NCR

GUIDELINES FOR REHABILITATION AND MANAGEMENT OF FLOODPLAINS

ecology and safety combined

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Preface

This report and the IRMA-SPONGE Umbrella Program

In recent years, several developments have contributed not only to an increased public interest in flood risk management issues, but also to a greater awareness of the need for improved knowledge supporting flood risk management. Important factors are:

- Recent flooding events and the subsequently developed national action plans.
- Socio-economic developments such as the increasing urbanisation of flood-prone areas.
- Increased awareness of ecological and socio-economic effects of measures along rivers.
- Increased likelihood of future changes in flood risks due to land use and climate changes.

The study leading to this report aimed to fill one of the identified knowledge gaps with respect to flood risk management, and was therefore incorporated in the IRMA-SPONGE Umbrella Program. This program is financed partly by the European INTERREG Rhine-Meuse Activities (IRMA), and managed by the Netherlands Centre for River Studies (NCR). It is the largest and most comprehensive effort of its kind in Europe, bringing together more than 30 European scientific and management organisations in 13 scientific projects researching a wide range of flood risk management issues along the Rivers Rhine and Meuse.

The main aim of IRMA-SPONGE is defined as: *"The development of methodologies and tools to assess the impact of flood risk reduction measures and scenarios. This to support the spatial planning process in establishing alternative strategies for an optimal realisation of the hydraulic, economical and ecological functions of the Rhine and Meuse River Basins."* A further important objective is to promote transboundary co-operation in flood risk management. Specific fields of interest are:

- Flood risk assessment.
- Efficiency of flood risk reduction measures.
- Sustainable flood risk management.
- Public participation in flood management issues.

More detailed information on the IRMA-SPONGE Umbrella Program can be found on our website: *www.irma-sponge.org*.

We would like to thank the authors of this report for their contribution to the program, and sincerely hope that the information presented here will help the reader to contribute to further developments in sustainable flood risk management.

Ad van Os and Aljosja Hooijer
(NCR Secretary and IRMA-SPONGE project manager)

Contents

Summary

The first three chapters of this report offer introductions, each from their own viewpoint. In the first chapter, the focus point is the river landscape in general. Amongst others the history of human interference in the river landscape, theories on the ecological functioning of rivers and summaries of hydrological and morphological processes are treated here. Because of its general nature the reference list of this chapter is somewhat longer than that of the other chapters, offering a number of entries for those interested in further reading. The second chapter gives an overview of relevant policy documents for the river landscape in the Netherlands.
The third chapter deals with some aspects in which the interrelations between the different rehabilitation measures (treated in more detail in chapters 4 to 10) come to light. These aspects are the ecological coherence in ecological networks, the effects of measures on design river water levels and aspects of dealing with polluted soils.

Chapters 4 to 10 each deal with one of the measures that might be considered in floodplain rehabilitation projects. In all of these seven chapters, first the measure and its reference situation are described; then attention is paid to the functioning of the area in which the measure is implemented, from hydrological, morphological and ecological viewpoints. Finally an overview of the suitability of the river stretches to the measure and a number of guidelines and recommendations for the implementation of the measure are given. For all of these chapters a similar structure was chosen, in order to secure easy access for users trying to find specific information quickly.

The last chapter deals with grazing management, the choices that must be made there, and the consequences these choices have for the further development of the area. This last chapter to some degree is relevant for all preceding chapters dealing with specific measures, but this time from the viewpoint of terrain management.

Introduction

This report offers practical recommendations and guidelines for the design of projects for ecological rehabilitation of floodplains. In these recommendations and guidelines express attention is paid to the prerequisites from the part of navigation and safety against flooding.

The reasons to publish these guidelines are twofold. In the first place the number of rehabilitation projects of floodplains has increased sharply as a result of the implementation of measures to increase the safety against flooding. In these cases the ecological rehabilitation plans mainly are a result of excavation works that are necessary to increase the safety level. Although ecological restoration comes second in these plans, it still can profit considerably from a properly designed floodplain. In the second place, everywhere in the river basins the layout and use of the floodplains are reconsidered critically. This is related to the revised level of the water levels during design discharge. Not only lowering of floodplains is considered from this point of view, but also all other possible obstacles in the floodplains and the functions of the area that cause such obstacles.

This report tries to reflect the state of the art results of research and views, and to make these available for use in planning and management. Because the research is proceeding and views change, it is difficult to secure a long 'storage life' of this publication. Therefore in due time a follow-up version will be considered, depending on the proven need and availability of required means.

This report aims to be a tool for all those involved in planning and management of floodplains and river landscapes. In the first place it aims at ecological aspects of planning and management, related to abiotic conditions; other functions such as recreation and agriculture are only considered indirectly. The functions of safety against floods and navigation, on the other hand, are given close attention by way of the preconditions they impose on river water levels and flow velocities. In spite of this orientation on ecological aspects the authors consider this report to be relevant to a wide range of disciplines, because in all rehabilitation and reconstruction projects ecology makes up an integrated part of the planning.

The aims of this report are:
- to give an overview of the measures that might be considered;
- to make clear which cross links and interrelations exist between the measures and the river system as a whole;
- to make clear which cross links and interrelations exist between the different measures;
- to provide the reader with a number of recommendations and guidelines about the way in which these measures might be planned and implemented in practice.

The level at which this report enters is that of a single floodplain. A short explanation is needed of the definition of a floodplain that is used in this report. The floodplain of a natural, unconstrained river is the whole area that is subject to flooding. Presently the area of the natural floodplains is reduced considerably by the construction of major embankments. Because usually the width of the present-day floodplains becomes wider and smaller with regular intervals, ‘a floodplain’ in this report refers to the area between two consecutive points where the distance between the main channel and the major embankment is minimal, the main channel and the major embankment. The size of such floodplains usually is some hundreds of hectares. Whenever useful, attention is paid to a larger scale, for example that of the river branch. Of the planning cycle, mainly the phases of the design and management are considered; the strategic choices that precede this phase are considered briefly, while the implementation and evaluation phases are not considered at all.

A number of subjects that are at least as important to the manager or planner as ecological aspects are not considered in this report. A thorough explanation of these subjects would interfere with the timely publication of the results presented here. Therefore no attention is paid to, for example, legal aspects, land purchasing procedures, or cost aspects. The problems related to the widespread presence of polluted soils in the floodplains are dealt with shortly, but only in a very practical way. As a consequence, this publication does not try to give a complete overview of all aspects and information that are needed during the design process.

A large number of authors have contributed to this report. In alphabetical order they are: Joost J.G.M. Backx, Jan Wouter C. Bruggenkamp, Tom (A.D.) Buijse, Hugo Coops, Perry Cornelissen, Gerben J. van Geest (Wageningen University), Noël (E.F.M.) Geilen, Rob E. Grift (Netherlands Institute for Fisheries Research (RIVO)), Luc H. Jans, Jolande de Jonge, Frederike I. Kappers, Maarten Platteeuw, Frank C.J.M. Roozen (Wageningen University), Margriet M. Schoor, Max H.I. Schropp, Anne Sorber, Esther Stouthamer, J. Theo Vulink, Henk A. Wolters and Marjolein van Wijngaarden. Maarten Platteeuw, Margriet Schoor and Henk Wolters edited this report. All authors are or were employees of Rijkswaterstaat, RIZA, the Netherlands, unless indicated otherwise.

1 Characteristics of the Rhine and the Meuse in the Netherlands

Henk A. Wolters, Jan-Wouter C. Bruggenkamp, Tom (A.D.) Buijse,
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1 Characteristics of the Rhine and the Meuse in the Netherlands

1.1 General characteristics

The Rhine originates in Switzerland at an altitude of more than 2500 m. The river forms part of the border between Germany and France, then flows through Germany, and enters the Netherlands at Lobith. The Rhine is fed by glaciers in the Alps, and further downstream by precipitation. Therefore the upper stretches of the Rhine have their highest discharges in the early summer months, whereas the highest discharges further downstream occur during the winter months. Due to the contributions from both glaciers and rain the discharge pattern during the year is relatively even.

The Meuse originates in France, approximately at 200 km north-east of Dijon, at an altitude of 400 m above sea level. The river flows through France, Luxemburg and Belgium and enters the Netherlands at Eijsden, just south of Maastricht. In the Meuse basin no large water bodies, in the form of ice and snow, are present, so the Meuse is fed year-round by rain. As a result discharges are high in winter and low in summer.

The Rhine and the Meuse discharge into the North Sea. In table 1.1 some characteristics are given for both rivers, table 1.2 gives some characteristics of the Dutch branches of both rivers.

Table 1.1
Characteristics of the Rhine and the Meuse.

	Rhine	Meuse
River basin		
Total length (km)	1,320	935
Basin area (km^2)	185,000	36,000
Basin area in the Netherlands (km^2)	20,000	6,000
Transported cargo (tonnes/year)	150 million	41 million
Data at the Dutch border		
Mean discharge (m^3/s)	2,220	250
Median discharge (m^3/s)	1,970	160
5% exceedance discharge (m^3/s)	4,470	770
95% exceedance discharge (m^3/s)	980	20
Maximum recorded discharge (m^3/s)	12,600	3,000
Minimum recorded discharge (m^3/s)	575	0
Design discharge (m^3/s)	15,000	3,800
Water level at mean discharge (m+MSL)	9.70	44.90
Annual load of sand and gravel (m^3/year)	500,000	50,000
Annual load of silt and clay (tonnes/year)	2,500,000	324,000
Mean silt content (mg/l)	30	19

1.2 Historical development of Rhine and Meuse

In the course of time, the river and its surroundings have shown many changes, due to natural morphological processes on the one hand and human interference, reacting to those natural processes, on the other hand. The present river area is the result of the interactions between the forces of nature and the efforts of man to master these. The actual situation in the Dutch river area is strongly influenced by a number of measures. Those measures have resulted in an artificial, intensively managed landscape, a

Table 1.2
Characteristics of the branches of the Rhine and the Meuse in the Netherlands.

	Bovenrijn	Waal/ Beneden-Merwede	Pannerdens Kanaal	Nederrijn/ Lek	IJssel	Grensmaas	Zandmaas	Bergse Maas/ Amer
length (km)	11	92	11	107	118	65	151	40
mean width of the summer bed (m)	330 - 440	260 - 370	140 200	130 - 200	100 - 120	100 - 150	100 - 150	150 - 250
mean width of the floodplains (m)	1000	950	1200	750	900	900	1200	400
area of the floodplains (ha)	1100	8700	1300	6600	10500	5900	18100	1600
water depth at mean discharge (m)	6.00	5.00 - 5.50	4.50	4.00 - 6.00	3.00 - 4.00	2.00 - 2.50	5.00 - 6.00	5.00 - 7.00
discharge distribution at free flow (%)	100	63-72	28 - 37	17 - 22	11 - 15	100	130	130
bottom slope (cm/km)	11	11	11	10	5 - 10	17	13	2
number of weirs	0	0	0	3	0	1	6	0

cultivated landscape with occasional stretches where natural processes are allowed some freedom. To sketch the historical development of the river area, several sources can be used (van der Ven 1993, Londo 1997, Stegewerns 1999).

1.2.1 Developments until the 20th century

Until approximately the year 1000 natural factors determined the development of the landscape. From this period on, human influence became ever more important. The scattered constructions of embankments for protection of settlements and agricultural lands on natural levees resulted in closed rings of embankments around the year 1400. This was the beginning of a process of ever further reduction of the room for rivers.

The demands from safety, shipping, water supply and a proper distribution of water, but especially the necessary discharge of water, ice and sediment have subsequently resulted in a number of works for regulation and normalisation.

1.2.2 Effects of human interference on the river system

All human interventions together have resulted in strong changes in the river systems. In many cases the interventions at first glance have served the goal for which they were designed. These measures have been effective, when compared to the original goals. However, all these interventions have had all sorts of effects on nature, ecosystems and landscape that we nowadays more and more feel to be negative. These effects are:

- the disappearance of many of the riverine marshes;
- the disappearance of many of the riverine forests;
- the disappearance of many of the shallow open water bodies;
- a strong reduction of natural river morphological processes.

The historical development of the river area can be sketched in the following milestones:

Table 1.3
Overview of the most important measures in the Dutch river area.

until ca 1000	natural river landscape
from ca 1000	building of embankments for protection of settlements and agriculture; development of towns and trade
from ca 1400	closed system of river embankments
1707	excavation of the Pannerdens Kanaal
1850 - 1890	excavation of the Nieuwe Merwede
1868	excavation of the Nieuwe Waterweg
1876	excavation of the Noordzeekanaal
1850 - 1875	regulation of the Waal for discharge of water and ice (building groynes)
1875 - 1916	normalisation of the Waal for shipping
1904	excavation of the Bergse Maas, separation of Meuse and Waal
1911 - 1916	normalisation of the Boven-Merwede
1918 - 1929	normalisation and canalisation of the Meuse between Maasbracht and Grave (cutting off bends, construction of weirs and ship locks)
1932	damming off of the Zuiderzee
1934	construction of the Julianakanaal
1929-1935	normalisation and canalisation of the Meuse between Grave and Lith (cutting off bends, construction of weirs and locks)
1938-1952	excavation of the Amsterdam-Rijnkanaal
1954-1971	normalisation and canalisation of the Nederrijn-Lek; construction of weirs
1958-1987	execution of the Delta Plan, including in October 1970 the closing of the Haringvliet sluices
1971	Lateraalkanaal along the Meuse

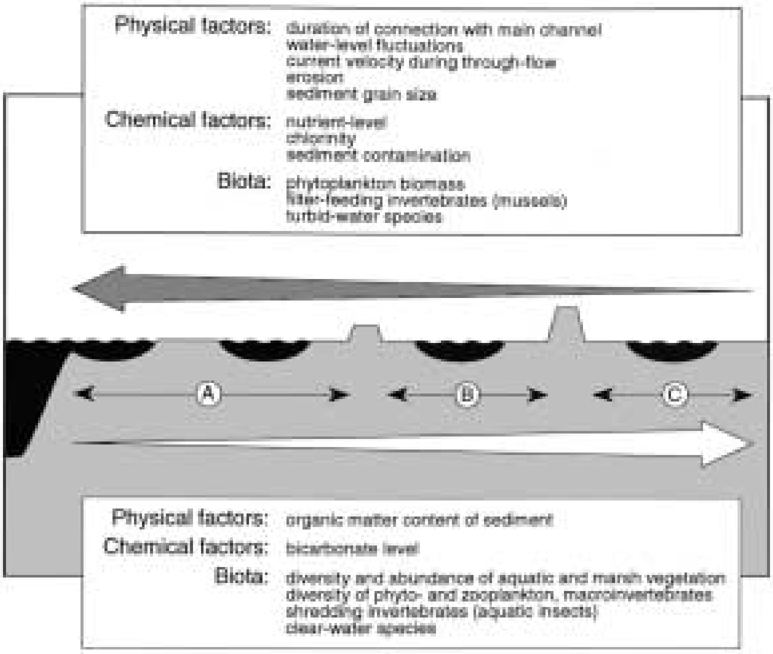
The Rhine and the Meuse now are constrained within embankments. As a result, by far the largest part of their natural floodplains is lost (van Urk & Smit 1989). Because of the absence of inundations the soil level of the embanked and reclaimed areas has subsided; a process that still continues. Contrary to the reclaimed areas, the floodplains along the river have aggradated with increased speed. Prior to the construction of the embankments, close to the river mainly sand was deposited. Now the sand has been covered by clay, sometimes meters thick. The sedimentation in the floodplains causes an increased speed of the process of water becoming land.

