MORPHOLOGICAL DEVELOPMENT OF MAN-MADE SIDE CHANNELS IN THE FLOOD PLAIN OF THE RIVER RHINE

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ABSTRACT

The flood plain area of the River Rhine in the Netherlands has been reduced considerably over the past centuries. In addition the river normalisations have had a severe effect on the biodiversity of the system. In order to cope with higher flood discharges in the future a new policy has been adopted. Instead of raising the level of the dikes once again, the flood plain level is to be lowered so as to convey a larger amount of water at the same water levels. One way of doing this is to create secondary channels in the flood plain. This has the additional benefit of increasing biodiversity by introducing shallow, slowly flowing water in the flood plain. At 'Gameren' on the River Waal one such project has been executed and monitored for a few years now. It appears that without additional measures these channels show a tendency to silt up. In spite of this, man-made secondary channels are promising means to reduce flood levels and increase biodiversity at the same time.

INTRODUCTION

The River Rhine

The River Rhine is one of the major rivers of Western Europe. It originates in the Swiss Alps, and flows through Germany and the Netherlands towards the North Sea. After crossing the German-Dutch border it splits up into three branches, of which the River Waal is the largest one, carrying about 70% of the Rhine flow. The catchment area of the Rhine covers 185,000 km^2 and with more than 54 million inhabitants and about 10% of the world's chemical industry, it is the most densely populated and industrialised basin in Western Europe. The average discharge at its mouth is 2,300 m^3/s, the highest flood on record occurred in 1926 and measured 13,000 m^3/s. Because the Rhine is fed from both precipitation and glaciers at different times of year, the amount of water flowing down the river is relatively stable, making it navigable all year round. The River Rhine is a major transport artery between the port of Rotterdam and the German hinterland. About 500 ships are crossing the German-Dutch border each day, carrying 150 million tonnes of freight per year. Figure 1 gives an overview of the Rhine branches in the Netherlands.

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Historical development and trends for the future

As from the 12th century the flood plain area of the Rhine has been gradually reduced by the construction of dikes. Protected against floods by these dikes, man converted the former flood plain to arable land. The continuing deforestation of the remaining flood plain facilitated the flow of water during floods, while at the same time pasture land was created. Over the centuries also the low-water bed was more and more constricted. The first interventions, such as constructing groynes, were aimed at preventing bank erosion and channel migration. Later on, river normalisations were carried out in order to create a single, deep and fast flowing (0.5 to 1.5 m/s) channel to accommodate larger and larger ships. The successive river training works of the 19th and 20th century confined a once freely meandering river to a single, straight channel. As a typical example, the development of the River Waal near Tiel in the 19th century is given in figure 2.

