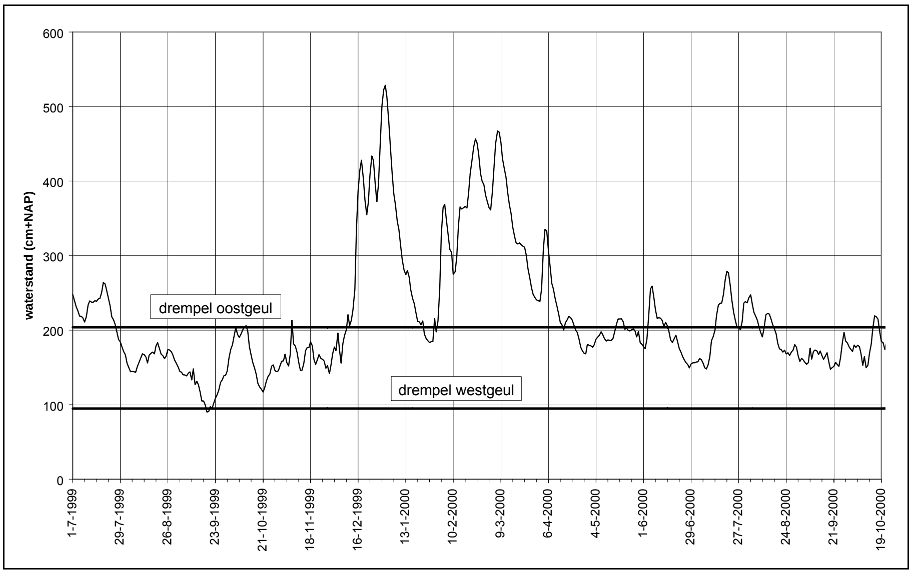


Figure 2.11. The water level at “Gameren” (km 937), July 1999 – October 2000. Upper straight line: threshold “G100”, lower straight line: threshold “G265” (source: Jans *et al.*, 2001).

The goal of the secondary channels at Gameren is to bring back natural processes. According to Jans *et al.* (1998) another reason for the secondary channels was safety; the secondary channel should compensate for the loss of carrying capacity which was caused by the movement of the winter dike towards the river.

Monitoring

The goal of the monitoring programme is to gain information on (Jans *et al.*, 2000):

- Undesired side effects
  - The level of sedimentation and the occurrence and strength of side currents in the main channel
  - The level of erosion of the dikes
  - Sedimentation of polluted silt
- Ecological developments
  - Whether the development of vegetation is bothering the created space for the river
  - The effort needed to keep the channel flowing
  - Effectiveness of the sediment trap
  - Settlement of target species for secondary channels
- Knowledge on ecological recovery, the hydro-morphological development and the management of secondary channels
  - Explain erosion and sedimentation patterns in the secondary and main channel
  - Identify failure factors in terms of habitat and eco-toxicology for target species that do not settle as expected.

In 1997 a monitoring programme was set up for the period 1998-2003 (Table 2.5).

Table 2.5. Monitoring programme for “Gameren” (Jans *et al.*, 1998)

Parameter \ Frequency (year^{-1})[*]	0.2	0.4	0.5	1	2	4	12
Registration management/developments	-/-	-/-	-/-	+/+	-/-	-/-	-/-
Spatial patterns micro-ecotopes in the secondary channel	-/-	-/-	-/-	+/+	-/-	-/-	-/-
Visual look shores	-/-	-/-	-/-	-/-	+/+	-/-	-/-
Grazing density	-/-	-/-	-/-	+/+	-/-	-/-	-/-
Bottom height Waal	-/-	-/-	-/-	-/-	-/-	+/+	-/-
Bottom height inflow opening	-/-	-/-	-/-	-/-	+/-	-/+	-/-
Bottom height secondary channel and shores	-/-	-/-	-/-	+/-	-/+	-/-	-/-
Bottom height sedimentation trap	+/-	-/-	-/-	-/-	-/+	-/-	-/-
Sediment thickness secondary channel + inflow opening	+/-	-/-	-/-	-/-	-/+	-/-	-/-
Sediment thickness sedimentation trap	+/-	-/-	-/-	-/-	-/+	-/-	-/-
Sediment composition sediment trap	-/-	-/-	-/-	+/+	-/-	-/-	-/-
Sediment composition secondary channel	-/-	-/-	-/-	-/-	+/+	-/-	-/-
Concentration and composition suspended sediment secondary channel	-/-	-/+	-/-	-/-	-/-	-/-	-/-
Discharge secondary channel	-/-	-/-	-/-	-/-	-/-	-/-	+/+
Stream velocity secondary channel	-/-	-/-	-/-	-/-	-/-	-/-	+/+
Stream pattern Waal	-/-	-/-	-/-	-/-	-/-	-/-	+/+
Floristic quality secondary channel and shores	-/-	-/-	+/+	-/-	-/-	-/-	-/-
Vegetation structure	-/-	-/-	+/+	-/-	-/-	-/-	-/-
Species and quantity composition evertebrates secondary channel	-/-	-/-	-/-	+/+	-/-	-/-	-/-
Species and size composition fish secondary channel	-/-	-/-	+/+	-/-	-/-	-/-	-/-
Foraging water birds	-/-	-/-	+[**]/+	-/-	-/-	-/-	-/-
Biological availability contaminates	-/-	-/-	+/+	-/-	-/-	-/-	-/-
Ecological effects of contamination	-/-	-/-	-/+	-/-	-/-	-/-	-/-
Chemical parameters bottom	-/-	-/-	-/-	+[***]/-	-/+[****]	-/-	-/-

[*] frequency for risk analyses and evaluation purposes / frequency for knowledge purposes.
[**] frequency = monthly, every second year.
[***] the sedimentation trap is monitored only once, after five years.
[****] the sedimentation trap is monitored every second year.

Results

The data collection and results are extensively described by Jans *et al.* (2000, 2001), Schropp *et al.* (2000, 2001) and Sorber *et al.* (1999). Here a short summary is given.
The morphological activity of “Gameren” is much larger than at “Opijnen” and “Beneden-Leeuwen” because the discharge of the secondary channel is larger (Table 2.1). Immediately after the opening of the two smaller channels erosion took place and created cliffs at the inflow openings of both channels and some parts of the shore of “G265”. Further in the two channels sedimentation occurred, thereby creating sand banks. In “G100” the sand bank covered half the channel and reached the height of the threshold in the entrance. In “G365” erosion took place downstream of the regulatory work and at the right shore at the inflow opening. Also the isolated pond became connected to the secondary channel. Before the connection of the secondary channel to the Waal, the highest point was at the bridge (0.0 m NAP) but after the inflow opening sedimentation took place and a sand bank developed. The morphological processes in the high water channels do not cause problems for the safety. However, downstream of the bridge in “G365” erosion takes place near the winter dike and here something should be done in the future to protect the winter dike.
No aquatic vegetation was found in “Gameren” except in some pools in “G100” that become isolated at lower water levels (*Callitriche palustris* and *Zannichellia*

palustris). Aquatic/shore vegetation was found in the secondary channels (*Polygonum amphibium*, *Sagittaria saittafolia*, *Butomus umbellatus*). The floristic quality of the shoreline vegetation is high in “Gameren”.

So far, the highest number of macro-invertebrates species was found in “G100” due to the species rich silt samples and the variety of habitats and depths. Besides, “G100” was a complex of flowing and non-flowing conditions during the sampling and “G100” is the only channel of “Gameren” with some vegetation. The number of rheophilic macro-invertebrates species increased after the opening of “G365” but this did not lead to a decrease in the number of non-rheophlic species. The diversity of macro-invertebrates in “Gameren” is sensational: much more species than in the Waal and moreover, species were found that were not found in the Waal itself.

The species richness of fish in “Gameren” varied between 12 and 15 species. Most of the species belonged to the eurytopic guild. But also nine rheophilic species were found: barbel, chub, dace, nase, gudgeon, asp, ide, stickleback and flounder. The percentage of rheophilic species declines, like in “Opijnen” from June to September, mainly caused by the drastic decline of barbels. Species of the limnophilic guild and rheophilic C (stickleback and flounder) species were rare. Relatively the most rheophilic fish was caught in “G100”, densities of rheophilic species increased the last years and the density of eurytopic stayed more or less the same. In “G265” the number of eurytopic species decreased. For rheophilic species, there was no clear trend. “G365” can be regarded as three separate water bodies. Mainly eurytopic species were found in the deep sand pit, the fish community of the oxbow lake and the “middle part” were more or less the same. The densities of rheophilic species in “G365” did not increase after the connection to the Waal. For obligatory rheophilic species “Gameren” (“G100” and “G265”) had the highest beneficial value as compared to “G365”, but for partially rheophilic cyprinids and for eurytopic species, this secondary channel showed no beneficial value above yet existing groin fields (Grift *et al.*, 2000b).

3 Danube

3.1 General

The present Danube (Fig. 3.1) is formed by the confluence of two streams, the Bigach and Breg, originating in the Schwarzwald Mountains, which meet at Donaueschingen at a height of 676 m (Stancik *et al.*, 1988). It is Europe's second largest river with a length of 2857 km and the only important European river that flows from west to east. (Hagmann, 1998). It starts in Germany and ends in the Black Sea. It crosses the borders of ten states (Germany, Austria, Slovakia, Hungary, Croatia, Republic of Yugoslavia, Bulgaria, Moldova, Romania and the Ukraine) making it the most "international" river in the world. Another eight states are in its drainage basin (Switzerland, Czech Republic, Poland, Slovenia, Bosnia-Herzegovina, Macedonia, Albania and Italy). The Danube basin area is 817,000 km^2 and drains eight percent of Europe's land mass and more than 80 million people live in the basin of the Danube (Hagmann, 1998).

Figure 3.1. The Danube (Source: Microsoft Encarta Online Encyclopedia, 2001).

The Danube can be divided into four sections (Fig. 3.2): (1) the upper reach, from its origin to Bratislava, (2) the middle reach, from Bratislava to the Iron Gate dams, (3) lower reach, encompassing all the Bulgarian and Romanian lowlands, and (4) delta. The two secondary channels investigated in this thesis are located in the upper reach (Regelsbrunn) and in the middle reach (Vén Duna).

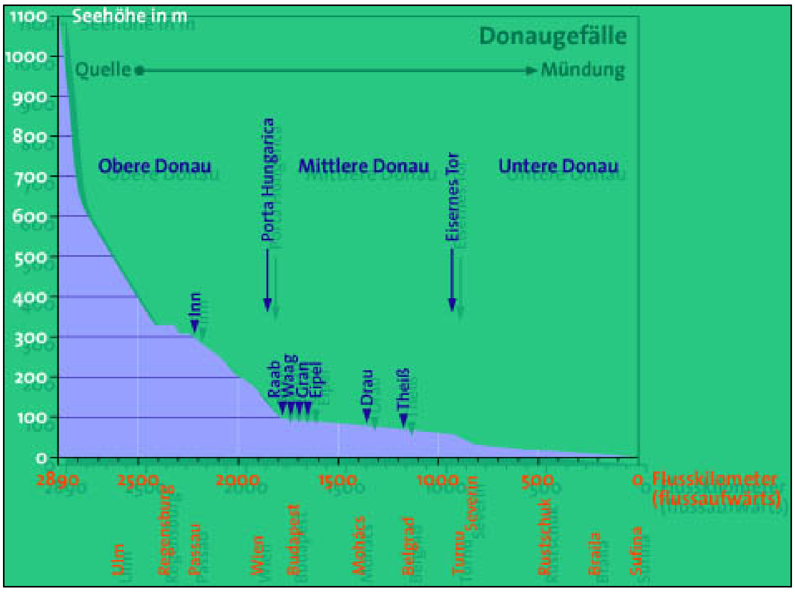


Figure 3.2. The fall of the Danube. The x-axis shows the river kilometers, the y-axis shows the sea level (m) (source: www.donauauen.at/wissen/index_1_2.cfm).

In the middle of the last century, the Danube was a wide branching river which divided into main, side and still arms, whose course was always changing and which had year round dynamic exchange with the floodplain (Hagmann, 1998). The Danube River has undergone a fate similar to that of most large river in temperate Europe and North America (Tockner *et al.*, 1998). Protection works against floods started in Hungary already in the 16th century (Zinke, 1999). Over the past 150 years, human impacts have fundamentally modified the river; it was channelized, polluted and finally impounded (Tockner *et al.*, 2000a). River works altogether are responsible for a loss of some 15-20,000 km^2 of Danube floodplains (Zinke, 1999). A second phase of engineering started with the construction of hydropower dams (1954), which almost completely disconnect the river from its floodplains (Schiemer, 1999). The process of engineering the Danube had a knock-on effect, damming one part of the river shifted the problem downstream, that engineers resolved with yet another dam (Schiemer, 2000). Over the past 50 years more than 90% of the Upper Danube and its major tributaries have been dammed for hydropower production (Schiemer *et al.*, 1999).

The Danube has different functions. Central European economy nowadays depend on the Danube since it plays a pivotal role for shipping, power generation, agriculture and municipal water (Tockner *et al.*, 2000a). The Danube has contrary to the Rhine, its annual high water not during winter (Fig. 3.3). They occur in spring and summer because of the snowmelt in the Alps (Heiler *et al.*, 1995). The Danube is characterized by high and constant amounts of nitrate and high inorganic particle concentrations (Heiler *et al.*, 1995). Important natural habitats in the Danube are the sandbanks, the eroding clay banks, the snag in the riverbanks and bank vegetation (Klink, 1992).