In the 19th century minor embankments were constructed, that reduced the inundation frequency and duration of the floodplain even more. They serve to enlarge the possibilities for agriculture over a larger part of the year.

The interventions have caused a less frequent, more abrupt and amplified inundation pattern of the floodplains. Van den Brink (1994) has sketched the effects of the construction of embankments and inundation frequency for water bodies inside as well as outside the embanked areas. Clear gradients can be seen, from physical, chemical and biological perspectives (figure 1.1).

In the 19th century also a start was made with normalisation works to maintain the main channel within certain boundaries by the construction of groynes; also bends were cut off. This process was completed around 1920 (van Urk & Smit 1989, Middelkoop & van Haselen 1999; table 1.3). The cutting off of bends resulted in higher flow velocities, which led to erosion of the main channel and further divergence between the main channel and the floodplain. The erosion of the floodplain by the river was made practically impossible by groynes. In the regulated Rhine and Meuse the main channels deepen and the floodplains aggradate.

Figure 1.1
Schematic view on the lateral dimension in the water bodies in the floodplains of the Rhine and the Meuse, with physical, chemical and biological factors.
A. water bodies that are and are not permanently connected to the main channel;
B. water bodies in the floodplain only directly connected to the river during floods;
C. water bodies behind the embankment, indirectly connected to the river by groundwater flow (seepage) (from: van den Brink 1994).



In the 20th century the Meuse between Linne and Lith and the Nederrijn and Lek from Driel to Hagenstein were equipped with weirs. This has had consequences for the longitudinal dimension of these rivers. Upstream migration of water-bound organisms such as fish and macro-invertebrates is only possible during short time intervals at high discharges when the weirs are fully opened. Moreover the flow velocities during periods of low discharge are reduced, causing the development of ecological communities that are less characteristic for rivers. Furthermore the water level in the stretches that are equipped with weirs influences the flora and fauna in the adjacent floodplains.

Another process worth mentioning is the mining of gravel in the Grensmaas; this caused the river water levels to fall relative to the level of the floodplains, thus leading to less frequent floods.

The interventions in table 1.3 are summarised in table 1.4; here a short indication is given of the secondary ecological effects of these interventions. As a consequence of differences in both the original character and the kind of interventions, the Rhine branches and the stretches of the Meuse each have their own specific problems. This also implies that each has its own opportunities for ecological restoration (WL/Delft Hydraulics 1998, Schoor *et al*. 1999, van Rooij *et al*. 2000).

Rehabilitation of the river area from an ecological perspective finds it direction and goals by comparison of the area with a natural lowland river system. Rehabilitation can simulate natural processes that no longer can take place in their natural way. Examples are the excavation of floodplains, by which marshes, stagnant water bodies or channels could be developed. These cannot be formed by natural processes, because the eroding capacity of the present day river is insufficient. Only at a limited number of locations these processes are still possible. Especially Schoor *et al*. (1999) give some indications of which processes are still possible and where this is the case.

Table 1.4
Ecological, hydrological and morphological effects of human interventions in the river basin.

Period	intervention	Effect
< 1500	construction of major embankments	subsidence in polder areas; floodplains aggradate; increased water level fluctuations
18th – 20th century	cutting off meanders	increase of flow velocities and deepening of the main channel
19th century	construction of minor embankments between main channel and floodplain	less frequent and more abrupt floods; reduction of sedimentation in floodplains; barrier between main channel and floodplain
19th and beginning 20th century	construction of groynes	main channel becomes narrower and deeper; stop on bank erosion and meandering
20th century	construction of weirs	discontinuity in the longitudinal dimension; stagnant conditions; reduction of water level fluctuations
	mining of gravel and sand	in the main channel: erosion; dehydration of the surroundings in the floodplain: unnaturally deep and large stagnant water bodies.

1.3 The ecological functioning of rivers

Collecting knowledge and understanding about the ecological functioning of rivers is a young discipline. Here a short overview is given of the main concepts that were developed since about 1980 and that have been influential for the present views and opinions.

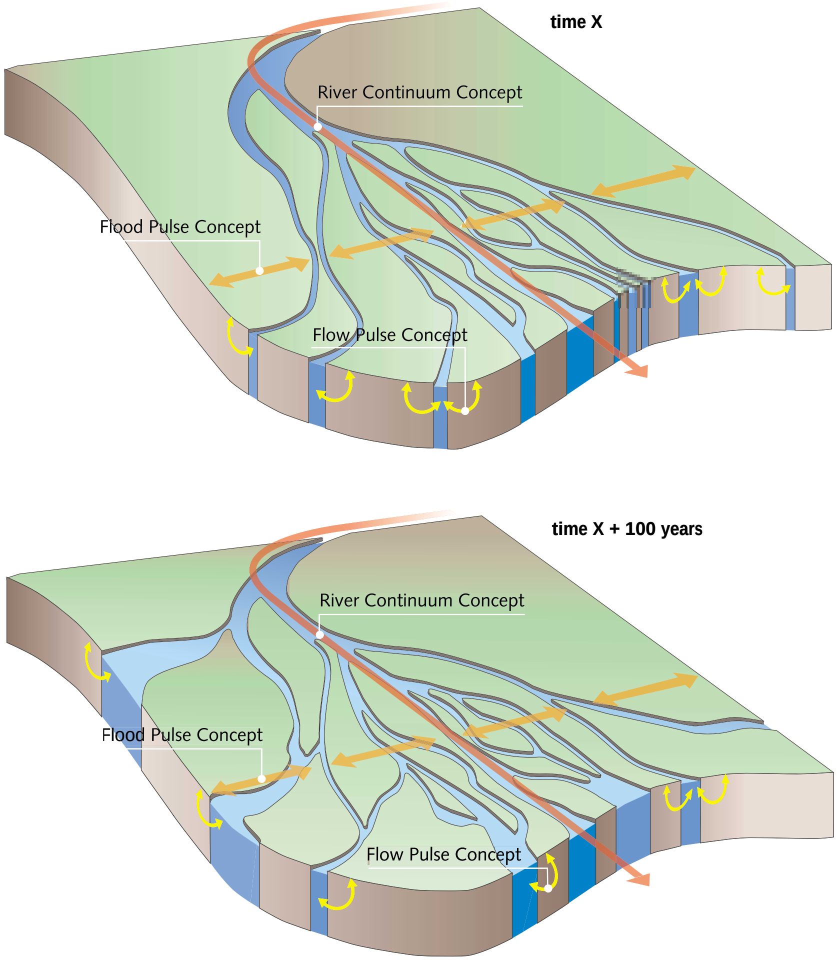
Rivers are open systems with interactive routes along four dimensions:
- longitudinal, in the flow direction: e.g. the transition from a mountain river to a braided river to a meandering river to an estuary or delta;
- lateral, perpendicular to the flow direction: the system of main channel and floodplain;
- vertical: the interactions between the river water and the groundwater in the surrounding area;
- in time: processes such as succession and rejuvenation.

In figure 1.2 these dimensions are indicated schematically.

The first important concept is the ‘river continuum concept’ (Vannote *et al*. 1980). This concept focuses mainly on the longitudinal dimension of rivers: transport processes in the main channel and composition of ecological communities.

Based on research in large, natural tropical rivers with highly predictable discharge regimes, the ‘flood pulse concept’ was developed (Junk *et al*. 1989). This concept focuses on the lateral interactions between the river and its floodplain. Especially along meandering rivers, such as the Rhine and the Meuse, floodplains originally are wide transition zones between land and water. These transition zones are very productive due to the alternation between wet and dry conditions. According to the flood pulse concept the main river functions mainly as a transport route, and not so much as a production zone. Recent additions to the flood pulse concept focus on the differences between the tropics and the moderate climate zone (Junk 1999) and on the role of fluctuations of the water level during

Figure 1.2
Schematic view of the four dimensions of a river system.



low discharges, the 'flow pulse concept' (Tockner *et al.* 2000). According to Junk (1999), in the moderate zone the effects of temperature and day length prevail over the flood pulse. Floods then have different consequences, depending on the season in which they occur.

While the flood pulse concept focuses on floods, the flow pulse concept focuses on the hydrological contact between a river and its floodplains through groundwater. Water level fluctuations in the river can cause upward or downward seepage in the floodplain, even when the flood-plains are not inundated through overbank flow. The groundwater flow velocities depend a.o. on the soil composition. The flow pulse concept describes the relation between the lateral and the vertical dimension. Both flora and fauna are influenced by the resulting water level fluctuations.

The *'serial discontinuity concept'* focuses on the effects of human interference as related to the construction of weirs (Ward & Stanford 1995). For example: the main channel becomes more stable and biodiversity decreases along weir-regulated river stretches.

The most important result of the conceptual developments is the recognition that rivers and their floodplains form one entity. Until about 1980 the word 'river' was more or less synonymous to the main channel, and little attention was paid to and knowledge available of the ecological communities that are characteristic of or adapted to more or less

predictable floods. Lorenz (1999) has initiated the translation of the concept mentioned above into indicators of sustainable river management.
She makes a distinction between indicators for abiotic processes, structural and functional biotic components and human interference.

1.4 Hydrological and morphological system characteristics of the Rhine and Meuse

1.4.1 Hydrology and hydrodynamics

The normalised daily discharges of the Rhine and Meuse are shown in figure 1.3. From this figure the difference in character of both rivers can be seen clearly. Characteristics such as level fluctuations, inundation depth and flow velocity are in these guidelines important features of a river or a river stretch. Both the Rhine and the Meuse show a gradual change in their course in the Netherlands, from large level fluctuations in the upstream parts to small level fluctuations downstream. This is illustrated in figures 1.4 and 1.5.

Figure 1.3
The 'flood pulses' of the Rhine and the Meuse at the Dutch border. The pulses are expressed as the ratio of the mean daily discharge to the mean annual discharge. Also indicated are the discharges of 10 and 90 % exceedance frequency, also in ratio of the mean annual discharge. It is clear that the floods occur in winter and early spring; the variance is much larger in the Meuse than in the Rhine.
Data 1950-1999.

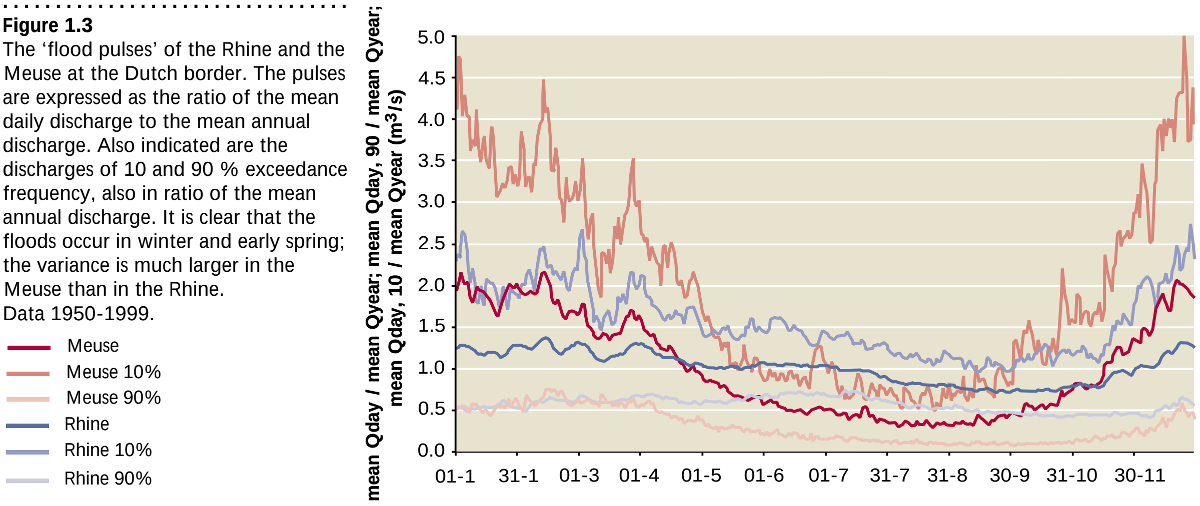


Figure 1.4
Exceedance duration of the water levels along the Rhine at Lobith, Tiel and Dordrecht, and along the IJssel at Olst, with respect to the median level. The fluctuations decrease in downstream direction.

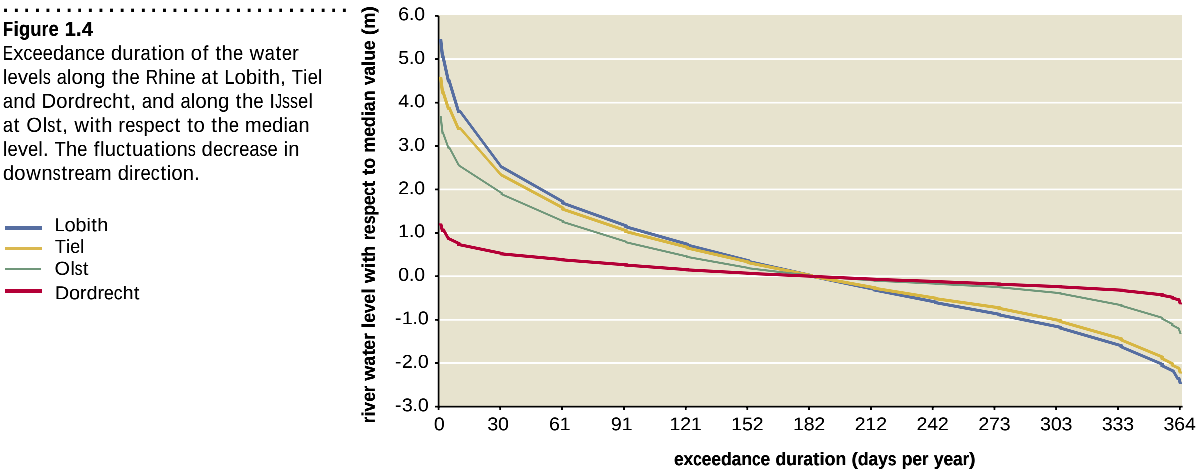


Figure 1.5
Exceedance duration of the water levels along the Meuse at Eijsden, Gennep and Moerdijk, with respect to the median level. The fluctuations decrease in downstream direction. Near Gennep the Meuse is regulated by weirs, resulting in the absence of extremely low water levels.