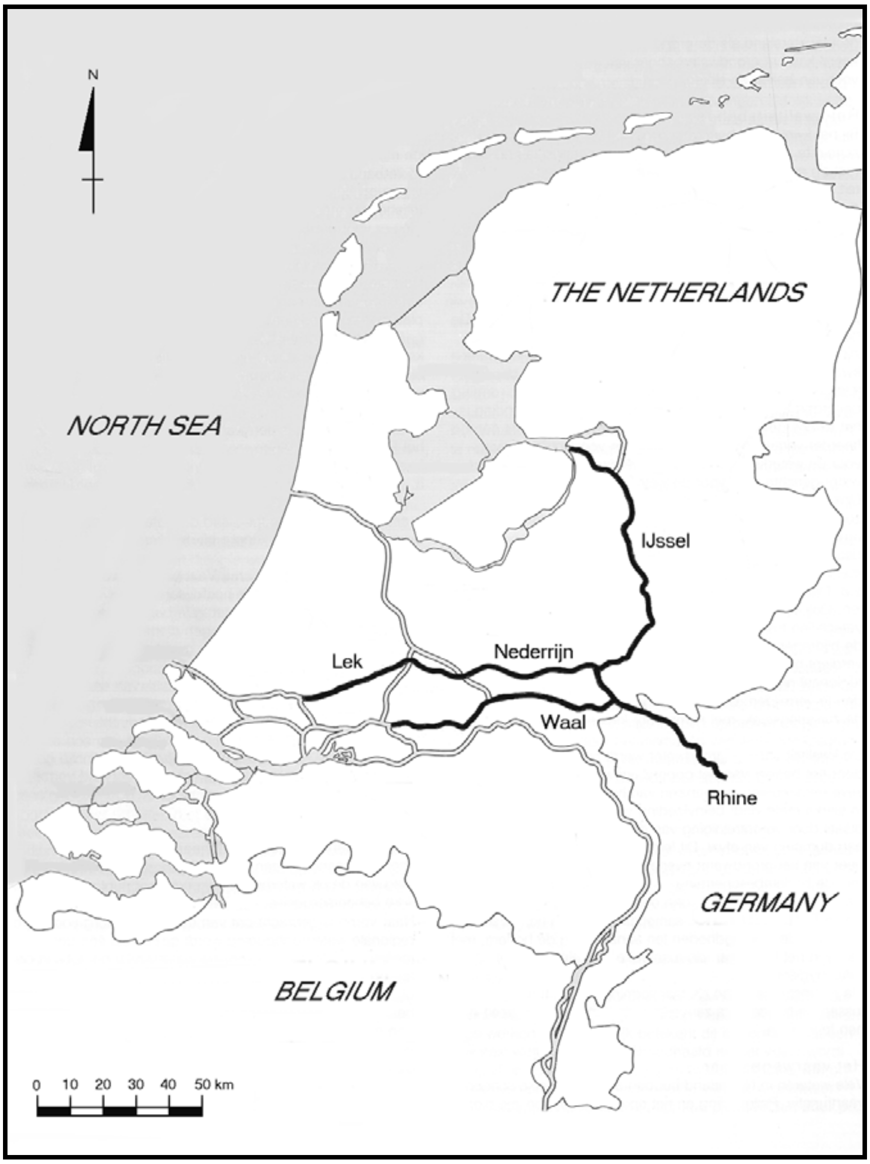

Figure 1. Rhine branches in the Netherlands

At present the flood plains of the Dutch Rhine branches are pocket-shaped with a typical length of about 2 kilometres and a maximum width of 1 kilometre. The total flood plain area now left is only 270 km^2. Since the river is prevented from meandering, no regeneration of the flood plain can take place. This means that what is still left of the flood plain is steadily silting up, thus reducing the discharge capacity during floods even further. On top of that the design discharge for flood protection shows a tendency to increase. In the Netherlands river dikes are designed to withstand a flood with a statistical return period of 1,250 years. At present the design flood discharge of the Rhine measures 15,000 m^3/s, but it is expected that it will increase to 16,000 m^3/s in the near future, and to 18,000 m^3/s beyond. This is equivalent to a rise in water levels of 0.20 m and 0.60 m respectively.

Loss of biodiversity

Normalisation of the river, and the aggradation and intensified agricultural use of the flood plain have had a devastating effect on the biodiversity of the river system. Aquatic life benefits from hydrological connectivity and from variations in flow velocity and water depth, and these have all but disappeared along the Rhine. On top of that the water quality of the Rhine had deteriorated severely, due to industrial, agricultural and household waste water disposal. It was not until the 1970s that a turning point in the approach towards the use of rivers was reached. As a first step the problem of water quality was addressed, and thanks to close international co-operation a significant improvement of the quality of the Rhine water has been achieved over the past three decades. With the water quality problem solved, the next task that lies ahead of us is the ecological rehabilitation of the river system. One way of doing this is to restore the hydrological connectivity between the flood plain and the low-water bed. Suitable habitats in terms of morphological and hydrological conditions have to be restored in order to benefit from the improved water quality. Nowadays the restricted hydrological and morphological dynamics of the flood plain are more limiting to a successful recovery of nature values than water quality.

To sum up the River Rhine is faced with two problems. The discharge capacity has been reduced by narrowing and siltation of the flood plain, while at the same time the design flood discharge has increased. Secondly, as a result of the normalisations the biodiversity of the river ecosystem has decreased dramatically.