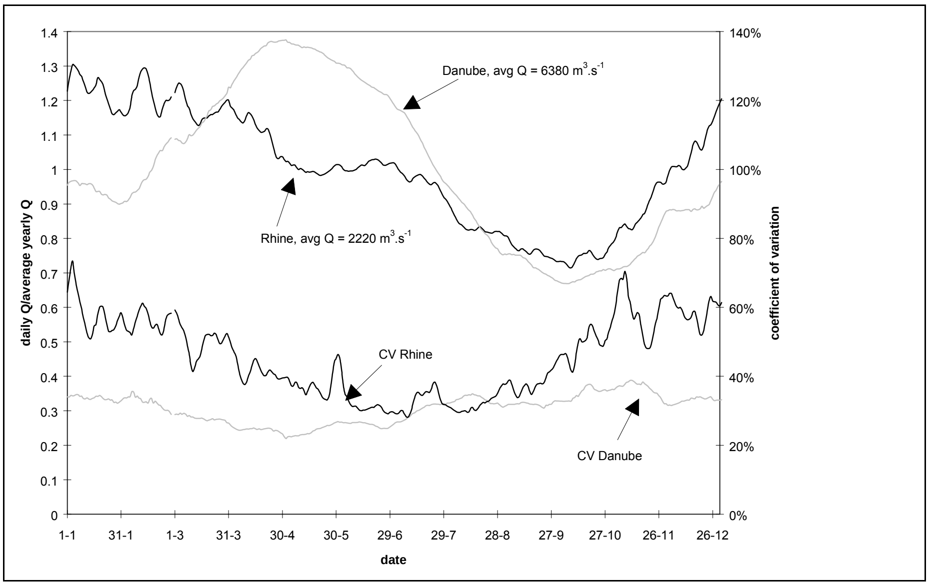


Figure 3.3. The flood pulses, expressed as the ratio between the average daily discharge (Q) and average yearly discharge in the rivers Danube (1932-1997) and Rhine (1901-1999) at comparable locations along their river courses downstream the last tributary and upstream the point where the rivers split into branches that form the delta. The coefficients of variation (CV) of the daily discharge is given on the right Y-axis (source: Buijse *et al.*, 2001).

3.2 Secondary channels

Two secondary channels of the Danube are included in this comparison: "Regelsbrunn" in Austria and the Vén Duna in Hungary (Table 3.1).

Table 3.1. Characteristics of the investigated secondary channels: Regelsbrunn and Vén Duna.

	Regelsbrunn	**Vén Duna**
Country	Austria	Hungary
River stretch	Upper reach	Middle reach
Position (kmr)	1901 - 1895	1483.9 – 1480.9
Area	Alluvial Zone National Park	Gemenc Protected Landscape Area
Opening	1998	1998
Flowing (days/year)	222	Almost all year
Discharge (%)	2	± 5.5 *
Stream velocity (m/s)		0.68 – 1.23 **
Length (km)	10	3.8
Width (m)	100	80-100
Depth (m)	1.5 – 7	3 ***

* calculated from data obtained from Sziebert (Fig. 3.12)
** data from obtained from Sziebert (Appendix B)
*** at low flow level (pers. comm. Bakonyi)

The Austrian stretch of the Danube is in the upper course of the river and is characterized by its steepness (average slope 0.043% (Fig. 3.2)) and high discharge due to large tributaries from the Alps (Heiler *et al.*, 1995). Due to its steepness, its stream velocity, its transport possibilities and temperature regime the Austrian Danube is classified as a mountain stream (Schiemer *et al.*, 2000). Biodiversity levels in the Upper Danube are high compared to other European rivers such as the Rhine or the Rhone (Ward *et al.*, 1999). This is due, in part, to the biogeography, i.e. the

west-east orientation of the catchment, which connects the area with the species-rich Ponto-Caspian region (Schiemer, 1999).
Large-scale river regulation began in the 19th century along the entire Hungarian stretch of the Danube in order to improve the navigability of the river and to reduce ice-jamming (Csányi *et al.*, 1994). The only existing large side arm systems are still present in the Szigetköz and the Gemenc area but both of them suffer from several recent human impacts (Csányi, 1998a). The Hungarian secondary channel in this comparison, the Vén Duna, is situated in the Gemenc area. In the Gemenc floodplain, which is for the largest part under forest, still remnants of the former natural alluvial hardwood and softwood forests are present (Marchand, 1993). Although the Danube is larger than the Rhine and the Danube in South Hungary is still 1450 km from its mouth at the Black Sea, these two river stretches can be compared because the river slope (Fig. 3.2) and width of the South Hungarian Danube are comparable to the Rhine entering the Netherlands (Schoor & van Splunder, 1993). The discharge varies considerably throughout the year, the mean discharge is 2300 m^3/s (Sziebert & Zellei, 1998), which is the same as in the Rhine entering the Netherlands.

3.2.1 Regelsbrunn

General

In 1983 a hydro-power dam in the Danube downstream of Vienna was scheduled to be built. However, due to protests of the public this plan was finally abandoned. Thereafter it took more than 10 years of negotiations and planning before a decision was reached to create an “Alluvial Zone National Park” along the Danube from Vienna to the Slovakian border, in order to preserve the largest remaining alluvial forest in Central Europe (Schiemer, 1999). This free-flowing section still shows its major functional attributes associated with the dynamics of water level fluctuations and bed-load transport, despite being highly influenced by former river regulation works. The backwater system (Fig. 3.4e) is dominated by a former river channel that was cut off from the Danube at its upstream end more than 100 years ago (Tockner *et al.*, 1998).
Before the reconnection to the Danube, the side arm maintained surface connection with the main stream for 183 days annually, but only at its downstream end (Tockner *et al.*, 1998)(Fig. 3.5). The main goal of the Danube Restoration Project was to increase the upstream surface connection with the river and the connectivity within the side channel to reduce retention time (Hein *et al.*, 1999). Improving hydrological connectivity and dynamics was achieved by a series of engineering measures: 1) lowering the riverside embankments by creating 30 m wide overflows at five positions where natural inflow channels exist (Fig. 3.6a). 2) additional artificial openings (10 m wide, 1.5 m high) at inflow channels allowing a regulated inflow above MW – 0.5 m (Fig. 3.6b). 3) weirs in the side arm system will be lowered or equipped with larger openings to allow shorter water retention in the backwaters, improve the rate of discharge and provide a more continuous water course (Schiemer *et al.*, 1999). The inlets allow water to flow into the floodplain for 222 days of the year and lowering the embankment provides heavy flow on 152 days (Schiemer *et al.*, 2000). The different positions of the inflow areas and the varying distances from the Danube allow several types of water bodies to be distinguished according to the degree of river influence (Heiler *et al.*, 1995).

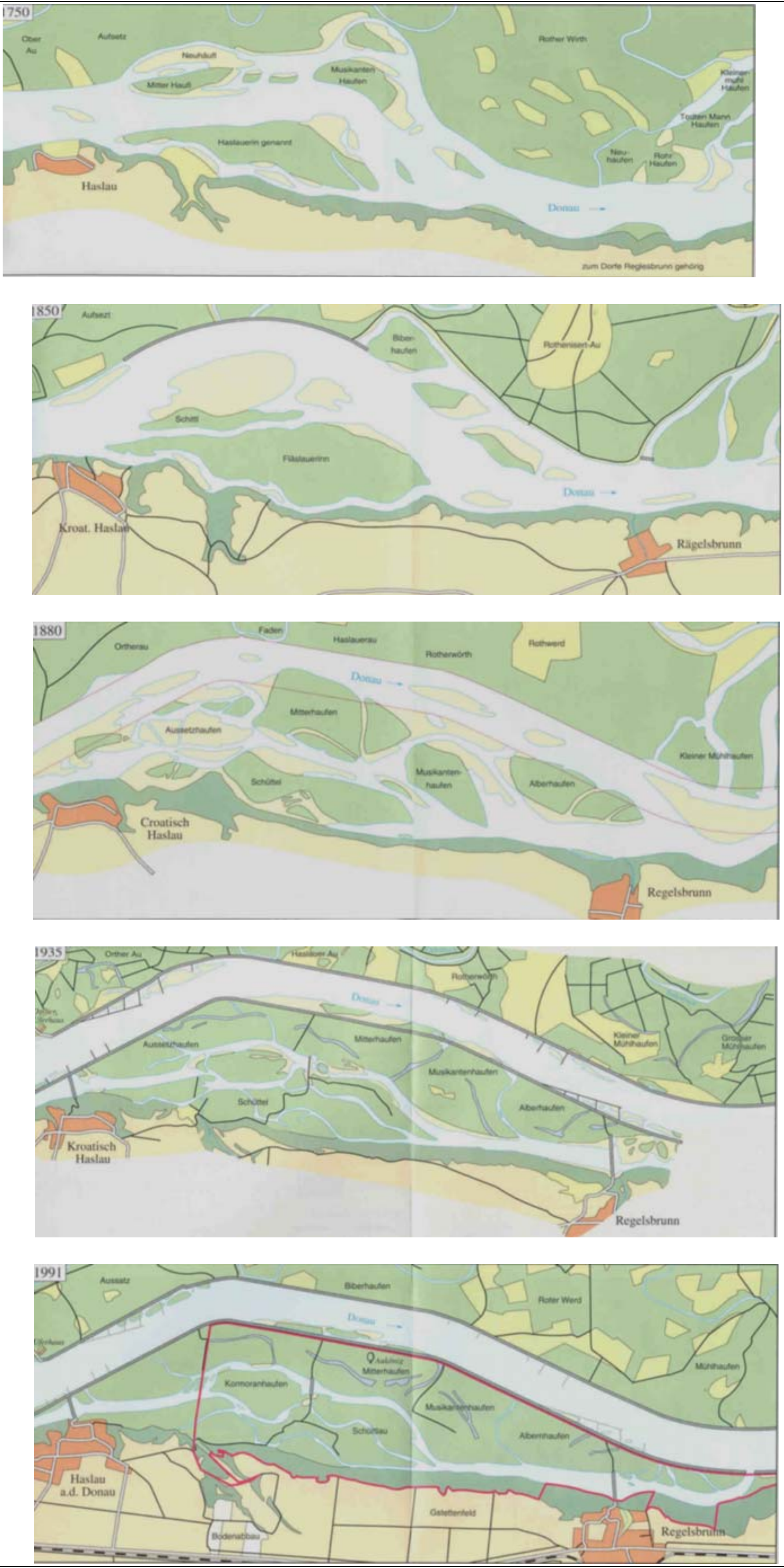


Figure 3.4. The Danube near Regelsbrunn, river km 1901-1895, a) 1750, b) 1850, c) 1880, d) 1935, e) 1991 (source: Landschaftshistorische Entwicklung der Regelsbrunner Au, WWF).

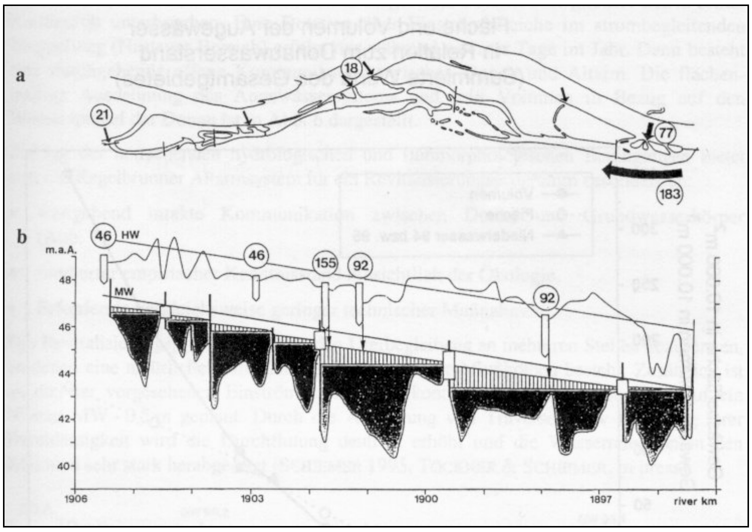


Figure 3.5. a) The backwater system at Regelsbrunn. Black bars represent weirs. Arrows indicate inflow areas (mean connectivity in days per year). b) Longitudinal transect at mean water level in relation to the dam (thin line) and to the water level of the Danube at mean (MW) and high (HW) water level. Restoration measures are indicated as white bars. Numbers indicate mean connectivity (days per year) after restoration (source: Schiemer *et al.*, 2000).

Figure 3.6. Engineering measures to improve the hydrological connectivity, a) lowering the riverside embankments, b) artificial openings at inflow channels (photos: Verheijen).

“Regelsbrunn” has been selected for restoration on the basis of the following considerations: a) floodplain water bodies and the Danube channel are still dynamically interconnected via groundwater flow. b) Only minor engineering work will be necessary to enhance hydrological connectivity considerably. c) An empirical database, including the main functional processes and habitat requirements of the biota, is available. d) The area is large enough to identify limnological processes which are representative for the whole river-floodplain system and e) the land is in the public domain (National Forest Authority) or is held in trust by WWF (Tockner *et al.*, 1998). Constraints for restoration include ensuring a minimum water depth of 250 cm in the main shipping channel for navigation (International Rhine-Maine-Danube Waterway) and protecting human settlements against floods. The free-flowing section is suitable habitat for more than 80% of the fish species occurring in Austria and for two-thirds of all dragonflies and about one third of the caddisflies (Tockner *et al.*, 1998).