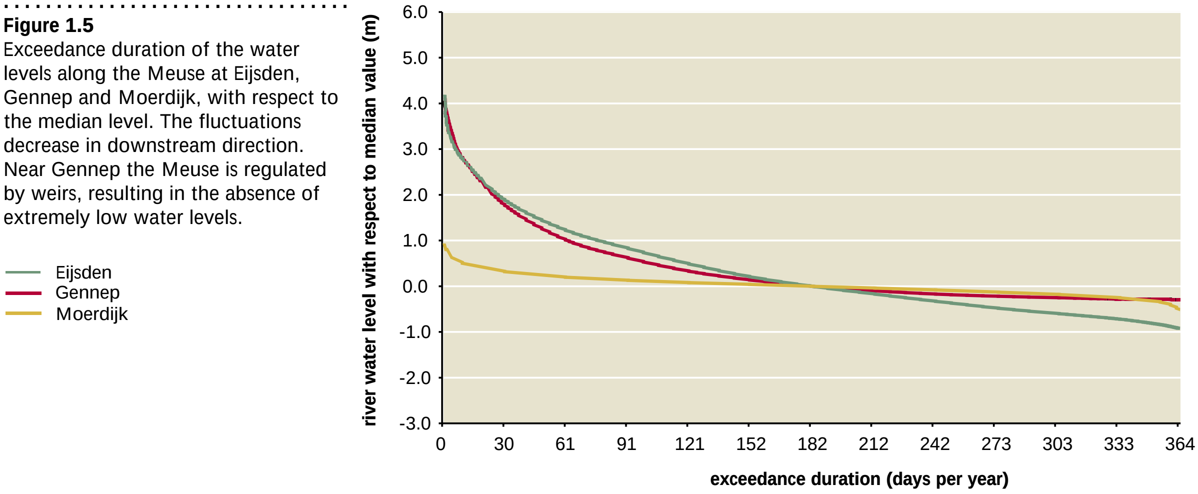
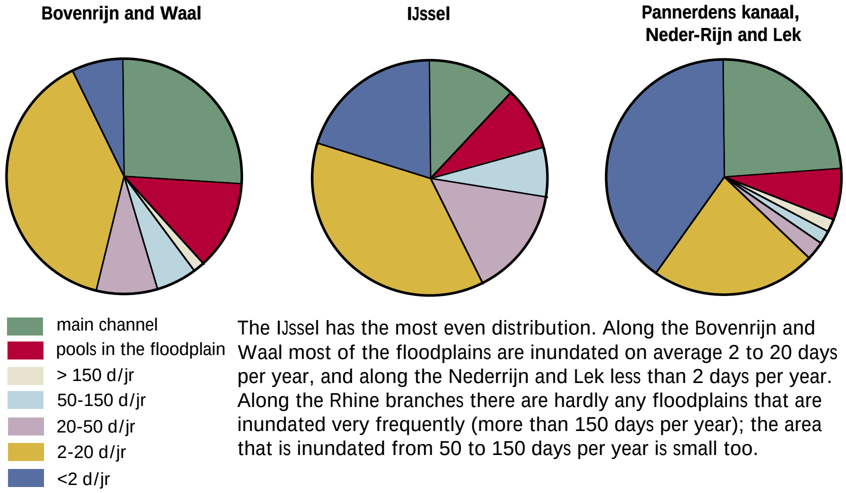


Figure 1.6
The relative share of inundation duration classes along the Rhine branches.



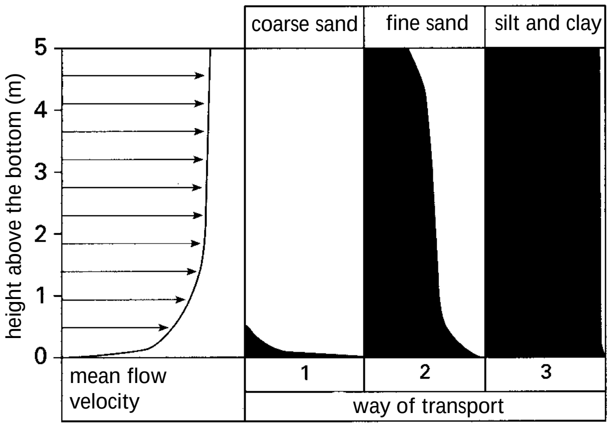
The IJssel has the most even distribution. Along the Bovenrijn and Waal most of the floodplains are inundated on average 2 to 20 days per year, and along the Nederrijn and Lek less than 2 days per year. Along the Rhine branches there are hardly any floodplains that are inundated very frequently (more than 150 days per year); the area that is inundated from 50 to 150 days per year is small too.

1.4.2 Morphology and morphodynamics

Transport of sediment
On annual basis the Rhine transports 500,000 m^3 of sand and gravel and 2,500,000 tonnes of silt. The Meuse transports 50,000 m^3 of sand and gravel and 300,000 tonnes of silt annually. About 90 % of the total amount of silt is transported in suspension, 10 % as bed load. In the Rhine branches about 25 % of the annual load is transported during floods, while these account for only 4 % of the time (Middelkoop 1997, ten Brinke *et al*. 2000).

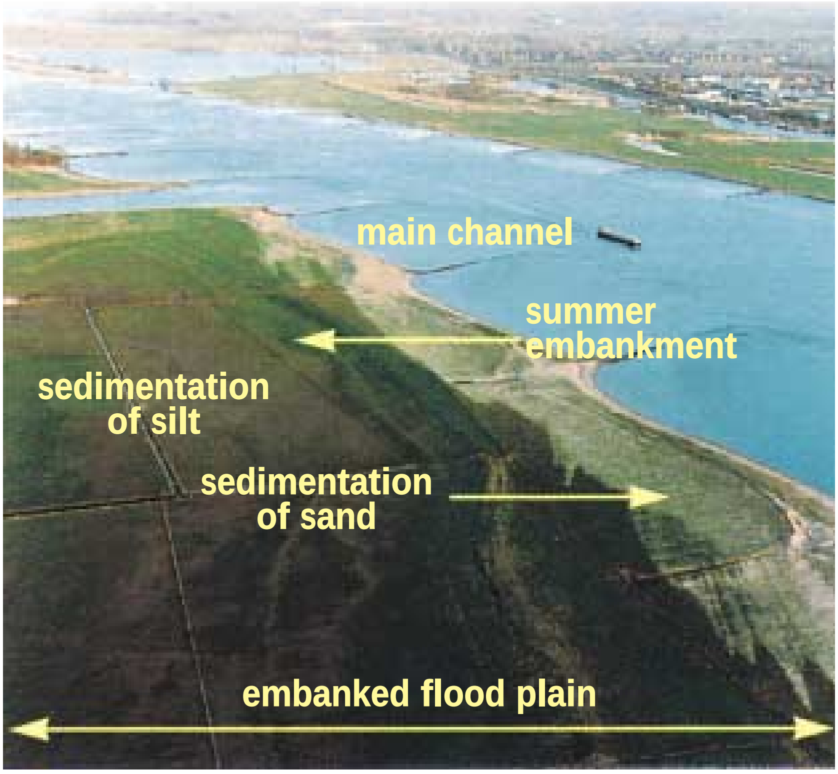
Transport and sedimentation of silt
The suspended material consists of a relatively fine sand fraction and a cohesive, clayey fraction with an organic component. This together is referred to as silt. Silt will be deposited at low flow velocities (indicatively lower than 50 cm/s), and otherwise be eroded or stay suspended. For the upstream parts of the Dutch rivers this means that no sedimentation of silt takes place in the main channel, but only in the floodplains during floods. On a yearly basis about 8 % of the total silt load that enters the Netherlands at Lobith is trapped by the floodplains. This corresponds to

Figure 1.7
Schematic view of the vertical distribution of the mean flow velocity and the transported material in a river bed (Berendsen 1998).



1.Rolling and saltation
(bed load)
2. Suspended load
3. Wash load

Figure 1.8
During floods the river deposits sand on the natural levees along the main channel. Behind the minor embankment silt is deposited (Middelkoop & van Haselen 1999).



200,000 tonnes (Middelkoop 1997, ten Brinke *et al*. 2000). In the Meuse even 50% of the annual load is trapped in the floodplains, corresponding to a load of 160,000 tonnes per year (Asselman 2000).

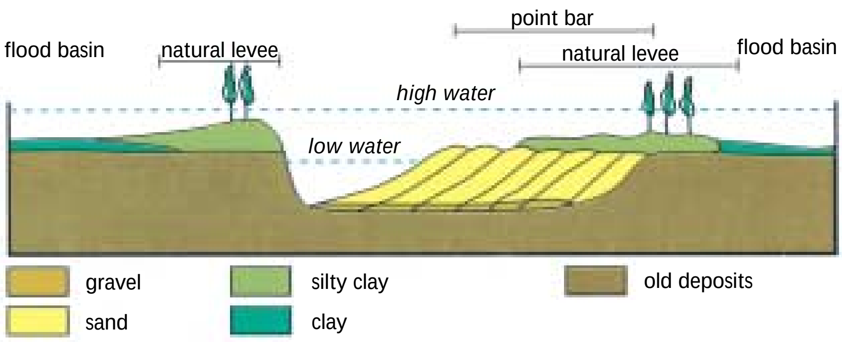
The net influx of silt into the estuary through the Waal, Lek and Meuse is 2.2 million tonnes per year. A large part of this silt is deposited in the Hollandsch Diep and Haringvliet, because these closed estuaries nowadays are more or less stagnant water bodies. In the northern branches of the estuary the silt transport has a more dynamic character, due to the influence of tidal movement. At the Nieuwe Maas there is a continuous inflow of marine silt, while at the Haringvliet sluices there is an annual outflow of 0.5 million tonnes. In total 6 million tonnes of silt are deposited in the Delta annually. This means that on many locations, especially in the port of Rotterdam, constant dredging is necessary (van Dreumel 1995).

Spiral flow

In a river bend the water at the surface flows to the outer bank. As a consequence the water level in the outer bend is somewhat raised; to compensate this, on the bottom of the riverbed water flows from the outer to the inner bend. This flow, together with the downstream water movement, forms the spiral flow (figure 1.9). The flow on the bottom transports sand from the outer to the inner bend (figure 1.10). In the inner bend point bars are formed. This happens especially during flood periods. Then much sand is available for transport, because near the bottom the amount of sand in suspension is large. The larger the ratio of width to depth of the river channel, the better point bars can develop.

Figure 1.9
The spiral flow in a meandering river. (Schoor & Sorber 1998).

Figuur 1.10
Cross section through a meandering river channel.



When a river cuts into ice pushed hills, Pleistocene river dunes, old river-beds or terraces, the amount of sand and gravel in the water increases. This material is deposited just downstream of the point where it was eroded. An example is found in the Meuse in Limburg where old river terraces are eroded.

Sedimentation of silt on floodplains
During flood periods water flows from the main channel into the flood-plains. In the floodplains the flow velocity is much lower than in the main channel; already when the flow lines diverge into the floodplain the flow velocity is reduced significantly.

The transport capacity of the river water is closely related to its flow velocity. For that reason the coarse material that the river transports remains in the main channel. The finer material (fine sand, silt and clay) is transported by the water in suspension into the floodplain. The largest part of the material, and the coarsest fraction, is deposited directly along the main channel. Here a natural levee develops, which aggradates during each bank overflow. After a large flood the river has deposited more than 10 cm of sand at certain locations on the banks. With increasing height of the natural levee ever-finer material is deposited. The mean grain size in the soil profile decreases from bottom to top.

Also in the lateral direction a gradient in grain sizes is found. The coarsest material that is transported out of the main channel during floods is deposited first; at greater distance from the river the finer material is deposited (figure 1.8).

The sedimentation pattern of silt on a floodplain is determined strongly by the topography of the floodplain. Especially the presence of minor embankments is important. Floodplains without minor embankments have a sedimentation rate that is 2 or 3 times higher than on floodplains with minor embankments. Furthermore floodplains without embankments are characterised by deposition of sand on the transition zone of main channel to floodplain (Middelkoop 1997). It was observed that every floodplain has a design discharge for the sedimentation of silt, i.e. that discharge at which the strongest sedimentation occurs. These discharges generally are the mid-range floods, which have a moderately high content of suspen-ded matter and a recurrence interval that is not too long (Asselman 1997).

The relief in the floodplain causes differences in inundation duration. Differences in sedimentation patterns occur, depending on the force and the recession characteristics of the flood. In floodplains that are bordered by a low minor embankment maximum sedimentation is found where the incoming flood overflows the embankment. The deposited material consists mainly of clay and sandy clay. Flow from the main channel into the floodplain occurs especially when the floodplain is low and no minor embankment is present, or where the floodplain widens. Also at locations where the flow cuts off an inner meander bend or gravitates to a deep pool in the floodplain, sand is deposited on the natural levee. This means that the embankments and other human interventions greatly affect the formation of natural levees.

In general one can state that the higher the inundation frequency, the faster the deposition rate is at a given location. Also the content of suspended matter plays a role; this depends on the height and shape of the flood wave. With increasing discharge the content of suspended matter increases. The exact pattern in which this happens may differ from event to event (Asselman 1997). All this means that the sedimentation rates on a floodplain vary widely, from some millimetres to several centimetres per year. Both field data and calculations indicate that erosion of floodplain soils plays no important role (Middelkoop 1997, Asselman 1997, van den Berg & van Wijngaarden 2000).

The differences in sedimentation rate on the floodplains along the Rhine branches are small, in the order of tenths of millimetres, with the highest rates along the Waal. Of the total sum of deposited sediment (200,000 tonnes per year) 50 % is trapped by the Waal, 30 % by the IJssel and 20 % by the Nederrijn/Lek. This distribution is also determined by the area of floodplains of each of these branches (Asselman 1999). In the Meuse basin it was found that the sedimentation rate along the Grensmaas is much higher (some centimetres per year) than along the Zandmaas (some millimetres per year). As an indication: about 70 % of the total sedimentation occurs along the Grensmaas, and 30 % along the Zandmaas (Asselman 2000). This is mainly the consequence of the exhaustion of the content of suspended matter in downstream direction. Also the minor embankments of the downstream floodplains play a role, because these cause a decrease of the inundation frequency.

For the future rehabilitation of floodplains, measures are considered that will increase the inundation frequencies and thereby the sedimentation rates. Locally this will cause aggradations of up to some cm per year. When the measures are taken on a large scale this may have important implications for the total sediment load that is caught by the floodplains. Computer calculations show that as a result of the rehabilitation of the floodplains as proposed in the ‘Room for Rivers’ policy, the yearly amount of sediment deposition will almost double. This means an annual increase of sedimentation of about 200,000 tonnes (Asselman 1999). Although this will not cause acute problems, on the mid-range term it must be taken into account in the design of plans (Cyclic rejuvenation of Smits *et al*. 2000).

Environmental quality of the deposited silt

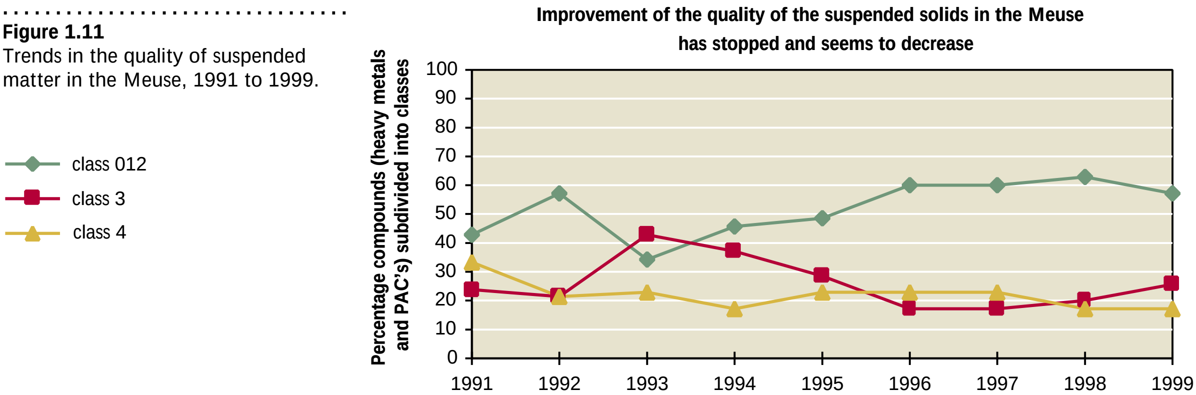
The environmental quality of the existing floodplain soils is determined by the quality of the silt during sedimentation. This quality reached its low during the period from 1960 to 1980, but has improved considerably since then (Beurskens *et al*. 1994, Middelkoop 1997, Zwolsman 2000a). Also in the Meuse basin the sediments of that period are worst polluted, but the improvement has not been as marked as in the Rhine basin (Zwolsman 2000a, van den Berg & van Wijngaarden 2000; Water in Beeld 2000).
As a consequence the quality of the suspended matter nowadays is much better in the Rhine than in the Meuse. As an indication it can be stated that in the Rhine the suspended matter reaches class 2, while in the Meuse it still has to be counted to class 3 or 4 (Zwolsman 2000a). A point of special interest here is that over the last few years ever more problematic substances are detected, especially in the field of endocrine disrupting compounds, of which the long-term effects are not yet understood (Water in Beeld 2000).