REDUCING FLOOD LEVELS BY RESTORING NATURE

Alternatives to dike reinforcement

The obvious solution to higher flood levels is to build higher dikes. This, however is no sustainable solution in the long run, since it does not address the cause of the problem. Moreover, the higher the dikes, the more serious the consequences in terms of damage and loss of life should a dike fail. This has been recognised by the Rhine bank states, who adopted the 'Action plan on Flood Defence' in 1998 (ICPR, 1998). One of the guiding principles of this plan is to store water in the catchment area and along the Rhine as long as possible. In the Netherlands, at the very downstream end of the Rhine, other types of measures are needed. To cope with the increase in the design flood discharge, a policy called 'Room for Rivers' was adopted in the Netherlands in the mid-nineties. According to this policy the current level of protection is to be maintained by increasing the discharge capacity of the river, rather than raising the level of the dikes yet again. Measures to achieve this end are lowering the level of the flood plain, removing obstacles in the flood plain, local dike realignment, and groyne lowering. Especially flood plain lowering is a good example of integrated water management. Not only does it reduce flood levels, but by the same token it offers opportunities for nature development. Lower flood plain levels mean more frequent inundations, leading to more wetlands and a potential increase in biodiversity. Execution of these plans can be very cost efficient when the excavated sand and clay are sold to the building industry. The only price to be paid is the loss of pasture land in the flood plain.

Studies have shown that in order to deal with an increase in the design flood from 15,000 to 16,000 m^3/s the entire flood plain of the Dutch Rhine needs to be lowered by more than 0.5 m. However, a uniform lowering of the flood plain would not be equally effective everywhere. For instance, there is no point in lowering a flood plain that acts predominantly as storage area for flood water. Other reasons for differentiation may be a contaminated topsoil for which a costly solution of disposal has to be found, or to spare sites of archaeological or cultural significance. If one area cannot be lowered for whatever reason, an extra effort has to be made in an area nearby. To this end the Rhine branches have been subdivided in stretches of 20 to 30 kilometres, each of which has been assigned a target in water level reduction. Further differentiation of lowering is found within a flood plain itself. Differentiation of excavation patterns works out well for the potential ecological value, which benefits from spatial variation in hydrological conditions. By giving the excavation the shape of a channel, more variation in water depth and thus in habitat is created.