Monitoring

The ecological monitoring programme (Schiemer *et al.*, 2000) consists of the following aspects:

- Hydrology:
    - Water level dynamics of the surface and ground water
    - Drain dynamics and water retention of the separate water bodies
- Geomorphology:
    - Morphology of water bodies and land, connection or isolation degree of water bodies;
    - Sediment composition
- Biotic indicators:
    - Phytoplankton
    - Aquatic and semi-aquatic macrophytes
    - Zoobenthos
    - Molluscs
    - Odonates
    - Fish
    - Amphibians
- Functional aspects:
    - Hydrochemistry
    - Dynamics of geomorphological processes, sediment load
    - Primary production and species composition of phytoplankton

Results

The situation before the opening was described extensively in a baseline study (Schiemer & Reckendorfer, 2000). It was expected that there would be (Schiemer *et al.*, 2000):

- stronger outflow of fine sediment from the floodplain
- more bed load dynamics
- rise of water level in the oxbow lakes
- increase of the aquatic area and a shift of the ATTZ to higher grounds
- increase of the primary production by phytoplankton
- higher ecological value for riverine species.

The completion of the construction work is still too recent to fully assess the results at this stage, although preliminary observations indicate initial success in reaching the restoration goals. One of the openings (“Sweet Hole”), widened from 10 m to a width of 70 m via natural dynamics of the river, and the first small river cliffs have been formed here. Gravel banks have also increased considerably. The migration routes for fish have been re-established for at least seven months of the year and there has been an increase in fish yields, because of the regeneration of fish breeding grounds. More kingfishers *Alcedo atthis* and sand martins *Riparia riparia* are present due to the increasing areas of river cliffs and beavers *Castor fiber* have started building dams again (WWFa). Some trees have been translocated in the floodplain (Fig. 3.7), via the new flooding dynamics, which is an important biodiversity issue (WWFb). Hydrological data were already present (Fig. 3.8).

Figure 3.7. Morphological developments at "Regelsbrunn" (photo: Verheijen).

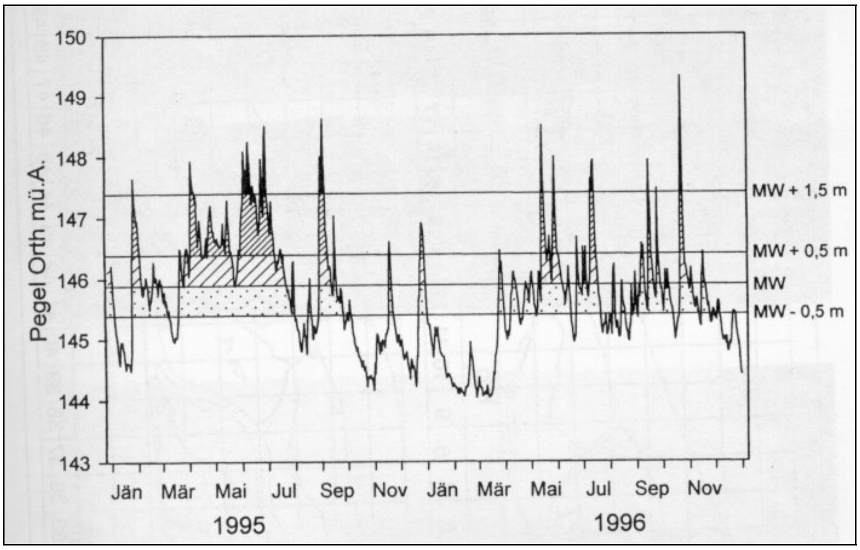


Figure 3.8. Hydrograph of the Danube illustrating (1) the status of hydrological connectivity before rehabilitation (black area – MW+1.5 m); (2) the floodplain connection via levee-lowering after rehabilitation (MW+0.5 m); and (3) the floodplain connection via artificial openings after rehabilitation (MW-0.5 m) (source: Schiemer *et al.*, 2000)

3.2.2 Vén Duna

General

Large-scale river regulation began in the last century along the entire Hungarian stretch of the Danube in order to improve the navigability of the river and to reduce ice-jamming (Csányi *et al.*, 1994). However, there was a landlord who did not join the Water Management Association, so his lands were not defended by dikes. This is the reason why a 5-6 km wide and 40 km long floodplain remained between the new dike and the bank of the Danube which is now the Gemenc floodplain (Zsuffa, 2000). The Nature Conservation Area is 17,779 hectares large and one of the aesthetically and perhaps ecologically most valuable parts of the numerous floodplains in Hungary (VITUKI Consult Rt., 1991). It is situated on the right bank of the Danube, between River Stations 1515 and 1465 km, from the mouth of the Sió Canal to the embankment of the Baja-Pörböly railway line (Fig. 3.9). The area still has a large number of species which, on a national or international scale are considered relatively rare (Marchand, 1993). The Vén Duna is situated in this Gemenc Protected Landscape Area.

Figure 3.9. The Gemenc area. Vén Duna is situated above Baja, on the western bank (map received from Sziebert).

The area in its present state with numerous oxbow lakes is a result of a flood-control and reclamation project. The flood-control and reclamation project included 15 cuts over the Danube section between Fajsz and Mohács, which shortened the bed by 96 km and created a round 30 km long oxbow system along the 46 km long main channel (VITUKI Consult Rt., 1991). Before that project the Danube was meandering freely through the area and the present oxbow lakes (like Vén Duna, Holt Duna (all meaning Old Danube)) were the main channel in those days. In 1886 however a short cut was made (Fig 3.10) for the benefit of shipping and to prevent ice jams (pers. comm. Sziebert).

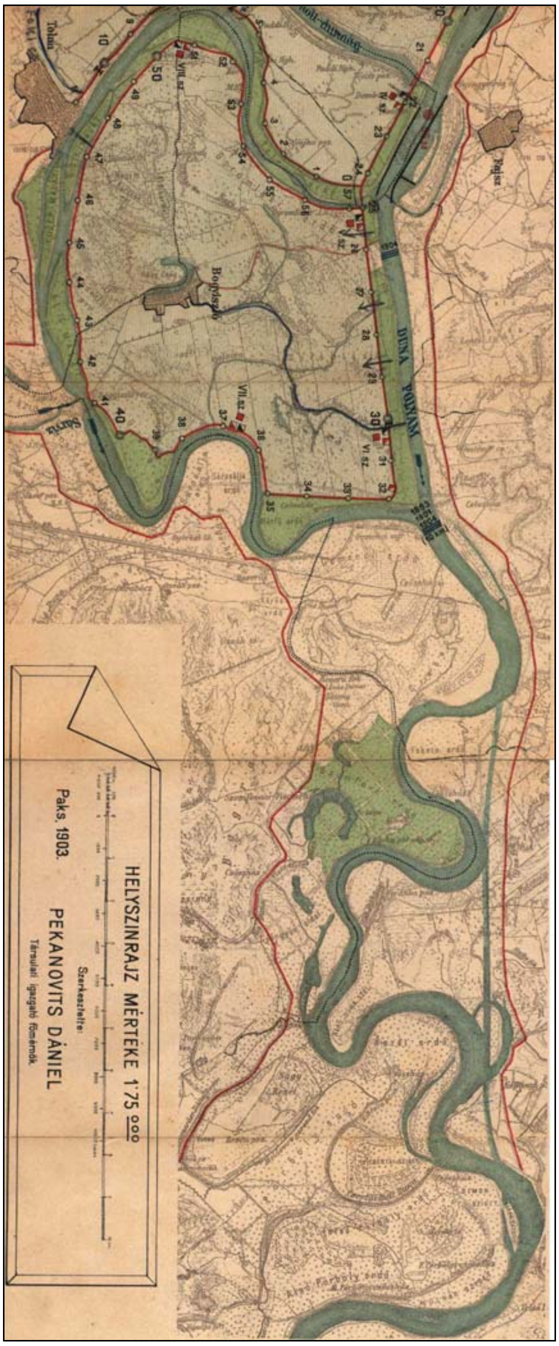


Figure 3.10. The Gemenc area in 1903 (map received from Sziebert).

However, instead of flowing through the short cut and thereby deepening and widening it the Danube kept on flowing through the Vén Duna (pers. comm. Sziebert). To force the Danube to flow through the short cut the Vén Duna was closed in 1911 by a cross-dike. The cross-dike was situated at a distance of about 800 m from the inlet. A small ”through” has been re-opened at about the middle of the channel (Fig. 3.11a). It could only provide some through flow above 400-500 cm Baja stage records (VITUKI Consult Rt., 1991). For shipping groins were built around the outlet of the Vén Duna in the late 1960s causing sedimentation in the outflow (pers. comm. Sziebert). Besides, forestry and hunting practices have imposed pressure on the floodplain. Also recreation and commercial fisheries play a role in the area (Marchand, 1993).

Figure 3.11. The opening in the cross-dike before (a) and after re-opening (b) (photos: a) Sziebert; b) Verheijen).

A rehabilitation programme started in 1997 as a scientific co-operation between the Institute of Inland Water Management and Waste Water Treatment (RIZA, the Netherlands) and several Hungarian research institutes in order to improve the ecological state and biotic value of this side arm (Csányi, 1998a). On 20 August 1998 the cross-dike was re-opened (Fig. 3.11b), reconnecting the Vén Duna to the Danube. Now the inlet is at ca. 150 cm Baja stage records, causing an almost permanent connection to the Danube (Fig. 3.12). For a good flow-through the outlet was dredged. The main goal of the reconnection with the Danube was to bring back flowing conditions in the Vén Duna. Some precautions were taken to avoid nuisance for the shipping. To avoid strong side-currents, especially near the bridge, the groin at the outflow was shortened and the two groins just before the outflow were removed and replaced by one parallel groin.

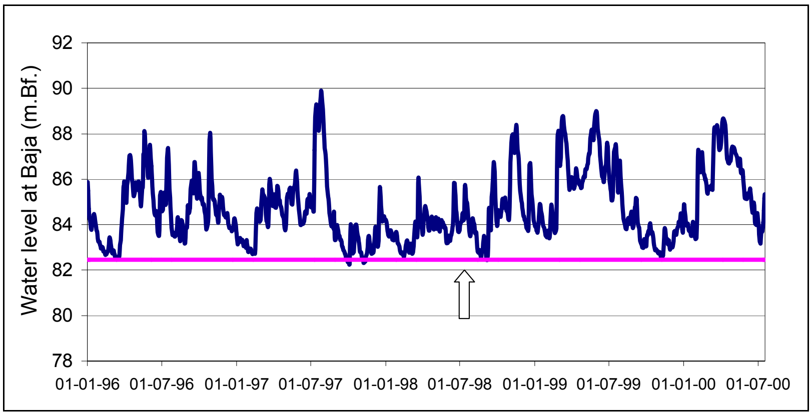


Figure 3.12. The water level of the Danube at Baja (m.Bf.) and the height of the inflow opening, 1996-2000. The re-opening is marked with the arrow.

Monitoring

Hydrological, morphological, water quality and ecological monitoring was carried out to describe the most important abiotic and biotic processes prior to an after the hydraulic intervention (Csányi, 1998b). The monitoring of water quality and the ecological monitoring was done by VITUKI Plc (Table 3.2). The hydrological and morphological monitoring was done by the Technical Faculty of the Eötvös József College in Baja. The monitoring is described by Csányi (1998a, 1998b, 1999, 2000).

Table 3.2. List of the sampling sites and sample types. (C: chemistry, P: phytoplankton, Z: zooplankton, M: macrozoobenthon, F: fish) (Csányi, 1998a; 1998b; 1999)

No.	Location	Sample
1	Vén Duna (between the Danube and the rock dam)*	C, P, Z, M
2	Vén Duna (600 m below the rock dam)*	C, P, Z, M, F
3	Vén Duna (400 m d/s Cserta-Duna confluence)*	C, P, Z, M
4	Vén Duna (200 m u/s the lower confluence)*	C, P, Z, M
5	Vén Duna (water body 10 m d/s the dam)**	M
6	Danube (1482.5 river km)*	C, P, Z, M, F
7	Vén Duna (arm at the island d/s the dam)***	M

* sampled at 09/19/97, 04/15/98, 07/14/98, 09/14/98, 11/02/98, 05/05/99, 06/18/99, 09/07/99, 10/20/99 and 11/11/99
** only sampled at 04/15/98, 09/14/98, 11/02/98 and 09/07/99
*** only sampled at 09/14/98 and 11/02/98

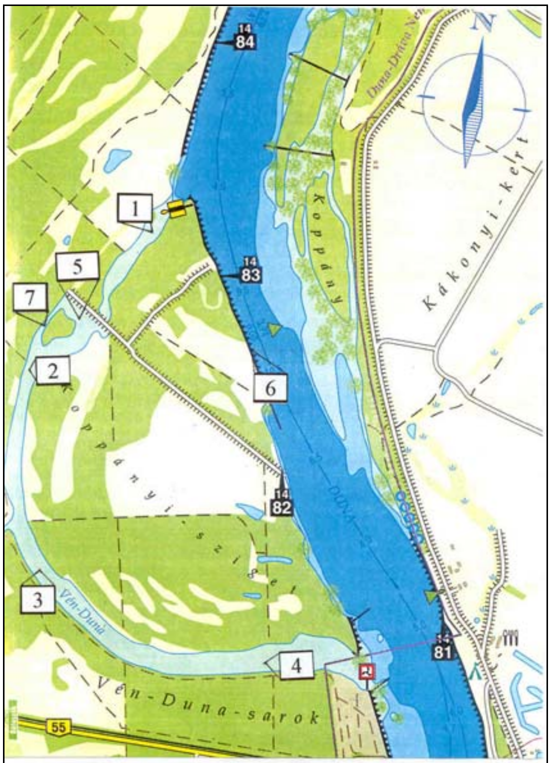


Figure 1. Map of the Vén-Duna indicating the sampling sites

Figure 3.13. Map of the Vén Duna indicating the sampling sites (source: Csányi, 1999).