In general the sediment that is deposited during floods has a better quality than the yearly average. This is caused by mixture with relatively clean sediment resulting from erosion of higher situated and cleaner soil layers (van der Heijdt & Zwolsman 1997, van den Berg & van Wijngaarden 2000, Zwolsman 2000b).

In general the severely polluted sediments from the period 1960 to 1980 are located in the upper 50 to 100 cm of the present floodplain profile. The most prominent problematic substances are the metals cadmium, zinc, mercury and arsenic, and the organic micro pollutants PAH's, PCB's, several pesticides and oil products. Both the soil layer on top of this highly polluted horizon and the soil layer beneath it have a better quality.

During rehabilitation works often meters of soil are excavated, which means that the sediments that were deposited over the last 100 to 200 years are removed. That means that the badly polluted sediments of the last century are removed completely; sometimes they are merely brought to the surface, for example in the banks of excavated secondary channels. One should take into account the possibility that future sediments will repollute the clean soil. This means that apart from the consequences of sedimentation in terms of maintenance and management, also the consequences in terms of environmental quality and ecotoxicological risks will ask for permanent attention.

Figure 1.11
Trends in the quality of suspended matter in the Meuse, 1991 to 1999.



1.5 Functions of the river area

Nature

The river area has an important function as transport route for species of organisms that move actively upstream, such as fish, and for organisms and seeds that are transported downstream by the flow. Also many species of birds have chosen their migration routes along the main rivers. The river as transport route is of great importance for the interactions between separate communities along the river corridor. The task of the river manager and designer in this respect is to secure optimal freedom of movement and transport possibilities, both along the longitudinal and the transversal axis.

The whole ecological network in a river basin depends on and is adapted to the natural, physical processes in the area. Those processes were influenced on an enormous scale by human interventions over the last century. By these interventions a number of natural, but for human use harmful processes were stopped or greatly reduced in their scale. The success of these interventions and the profit they brought to man are evident. Nowadays the question to designers is if the processes that are vital for the ecological functioning can be given a chance again, without being harmful for vital conditions for man, such as safety against flooding and shipping.

Safety
The demands of safety against floods are to a large degree preconditional for what can and cannot be allowed in the floodplains. All elements in the floodplains that impede the water flow, such as elevated areas, access dams and trees, cause the upstream water levels to increase.

The restrictions on the hydraulic resistance of floodplains are made more severe by the current tendency of ever increasing design discharges.
The increase in design discharge that is now considered, from 15,000 m^3/s to 16,000 m^3/s, causes an increase of design water levels between 15 and 30 cm. With unaltered policy this would call for yet another round of embankment improvement. The present policy however aims at preventing the necessity of works on the embankments, by taking measures in the floodplain that increase the wet cross section of the floodplain and/or decrease the resistance to water flow.

Design discharge and design flood levels
The major embankments in the Netherlands along the lower Meuse and the Rhine and its branches are designed for a discharge that is exceeded once in 1250 years. This discharge is called the design discharge.
The water levels that are expected during this design discharge are called design flood levels.

The problem with this approach is that it is difficult to determine, from the available data set of about 100 years, the discharge and water level with a recurrence interval of 1250 years. To do this statistical techniques are available, but once an extreme and rare discharge takes place, such as those in 1993 and 1995, this quickly calls for the need to recalculate the design discharge.

As a consequence the new design discharge will be set at 16,000 m^3/s for the Rhine at Lobith, instead of the present 15,000 m^3/s. The design discharge in the Meuse at Eijsden is 3,800 m^3/s.

Another trend that is relevant here is the influence of climate changes on the design discharge. According to recent investigations the design discharge of the Rhine is now expected to increase about 5 %, of the Meuse about 10 %. This will call for exact monitoring and possibly further adaptations of the design discharges and policies to cope with them.

Shipping
The function of rivers as a navigation route must be taken into account in floodplain rehabilitation projects, because of the demands on minimal depth and the management of weirs on some river branches.

On the Waal presently the goal is to have a navigation channel of at least 150 m width and 2.5 m depth at the water level that is exceeded 95 % of the time. In the future Rijkswaterstaat plans to increase the width and depth of the navigation channel, in order to enable two six-unit multiple barge sets and one twin-vessel set to pass at any point. To reach this goal the river stretch between the Pannerdense Kop and Zaltbommel will be widened to 170 m width and 2.80 m depth. Between Zaltbommel and Rotterdam the river already meets these specifications.

In the navigation channel of the Meuse the depth is 3 m. The Meuse will be adapted for two-unit multiple barge sets over its complete length; for this purpose the depth must be increased to 3.5 m.

A number of rehabilitation measures in the floodplain, such as the excavation of secondary channels, the removal of minor embankments or the excavation of complete floodplains may influence the flow patterns in the main channel. By diverting part of the flow to the floodplain the flow velocity in the main channel will decrease, which could cause deposition of sand and gravel. This process could develop far enough to jeopardise navigability. For each location and measure a judgement must be made as to whether or not the changes will remain within the boundary conditions.

Other functions
Recreation is a function that is closely related to nature development in floodplains. Nature development can make areas attractive for recreation, while the other way round, this attraction can help to increase the public support and awareness for river and floodplain rehabilitation projects. However, in this version of these guidelines, recreation is not considered. If desirable in a follow-up version this function can be addressed.

Agriculture use plays a major role in a large part of the present Dutch floodplains. During the past years a policy change was made in favour of nature in the floodplains while agriculture should intensify in the hinterland, but agriculture is still important and will remain important in the near future. If desirable in a follow-up version this function can be addressed.

Other functions such as mining of clay, sand and gravel, drinking water supply, living and industrial areas are important in the floodplains, but are not taken into consideration here.

1.6 Landscape

The way in which nature and landscape are experienced by people changes in the course of time. This leads to changes in questions, and by the changes in context also to changes in design demands and design approaches.

As an historical reference for the view and spatial qualities of the river landscape the Verkade-albums by Jac. P. Thijsse about the IJssel (1916), ‘Where we live’ (1937) and ‘Our Large Rivers’ (1938) are of great value. Like no other they show the view of the former river landscape and show how strongly the landscape has changed since then, but also how it has remained the same in a number of aspects. The many functions of the river have left clear marks on the landscape. It is clear that the interaction between cultivation and nature, between man and his environment, has shaped the landscape in the past and still shapes it today. In this respect it is important to be aware of the fact that the attitude towards nature and landscape changes in the course of time.

At the end of the 19^{th} century the first realisation of the necessity of protection of nature and landscape develops. In the course of the 20^{th} century, especially after World War II, the environmental pollution and urbanisation increase much more. This brings about nature protection organisations, which acquire and manage areas in the whole country.

At the same time the rivers become the icon for the national feeling for the landscape; some marked examples can be found in poems and novels by Marsman, Nijhoff and Coolen.

In the first half of the seventies for the first time an extensive mapping of the nature and environmental characteristics of the floodplains was carried out. The goal of this mapping was to improve the quality of spatial planning projects connected to the planned large-scale mining of sand and clay and to urbanisation plans. The same mapping data were later used in advice for the planning of embankment improvement projects, which until then had had devastating effects on landscape values. This advice summed up to the conclusion that by adapted design the execution of the plans on the one hand should take better account of values of landscape, nature and culture history, and on the other hand with the questions related to design water levels. This work also led to guidelines on the design on the lay-out of embankments. In two pilot projects these new views were brought into practice. 'Integrated plan development' and a 'vision on landscape', aimed at possible solutions, proved to be valuable instruments to realise a balanced integration of different interests in the rehabilitation of the river area. In the river embankment plan of the province of Gelderland, considerations on the values of landscape, ecology and culture history also have been taken account of explicitly.

In the meantime in 1987 in the 'Plan Ooievaar' (Ooievaar refers to the black stork, a typical occupant of floodplain forests) a spatial development proposal had been designed, in which both in the active floodplains and the reclaimed landscape the development of agriculture and of nature were both addressed (De Bruin *et al*. 1987). Until now only the part of this plan on ecological rehabilitation of the floodplains seems to have found its way into spatial planning practice.

The 'plan Ooievaar' offered a new vision on the development of the river area and initiated part of the development of the concept of a 'National Ecological Network' for the spatial planning in the Netherlands. The identification of the large rivers as one of the main components of this National Ecological Network was reconfirmed a.o. in the National Policy Plan on Nature (see chapter 2).

The first series of concrete floodplain rehabilitation projects were started in the beginning of the nineties by purchasing terrains, and changing the ways these were used and managed. Examples are the 'Blauwe Kamer' along the Lower Rhine and the 'Duursche Waarden' along the IJssel (Pruijssen 1999). In the same period the WWF drew attention to the possible link between nature development and mining of sand and clay in floodplains (WWF 1993).

1.7 Stretches of the Rhine and Meuse

In the development of rehabilitation plans in the river area the question has to be addressed in which parts of the area certain measures can be useful, in which not, and why. In order to answer these questions a proper classification of river stretches and their characterisation is necessary.
In this paragraph such classification is made, based on both geo- and hydromorphological and on ecological and landscape criteria (a.o. Jansen & Rademakers 1993, Londo 1997, Maas *et al*. 1997, Stegewerns 1999, Maas 2000).

At the level of river basins the Dutch parts of Rhine and Meuse can be characterised as lowland rivers. Only the upstream part of the Meuse in the Netherlands, in the province of Limburg, is a middle course river (Stegewerns 1999).
In the river area in the Netherlands the following parts can be distinguished: the valley of the Meuse in Limburg, the central river area with the branches of the Rhine and the Meuse, the valley of the IJssel and the coastal rivers with the coastal zone in the province of Holland. The present course of the main rivers is more or less fixed. In the middle part of the river area the Waal is flowing, as a wide continuous main stream. South of the Waal flows the canalised Meuse, bordered on one side by the higher sandy area of Brabant. North of the Waal flows the Nederrijn/Lek, for a large part regulated by weirs, and bordered on its north banks by the elevated areas of the Veluwe and the Utrechtse Heuvelrug, both glacial relicts. Between the Veluwe and Salland the narrow, strongly meandering IJssel flows north to Lake IJsselmeer.

On a more precise scale it is found that the various river stretches show important differences. That is why the rivers are subdivided into a number of stretches with more or less homogeneous characteristics.

Figure 1.12
Classification of stretches in the Rhine and Meuse in the Netherlands.

The Rhine enters the Netherlands as the Bovenrijn and bifurcates into the Waal and the Pannerdens Kanaal. At the end of the Pannerdens Kanaal the river bifurcates again, into the Nederrijn/Lek and the IJssel.
In these guidelines the classification is adopted that was proposed in the 'Room for Rhine branches' document, part Nature. In this document 14 branches are discerned in the Rhine branches, and 9 in the Meuse, according to figure 1.12 (Rademakers *et al*. 1996). The classification is based on hydro- and morphodynamical characteristics, geomorphology of the surrounding landscape, the presence of weirs and the intensity of professional shipping.

The Grensmaas discharges freely. Here no shipping is found, because the navigation route follows the parallel Julianakanaal. The minimum discharge is a few m^3/s, the peak discharge is 3120 m^3/s. The flow velocities in the Grensmaas are relatively high and vary strongly. This is caused by the large bottom slope of 43 cm/km. The water level can rise maximum 10 to 12 m, at a discharge of 3380 m^3/s, which discharge has a recurrence interval of 250 years.

Table 1.5
The stretches in the Rhine and Meuse with some of their characteristics.

stretch	length (km)	area floodplains (ha)	weir/free discharge	other characteristics
Rhine and branches				
Bovenrijn	11	1000	f	only eroding Dutch Rhine stretch upward seepage from Montferland high river dynamics; sandy and gravel banks this stretch is the most intensively navigated together with the Waal stretches.
Bovenwaal	16	1900	f	strongly meandering upward seepage from the Nijmegen ice pushed hills highly dynamic, sand dunes and sand banks
Middenwaal	44	3000	f	weakly meandering dynamic sand river
Oostelijke Benedenwaal	17	1900	f	more meandering than the Middle Waal dynamic sand river
Westelijke Benedenwaal	12	1400	f	low water levels more stable; natural levees lower; floodplains narrower; backswamps larger than more upstream. Transition from upper to lower river.
Pannerdens Kanaal	7	800	f	partly excavated, not natural at low discharge the influence of the weir at Driel can be noticed.
Rijn near Arnhem	14	1000	f/w	much influenced by the city of Arnhem influence of the Driel weir at low levels weakly meandering sand river
Doorwerthse Rijn	15	1000	w	at the end of Veluwe hills upward seepage from the Veluwe weirs have strong influence during low discharge dynamic conditions only in the stream bed and banks floodplains have relatively high elevation
Nederrijn and Lek	45	4000	w	strong influence of weirs upward seepage from the Utrechtse Heuvelrug
Boven-Lek	24	1200	f	transition from upper to lower river floodplains narrower, embankments higher, reeds in eastern part sand dynamics in western part tidal influence

stretch	length (km)	area flood-plains (ha)	weir/free discharge	other characteristics
Boven-IJssel	26	2700	f	upward seepage from the Veluwe wide meanders are relicts of the past, the present river cannot create them small scale sand river
Midden-IJssel	33	3200	f	upward seepage from the Veluwe banks are protected over almost entire length
Sallandse IJssel	34	3100	f	relatively straight stretch floodplains do not take part in discharge morphodynamics are strong, hydrodynamics limited upward seepage from the Veluwe
Beneden-IJssel	23	1100	f	some parts are dynamic, with natural levees influence of set-up by wind
Meuse				
Boven-Maas	14	350	w	steep bottom slopes; strong fluctuations in discharge; wide, deep channel in cretaceous sediments
Grensmaas	36	2400	f	steep bottom slopes; strong fluctuations in discharge; wide, deep channel in tertiary sediments until this stretch the mean flow velocity is higher than 1 m/s. No professional shipping
Plassenmaas	43	5900	w	widely meandering sand- and gravel river mean flow velocity from here less than 0.5 m/s
Peelhorstmaas	35	3500	w	stretch along the high Peelhorst area stable, straight sand river, narrow and straight valley
Venloslenkmaas	32	6100	w	here the river has more room again; flooding of lower terraces is possible; wide and straight valley
Maaskantmaas	54	3300	w	weir-regulated, canalised
Beneden-Maas	34	3000	f	lower river with limited tidal movement embanked floodplain; rather wide sandy natural levees; clayey backswamps; wide high floodplains
Afgedamde Maas	11	1500	f	former lower stretch, one-sidedly connected
Bergse Maas	24	500	f	lower river with little slope and clear tidal movement summer bed and relief excavated by man
Lower Tidal Stretches				
North Nieuwe Maas; Nieuwe Waterweg Hollandsche IJssel Lek	-	-	f	lower rivers with tidal influence straight and stable right bank in peat or clay on peat left bank in tidal sediments (marine clays)
Middle Noord; Boven-Merwede; Beneden-Merwede; Oude Maas; Spui; Dordtse Kil	-	-	f	lower rivers with tidal influence meandering sandy stretch to widened, stable clay stretch tidal parts in marine clays
South Nieuwe Merwede; Biesbosch; Amer; Hollandsch Diep; Haringvliet; Bergse Maas.	-	-	f/w	lower rivers and estuary (in the past with tidal influence) predominantly widened, stable clay stretch situated in tidal flats