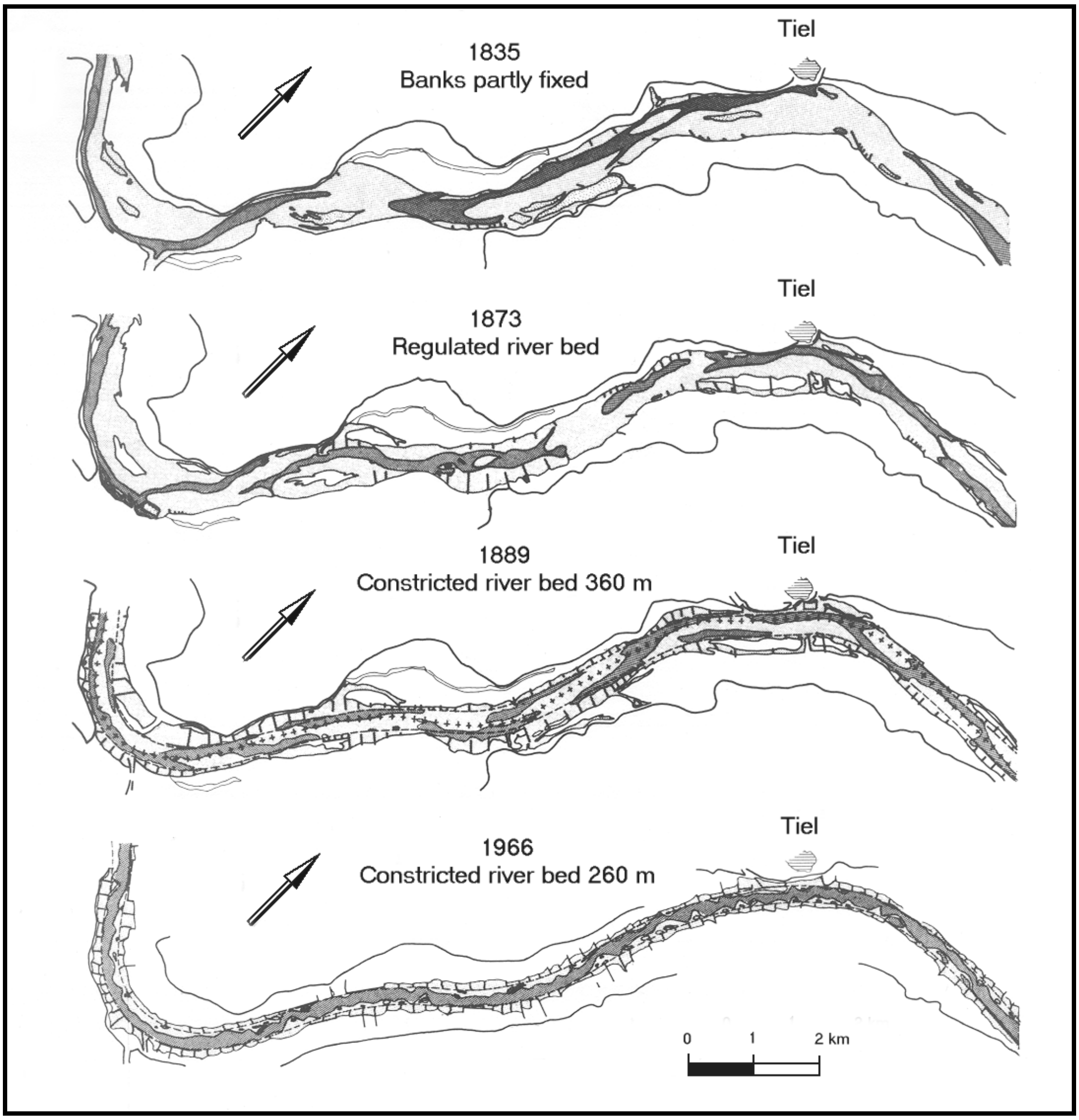

Figure 2. Flood plain development of the Waal near Tiel

Secondary channels

Permanently flowing side channels (or secondary channels) used to be a common phenomenon in the flood plain of the Rhine. Until the 19th century side channels developed as a result of the formation of islands in the main channel. Within a few decades they silted up, starting at the upstream end. Related specific habitats like shallow, slowly flowing water associated with these channels have disappeared since the river normalisations of the late 19th and early 20th century. Nowadays the hydrological and morphological conditions of the Rhine are such that these side channels will not return by natural means. The construction of side channels will promote the development of riverine-type habitats, whilst preserving the navigability of the main channel and increasing the conveyance of the river. In this type of channel moderate flow velocities and gently sloping banks offer favourable conditions for ecological development, as opposed to the deep, fast flowing main channel of the river and the isolated waters in the flood plain. Connecting the main channel to the flood plain may create better spawning conditions for fish.

The ecological significance of side channels, either natural or man-made, has been widely recognised. European examples of restored secondary channels can be found along the River Danube in Austria (Schiemer *et.al.*, 1999) and Hungary (Marchand *et.al.*, 1994), and along the River Rhone in France (Henry *et.al.*, 1995). In the Netherlands different types of side channels are planned or have been realised. In contrast to the European examples, these are mostly newly excavated channels. No deliberate attempt is made to follow the course of old channels. There is no morphological reason to restrain oneself to these old channels, since they were formed at a time when the river regime was totally different than it is today, or will be in the future. Moreover, whatever ecological value is still left in the flood plain today, is mostly found in these former river channels, so dredging them would mean an even greater loss of biodiversity. The design principles of secondary channels and some planned project locations are discussed in Schropp (1995) and Schropp *et. al.* (1998).

Morphological consequences

Creating secondary channels in a flood plain will cause a change in the flow patterns of the river, which in turn will have its effect on morphological processes. Although an increase in morphological activity is usually regarded as beneficial for nature development, their are some risks to be considered.

First of all, withdrawing water from the main channel leads to aggradation of the low-water bed, which may cause draught restrictions for inland shipping at low water levels. Exactly how much aggradation is still acceptable depends on local conditions, but for the River Waal a value of 0.20 m is regarded as a maximum. The discharge available to a secondary channel is therefore limited to only a few percent of the total river discharge.