Some of the results of the monitoring programme (Csányi, 1998a; 1998b; 1999; 2000) were reviewed by me and graphs were made to get an overview of the results of re-opening the Vén Duna. Also some hydrological data from Sziebert was reviewed too.
The fish species were divided into guilds according to Lelek (1987) and to Csányi (1998b). Although Csányi (1998b) classified pike (*Esox lucius*) as a limnophilic species, in this report it is classified as a eurytopic species. Pike only remains in the vegetation until the length of 45 cm (Bakker, 1992). The total number of fishes caught (divided into guilds) is shown in figure 3.14. In figure 3.15 the number of species caught is shown (also divided into guilds).
The zooplankton is divided into rheophilic and non-rheophilic species according to Csányi (1999).

Results

The results of the monitoring programme are described by Csányi (1998a, 1998b, 1999, 2000). Here results are given of the reviewed fish and hydrology data. Eurytopic fishes still dominate the community of the Vén Duna after the re-opening (Fig. 3.14a). The percentage of rheophilic fish in the Vén Duna did increase after the re-opening. Especially the catch of 30 august 1999 showed a large percentage of rheophilic fish but on that day the Danube did also show an increased percentage of rheophilic fish (Fig. 3.14b). The percentage of limnophilic fish in the Vén Duna decreased after the re-opening of the Vén Duna but unlike the Danube, there were still some limnophlic fish present.

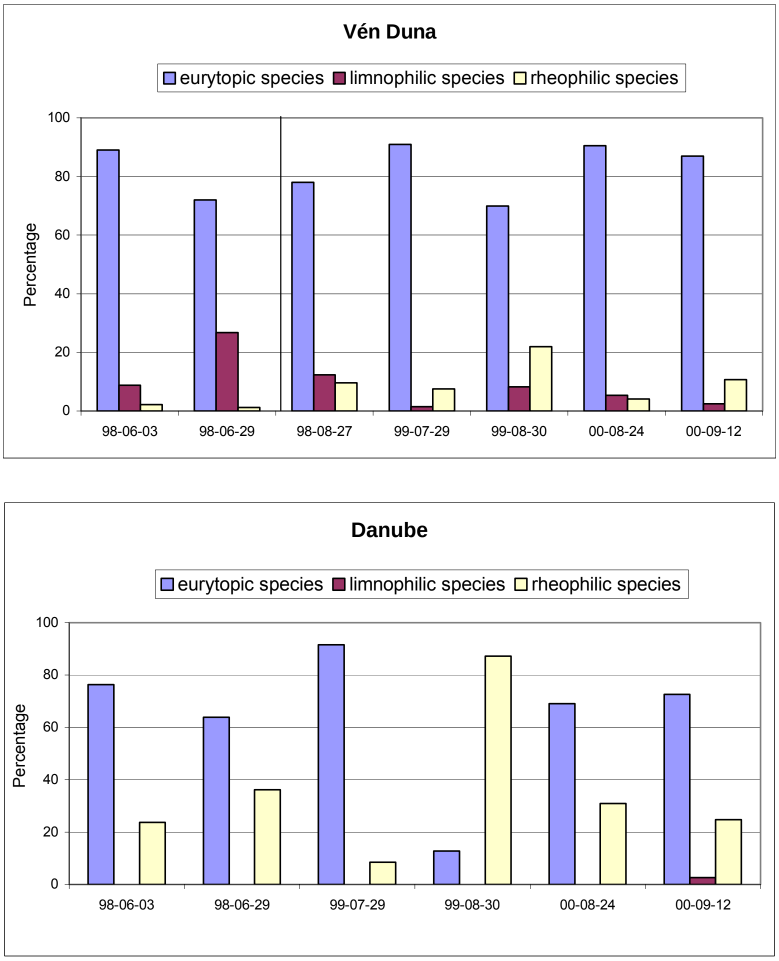
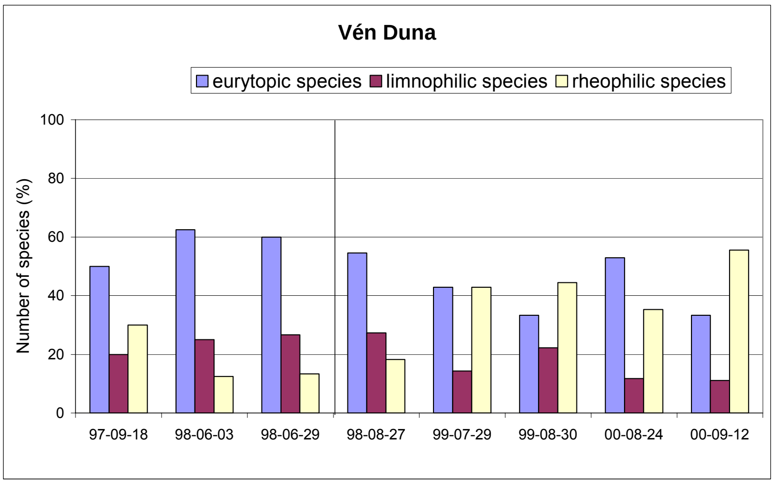


Figure 3.14. The number of fish (divided into guilds) caught. a) Vén Duna (the line indicates the opening of the cross-dike), b) the Danube.

The fish community was no longer dominated by eurytopic species after the reconnection to the Danube (Fig. 3.15a). Before the re-opening most species were eurytopic species, but after the re-opening it seems there was a shift towards the dominance of rheophilic species while the number of rheophilic species in the Danube stayed more or less the same, which was to be expected (Fig. 3.15b). The number of limnophilic species decreased after the re-opening.
The results of reviewing the zooplankton data are listed in Appendix C.



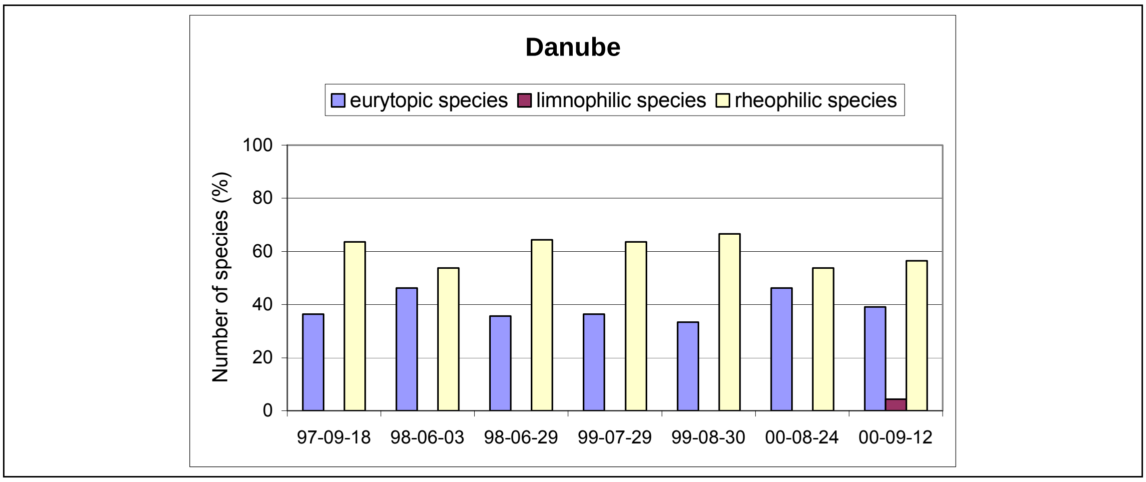


Figure 3.15. The number of species, divided into guilds. a) Vén Duna (the line indicates the opening of the cross-dike), b) Danube.

The discharge of the Vén Duna smoothly increases to ca. 5.5 % of the discharge of the Danube (Fig. 3.16). At high Danube discharges the discharge through the closed Vén Duna was the same as the discharge through the re-opened Vén Duna. This can be explained by the fact that at high discharges the Danube flows directly into the Vén Duna and thus, does not use the inflow opening anymore (pers. comm. Sziebert). That is why the graph was cut around that Danube discharge. The graph was made by combining graphs from Sziebert (Appendix D).

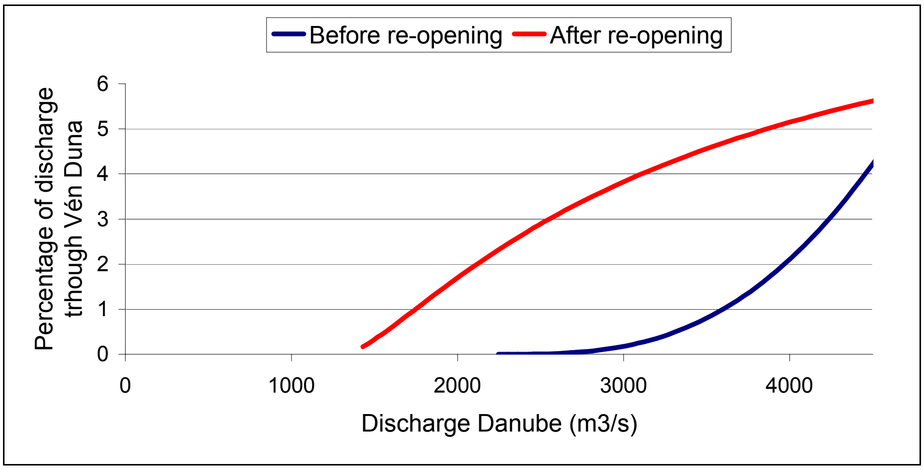


Figure 3.16. The percentage of the Danube discharge that flows through the Vén Duna.

4 Comparison

To be able to make a proper comparison, the different channels are grouped in this chapter. The positive and negative characteristics of the secondary channels are listed (Table 4.1). The subdivisions are made on the basis of different criteria. Because all secondary channels have different characteristics, a secondary channel is almost every time with other secondary channels in one group.
The first grouping is based on topographical location. The Dutch secondary channels in this comparison are all located along the Rhine, while the secondary channels in Austria and Hungary are situated along the Danube. This is an important difference. The characteristics of the two rivers differ. The sediment transport on the Danube (approx. $1\text{-}2 * 10^6\ m^3/y$) is about two to three times as high as on the Rhine. The Danube is almost two times longer and the river basin five times larger (Schoor & van Splunder, 1993), which is relevant for species richness. The Danube has its annual high waters during summer time while the Rhine shows the largest discharge in winter time (Fig. 3.3). The Danube is flowing from Central Europe to the Black Sea (Fig. 3.1), while the Rhine flows from Central Europe to the North Sea (Fig. 2.1). This has impacts for ecology, climate etc. For instance, the species composition of the two rivers differs. However this difference tends to be reduced after the opening of the Rhine-Main-Danube canal. For instance asp, which is present in high numbers in the Dutch Rhine nowadays, is thought to have entered the Rhine basin through this connection but may also have escaped from flooded ponds where they were stocked (pers. comm. Buijse). Nowadays the Danube has a considerably greater habitat potential than the Rhine does (Klink, 1992). This is due, in part, to the biogeography, i.e. the west-east orientation of the catchment, which connects the area with the species-rich Ponto-Caspian region (Schiemer, 1999). Besides, the Rhine is also more regulated than the Danube (Schoor & van Splunder, 1993). Another difference between the Rhine and Danube is that the Rhine is one of the most important commercial inland waterways in the world (Microsoft Encarta Online Encyclopedia, 2001). The Rhine is navigated on a much larger scale than the Danube.
Another grouping is based on differences in the river stretch along which the secondary channels are located. The Dutch secondary channels are all situated along the lower stretch and freshwater tidal region of the river. The Vén Duna is located at the middle reach of the Danube. However, it can still be grouped (in this manner) together with the Dutch channels. In Hungary, the mean discharge of the Danube is comparable with the Rhine discharge in the Netherlands and the river slope and width are comparable to the Rhine entering the Netherlands (Schoor & van Splunder, 1993). “Regelsbrunn” on the other hand is in the upper course of the Danube which is characterised by its steepness and relatively high discharge due to large tributaries from the Alps (Heiler *et al.*, 1995). Due to the straightening of the river stream velocities also increased (rhithralisation), but this is the case for all secondary channels. Due to the different locations along the rivers some characteristics differ. For instance the stream velocity and the morphological processes of “Regelsbrunn” which take place on a larger scale than in the Dutch and Hungarian secondary channels. The sediment along the Austrian stretch consists of gravel, while along the Vén Duna fine sand (approx. 300 μm) settles. On the river Rhine it exists of coarse sand (approx. 900 μm) (Schoor & van Splunder, 1993).
The secondary channels can also be grouped on the basis of morphology. On one hand, there are the channels along the Danube, both consisting of a channel of several kilometres. But on the other hand, the shorter secondary channels along the Rhine. The Dutch secondary channels can be divided into two categories: “Opijnen” and “G100” and “G265” are maximally 1 km long and “G365”, “Plan Doorstroming” and “Beneden-Leeuwen” which have a length intermediate to these two groups. The