1 Characteristics of the Rhine and the Meuse in the Netherlands

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2 Landscape policy

Jan Wouter C. Bruggenkamp

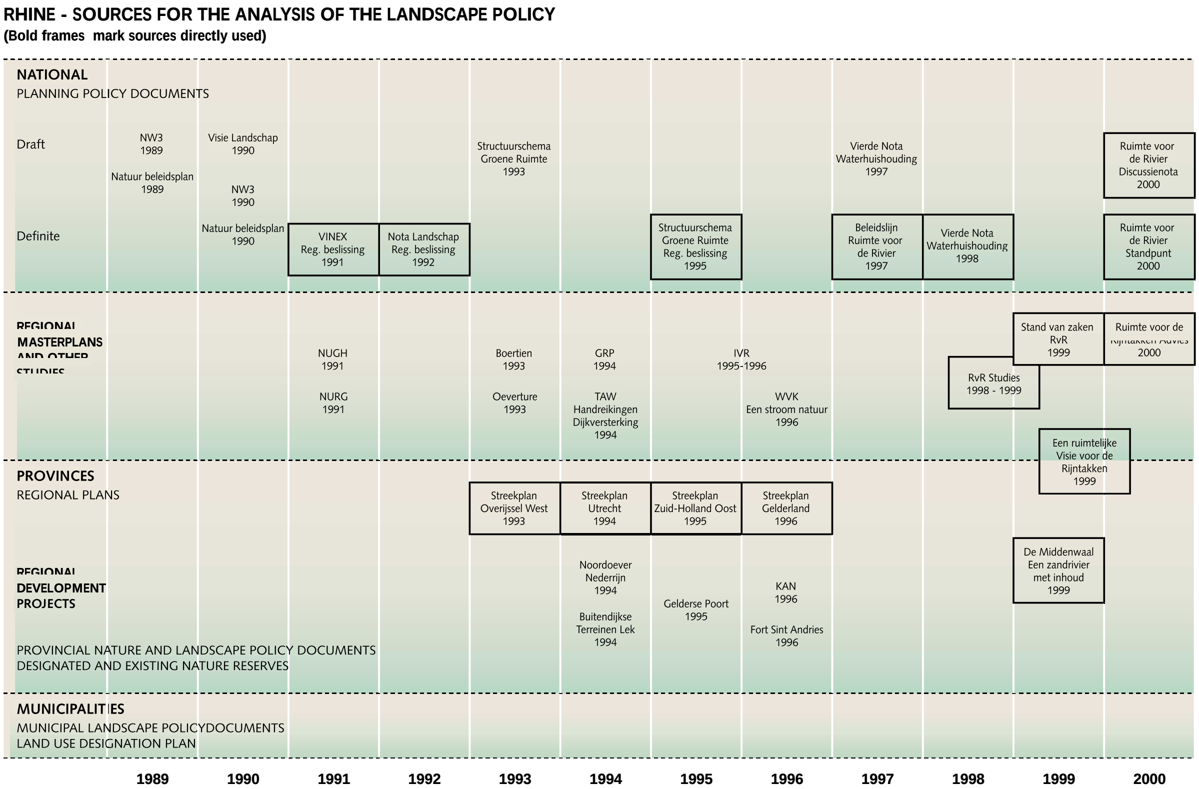
Contents

2 Landscape policy

An analysis of the planning policies for the river landscapes is based on existing policy documents. These can be divided in documents on a national level, provincial level and municipal level. In this paragraph only the national and provincial level will be examined. But it should be reminded, that a concrete redesigning of the floodplain has to be related to the local situation and therefore be guided by the (inter)municipal ‘nature and landscape planning policy document’ (in Dutch: ‘Beleidsplan voor natuur en landschap’). Plans for redesigning the floodplain as a result of national and provincial planning policies will always have to be checked against and integrated with the local planning policy and interests. Before construction the plans will have to be checked against and/or incorporated in the municipal ‘land use designation plans’ (in Dutch: ‘Bestemmingsplan’).

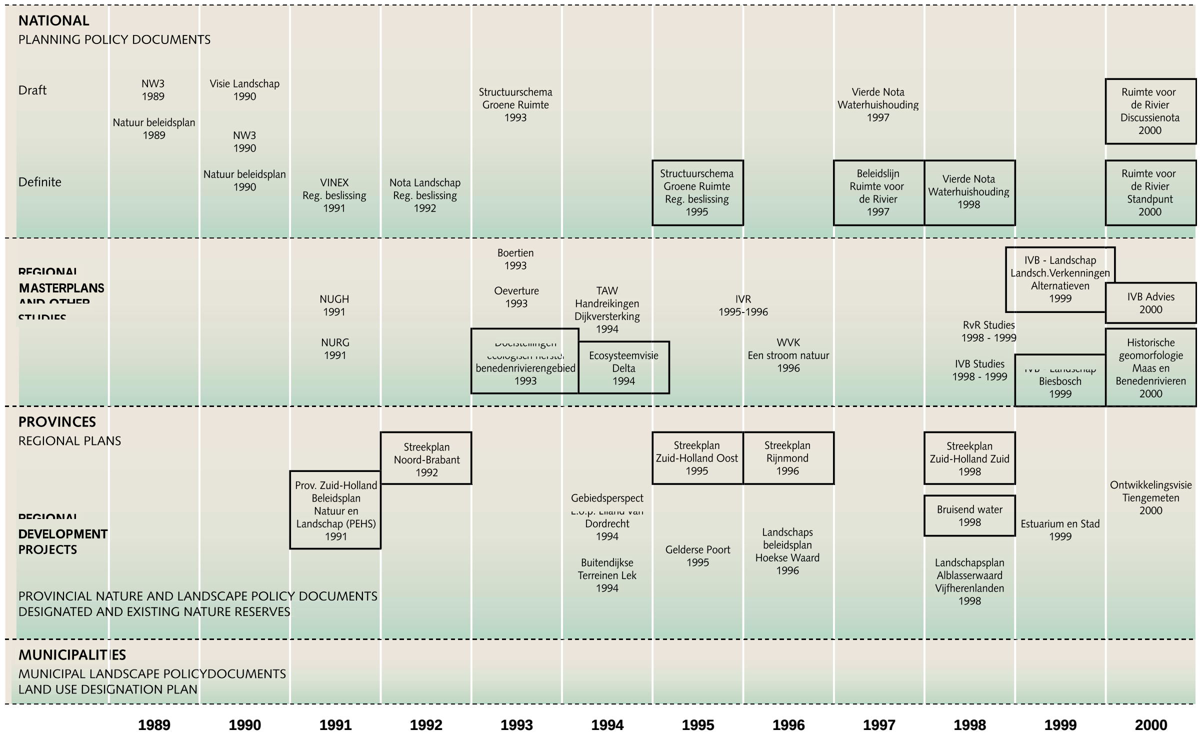
Figure 2.1 gives an overview of the most relevant planning documents related to the river area, on a national and regional level.
On the national level they include: ‘Draft National Policy Documents’ (in Dutch: ‘Beleidsvoornemen’), ‘Definite National Policy Documents’ (in Dutch: ‘Regeringsbeslissing’), ‘Regional Masterplans’ (in Dutch: ‘Regionale Uitwerkingen’) and other planning studies, in which authorities of both or all three levels may be involved.

Figure 2.1
Overview of the most relevant policy documents and studies related to the rivers in the Netherlands, on a national and a regional/provincial level. The information has been separated into three diagrams, for the Rhine Branches, the river Meuse and the tidal zone of the Rhine Branches and the Rhine and Meuse estuaries.



IVB - SOURCES FOR THE ANALYSIS OF THE LANDSCAPE POLICY

(Bold frames mark sources directly used)



MEUSE - SOURCES FOR THE ANALYSIS OF THE LANDSCAPE POLICY

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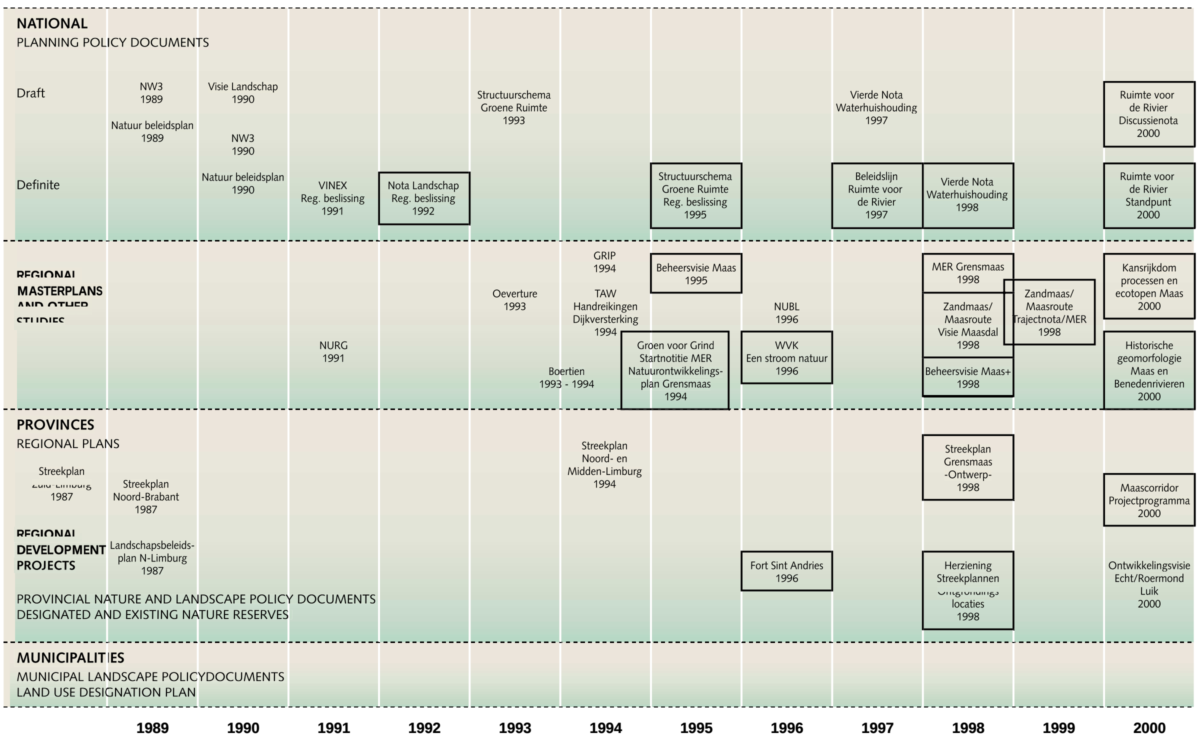


On the provincial level are included: the ‘Regional Plans’ (in Dutch: ‘Streekplannen’), Regional Nature and Landscape Development Projects’ (in Dutch: ‘Ontwikkelingsvisies en Gebiedsvisies’) and ‘Provincial Nature and Landscape Planning Documents’ (in Dutch; ‘Provinciaal Beleidsplan Natuur en Landschap’)

2.1 On the national level

Relevant National Policy Documents
Next national policy documents are relevant for the development of the river landscape:

- the Fourth Policy Document on Physical Planning (VROM 1991)
- the First Nature Policy Plan (LNV 1990)
- the Second Nature Policy Plan (LNV 2000)
- the Policy Document on Landscape (LNV 1992)
- the National Policy Document on the Countryside (LNV 1995)
- the Memorandum on ‘Room for the Rivers’ (VenW 1997)
- the Fourth Policy Document on Water Management (VenW 1998)
- the Discussion and Decision Policy Documents on ‘Room for the Rivers’ (VenW 2000)

The Fifth Policy Document on Physical Planning is in preparation.

Follows a summary of the relevant main points in the various policy documents.

Fourth Policy Document on Physical Planning of the Netherlands (VROM 1991)
For the winter bed of the rivers a landscape development course has been stated with nature and ecological qualities as main aim.
The policy contains:

- conservation, restoration and development of ecosystems.
- restoration of ecological relations of the riverbed with other areas.

Other functions than nature, such as urbanization, recreation, infrastructure, agriculture, forestry and sand or clay mining, are only acceptable if they do not harm the ecological functions of the winter bed. Mining activities should be performed to result in nature and ecological restoration.
Ecological relations of the riverbed of the Rhine Branches should be restored with the high grounds of the Veluwe and the Utrechtse Heuvelrug, with the area of the Gelderse Poort and the German Rhine Valley.

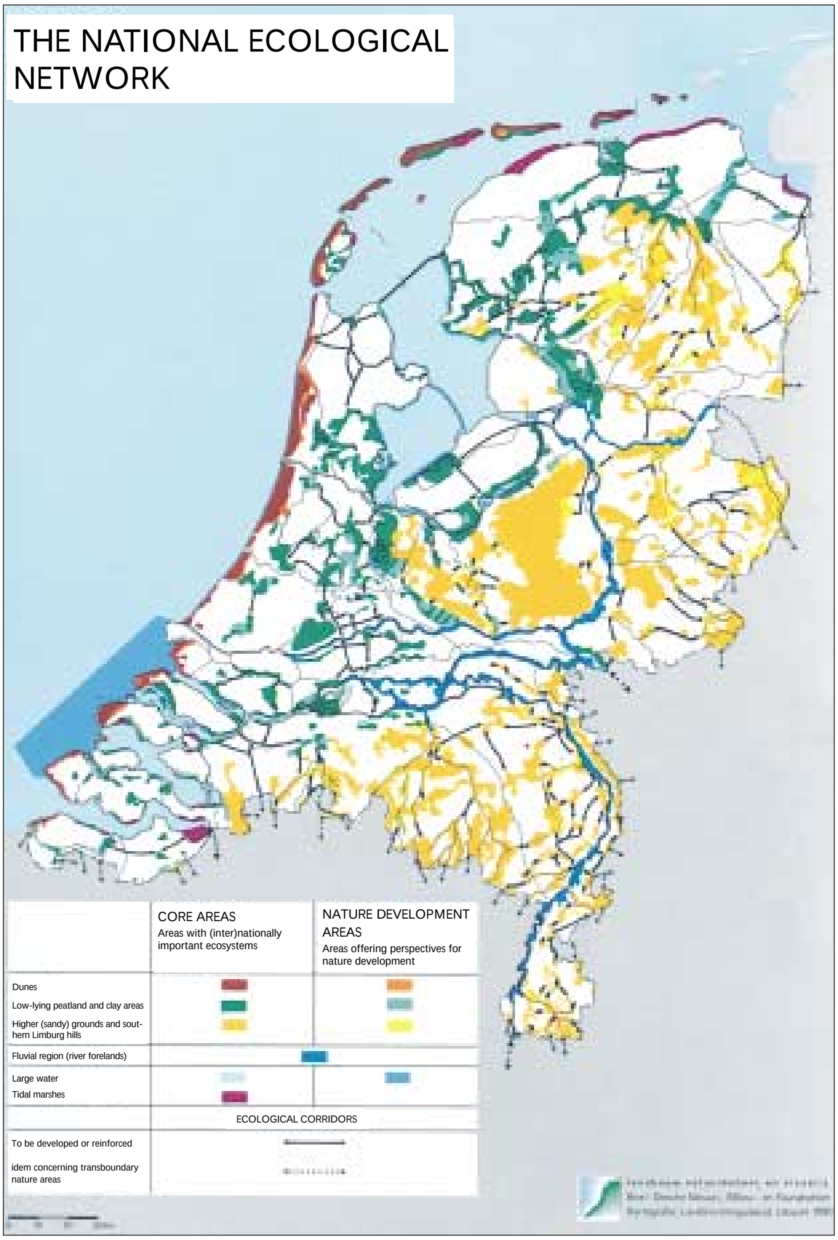
The National Policy Plan on Nature (LNV 1990)
The Nature Policy Plan identifies the large rivers in the Netherlands as an essential structural component of the National Ecological Network (LNV 1990).