The cross-sectional profile of the main channel will generally be much larger than that of a secondary channel. When the sediment load is distributed in proportion to the discharge, the smaller branch will eventually silt up. So in order to guarantee a permanent flow of water in a secondary channel, the bulk of the sediment load has to be carried through the main channel, although this may result in some bed level rise there. There are several options to make sure as little sediment as possible is entering the secondary channel. Ideally, the intake of a secondary channel is located in the outer bend of the main channel. The heliodical flow in a river bend will direct the bed load towards the inner bend, away from the intake. If situating the intake in an outer bend is not possible, there are still several techniques available to minimise the inflow of bed load, a number of which are derived from water intakes at irrigation schemes. Bottom vanes for instance produce a heliodical flow in a straight river stretch, thus diverting the bed load away from the intake, an example of which can be found in Odgaard *et. al.* (1991). An intake situated in the deep, outer bend of the main channel offers the opportunity to create an intake sill, reducing the inflow of bed load even further. At the intake preferably the angle between the side channel and the main channel is only small, because contrary to intuition a connection at a right angle results in a larger bed load inflow than one at an acute angle (Bulle, 1926). A further threat to the proper working of secondary channels is the deposition of suspended load. The low flow velocities will cause the sediment content of the water to settle, thus reducing the gain in conveyance attained by the excavation. This can be avoided by creating a sediment trap at the upstream end of the side channel, but this requires a lot of space which is not always available, and there is risk that it also acts as a trap for macroinvertebrates and young fish.

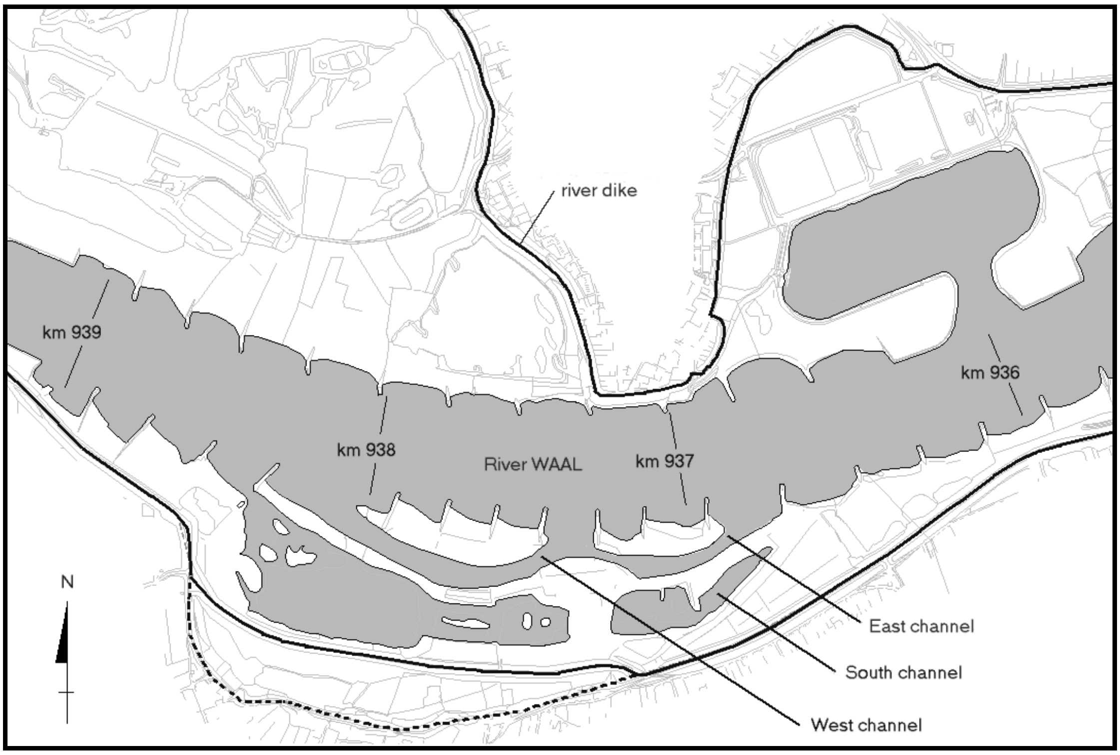

Figure 3. The 'Gameren' flood plain

A third morphological aspect is the danger of secondary channels meandering freely in the flood plain, thereby eventually undermining nearby dikes. To avoid this, a safety margin of about 100 m between the side channels and the dikes has to be maintained. Channel banks consisting of clay further help to reduce the risk of channel migration.