differences in length have several consequences. For instance for safety purposes; longer channels can contain more water during high waters. Another consequence is the effect of sedimentation. In a secondary channel that is long compared to the length between the inflow and outflow, the stream velocity decreases in the secondary channel resulting in sedimentation. Sedimentation can be prevented by sedimentation traps like the sand pits in "Beneden-Leeuwen" and in "G365". Another consequence of a long secondary channel could be a larger variety of habitats, simply because there is more space for several habitats. Another consequence of a long secondary channel is that the effects of shipping, like changes in stream velocity and flow direction, are less severe. This is especially important along the Rhine where shipping takes place on a large scale: ships pass by every three minutes.
Not all secondary channels are connected to the river the whole year. The Vén Duna and "G365" are connected whole year. "Plan Doorstroming" forms a special group, because it is flushed every day but is not flowing the whole day. This is due to tide. But the other secondary channels do not flow whole year. Schropp (1994) and Wolters *et al.* (2000) state that the period during which the secondary channel conveys water has to be as long as possible. Hydraulic connectivity of the river and its floodplains is a key factor of floodplain rivers for productivity and species diversity (Schiemer & Zalewski, 1992; Schiemer, 2000). Changes in the frequency and intensity of connection to the river can directly influence both the planktonic production as well as the overall energy pathways in the water column (Hein *et al.*, 1999). With increasing disconnection, rheophilic elements and those species that require connectivity will decline (e.g. biodiversity of fish, macrozoobenthos) (Schiemer *et al.*, 1999).
Depth and the slope of the shores are important morphological characteristics of a secondary channel. From an ecological point of view, gentle slopes are generally preferred, since they offer large areas of shallow water depths (Schropp, 1994) and function as refugia for 0+ fish against the wash-out effects of floods (Schiemer & Zalewski, 1992). But secondary channels also should maintain a certain depth to ensure the channel contains water and is flows most of the time. The Vén Duna is mostly rather deep and also "Regelsbrunn" consists of deep parts but there the variation in habitats and thus the variation in water depths and shore slopes, is large. "Opijnen", "G265" and "G100" all are shallow secondary channels. The shores at "Beneden-Leeuwen", "G100", "G265" and Vén Duna (except around the island at the inflow, there the channel is shallow and has gentle slopes) are steep, while in "G365", "Plan Doorstroming" and "Regelsbrunn" different slopes are present. "Opijnen" has a shoreline with gentle slopes.
Another difference is the difference of authenticity. "Regelsbrunn", Vén Duna, "Plan Doorstroming" all are cut-off river branches which are reconnected to the main river again. Those are all located in a national park, respectively Alluvial Zone National Park, Gemenc Protected Landscape Area and the Biesbosch. While "Gameren", "Beneden-Leeuwen" and "Opijnen" are examples of (partly) excavated channels. Excavated channels have the advantage that the characteristics and functions of the channel can be determined in advance. The goals that should be reached can be taken into account by designing the secondary channel. Reconnected channels do not have this advantage, one should wait and see if the goals will be reached. But on the other hand, it is easier to re-open an existing river branch. The only thing what is required is to reconnect the channel and possibly dredge the channel. An existing river branch has also an aquatic community before the reconnection while newly excavated secondary channels first have to be colonised from scratch. In the Netherlands re-opening of former river branches is difficult because mostly these old oxbow lakes are situated at the foot of the dike. The stability of the dikes may become at risk when eroding processes come too close.
The monitoring programmes of the various secondary channels differed. "Opijnen", "Beneden-Leeuwen" and "Gameren" were all monitored by RIZA, which makes sure

that the secondary channels can be easily compared. For “Regelsbrunn” there was also an extensive monitoring programme. The baseline monitoring was done thoroughly, results after reconnection are not available yet. The monitoring of the Vén Duna was not done in such an accurate way. Partly this was agreed upon when the monitoring programme was set up. The monitoring was not done in a standardised way. Of course this makes it difficult to analyse results and it is even more difficult to use the results for comparisons with other secondary channels. Also the monitoring of “Plan Doorstroming” was, because of various reasons, not done as accurate as possible.
Although the secondary channels show some differences, they also have things in common. The first thing is that in all secondary channels the rheophilic community, both macro-invertebrates and fish, increased immediately after the re-opening. This seems logical because a (mostly) stagnant water body changed into a flowing water body. But on the other hand, it is remarkable that all, that different secondary channels show this trend. Of course there are differences in the degree of increase. Another similarity is that the feared nuisance for shipping did not occur at any location.

Table 4.1. The positive and negative characteristics of the secondary channels.

	Positive	Negative
Plan Doorstroming	• variation of habitats • flushed every day • situated in nature reservation park	• not flowing whole day • monitoring programme
Opijnen	• gentle slopes • variation of stream velocities • monitoring programme	• not flowing permanently • little morphological activity
Beneden-Leeuwen	• variation of habitats • monitoring programme	• steep slopes • low stream velocity • not flowing permanently • little morphological activity
Gameren	• flowing permanently (“G365”) • variation of habitats • morphological activity • monitoring programme	• partially drying out (“G100)
Regelsbrunn	• variation of habitats • baseline study • morphological activity • situated in nature reservation park	• not flowing permanently
Vén Duna	• flowing permanently • situated in nature reservation park	• monitoring programme • depth, steep slopes

5 Discussion

5.1 Discussion

In this chapter the results and the comparison of the secondary channels will be discussed. But before the results will be discussed there are a few things that should be paid attention to. First of all, what is the reason to open secondary channels?

Ecological improvement is stagnating and therefore restoration measures must not consider water quality improvements alone (van den Brink *et al.*, 1996). The connection of former channels must be considered in the management of large river systems (Amoros & Roux, 1988). Recent investigations of biodiversity in floodplains emphasise the importance of different degrees of connectivity and habitat heterogeneity for a high biodiversity (Tockner *et al.*, 2000b). By reconnecting floodplain water bodies the number of habitats increases. The connection of water bodies to the river should focus mainly on secondary channels. Downstream-connected water bodies are easier to reach for riverine organisms than isolated waters. But due to the lack of flow, certain processes will not take place. For instance, the possibility of a fish larvae to reach a floodplain water body passively is probably higher for a secondary channel which has an upstream opening with an inflow of water than for a downstream connected oxbow lake (Grift *et al.*, 2000a). However, the decision to open a secondary channel for ecological purposes should be taken with caution. By reconnecting isolated water bodies, the present ecological value of the water body should be taken into account. The ecological value of isolated former river channels is relatively high (Simons *et al.*, *in prep.*) and these vegetated water bodies are important for limnophilic fish (Grift, 2000) and connecting these channels to the river is undesirable, since present value may be lost (Grift *et al.*, 2001; Verheijen, 1999).
Another reason in favour of secondary channels is the advantage for the safety against floods. By opening secondary channels and lowering the floodplain more water can be stored during high waters.
There are no reasons for shipping to open a secondary channel. Secondary channels can only bother shipping. Disruption of the sediment transport may lead to the summer bed silting up and hence to a restriction of the navigable depth (Schropp, 1994). Thereby may the outflow lead to side-currents which hamper the ships. All secondary channels that were reviewed in this study did not have any negative side effects for shipping.
Secondly, is it possible at all to make a comparison between the secondary channels? The Rhine is more regulated than the Danube: groins can be found everywhere along the banks of the Rhine tributaries, while they are present just here and there along the Danube (Schoor & van Splunder, 1993) and the Danube presently has a considerably greater habitat potential (Klink, 1992). Although all secondary channels have different characteristics, still the secondary channels can be compared. All secondary channels are man-made and opened in more or less the same period. So they all are probably in the same initial development stage. Furthermore all secondary channels are situated along a large regulated river in Europe. Most of the larger rivers in the northern hemisphere are regulated, flow in most is totally controlled by dams and diversions, except for some free-flowing reaches and during extreme floods (Stanford *et al.*, 1996). So the same processes are important for all secondary channels. Due to the fact that both rivers are located in Europe, the difference in, for instance, climate and biodiversity is small. It would be different if they were located in different climatic regions. For instance, in the Amazon where flooding is a regular and predictable event while in Europe it is neither regular nor predictable (Reimer, 1991). Also both rivers have similar functions. Shipping, power generation, drinking water and agriculture are important functions of both rivers. All projects have more or less the same goal for the secondary channel; bringing back flowing conditions and to get back a rheophilic fish and macro-invertebrates community. Also the constraints are more or less the same; shipping should have no nuisance. The shipping channel should stay at a minimum depth and width. And finally, all secondary channels, except “Regelsbrunn”, are situated along comparable river stretches. The rivers flowing form the east to the west in the Netherlands are alluvial rivers (de Bruijn *et al.*, 1987) and the Danube becomes alluvial downstream of Vienna after leaving the Alps (Zsuffa, 2000). So it can be

concluded that the secondary channels can be compared.
Although the reasons to open secondary channels and the comparability of the secondary channels is discussed, one should take into account that all secondary channels are different. All secondary channels have good characteristics, as well as other characteristics that are not so favourable to reach the goals set. You always have to choose between options and often a compromise has to be made. Also other interests (e.g. shipping, safety) play an important role. So the perfect secondary channel probably cannot exist along highly developed and modified rivers like the Rhine and Danube. To get a "map" of the most ideal secondary channel concerning all constraints etc., one should probably use a statistical programme (CANOCO for instance), in that way one may be able to make a statistical perfect secondary channel. This study however was a first look at the different European secondary channels and not an extensive analysis of the different (ecological) data, which would be required for such an analysis. And thereby one can question whether it is desirable to have secondary channels that are all the same. Various secondary channels can have their own unique characteristics and functions. As an example, for most rheophilic cyprinid fish species lowland floodplain water bodies do not function as spawning and refuge areas but only as nursery areas for juvenile fish in summer (Grift *et al.*, 2000a). A function of the Dutch secondary channels could be nursery areas for fish, while upstream areas could function for spawning of rheophilic fish species.

What should a secondary channel look like? The first criterion is connectivity. The secondary channel should be connected to the main channel for as long as possible. Naiman *et al.* (1992) stated that connectivity is fundamental for the long-term maintenance and vitality of stream systems. Furthermore Grift *et al.* (2001) stated that connectivity of a water body with the main channel and the presence of flowing water are important factors driving the structure of the juvenile fish community. In view of this demand for permanent flow, secondary channels on impounded river stretches are less attractive (Schropp & Bakker, 1998). The Vén Duna and "G365" are both permanently flowing. Another criterion is that there always has to be a certain depth of water in at least a part of the secondary channel, even at the lowest river stages (Schropp, 1994). Related to the depth of the secondary channel is the slope of the shores. Gentle slopes are preferred. They offer a large area of relatively shallow water depths (Schropp, 1994) with a wide variety of stream velocities (van Wijngaarden, 1998) and function as refugia for juvenile fish against the wash-out effects of floods (Schiemer & Zalewski, 1992). They also give different kinds of bank habitat, leading to high species diversity (Schoor *et al.*, 1999). On the other hand areas with cliffs could also be favourable, for instance for kingfishers and sand martins. "Opijnen" is an example of a secondary channel with gentle shores and "Regelsbrunn" and "Gameren" possess such cliffs. Another characteristic of the "ideal" secondary channel is the presence of various habitats in the channel. Schropp (1994) stated that the ecological development of the floodplain will be greatly stimulated when there is a certain spatial variation of water depths, flow velocities and bank slopes, offering opportunities to a wide variety of vegetation and animal species. A variety of physical structures in combination with the flood pulse result in great habitat diversity (Junk *et al.*, 1989). And higher levels of biological richness and bioproduction are most likely to occur in ecosystems with a long legacy of high spatial and temporal environmental heterogeneity (Standford *et al.*, 1996). Physical habitat structure, which is strongly determined by ecotone complexity, is apparently a key factor for fish communities (Schiemer & Zalewski, 1992). This could be achieved by secondary channels, which are connected to various water bodies with different characteristics. This is also positive because different degrees of connectivity are important for a diverse flora and fauna (Tockner *et al.*, 1999b) and all fish species need shallow stagnant areas as nursing areas in early life stages (Grift *et al.*, 2000b).

“Regelsbrunn”, “Beneden-Leeuwen” and “Plan Doorstroming” are examples of secondary channels that are connected to different water bodies. “Opijnen” en “G365” are not connected to different water bodies but due to the narrowing of the former groin fields in “Opijnen” and the connection between the oxbow lake and the sand pit in “G365” they also consist of different habitat types. The secondary channel should also comply with some morphological characteristics. A guideline to guarantee the safety of the levees is that the distance between the toe of the dike and the bank of the secondary channel should be at least 100 m (Barneveld *et al.*, 1993). To reduce the inflow of sediment, a location in the outer bend is desirable. The helical flow transports sand from the outer bend to the inner bend where it forms sand banks (Schoor & Sorber, 1999). Another morphological characteristic should be the orientation of the inflow and outflow. The angle between the main channel and the secondary channels should be more than 90^{o} in order to keep sedimentation low. To avoid side-currents which could bother the ships, the outflow should not be perpendicular to the main channel.