The National Policy Document on Landscape (LNV 1992)
Principle aim of the national policy on landscape is:

- the preservation, restoration and development of a landscape of high quality, focusing on identity and sustainability of the landscape.

To realize this aim the landscape has to meet aesthetic, ecological and economic demands. (LNV 1992)

Figure 2.2
The National Ecological Network
(LNV 1992 Kaart 12).



According to the National Landscape Policy the change of the river landscape will be steered by:

- the realization of the National Ecological Network;
- the realization of the Central Urban Ring in the Netherlands;
- the adaptation and renewal of the main infrastructure.

Nature development in or next to the winter bed may lead to a new identity of the rivers.

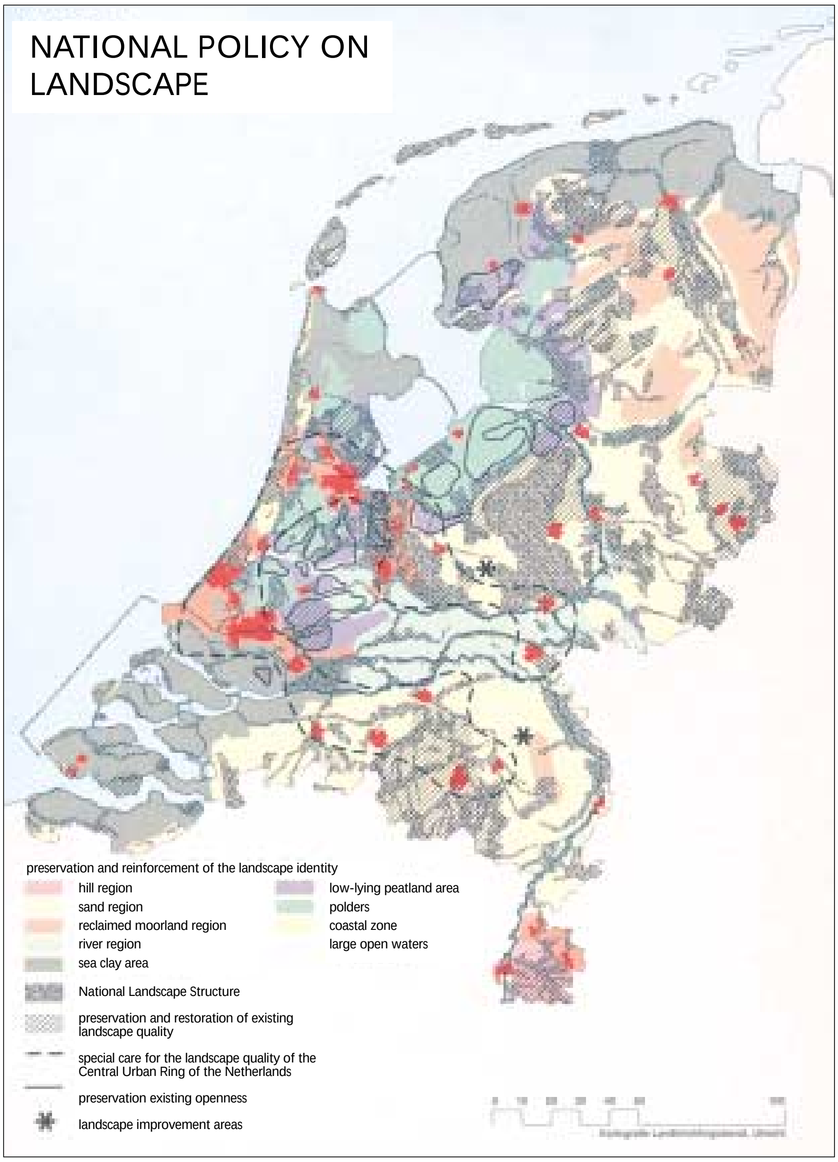
For the Rhine Branches the national landscape policy draws attention to some special points of interest:

- the specific landscape identities of the river region and the adjacent sand regions should be preserved and strengthened;
- the development of the rivers as a component of the National Landscape Structure of the Netherlands should be linked with the sectoral policies on forestry, nature and recreation;

- the IJssel Valley and the IJssel Delta (‘Kampereiland’) have been indicated as ‘landscape improvement areas’, in which the existing landscape quality has to be preserved and restored;
- the ‘Nederrijn-Lek’ and the bifurcations of the Rhine in the urbanizing conglomeration of Arnhem-Nijmegen are part of the Central Urban Ring of the Netherlands, in which special attention to landscape quality is needed;
- the existing openness of the IJssel Delta should be preserved.

In Figure 2.3 these points of interest from the national landscape policy for the Rhine Branches, have been visualized.

Figure 2.3
Map of the National Policy on Landscape (LNV 1992).



The National Structure Plan on the Countryside (LNV1995)
The national nature and landscape policies have been incorporated in the National Structure Plan on the Countryside (LNV1995). The policy has been specified in a target image and a series of strategies, resulting in a range of policy implementation programs.

The Fourth Policy Document on Water Management (VenW1998)
In the Fourth Policy Document on Water Management for the large rivers the challenging problem is stated: how to maintain safety against floods, even with increased design discharges, combined with preservation of the landscape values (scenic, ecological and geo- and cultural-historical), navigation and nature restoration and development.

Subsequently in this document a target image is presented, following an earlier developed vision for the central river region (Stuurgroep NURG 1990), in which the landscape of the large rivers in the course of the coming decades will change drastically. Especially by the widening and deepening of the winter bed which will accommodate a safe discharge of water, ice and sediments, moreover by the establishment of retention basins and moving of major embankments.

As a consequence land use will change. Non-river related functions will have to leave the winter bed; agriculture will give up territory; nature and recreation will get new opportunities. River-related ecotopes may develop extensively. Aiming at sustainability of populations, large units of nature areas will be established. The 'river-nature' needs maintenance, though, lest the secondary channels will not silt up and vegetation will not be an obstacle in view of hydraulics. Part of the polluted sediments that result from widening and deepening the riverbed may be dumped in existing sand, gravel or clay pits in the floodplain or used in a special manner in nature restoration projects and embankments (see Policy Document on Active Management of Soils in the River Bed, V en w 1997b).

Room for the Rivers: Memorandum, Discussion and Decision
In the Memorandum on 'Room for the Rivers' (1997), the 'Discussion Document on 'Room for the Rivers' (2000) and the Decision Document on 'Room for the Rivers' has been stated, that because of the need for safety against floods, more room will have to be created for the rivers. This objective has got the utmost priority. The implication of drastic changes in the river landscape has been subordinated to the top priority of safety against floods.

The Regional masterplans and other studies, related to 'Room for the Rivers'
The national physical planning policy, defined in the Fourth Policy Document on Physical Planning of the Netherlands (VROM 1991) has been made more concrete in some regional masterplans:
- the Masterplan for the Central Rivers Region (NURG 1991), which will be updated soon;
- the Masterplan for the Green Heart (NUGH 1991).

These masterplans and a variety of studies, many related with the 'Room for the Rivers'-program, contain essential information about potential and advisable nature and landscape development courses for the rivers and especially concepts for the winter bed:
- the Management Vision of the river Meuse (RWS-DLI 1998);
- the results of the Maaswerken Project, including a landscape development vision (Maaswerken, 1998);
- the results of the 'Room for the Rhine Branches Survey' (in Dutch: 'Ruimte voor de Rijntakken', RWS-DON 1998-2000);
- the results of the 'Tidal Rivers Survey (in Dutch: 'Integrale Verkenning Benedenrivieren', RWS-DZH 2000);

- the Expansibility Study (in Dutch: ‘Spankracht Studie’, 2001-2002, in progress);
- the results of the ‘Meuse Survey’ (in Dutch: Integrale Verkenning Maas, 2001-2002, in progress)

It will be clear, that these policy documents and studies reflect advancing insight and further cristallisations of the ideas and concepts for planning and design of the future river landscape.

Conclusions and points of attention of the policy at the national level
In the policy program directed to the ‘preservation and restoration of existing landscape qualities’ (as stated in the Policy Document on the Countryside), interventions, measures and developments are not permitted, that affect the cultural-historical values, environmental coherence, scenic beauty and/or geo-historical values.

Recent planning policy as stated in the Fourth Policy Document on Water Management (1998) and the policy on ‘Room for the Rivers’ (VenW 1997-2000) contain a change of course. The necessary measures to widen the winter bed aiming at safety against floods implicate drastic changes in the river landscape. The ‘Room for the Rivers’-policy therefore implies a change in the National Landscape Policy.

The points of attention for the river landscapes, as specified in resp. the Policy Documents on Landscape and the Countryside will have to be re-interpreted and reconsidered.

The State government applies the points of attention for landscape planning and design, as stated in the National Policy Document on Landscape (Nota Landschap pp. 100-105), to all planning projects in which the government is involved. The general interest in cultural-historical values, which has become common in the Netherlands since the publication of the National Policy Document on Cultural-historical values: ‘Belvedère’ (1998), finds a full-grown forerunner in these points of attention for landscape planning and design in the Policy Document on Landscape (LNV 1992).

2.2 On the provincial level

On the provincial level the Regional Plans (‘Streekplannen’) with their functional zoning, have a central role. The Regional Plans are based on current national policy, as reviewed above. In all Regional Plans the concern for the quality of nature and landscape is firmly expressed; preservation and strengthening of nature and landscape are important objectives.

The more recent a regional plan is, the more the national policies have been considered. Thus the Memorandum ‘Room for the Rivers’ (1997) already had been incorporated into the Regional Plan for Gelderland (1996).

The Regional Plans, depending on size and character of the covered area and its development problems, differ in contents, methodology and in amount of detail. Therefore in order to get a clear overall picture of the current landscape policy for the whole of the rivers, the Meuse, the Rhine Branches and the Tidal Rivers, a partial translation and interpretation of the functional zones in the regional plans has to be made.

In the 'Room for the Rhine Branches - Landscape study' (RIZA 1998) the relevant information out of the Regional Plans has been analysed and equalised. See the intermezzo and Figures 2.4 and 2.5 for a summary.

For the Meuse and the Tidal Rivers in Zuid-Holland a similar analysis has not yet been finished.

Intermezzo: Analysis of the landscape policy on provincial level for the Rhine Branches (after: RVR-Landscape study, RIZA 1998)
To implement the chosen development course as indicated in the functional zoning, in the regional plans three different landscape strategies have been distinguished:

- landscape conservation
- landscape adaptation
- landscape renewal

Landscape conservation means: preservation (and restoration) of the physical landscape structure.
Landscape adaptation means: changes/adaptations are possible and sometimes needed, but with full consideration of the existing landscape structure. Also functional changes are possible. Strengthening of the landscape structure by rather large interventions fits into this strategy.
Landscape renewal means: great functional and/or physical changes occur, affecting the landscape character and identity.

The **floodplains of Rhine, Waal and IJssel in the province of Gelderland** have been *functionally indicated with main accent on nature*.
In the areas with country estates the natural function is strongly linked with forest and agriculture. In the Regional Plan for Gelderland agriculture is seen as an important economic structural component of the landscape and consequently of the scenery.
In respect to the making 'Room for the Rhine Branches', it is also important that diverse parts of the floodplain have been indicated as: sites of special geo-scientific or cultural-historical interests, i.e. with geomorphological and/or special soil values (in Dutch: 'aardwetenschappelijk' or 'aardkundig') and sites with 'open fields' and other old arable land (in Dutch: 'essen en andere bouwlanden'). These sites should be conserved and managed with care. Beside this, the openness of the meadow bird areas in or near the floodplains, which have been indicated in the regional plans, need to be preserved.

The landscape strategy for the floodplains in Gelderland is mainly: *adaptation*, except for the Rhederlaag area, which has been indicated with: *renewal*.
In the special 'strategic action areas', as shown in the regional plan of Gelderland, the policy aims at raising the ecological values, especially by the improvement of the interconnections with the nature and forest areas of the high grounds of the Veluwe.

The **IJssel floodplains in the province of Overijssel** have been indicated in two functional categories.
The first functional category has its *main accent on landscape and nature, with joint use of agriculture and recreation*.
Active conservation and adaptation of the (open and small-scale) landscape and nature. Characteristic geographic relief should not be affected.

Development of ecological values should be enhanced.
The second functional category *consists of natural areas*. Restoration, preservation and development of ecological and landscape values are promoted. Essentially the silence and quiet in these areas should be secured. Characteristic geographic relief should not be affected.

Adaptation is the dominant landscape strategy for the IJssel floodplains of Overijssel. Nature restoration has been indicated directly north of Deventer, in the 'Duursche Waarden' close to Fortmond, the IJssel winter bed near Zwolle, near Zalk and at the IJssel estuary.

The **Rhine-Lek floodplains in the Province of Utrecht** belong mainly to functional categories with a main accent on nature and landscape (with or without a permanent role for agriculture). Some locations have been indicated for agriculture as the main land use or even for urbanization (near Hagestein, near Tull en 't Waal). The idea is to interweave these with ecological values. The ecological link with the Utrechtse Heuvelrug should be enhanced.

The dominant strategy for the floodplains is *adaptation*. Only near Hagestein *renewal* has been indicated.

Plans for nature restoration and development are prominent as part of the Master plan: Project 'Noordoever Nederrijn'. It covers the northern floodplains of the Rhine between Arnhem and Wijk bij Duurstede, so in both provinces, Utrecht and Gelderland.

The **River Lek floodplains in the Province of South-Holland** belong to functional categories with a main accent on nature and landscape, sometimes with a permanent role for agriculture. Always the ecological and landscape values are protected, for which agriculture is an important factor. The floodplains have also been indicated as 'soil-protection area'. Some sites have been indicated as nature development area.

The strategy for the River Lek floodplains in the Province of South-Holland has been explicitly stated as *landscape conservation*, in spite of the abovementioned indications for nature development.

2.3 Conclusions

The national landscape policy
The landscape policy on the national level has been stated in the National Policy Documents on the Landscape ('Nota Landschap', LNV 1992) and the National Structure Plan on the Countryside ('Structuurschema Groene Ruimte', LNV 1995).

The Policy Document on Landscape presents, among other things, an important series of points of interest for planning and design of the river landscape. The national landscape policy has been fully incorporated in the National Structure Plan on the Countryside.