RESULTS OF THE 'GAMEREN' CASE-STUDY

One of the locations in the Netherlands where secondary channels have been realised is the ‘Gameren’ flood plain along the River Waal, see figure 3. In this area of about 1.5 km^2 three side channels were excavated in 1996, of which the two smaller ones were connected to the Waal that same year and the larger one in 1999 (table 1). The excavated sand and clay were used to reinforce a nearby dike that was not yet up to standard. The large, South channel is permanently flowing and has an average discharge of about 50 m^3/s, or 3% of the average Waal discharge. The two smaller East an West channels are only flowing during relatively high flow conditions. In order not to exceed the discharge limits, control structures in the form of sills and constrictions are incorporated in the channels.

Since these are some of the first man-made secondary channels in the Netherlands, the 'Gameren' flood plain serves as a pilot project for future nature development projects. Morphological and ecological developments will be closely monitored based on a detailed monitoring plan which is directed at:

1. Possible bed level aggradation of the main channel.
2. Erosion and sedimentation processes in the side channels.
3. Side channel discharge and flow patterns.
4. Sediment composition and quality.
5. Ecological rehabilitation (fish, macroinvertebrates and vegetation).
6. Toxicological effects of contaminated soils

All parameters are measured once a year, except for the bed level of the main channel (every three months) and the side channel discharge (every month). In addition to the yearly levelling of the side channels field sketches are drawn after every flood to document morphological changes. Water levels and total river discharge are measured on a routine basis a few kilometres away from the project location, so there is no need to measure them at the project location as well.

secondary channel	length (m)	discharge (m^3/s)	flow (days/year)	connected
East	600	10	100	November 1996
West	900	30	265	November 1996
South	1900	50	365	October 1999