Results

Immediately after the opening of the secondary channels in the Netherlands an increase in rheophilic fish species was visible. The number of rheophilic juvenile fish increased a lot. However, the secondary channels are not used for spawning of rheophilic fish species. Most obligatory rheophilic cyprinids are lithophilic species depositing eggs on gravel bottoms where embryos and larvae develop and this type of coarse substratum is absent in floodplains and main channel of the lower River Rhine in the Netherlands. So this may have been a misplaced expectation in the end. Favourable spawning conditions are only found as early as upstream in Germany. Floodplain water bodies along the River Rhine in the Netherlands most probably do function as nursery areas for rheophilic species. Connected and isolated floodplain water bodies along the River Rhine are essential for reproduction of eurytopic species, and form important source areas, since the main channel currently offers no suitable habitat for reproduction (Grift *et al.*, 2000a). In “Opijnen” habitat availability met habitat requirements of rheophilic fish best and consequently, it was most suitable for these fish. For obligatory rheophilic species “Gameren” (“G100” and “G265”) had the highest beneficial value as compared to the locations (“Beneden-Leeuwen”, “Opijnen” and “G365”), but for partially rheophilic cyprinids and for eurytopic species, this secondary channel showed no beneficial value above yet existing groin fields (Grift *et al.*, 2000b).
From the figures of the fish catch in the Vén Duna (Fig. 3.10 & 3.11) it seems that the re-opening of the Vén Duna was beneficial for rheophilic fish. Both the percentage of rheophilic individuals as the percentage of rheophilic species increased after the re-opening. However, some reservation should be taken. First of all, the fishing throughout the years was not done in a constant way. One year, only electric fishing was done while the other year also nets were used. So the comparability of the data is rather difficult. Electric fishing for instance is only reliable in shallow, vegetated water and has different selectivity for different species and sizes. By only using electric fishing a lot of data about the fish community is probably missing. Another thing is that it was not clear from the data of Csányi (1998a, 1998b, 1999, 2000) whether the caught fish were juvenile or older fish. The early life history stage is the most critical stage due to its narrow requirements with regard to current velocity, temperature and food availability (Schiemer, 2000). So no conclusions could be drawn about the function of the Vén Duna. Is it, like the Dutch secondary channels, mainly a nursery area? Or do rheophilic species really spawn in the Vén Duna? For “Regelsbrunn” almost no results were present yet, but first observations were promising. Also the number of rheophilic macro-invertebrate species increased in the secondary channels. But it should be taken into account that the largest amount of

the rheophilic macro-invertebrates found in the Dutch secondary channels originates from the Danube.
As said before, the secondary channels in this comparison did not cause any problems for shipping (so far). Neither by sedimentation nor by side-currents. The percentage of the discharge through the secondary channel ranged from 0.5 to 5.5 % discharge.

5.2 Conclusion

An almost immediate (rheophilic) colonisation of the secondary channels and no problems for shipping and safety make the first results of the secondary channels promising and should be the reason to open more secondary channels along the large rivers of Europe.
Each secondary channel should have its own characteristics and function but there are some important features. The secondary channel should be connected most of the time and should be located at a free-flowing river stretch so there will always be flowing conditions present. It should have different habitat types to attract as many species as possible. To ensure the safety it should be located at least 100 m from the toe of the dike. Morphological processes should be allowed but to an extent that the secondary channels will stay open.

References

- Adams, W.M., Perrow, M., 1999. Scientific and institutional constraints on the restoration of European floodplains. In: Floodplains: Interdisciplinary approaches. Marriott, S.B., Alexander, J. (eds). Geological Society, London, Special Publications, 163, 123-137.
- Amoros, C., Roux, A.L., 1988. Interaction between water bodies within the floodplains of large rivers: function and development of connectivity. In: Schreiber, K.L. (Eds.). Connectivity in Landscape Ecology. Proceedings of the 2nd International Seminar of the International Association for Landscape Ecology. Münstersche Geographische Arbeiten 29, 125-130.
- Amoros, C., Roux, A.L., Reygrobellet, J.L., Bravard, J.P., Pautou, G., 1987. A method for applied ecological studies of fluvial hydrosystems. Regul. Rivers 1, 17-36.
- Bakker, H.D., 1992. Habitatgeschiktheidsindexmodel: de snoek Esox lucius (L.). Organisatie ter Verbetering van de Binnenvisserij.
- Barneveld, H.J., Nieuwkamer, R.L.J., Klaassen, G.J., 1993. Secondary channels opportunities for and limitations of habitat resoration. In: Rehabilitation of the international conference, Arnhem, 15-19 March 1993, 335-345.
- Bayley, 1991. The flood pulse advantage and the restoration of river-floodplain systems. Regul. Rivers: Res. Mgmt. 6, 75-86.
- Brink, F.W.B. van den, Velde, G. van der, Buijse, A.D., Klink, A.G., 1996. Biodiversity in the Lower Rhine and Meuse river floodplains: its significance for ecological river management. Netherlands journal of aquatic ecology Vol 30, nr. 2-3, 129-149.
- Bruin, D. de, Hamhuis, D., Nieuwenhuijze, L. van, Overmars, W., Sijmons, D., Vera, F., 1987. Ooievaar. De toekomst van het rivierengebied. Stichting Gelderse Milieufederatie.
- Buijse, A.D., H. Coops , M. Staras, L.H. Jans, G.J. van Geest, R.E. Grift, B.W. Ibelings, W. Oosterberg & F.C.J.M. Roozen. 2001. Favourable options for recovery of aquatic river-floodplain interactions along large lowland rivers. Paper presented at the 1st International symposium on the landscape dynamics of riverine corridors, Ascona, Switzerland, March 25-30, 2001.
- Bureau Stroming en Grontmij Gelderland, 1996. Waaier van Geulen. Hoofdlijnen MER en Inrichtingsplan. Delgromij, Arnhem.
- Cals, M.J.R., Postma, R., Buijse, A.D., Marteijn, E.C.L., 1998. Habitat restoration along the River Rhine in the Netherlands: putting ideas into practice. Aquatic Conserv: Mar. Freshw. Ecosyst. 8, 61-70.
- Csányi, B. (eds), 1999. Monitoring in the Gemenc Protected Landscape Area: Hydrological, morphological, water quality and ecological data of the Vén-Duna and River Danube in 1999, one year after reopening the dam. VITUKI Rt. Budapest.
- Csányi, B. (eds.), 1998a. Baseline survey in the Gemenc Protected Landscape Area: hydrological, morphological, water quality and ecological data of the Vén-Duna, River Danube and Nyéki-Holt-Duna in 1997-1998, prior to restoration. VITUKI Rt., Budapest.
- Csányi, B. (eds.), 1998b. Monitoring in the Gemenc Protected Landscape Area: Hydrological, morphological, water quality and ecological data of the Vén-Duna and River Danube in 1998, after reopening the dam. VITUKI Rt. Budapest.
- Csányi, B., Gulyás, P., Németh, J., 1994. A synbiological survey of the side arms of the Gemenc Protected Landscape Area. Limnologie aktuell. Vol 2.

Kinzelbach (Hg.): Biologie der Donau. Gustav Fischer Verlag, Stuttgart, Jena, New York.

- Directie Zuid-Holland, 1992. Doorstroming. Een plan voor natuurontwikkeling in de Dordtse Biesbosch.
- Duel, H., During, R., Specken, B., 1994. Nevengeulen: verkenning naar de ecologische betekenis van inrichtingsvarianten. Publicaties en rapporten van het project 'Ecologisch Herstel Rijn en Maas' no. 56-1994. RIZA, Lelystad.
- Garritsen, T., Vonk, G., Vries, K. de, 2000. Visions for the Rhine. RIZA, Lelystad.
- Grift, R.E., 2000. Perspectives for fish in river restoration. Manuscript.
- Grift, R.E., Buijse, A.D., Densen, W.L.T. van, Klein Breteler, J.G.P., Machiels, M.A.M., Backx, J.J.G.M., 2000a. The ecological functioning for fish of floodplain water bodies connected with the main channel of the River Rhine. Submitted to Regul. Rivers: Res. Mgmt..
- Grift, R.E., Buijse, A.D., Densen, W.L.T. van, Klein Breteler, J.G.P., 2001. Restoration of the river-floodplain interaction: benefits for the fish community in the River Rhine. Arch. Hydrobiol Supplement 135 (Large Rivers 12), 173-185.
- Grift, R.E., Buijse, A.D., Densen, W.L.T. van, Machiels, M.A.M., Kranenbarg, J., Klein Breteler, J.G.P., Backx, J.J.G.M., 2000b. The habitat suitability of reconnected floodplain water bodies for fish. Submitted to Regul. Rivers: Res. Mgmt..
- Hagmann, L., 1998. Green Danube. A European Lifeline. WWF Journal No. 3. WWF Switzerland.
- Heiler, G., Hein, T., Schiemer, F., Bornette, G., 1995. Hydrological connectivity and flood pulses as the central aspects for the integrity of a river-floodplain system. Regul. Rivers: Res. Mgmt. 11, 351-361.
- Hein, T., Heiler, G., Pennetzdorfer, D., Riedler, P., Schagerl, M., Schiemer, F., 1999. The Danube restoration project: functional aspects and planktonic productivity in the floodplain system. Regul. Rivers: Res. Mgmt. 15, 259-270.
- Jans, L., Backx, J., Greijdanus-Klaas, M., Jonge, J. de, Meij, V. van der, Oosterbaan, J., Scheer, A. van der, Schropp, M., Wijngaarden, M. van, 2001. Monitoring nevengeulen. Integrale jaarrapportage 1999/2000. RIZA.
- Jans, L., Buijse, T., Heijdt, B. van der, Jonge, J. de, Kok, F., Sorber, A., Wijngaarden, M. van, 1998. Monitoring nevengeulen (1998-2003). Monitoringsprogramma voor nevengeulen in de Gamerensche, de Stiftse en de Afferensche & Deestsche Waarden: morfologie, hydraulica, ecologie, bodemchemie en ecotoxicologie. Projectplan. RIZA Werkdocument 98.071X. RIZA, Lelystad.
- Jans, L., Wijngaarden M. van, Oosterbaan, J., Schropp, M., Scheer, A. van der, Backx, J., Jonge, J. de, 2000. Monitoring nevengeulen. Integrale jaarreportage 1998/1999. RIZA Werkdocument 2000.034X. RIZA, Lelystad.
- Johnson, B.L., Richardson, W.B., Naimo, T.J., 1995. Past, present and future concepts in large river ecology. How rivers function and how human activities influence river processes. Bioscience Vol. 45 No. 3 134-141.
- Junk, W.J., 1999. The flood pulse concept of large rivers: learning from the tropics. Large Rivers Vol. 11, No. 3. Arch. Hydrobiol. Suppl. 115/3, 261-280.
- Junk, W.J., Bayley, P.B., Sparks, R.E., 1989. The flood pulse concept in river-floodplain systems. In D.P. Dodge (ed.) Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106, 110-127.
- Klink, A.G., 1992. Aquatic macro-invertebrate fauna of the Danube at Gemenc, Hungary. In: Gemenc Floodplain Rehabilitation. Working document 8. Ecological studies.

- Lelek, A., 1987. The freshwater fishes of Europe. Vol. 9. Threatened fishes of Europe. Aula, Wiesbaden.
- Marchand, M. (eds), 1993. Floodplain Rehabilitation Gemenc. Main report. Delft Hydraulics/RIZA/VITUKI.
- Microsoft Encarta Online Encyclopedia 2001, 2001. Danube. http://encarta.msn.com © 1997-2001. Microsoft Corporation.
- Microsoft Encarta Online Encyclopedia 2001, 2001. Rhine. http://encarta.msn.com © 1997-2001. Microsoft Corporation.
- Middelkoop, H., Haselen, C.O.G. van (eds.), 1999. Twice a river. Rhine and Meuse in the Netherlands. RIZA report no. 99.003. RIZA, Arnhem.
- Muhar, S., Schmutz, S., Jungwirth, M., 1995. River restoration concepts – goals and perspectives. Hydrobiologia 303: 183-194.
- Naiman, R.J., Lonzarich, D.G., Beechie, T.J., Ralph, S.C., 1992. General principles of classification and the assessment of conservation potential in rivers. River conservation and management. Boon, P.J., Calow, P., Petts, G.E. (eds.). John Wiley & Sons Lt.
- Paalvast, P., 2000. Doorstroming. Een natuurontwikkelingsproject in de Dordtse Biesbosch. Monitoring 1991-1997. Rijkswaterstaat directie Zuid-Holland. Notanummer: AP/3563610/2000/002.
- Petts, G.E., 1989. Historical analysis of fluvial hydrosystems. In: Petts, G.E. (eds): Historical change of large alluvial rivers: Western Europe. John Wiley & Sons Ltd.
- Reimer, G., 1991. The ecological importance of floodplains for fish at the river March (Austria). Arch. Hydrobiol. 121: 355-363.
- Schiemer, F., 1995. Revitaliserungsmaßnahmen für Augewässer – Möglichkeiten und Grenzen. Arch. Hydrobiol. Suppl. 101, Large Rivers 9, 383-398.
- Schiemer, F., 1999. Conservation of biodiversity in floodplain rivers. Arch. Hydrobiol. Suppl. 115 / 3 (Large Rivers 11), 423-438.
- Schiemer, F., 2000. Fish as indicators for the assessment of the ecological integrity of large rivers. Hydrobiologia 422/423, 271-278.
- Schiemer, F., Baumgartner, C., Tockner, K., 1999. Restoration of floodplain rivers: the 'Danube restoration project'. Regul. Rivers: Res. Mgmt. 15, 231-244.
- Schiemer, F., Reckendorfer, W., 2000. Abhandlungen der Zoologisch-Botanischen Gesellschaft in Österreich. Das Donau-Restaurierungsprojekt. Gewässervernetzung Regelsbrunn. Verlag der Zoologisch-Botanischen Gesellschaft in Österreich, Wien.
- Schiemer, F., Tockner, K., Baumgartner, C., 2000. Das Donau-Restaurierungs-Programm: Rahmenbedingungen und Untersuchungskonzept. Abh. Zool. - Bot. Ges. Österreich 31, 1-25.
- Schiemer, F., Zalewski, M., 1992. The importance of riparian ecotones for the diversity and productivity of riverine fish communities. Netherlands Journal of Zoology 42 (2-3): 323-335.
- Schoor, M.M., Sorber, A.M., 1999. Morphology, Naturally. ISBN 9036952735. RIZA, Arnhem.
- Schoor, M.M., Splunder, I. van, 1993. Floodplain rehabilitation Gemenc. The relation between vegetation and hydrology/geomorphology. Vegetation studies. Working document 1b, RIZA, Arnhem.