Figure 2.4
Functional zoning according to the Regional Plans
(Map 10 of the RVR - Landscape Survey (RIZA 1998)

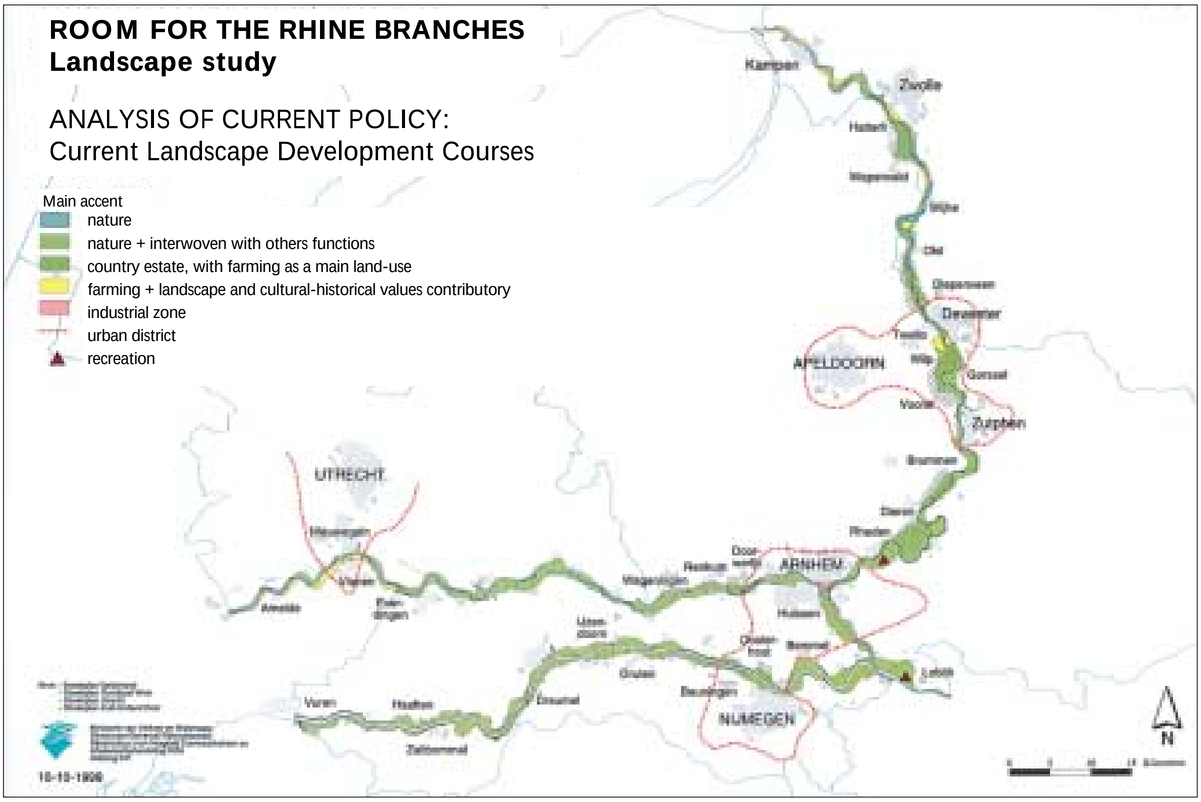
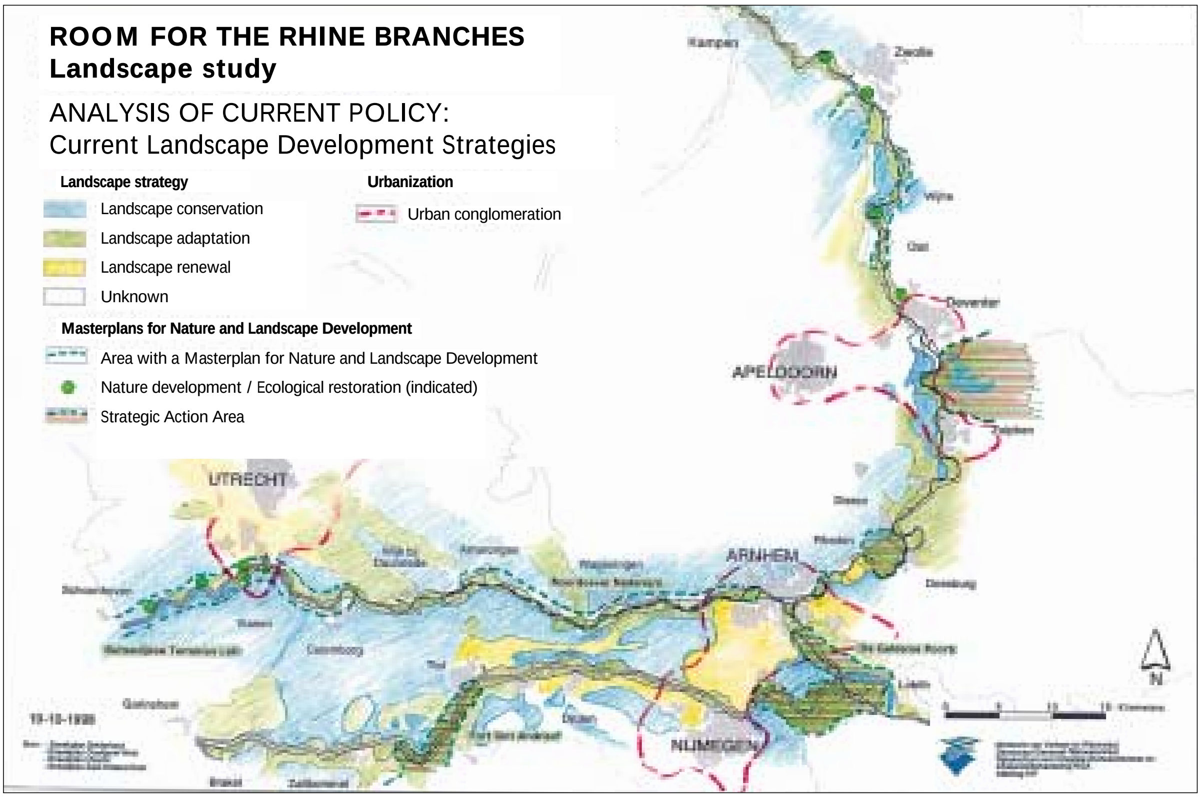


Figure 2.5
Landscape development strategies after the Regional Plans
(Map 11 of the RVR - Landscape Survey (RIZA 1998)



The national landscape policy for the river areas is mainly directed to:

- *landscape conservation*: preservation and restoration of existing landscape quality;
- preservation, restoration and development of the rivers as component of the *National Landscape Structure*
- realization of the *National Ecological Network* and the development of *dynamic nature* in the river region.
- the great importance of *good planning and design*, not only for the river and/or the floodplain, but especially in those areas where urbanization meets the floodplain.

The National Policy Document on Water Management (VenW 1998) indicates for the floodplain:

- the need for safety by interventions as researched in the 'Room for the Rivers' Policy Program;
- the development of (managed) *dynamic nature*, while agriculture is loosing territory;
- the preservation of and consideration with landscape, natural and cultural-historical values.

The great wish for safety as expressed in the Policy Document on Water Management, has its effect on the landscape policy for the rivers.
The current landscape policy: 'preservation and restoration of the existing landscape quality' has to be widened to: 'development and renewal'.
The points of attention for landscape planning and design, as stated in the National Policy Document on Landscape (Nota Landschap pp. 100-105), therefore need to be reviewed and re-interpreted.

The provincial landscape policy
The Regional Plans, in which the landscape policy on a provincial level is stated, differ in the way they accommodate the considered 'Room for the Rivers'-measures. Mostly a development into 'new nature' has been accommodated for. River widening measures like lowering the floodplain, in general will lead to reduced suitability for agricultural use, and more suitability for the development of dynamic 'new nature'.

A comparison of provincial and national landscape policies
The opportunities for nature development in the floodplain, as given in the regional plans, in general match with the link between nature development and river widening, as intended in the national planning policy.
Just in a few places this does not hold true, as where the regional plans do stress the importance of conserving their agricultural character.
This occurs especially along the River IJssel and the River Lek. Here the regional plans do not leave much room for river widening.
The comparison between the provincial and national landscape policies shows therefore also that on a provincial level agriculture is much more seen as a structural component and supplier of essential elements for the landscape.

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3 Reconstruction measures in the floodplains of the Rhine and Meuse

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Contents

3 Reconstruction measures in the floodplains of the Rhine and Meuse

3.1 Introduction

At this moment the main function of most of the floodplains is agriculture. The total area of the floodplains that serves to accommodate and discharge floods, is limited when compared to the natural situation. A number of elements in the floodplains, such as minor embankments, together with the small level differences, cause the flooding patterns to diverge quite far from the natural ones. During floods the floodplains are filled quickly, as one unit, and with several meters of water. Gradual transitions from land to water are almost absent, and there is a constant deposition of clay, which causes a constant increase of the surface level of the floodplains (Klijn & Duel 2001).

Reconstruction of the floodplains should therefore aim at restoration of the natural dynamics of the river. That means that seasonal and yearly fluctuations of river water levels must make themselves felt more directly in the floodplains, in order to create more gradients in space and in time. This helps in creating a landscape with more variation and gradients, with a higher river-related biodiversity, and with enough space to develop sustainable populations.

For the reconstruction of individual floodplains a range of measures is conceivable. However, not in all floodplains all measures can or should be realised. Neither does each measure make sense in every floodplain. One should start by defining a floodplain's potential contribution to the ecological coherence of the river branch and the main ecological structure. Subsequently, a list should be made of the measures that offer good opportunities to develop the desired ecotopes in that floodplain. Last but not least, a check should be made on the interrelations of these measures with safety against flooding and shipping demands.

The reconstruction measures that have been planned and carried out over the past years often aimed at safety against flooding. The idea of these measures is to increase the discharge capacity of the winter bed in order to decrease the design water levels. Secondly there are measures that aim at the promotion of a more natural vegetation along rivers, which lead to an increase of the design water levels. In this chapter some general rules are offered with which to estimate quickly, for the stretches of the Rhine, which effects the measures will have on design water levels.

Another general problem of the reconstruction of floodplains is the presence of polluted sediments. Since reconstruction, both aiming at ecological restoration and at increase of safety against flooding, often goes hand in hand with large-scale excavations, these polluted sediments can be brought into circulation again. For each reconstruction plan the scope of this problem must be defined well, in order to make a right judgement on the situation and the measures to be chosen.

This chapter starts with the question of ecological coherence and its consequences for the desired combination of ecotopes in a given floodplain.

Subsequently per river stretch a list is offered of measures that do or do not seem feasible there. Then some rules of thumb are offered for an estimation of the effects that these measures might have on design water levels. Finally the problem of polluted sediments and how one can deal with them is treated in general terms.

3.2 Ecological coherence in the reconstruction of floodplains

Experience in ecological restoration has taught that it is not sufficient just to create new nature areas in the river floodplains; nature areas should also be large enough. A problem is that often the room is lacking for large connected areas. Moreover, the remaining areas are claimed by other functions such as agriculture and safety. A possible solution to offer sufficient possibilities for such organisms as large birds and mammals, is to create a system of smaller areas, at distances that can be covered by these organisms; the so-called ecological networks. For this reason attention for the spatial and ecological coherence is essential in the reconstruction of floodplains. Such coherence must be sought not only between different river stretches, but also between the riverbed and the embanked area bordering it.

The concept of ecological networks for rivers was worked out in the model LARCH-river. This model was developed by RIZA, in co-operation with Alterra. The model analyses the network on the level of species.
To do so, so-called indicator species were selected, that are representative for certain types of nature. Within the LARCH-river model the ecological coherence is considered as the degree to which the landscape by its spatial characteristics offers room to sustainable populations of species that are sensitive to fragmentation of their habitat. Because species have different needs for room in order to develop sustainable populations, a number of scales are defined, based on the distance that can be covered within a network. These scales are: local, regional and national/international (table 3.1).

Table 3.1
Description of scales (a.o. Foppen *et al.* 1998) and guidelines for the minimal distance for species of these levels in a river area (Liefveld *et al.* 2000).

Scale	Network fusion distance (dispersion capacity)	Guideline for distance
local (floodplain)	< 3 km	-
regional (river stretch)	3 - 30 km	10 km
national (river branch)	30 - 100 km	40 km
international (basin)	> 100 km	100 km

When to apply in planning
It is recommended to take account of the added value of a design that shows ecological coherence, based on the concept of ecological networks, in the planning phase already. Also an ecological network analysis can be carried out as a check to see if a reconstruction plan agrees with the demands on spatial coherence of ecotopes that are required by sustainable populations.

The concept of ecological networks can be used at several phases in reconstruction projects. The first moment is during the development of visions or plans for river stretches and separate floodplains. In this phase, the ecological coherence between the area under study and its surroundings, and within the area under study, must be addressed. Thus the danger of creating isolated areas is avoided, and attention is paid to the interconnecting character of the river. Together with the abiotic boundary conditions the spatial ecological coherence defines the room for planners. In a follow-up the ecological network evaluation can be used to rank and optimise different scenarios.

Until now the ecological network approach has mainly been applied as a check, for the identification of ecological effects of planned reconstruction projects. Recently in the Meuse basin a further elaboration has been completed in which the basic principles of ecological networks were used to define guidelines for earlier stages in spatial planning (Liefveld *et al*. 2000).

How to apply
The first basic principle is that the spatial coherence must be addressed at a higher scale than the scale of the area under consideration. When looking at the reconstruction of a floodplain, first the function must be defined of this floodplain within the river stretch it is part of; both in terms of desired type of nature and in terms of areas. The estimation is that in general for the species of the local level there is enough room available within the floodplain. The spatial coherence at the higher scales is therefore important mainly for the species of the regional and the (inter)national scales.

The second basic principle is that attention must be paid to critical values. Some ecotopes can only develop under specific conditions on specific locations. Examples are hardwood river forest, marshlands and secondary channels. For less critical ecotopes it is easier to find room elsewhere, possibly even in embanked areas.

During application in planning the goal should be that one is going to create areas of maximum size, in order to minimise losses due to fragmentation. A first possible guideline could therefore be, to create at least a key area. This stems from the fact that a network is more likely to be sustainable if it contains one or more key areas (Verboom *et al*. 1997). The corresponding surface area for a key area depends on the species considered. For application in planning it is necessary to find a measure that is somehow linked to an ecotope or a cluster of ecotopes. Based on 114 selected species, potential inhabitants of river ecotopes and with known and specific demands on habitat, size and coherence of ecotopes, Liefveld *et al*. (2000) have defined nine groups for the Meuse with clearly different scale demands on their living area (table 3.2). For the Rhine the same selection of species can be used. Per cluster of ecotopes a check was made on what the size should be of an area, to house a key population of each of these nine groups of species (table 3.3; Liefveld *et al*. 2000).

Once a key area has been created, the next step is to find the maximal distances, within which additional smaller areas with similar ecotopes are needed, in order to form a genuine network. For this table 3.1 gives approximations for the species and species groups of the different scales.

Some ecotopes are easier to create or can be created over a larger area than others. For a proper design, it is important to pay attention to the so-called critical ecotopes first: ecotopes that are difficult to realise or that

Table 3.2
Functional species groups and their characteristics in the system for analysis of ecological networks (a.o. Buit *et al.* 1998, Liefveld *et al.* 2000).

species groups	dependent on terrestrial area for dispersion	number of species for Rhine and Meuse
small birds	no	40
middle size birds	no	32
large birds	no	26
small mammals	yes	4
large mammals	yes	3
reptiles	yes	1
amphibians	terrestrial and water dependence	2
fish	water dependence	3
insects, macrofauna	not or limited	3

Table 3.3
Area needed per cluster of ecotopes (indicated in the first row) for accommodation of a key population for each of the nine groups of species for river ecotopes (from Liefveld *et al.* 2000).

area (ha)	shallow water	sandy and silt shores, banks	marsh	grassland	tall vegetation	forest
5	insects	insects				
50	fish		small mammals			
200		amphibians				small mammals
500				reptiles		
1000		small, medium-sized and large birds	small birds	insects	amphibians	
1500	midsize and large birds		medium-sized and large birds			medium-sized and large birds
5000				small birds	small birds	small birds
10000				medium-sized birds	medium-sized and large birds	
25000			large mammals	large birds		large mammals

cannot be realised everywhere. The abiotic opportunities for the development of these ecotopes give an estimate of the chances of the corresponding natural values. Other functions, for example safety, may impose certain boundary conditions. All these conditions together result in search areas for the development of suitable ecotopes. Combined with the demands for ecological coherence of natural values, this can form a framework for planners within which scenarios can be developed. These scenarios can be checked and optimised by network analysis on their spatial ecological coherence.