Table 1. Secondary channels in the 'Gameren' flood plain

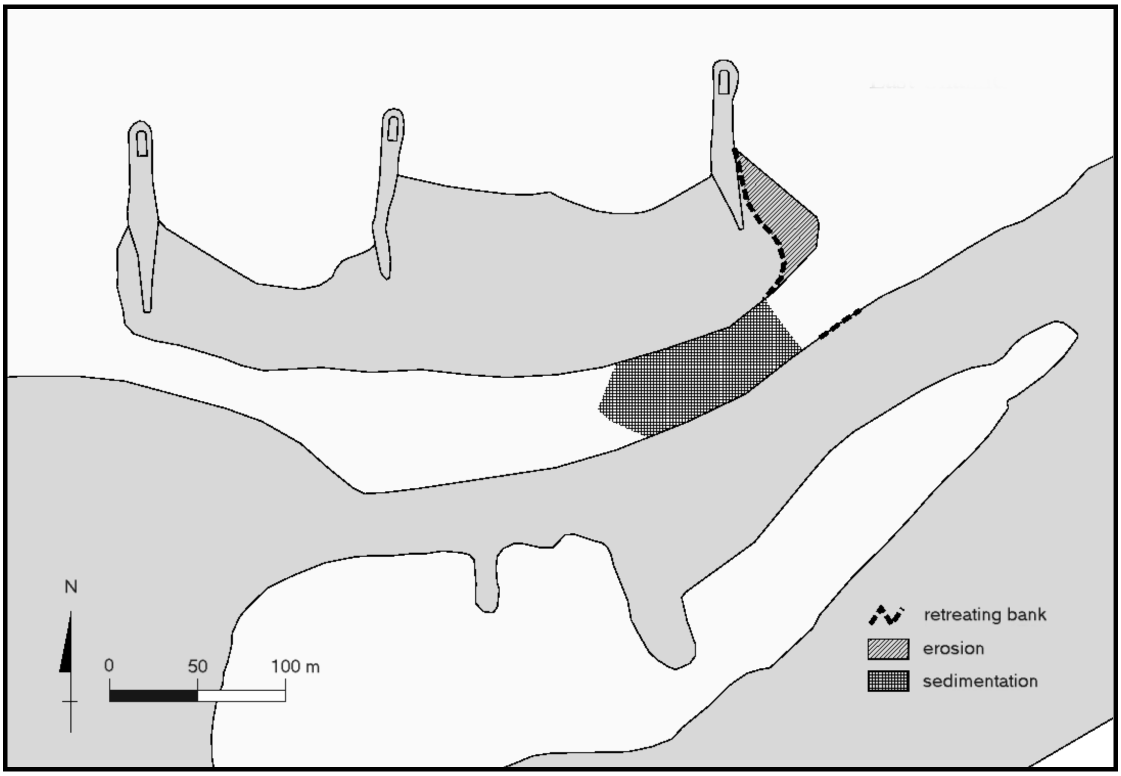

Figure 4. Morphological development East channel

The monitoring programme started in 1997, and now, after three years of measurements, we are able to draw some preliminary conclusions. On the basis of model results it was expected that the bed level of the main channel would rise, but no aggradation has been observed so far, nor have there been any navigational problems reported for this stretch of river. Apparently any aggradation of the main channel caused by the two periodically flowing side channels is obscured by the natural variation of bed level. It is believed that once the large, permanently flowing South channel is fully operational, an effect on the main channel bed level will be detected.

As to the side channels only results on the morphodynamic development of the East and West channel can be reported thus far. The South channel was connected to the main channel only last year, and no data on its development are available yet. As a departure from the guidelines no intake structure or sediment trap was included in any of the side channels at 'Gameren'. Apart from saving costs it also offered the opportunity to learn how soon these channels would actually silt up. As a result major sand deposition has taken place in the East channel, where a bank-to-bank alluvial fan has spread more than halfway into the channel, see figure 4. The progress of the sedimentation front is closely related to flood events, but until now the bed level is not becoming any higher. In the West channel a similar process of sedimentation has taken place, only here sand bars are developing instead of a bank-to-bank alluvial fan, see figure 5. Both channels suffer from significant bank erosion, especially at the unprotected inlets. A large part of this is caused by passing ships, whose translation waves penetrate the side channels. Contrary to expectations most of the sediment deposits consist of sand, and hardly any fine silt is found.