- Schoor, M.M., Wolfert, H.P., Maas, G.J., Middelkoop, H., Lambeek, J.J.P., 1999. Potential for floodplain rehabilitation based on historical maps and present-day processes along the River Rhine, the Netherlands. In: Floodplains:

Interdisciplinary approaches. Marriott, S.B., Alexander, J. (eds). Geological Society, London, Special Publications, 163, 123-137.

- Schropp, M., Wijngaarden, M. van, Scheer, A. van der, Heijdt, B. van der, 2001. Monitoring nevengeulen. Morfologische en chemische monitoring geulen Gamerensche Waard. Datareportage 1999/2000. RIZA Werkdocument 2001.003X. RIZA, Arnhem.
- Schropp, M., Wijngaarden, M. van, Scheer, A. van der, Heijdt, B. van der, 2000. Monitoring nevengeulen. Morfologische en chemische monitoring geulen Gamerensche Waard. Datareportage 1998/1999. RIZA Werkdocument 2000.006X. RIZA, Arnhem.
- Schropp, M.H.I., Bakker, C., 1998. Secondary channels as a basis for the ecological rehabilitation of Dutch rivers. Aquatic Conserv: Mar. Freshw. Ecosyst. 8, 53-59.
- Schropp, M.M., 1994. Principles of designing side channels. In: Living with water. International Conference on Integrated Water Resources Management. Amsterdam.
- Simons, J., Bakker, C., Schropp, M., Jans, L., Kok, F., *in prep.*. Man-made secondary channels along the river Rhine (the Netherlands); results of post-project monitoring. Regulated Rivers.
- Simons, J., Bakker, C., Sorber, A. M., 2000. Evaluatie nevengeulen Opijnen en Beneden-Leeuwen 1993-1998. RIZA rapport 2000-040. RIZA, Lelystad.
- Sorber, A., Wijngaarden, M. van, Heijdt, B. van der, Scheer, A. van der, 1999. Monitoring nevengeulen. Morfologische en bodemchemische monitoring oost- en westgeul Gamerensche Waard. Datareportage 1997/1998. RIZA Werkdocument 99.012X. RIZA Lelystad.
- Stancik, A., Jovanovic, S., Sikora, A., Ürge, L., Miklós, D., 1988. Hydrology of the river Danube. Publishing House Príroda, Bratislava.
- Stanford, J.A., Ward, J.V., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., Coutant, C.C., 1996. A general protocol for restoration of regulated rivers. Regul. Rivers: Res. Mgmt. 12, 391-413.
- Sziebert, J., Zellei, L., 1998. Sediment transport in the Danube and the Vén Duna side branch. VITUKI Rt., Baja.
- Tockner, K., Baumgartner, C., Schiemer, F., Ward, J.V., 2000a. Biodiversity of a Danubian floodplain: strucural, functional and compositional aspects. Biodiversity in wetlands: assessment, function and conservation, volume 1. Edited by Gopal, B., Junk, W.J., Davis, J.A. (141-159) Backhuys Publishers, Leiden.
- Tockner, K., Malard, F., Ward, J.V., 2000b. An extension of the flood pulse concept. Hydrol. Process. 14, 2861-2883.
- Tockner, K., Pennetzdorfer, D., Reiner, N., Schiemer, F., Ward, J.V., 1999a. Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river-floodplain system (Danube, Austria). Freshwater Biology 41, 521-535.
- Tockner, K., Schiemer, F., Baumgartner, C., Kum, G., Weigand, E., Zweimüller, I., Ward, J.V., 1999b. The Danube restoration project: species diversity patterns across connectivity gradients in the floodplain system. Regul. Rivers: Res. Mgmt. 15, 245-258.
- Tockner, K., Schiemer, F., Ward, J.V., 1998. Conservation by restoration: The management concept for a river-floodplain system on the Danube River in Austria. Aquatic Conserv: Mar. Freshw. Ecosyst. Vol. 8 no. 1, 71-86.
- Tockner, K., Ward, J.V., 1999. Biodiversity along riparian corridors. Large Rivers Vol. 11, no. 3. Arch. Hydrobiol. Suppl. 115/3, 293-310.
- Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130-137.

- Verheijen, A.J.A., 1999. Invloed van morfologie en inundatiefrequentie op de visgemeenschap van rivierplassen. Afstudeerverslag Leerstoelgroep Visteelt en Visserij, Wageningen Universiteit.
- VITUKI Consult Rt., 1991. Floodplain rehabilitation Gemenc. Restoration of the fresh water supply of side branches in the Gemenc Protected Landscape Area. Working Document 2. VITUKI Rt., Budapest.
- Ward, J.V., Tockner, K., Schiemer, F., 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivty. Regul. Rivers: Res. Mgmt. 15, 125-139.
- Wijngaarden, M. van, 1998. Sedimentatie en erosie van zwevend stof in nevengeulen. RIZA rapport 97.078. RIZA Lelystad.
- Wolters, H., Schoor, M., Platteeuw, M., Bruggenkamp, J-W. (red.), 2000. Nieuwe natuur in de uiterwaarden. Praktische wenken voor de combinatie van natuur en veiligheid bij herinrichting. RIZA, Lelystad.
- WWFa. Wise use of floodplains. Regelsbrunner Au Restoration Project. http://www.panda.org/europe/freshwater/floodplains/cases/regels4.html.
- WWFb. Wise use of floodplains. Regelsbrunner Au Restoration Project. http://www.panda.org/europe/freshwater/floodplains/cases/regels5.html.
- WWF, 1993. Living Rivers. World Wide Fund for Nature, Zeist. ISBN 90-74595-03-0.
- Zinke, A., 1999. Dams and the Danube: Lessons from the environmental impact. Presentation at WCD Forum, Prague.
- Zsuffa, I.J., 2000. Multi-criteria decision support or the revitalisation of river floodplains. Doctoral thesis, Wageningen University.

Appendix A

Interviews.

Questions

1. What are the characteristics of the main channel?

2. What are the characteristics of the secondary channel?

3. Why is the secondary channel situated on that particular place?

4. What are the constraints for the secondary channel?
   safety, shipping, ecology

5. What are the goals for the secondary channel?
   safety, ecology (ecotopes, processes, species)

6. How is the secondary channel monitored?

7. What were the results of the secondary channel (expected and unexpected)?

8. Which goals are reached?

9. How long did it take before recovery took place?
   physical processes, colonisation

10. How will the secondary channel develop? Will it be allowed to develop naturally or will it be regulated?

11. Recommendations?

Answers

Csanyi Béla

2) Discharge through Vén Duna: < 1% of the Danube discharge

4) None

5) Ecology, increase habitat types, no formulated goals

9) Immediately

Bakonyi Peter (director Vituki)

2) 80-100 m wide, 3 m depth (at low navigation level), uniform depth., 4.3 km long

4) Cross current (in-flow almost "loodrecht") not too strong and navigation depth should not decrease due to sedimentation. Both effects turned out to be very small. In the secondary channel ecology is the requirement.

5) Bring back flowing conditions

7) The channel is flowing (almost all year). Aquatic community is almost like the one in the Danube. More fish than before. Unexpected result was the new sand bank next to the island (see drawing, not enclosed).

10) Naturally but controlled (in-flow opening may not become larger, secondary should stay open)

Sziebert Janos (and Zsuffa István) (Eötvös József föiskola, Baja)

2) Flow velocity: 0.1-0.3 m/s. Depth: minimum +78 Baltic Sea level. maximum ca. +87 Baltic Sea level.

4) No flowing is allowed below the lowest navigation level. This demand however is not fulfilled. The opening is in fact deeper than that. To make the side current less strong the groyne at the outflow was shortened 30 metres and a parallel groyne before the outlet was built.

5) Flowing water (and thus return of rheophilic species). The objectives are pure ecological.

7) Not all measurements have been analysed yet. Meandering processes will take place between the opening and the Danube.
Width of the opening is smaller than planned and the opening is deeper than planned (which is a good thing for ecology)

9) The goal of flowing water was reached immediately after the re-opening.

10) Dredging to keep the flowing water. But is not certain about that.

11) Dredging was not done right. The dredged material was put on the banks and was washed away and settles behind the island. The monitoring is not done right. Now it is occasionally monitored.

General) Until 1886 the Vén Duna was the Danube. In 1886 a short cut was created. The Danube still "used" the Vén Duna, so the rock closure was made in 1911 to force the Danube to flow through the new bed. In the 60's groynes were built near the outflow of the Vén Duna, causing sedimentation in the outflow opening.

Lanyi Eszter (WWF Hungary)

The WWF supports (financially) the reconnection of the former channels and oxbow lakes in the Gemenc region. Now they support the reconnection of the Rezeti Duna (Eszter did not know if the Rezeti Duna was permanently connected to the Danube or

just above a certain water level) but finally all former channels and oxbow lakes should have a connection with the Danube. Higher water levels are better for the fish community.
There are also other reconnection programmes in Hungary: Szigetköz and along the Tisza (but this is just in the planning phase).
She had no idea about how the people think about this programme.

Luc Jans

3. Vaak valt de aanleg samen met dijkonderhoud of -verhoging. Gameren ligt op getijdeovergang en voor de veiligheid (bij Gameren werd de winterdijk dichter bij de rivier gelegd).
7. Sterkere erosie dan verwacht in Gameren. Geen aanzanding hoofdgeul.
9. Paar jaar.
10. De nevengeul zal waarschijnlijk uitgebaggerd worden i.v.m. veiligheid (dichtgeslibde nevengeul kan geen water bergen).
11. Zorg voor genoeg ruimte voor de nevengeul, zodat erosie mogelijk is.
    Niet te diep, flauwe oevers.
    Effect scheepvaart verminderen
12. Welke soorten zitten daar?

Interessant: kleiput Gameren verbonden.

Max Schropp

9. Enkele jaren.
10. Ontwerp aanscherpen. Is onderlinge vergelijkbaarheid wel mogelijk?

Bulle effect: minder aanzanding bij hoek hoofdgeul-nevengeul < 90^o dan bij 90^o.

Jennie Simons

3. Beneden-Leeuwen: probleem: aanzanding → Kaliwaal zandvang + strang → nevengeulen. Kleiwinning voor dijkverzwaring uit uiterwaard.
4. Beneden-Leeuwen: geen veiligheidsdoelstelling mits het niet onveiliger wordt. Geen effect op de hoofdgeul.
7. Onverwacht: meteen rheofielen in Opijnen, erg veel steltlopers in Opijnen (vooral in ’95), positieve houding bevolking. Geen planten in Opijnen.
9. Fysisch: meteen, ecologie: vis meteen, macrofauna wat later (macrofauna neemt toe maar neemt in de hele Rijn toe)
10. Opijnen om ecologische redenen openhouden, mag zich nog ontwikkelen. Wilgen laten staan ja/nee.
11. Flauwe oever, geul diep genoeg zodat er altijd stroming is, brede range stroomsnelheden (moeilijke combinatie). Betrek de plaatselijke bevolking erbij.
12. Onderzoeksgegevens beschikbaar (vis, macrofauna, libellen in relatie met abiotische factoren. Ervaringen.

Frank Kok

3. Gameren: vaargeul diep
   Opijnen: strekdam
   Beneden-Leeuwen: voorbeeldproject “Levende rivieren”
4. Geen hinder voor scheepvaart.
5. Algemeen doel riviersysteem: toelaten natuurlijke processen → stroming → erosie, sedimentatie → nevengeulen.
   Waarom nevengeulen: zeldzaamheid, karakteristiekheid.
   Gameren: geen doel veiligheid
   Voor alledrie: natuurlijke processen
8. Hij stroomt. Te vroeg om te zeggen of ecologische doelen bereikt zijn.
9. Fysisch: meteen na opening, na 5 jaar uitgekristaliseerd en daarna “gewone” rivierprocessen.
   Kolonisatie: binnen half jaar (soorten moeten wel aanwezig zijn) (nevengeul is dynamisch → sedimenttransport groot → droogvallen → ongunstige omstndigheden → snelle kolonisatie
10. Natuurlijke ontwikkeling (dichtslibben mag)
12. Dynamiek in tijd, hoe ontwikkelt zich dat?
    Wat gebeurt er met bomen?
    Wat is de karakteristieke levensgemeenschap van de Donau?
    In Nederland is het grootste deel van de macrofaunasoorten afkomstig uit de Donau. Zijn die soorten ook zo goed vertegenwoordigd in de Donau?
    Zijn er ook organismen die aanliggende terreinen gebruiken (land-waterrelatie.Beer-zalm)
    Wat is de invloed van beschaduwing op de levensgemeenschap in de nevengeul? Positief of negatief? (Direct gevolg: nieuw substraat, indirect; beschaduwing)
    Hoe erg is het als nevengeul niet permanent stroomt?