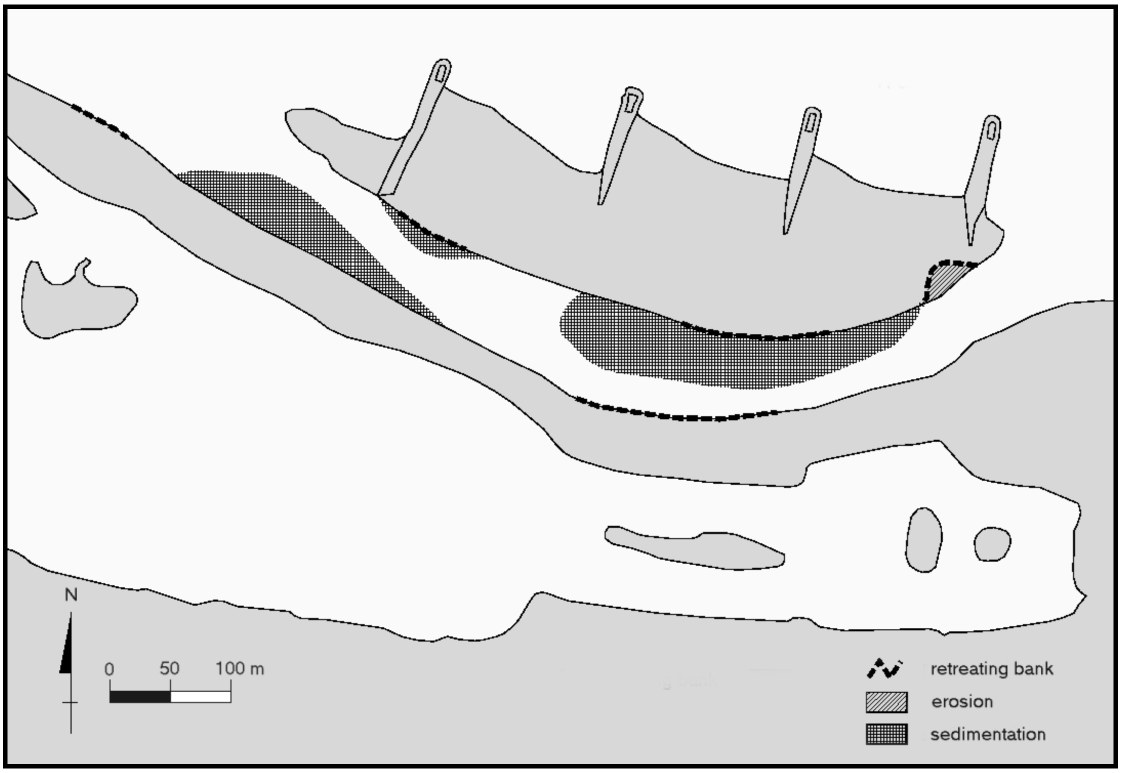

Figure 5. Morphological development West channel

The accumulation of sand in the East and West channels has nearly covered the discharge control structures that are present there. In spite of this, the discharge flowing through the side channels is somewhat less than was expected beforehand. With regard to flow patterns the influence of shipping appears to have been underestimated in the design phase of 'Gameren'. At low water depths the translation waves of passing ships cause the flow in the side channels to fully reverse. Bearing in mind that the purpose of secondary channels is to create a stable, slowly flowing environment for aquatic life, a full reversal of flow every 5 minutes must have a negative effect on the ecological development of the channel system.

DISCUSSION

In the Netherlands a few secondary channels have been created recently, and these locations have been monitored for a few years now. It is too early yet to draw final conclusions about their morphological development, particularly since the processes go relatively slow. Therefore monitoring these projects will continue for another number of years, and hopefully these pilot projects will lead to a better understanding of the relevant morphological and ecological processes, and to improved design guidelines for man-made side channels.

In a wider context flood plain lowering and man-made secondary channels, possibly in combination with retention, are promising alternatives to yet another series of dike reinforcement along the Rhine branches in the Netherlands. It deals with the loss of conveyance and has the added bonus of nature development by resetting the terrestrification process. This approach can be of value for river managers abroad, who are faced with similar problems. Although the scale of the river may be different, the same principle applies.

REFERENCES

Bulle, H., (1926) "Untersuchungen über die Geschiebeableitung bei der Spaltung von Wasserläufen", VDI-Verlag G.M.B.H., Berlin (in German).

Henry, C.P.; Amoros, C., Giuliani, Y., (1995) "Restoration ecology of riverine wetlands: II. An example in a former channel of the Rhone River", Environmental Management, Vol. 19, pp 903-913.

ICPR, (1998) "Action plan on flood defence", International Commission for the Protection of the Rhine, Koblenz , Germany.

Marchand, M., Marteijn, E.C.L., Pedroli, G.B.M., Velzen, E. van, Bakonyi, P., (1994) "The Gemenc floodplain rehabilitation project: A policy analysis for the rehabilitation of a Danube floodplain, Hungary", Water, Science and Technology, Vol. 29, pp. 367-370.

Odgaard, A.J., Wang, Y., (1991) "Sediment management with submerged vanes. II: Applications", Journal of Hydraulic Engineering, Vol. 117, pp. 284-302

Schiemer, F., Baumgartner, C., Tockner, K., (1999) "Restoration of floodplain rivers: The Danube restoration project", Regulated Rivers, Vol. 15, No. 1-3, pp. 231-244.

Schropp, M.H.I., (1995) "Principles of designing secondary channels along the River Rhine for the benefit of ecological restoration", Water, Science and Technology, Vol. 31, pp. 379-382.

Schropp, M.H.I., Bakker, C., (1998) "Secondary channels as a basis for the ecological rehabilitation of Dutch rivers", Aquatic Conservation: Marine and Freshwater Ecosystems, Vol 8, pp. 53-59.