Henk Kraaijeveld

1)
Dordtse Biesbosch.
Wilgenvloedbos.
Nieuwe Merwede width: 2 km

2)
Dam van Engeland: 0.45 m +NAP
MLW: 0.40 +NAP (Deeneplaat)
MHW: 0.69 +NAP (Deeneplaat)

Opening December 1992 (int. Kraaijeveld)

Length: ca. 2.5 km

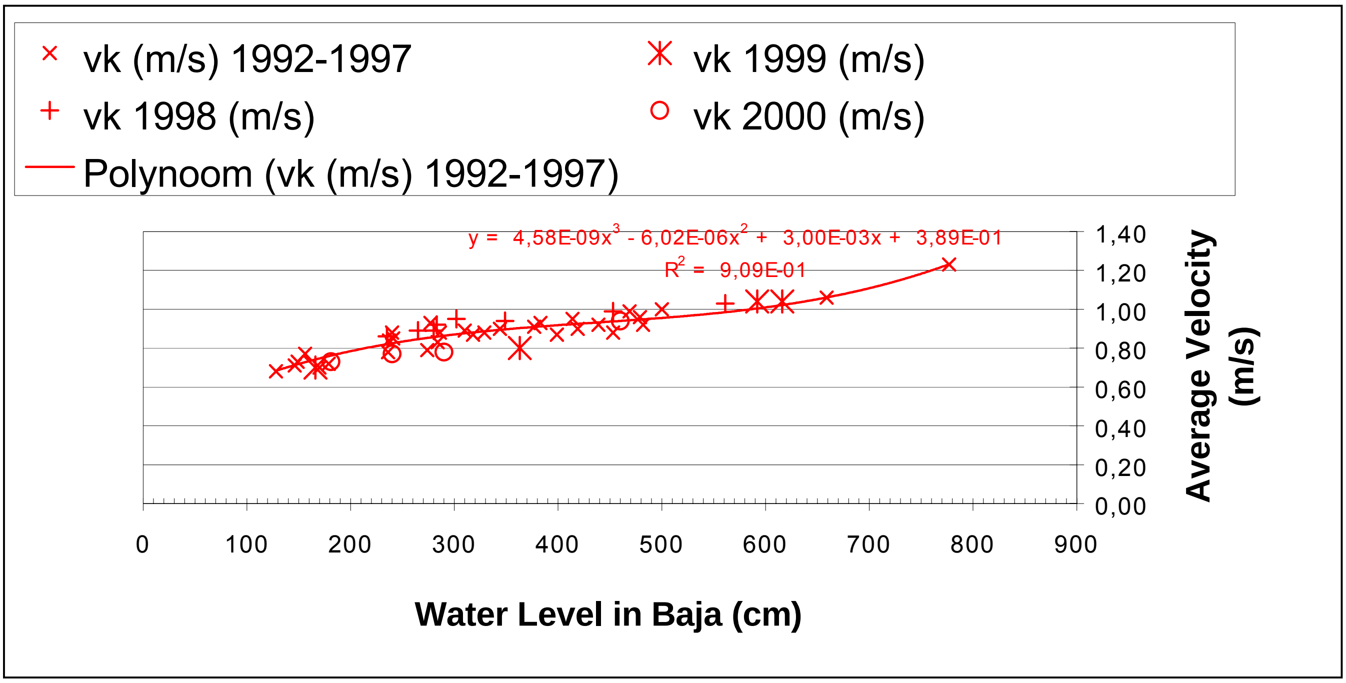
978-982 kmr (eigen inzicht)

Bij afgraven Nieuwe Merwede werd specie opgespoten in plangebied. Dam van Engeland werd gebouwd om te voorkomen dat het zand weer uit zou spoelen in de Nieuwe Merwede.
Krekenstelsel met invloed getij. Door sluiting van Harinvliet viel getijdeinvloed weg en verlandden de kreken.

Twee hoofdgeulen: Noorder Gat van Kielen en Zuider Gat van Kielen. Veel takken.

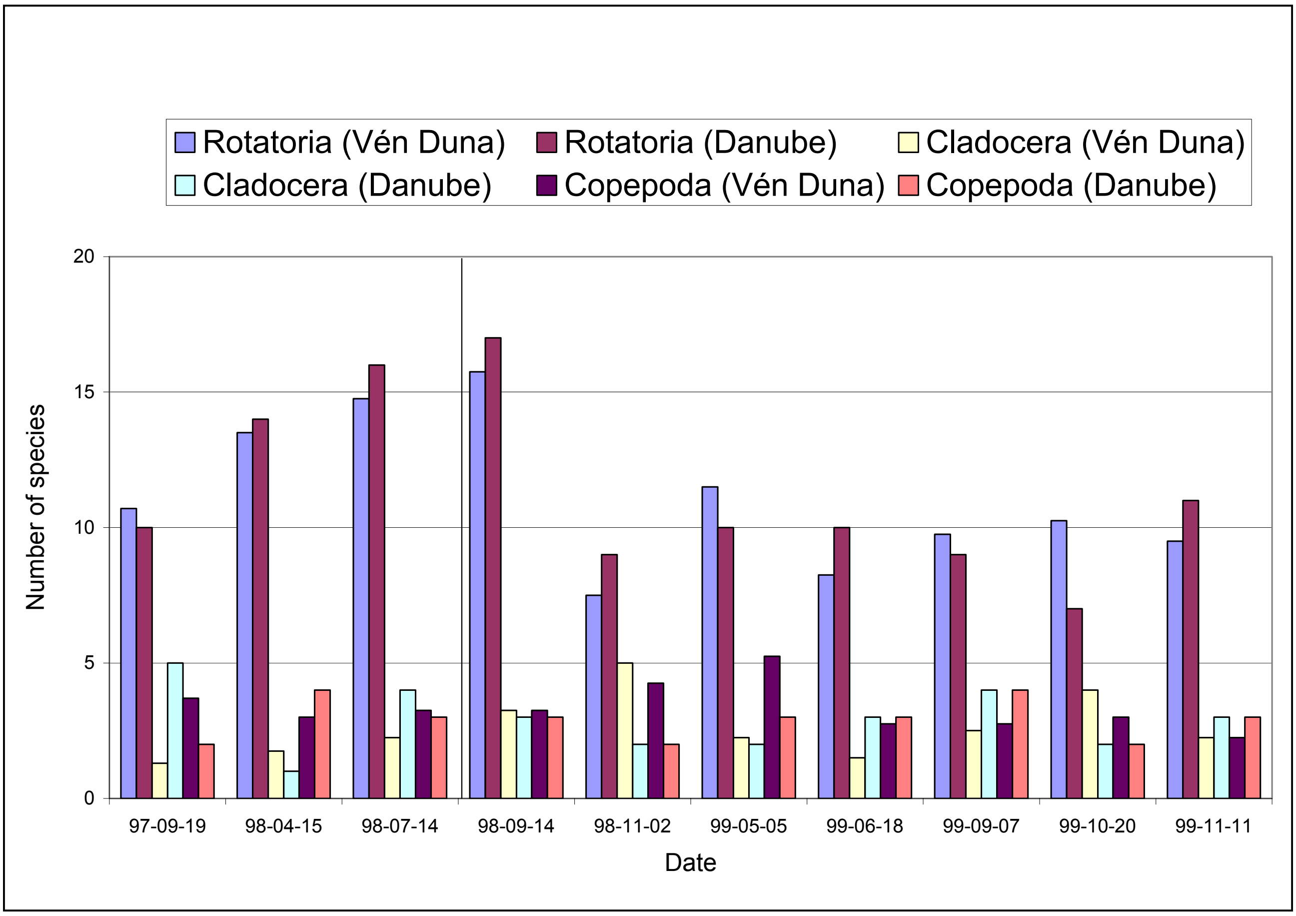
4)
Geen beperkingen door scheepvaart (Nieuwe Merwede is ter plaatse 2 km breed) of veiligheid (dijken zijn niet in de buurt). Rustgebied voor vogels moest gerespecteerd worden.

Appendix B



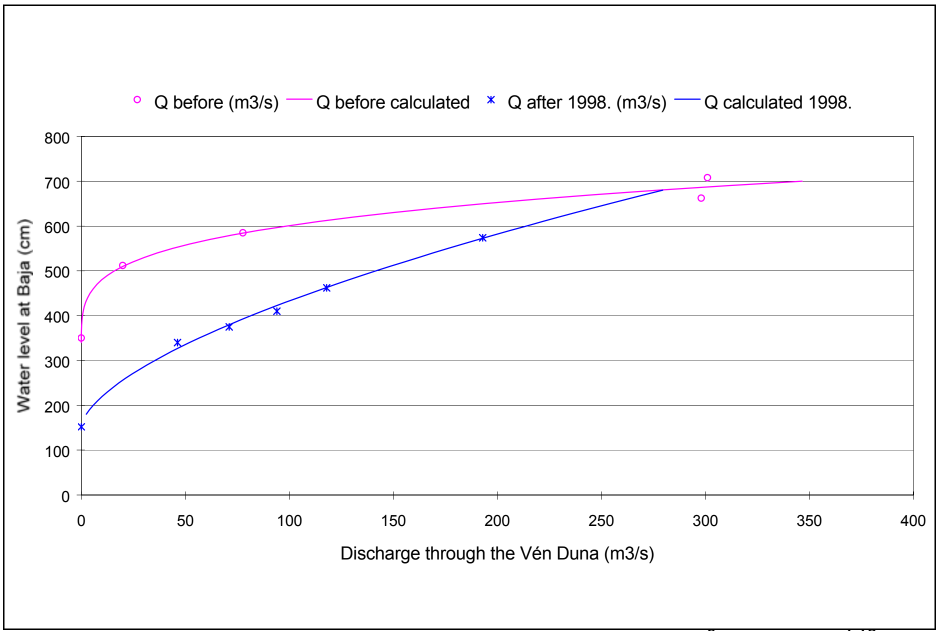
vk (m/s) 1992-1997
vk 1999 (m/s)
vk 1998 (m/s)
vk 2000 (m/s)
Polynoom (vk (m/s) 1992-1997)
y = 4,58E-09x3 - 6,02E-06x2 + 3,00E-03x + 3,89E-01
R2 = 9,09E-01
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0
100
200
300
400
500
600
700
800
900
Average Velocity (m/s)
Water Level in Baja (cm)

Appendix C

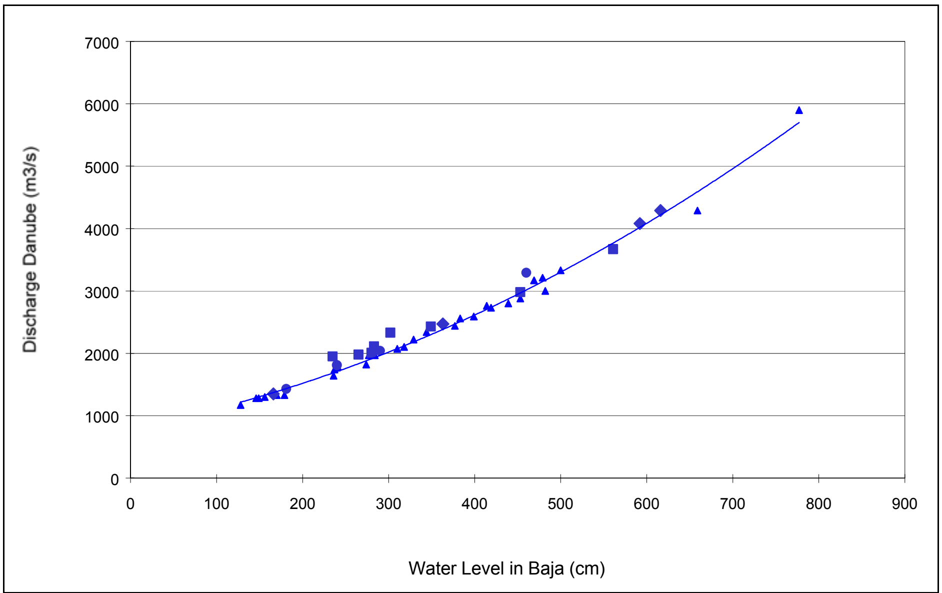


Rotatoria (Vén Duna)
Rotatoria (Danube)
Cladocera (Vén Duna)
Cladocera (Danube)
Copepoda (Vén Duna)
Copepoda (Danube)
Number of species
0
5
10
15
20
97-09-19
98-04-15
98-07-14
98-09-14
98-11-02
99-05-05
99-06-18
99-09-07
99-10-20
99-11-11
Date

Appendix D



The Vén Duna rating curve (Sziebert). Before opening: $y = 8.29 \cdot 10^{-9} \cdot (x - 320)^{4.12}$. After opening: $y = 9.94 \cdot 10^{-3} \cdot (x - 151)^{1.63}$.



Water level – discharge graph (Sziebert): $y = 0.0047x^2 + 2.6549x + 799.67$.

From these two graphs the equation of Figure 3.12 can be calculated, resulting in:

Before opening:
$y = 3.23 \cdot 10^{-19} \cdot (x - 320)^{8.23} + 2.20 \cdot 10^{-8} \cdot (x - 320)^{4.12} + 799.67$

After opening:
$y = 4.65 \cdot 10^{-7} \cdot (x - 151)^{2.67} + 2.64 \cdot 10^{-2} \cdot (x - 151)^{1.63} + 799.67$

y = discharge Danube
x = discharge Vén Duna.