The starting point in all network studies performed and to be performed is, that the ecotopes to be made are of optimal quality. The analysis then only has to deal with the size and location of the ecotopes. In table 3.4

Table 3.4
Overview of some critical ecotopes, analysis method in network analyses, processes relevant to these ecotopes and measures that promote or enable these processes.

Zone	critical ecotopes	possible indicator species	minimum size for key area	natural processes and factors	measures
permanent water (flowing)	secondary channel shallow river bed	barbel	50 ha	level difference and slope • free flow • alternating bank formation • pointbar- en scrollbar formation • meander cutting • tidal movement	• creation of secondary channels • ecologically sound banks • removal of bank protections • construction of bank protection dams in the water zone
permanent water (stagnant)	isolated floodplain channel isolated open water bodies	perch	50 ha	• low location in the winter bed and hardly ever in contact with the river • inflow as groundwater or from higher grounds • meander cutting • silting up of channels and pits	• creation of stagnant water bodies • excavation of floodplains
bank	natural banks natural levees river dunes	kingfisher, common sandpiper	1000 ha	• bank erosion • river bank formation • regressing erosion of side stream mouths • large ratio of depth to width: many gradients on the banks • low ratio of depth to width: steep banks • location in bend • streampower high: much sand transport • soil composition • level • exposition to prevailing wind	• restoration of the transition zone on the banks • creation of ecologically sound banks • removal of bank protections
low floodplain	softwood riverine forest grassland	middle spotted woodpecker, corncrake, corn bunting	1500 ha (forest) 10000 ha (grassland)	• recent depositions with regular inundations • on sandy banks without groynes • on low floodplains more likely • silting up of floodplain	• excavation of floodplains • removal of minor embankments • adjustments in management (e.g. allow succession vs. grazing)
marsh	marsh marsh forest	beaver, otter, great bittern, night-heron	1500 ha to 25000 ha	• low location in the winter bed and hardly connected to the river • influx by groundwater or from nearby higher grounds • meander cutting • silting up of channels and pools • silting up of floodplain	• excavation of floodplains • removal of minor embankments • adjustments in management • filling of deep sand and clay pits
elevated area	hardwood riverine forest grassland on natural levees	middle spotted woodpecker, badger	1500 ha to 25000 ha	• low-dynamic environment with low inundation frequency	• adjustments of management (allow succession vs. grazing)

indications are given for the execution of the analysis for a number of critical, often difficult-to-realise ecotopes. Also indicated are the processes that determine the development of these ecotopes, and the measures that could lead to their development. In the following chapters these measures are addressed in more detail, and recommendations are given on how they should be implemented. The detailed design of the measures (for example the dimensioning of a secondary channel or the exact depth and relief of an excavation) can determine to some extent the quality of the ecotopes that will develop at these locations.

Measures and ecotopes

A more complete overview of the relations between the river ecotopes of Rademakers & Wolfert (1994) and measures is given in table 3.5.
These relations are not exclusive; a measure can help to develop the development of several ecotopes, and the other way round, one ecotope can be developed by several measures. At the moment a large number of restoration projects is being planned or implemented along the Rhine branches and the Meuse, which aim at the enhancement of ecological values and increase of safety. These measures are given in table 3.5, with a subdivision into measures for reconstruction and for management.

Measures per river stretch

Along the outlines mentioned, now for the whole of the Meuse and the Rhine branches a vision can be developed on the measures that are desirable per stretch, from an ecological viewpoint. Table 3.6 summarises

Table 3.5
Relations between reconstruction and management measures and ecotopes to be realised. The measures that will be treated in more detail in this report are marked; indicated is also in which chapters these measures are addressed (code according to Postma *et al.* 1996).

		MEASURE																							
		SPATIAL DESIGN																			MANAGEMENT				
		Removal of clay layers with nature development purpose	**Construction secondary channel**	**Construction claypit/oxbow lake**	Partial filling up of former sand pits	**Stimulation of river dune development**	Widening of main channel	construction of fish passage	**Closing off groyne sections**	Development of sand flats	**Marsh development**	Artificial bank defence	**Cleaning of water bottom**	**Restoration ecological connections**	Realisation of low-current retention zones	**Realisation co-fluctuating zones**	**Realisation co-flowing zones**	Restoration tidal influences	Restoration gradient fresh-salt water	Construction seepage reduction screen	**Allowing spontaneous succession**	**Extensive natural grazing**	Nature-oriented pasture management	Nature-oriented marshland and reedland management	**Forest development**
	chapter	**6**	**5**	**4**		**9**			**5**		**10**		**3**	**3**		**6, 7**	**5, 6, 7**				**11**	**11**			**11**
ECOTOPE	code*																								
Hardwood floodplain forest	BH																				X	X			X
Softwood floodplain forest	BZ	X			X				X	X	X	X		X	X	X	X	X	X	X	X	X		X	X
Grassland on levee	GO					X									X	X	X				X	X	X		
Floodplain grassland	GU	X							X	X					X	X	X	X	X		X	X	X		
Marsh	M	X			X				X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	
Natural bank	ON						X		X	X		X	X	X			X	X	X		X	X		X	
River dune/Tall herbs on levee	RO			X		X								X							X	X	X		
Tall herbs on floodplain	RU	X							X	X					X	X	X	X	X		X	X	X		
Dynamic oxbow lake	WD	X	X	X				X	X			X	X	X	X	X	X	X	X	X	X	X			
Secondary channel	WN		X					X					X	X			X	X	X		X	X		X	
Pond	WP							X					X		X	X	X	X	X	X	X			X	
Isolated oxbow lake	WS	X		X	X			X	X			X	X	X	X	X	X	X	X	X	X			X	
Deep main channel	ZD						X	X					X	X					X		X				
Shallow main channel	ZO						X	X	X	X		X	X	X			X	X	X		X	X		X	

* codes after Postma *et al.* 1996: "Een stroom natuur".

the restoration measures and the river stretches where these seem promising. This is being worked out in more detail by Bruggenkamp (*in prep.*) who also summarises the suggestions that were given in earlier policy studies.

Table 3.6
Overview of the measures per river stretch, where these can be appropriate from the point of view of improvement of nature values.

	Bovenrijn	Bovenwaal	Middenwaal	O Benedenwaal	W Benedenwaal	Pannerdens Kanaal	Rhine around Arnhem	Rhine around Doorwerth	Nederrijn-Lek	Boven-Lek	Boven-IJssel	Midden-IJssel	Sallandse IJssel	Beneden-IJssel	Bovenmaas	Grensmaas	Plassenmaas	Peelhorstmaas	Venloslenkmaas	Maaskantmaas	Beneden-Maas	Afgedamde Maas	Bergse Maas	Getijdemaas	Lower river area	
Removal of clay layers with nature development pupose	++	++	++	++	++	++	-	-	-	-	++	++	-	-	++	++	-	-	-	-	-	-	-	-	+	
Construction secondary channel	++	++	+	+	++	+	+	++	0	-	+	+	+	-	+	++	0	0	0	0	+	-	0	+	0	0 = local
Construction claypit/oxbow lake	+	+	+	+	+	+	+	+	++	++	++	++	++	++	-	-	+	++	++	++	++	-	-	-	-	
Partial filling up of former sand pits	-	-	+	+	+	-	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	
Stimulation of river dune development	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Widening of main channel	+	+	+	-	-	+	+	+	+	+	+	+	+	-	+	+	+	+	-	-	-	-	-	-	-	
Construction of fish passage	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	+	+	+	-	-	-	-	
Closing off groyne sections	-	++	++	++	++	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Development of sand flats	+	+	+	+	+	-	-	-	-	-	+	+	+	-	+	0	+	+	+	+	+	-	-	+	+	0 = gravel beds
Marsh development	0	0	0	0	0	-	-	-	++	++	-	-	-	+	-	-	++	-	++	++	++	+	+	+	++	0 = inner dike
Artificial bank defence	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	++	
Cleaning of water bottom	+	+	++	++	++	+	+	+	++	++	+	+	+	++	+	+	+	+	+	+	++	++	++	++	++	
Restoration ecological connections	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Realisation of low-current retention zones	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	
Realisation co-fluctuating zones	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Realisation co-flowing zones	+	+	+	+	+	+	+	+	-	-	+	+	+	-	+	+	+	+	+	+	+	+	+	-	-	
Restoration tidal influences	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	
Restoration gradient fresh-salt water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	
Construction seepage reduction screen	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	+	-	-	+	+	-	-	-	-	-	
Allowing spontaneous succession	+	+	+	+	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Extensive natural grazing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Nature-oriented pasture management	+	+	+	+	+	+	+	+	-	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	-	
Nature-oriented marshland and reedland management	0	0	0	0	0	-	-	-	++	++	-	-	-	+	-	-	++	-	++	++	++	+	+	+	++	0 = inner dike
Forest development	++	++	+	+	+	+	+	+	-	-	++	+	+	+	++	+	+	++	++	+	+	+	+	+	+	++ = hardwood possibilities

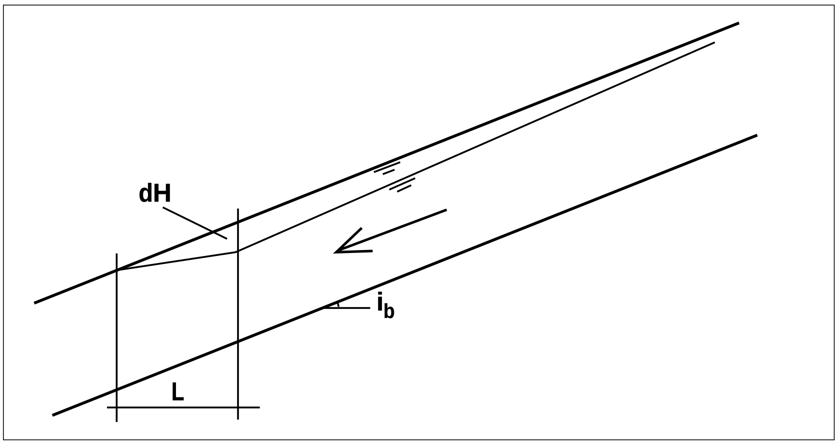
3.3 Effects of floodplain reconstruction measures on design water levels

The reconstruction of a floodplain usually leads to changes in the design water levels. These are reduced by measures that provide more room for water discharge, such as floodplain lowering, the excavation of secondary channels and floodplain waters, or the removal of minor embankments. An increase of the design water levels can be expected when the vegetation changes to taller types, leading to a higher hydraulic roughness coefficient.

In figure 3.1 the effect of increased room for discharge on the design water level is depicted. Without measures the bottom slope (I_b) is equal to the slope of the water level. By the measures over a length L, the water level slope is decreased at the location of the measures. In lowland rivers such as the Rhine and Meuse in the Netherlands, the effect of the measure on water levels is always equal to zero at the downstream limit of the measure, and maximal at the upstream end. The maximum design water level reduction is equal to $dH = (i_{old} - i_{new}) \cdot L$. This leads to the conclusion that the theoretical maximum decrease of the design water level reduction of a specific floodplain reconstruction project is attained, if $i_{new} = 0$. This cannot be attained, however, because if the slope is equal to zero, no flow can occur.

Upstream of the measure, the effect decreases asymptotically to zero. The distance at which half the maximum design water level reduction is reached, upstream of the measures, is inversely proportional to the water level slope and the water depth. In other words: the steeper the water level slope and the shallower the water, the faster the reduction of the

Figure 3.1
Sketch of the principle of the effect on design water levels of measures in floodplains, aimed at increase of the discharge capacity.
dH = max. reduction of design water level;
L = length of the measure;
i_b = bottom slope.



effect on the water level. In the Rhine and Meuse the distance at which half the maximum effect is reached, is about 10 km; the exception is the Border Meuse, where this distance is only a few km, due to the relatively steep water level slope. On the other hand the maximum effect on design water levels (dH) is larger with increasing water level slope and depth.

If in a given river stretch measures are taken in different floodplains, all of these have an effect in upstream direction. At the upstream limit of the stretch the result is the summed, partly attenuated effects of all of these measures.

Guidelines for the determination of the hydraulic effect
The changes in the design water levels as a result of measures are usually small, some centimetres, compared to the water depth during design discharge. This results in a near linear relation between measures and their effects: doubling the excavation volume doubles the effect. This linearity is lost when deep excavation depths are considered (more than 5 m), or large excavation lengths (more than 5 km). Within these limits the effect is only a function of the volume of soil that is excavated, and not a function of the layout of the excavation. A deep excavation on a small area has the same effect as a shallow excavation over a large area, if the total volumes of excavation are equal. This implies that the excavation of a secondary channel has approximately the same effect as an integral excavation of a floodplain of the same volume. All this refers only to parts of the floodplain that take part in water discharge during floods; excavations in parts of a floodplains that merely have a storage function have hardly any effects on design water levels at all.

These linear relations can be used to define, for all separate river stretches, relations between the excavated volumes and their effects on the design water levels. In doing so, the following approach was chosen. The Rhine branches are subdivided into a number of stretches, and each stretch is characterised by its cross section. The parameters of this cross section, such as widths and hydraulic roughness, are derived from calculations by the SOBEK-model for the Rhine branches, using a stationary discharge of 16,000 m^3/s. Subsequently in each cross section an enlargement or a change in hydraulic roughness is introduced, and from these two situations a difference in water level is calculated. Table 3.7 presents the results for all stretches. The table only refers to the upper river area of the Rhine in the Netherlands; for other rivers and stretches the results are not yet

Table 3.7
Effects per unit excavation and change of hydraulic roughness on the design water levels. The effect of an excavation on the design water levels at equal hydraulic roughness is given in the third column, expressed in mm per million m^3 of excavation. The fourth column gives the effect of a change in hydraulic roughness without excavation. This effect is expressed as a decrease per unit Chézy value, in mm per km^2 of floodplain with adjusted roughness.

River branch	river stretch	Effect excavation (mm/Mm^3)	Effect roughness mm/(km^2 . $m^{1/2}$/s)
Bovenrijn	Lobith – Pannerdense Kop	-48	+3
Waal	Pannerdense Kop – Nijmegen	-45	+3
Waal	Nijmegen – Tiel	-39	+3
Waal	Tiel – Zaltbommel	-47	+4
Waal	Zaltbommel – Gorinchem	-66	+5
Pannerdens Kanaal	Pannerdense Kop – IJsselkop	-91	+6
Nederrijn	IJsselkop – Driel	-168	+9
Nederrijn	Driel – Amerongen	-91	+5
Nederrijn	Amerongen – Hagestein	-75	+4
Lek	Hagestein – Schoonhoven	-78	+5
Lek	Schoonhoven – Krimpen	-89	+3
IJssel	IJsselkop – Dieren	-158	+7
IJssel	Dieren – Deventer	-84	+4
IJssel	Deventer – Wijhe	-77	+4
IJssel	Wijhe – Zwolle	-95	+5

available. In the lower river stretches a complicating factor is the influence on design water levels by sea water levels. Here measures in the floodplains hardly contribute to a reduction of the design water levels.

From table 3.8 it can be concluded that the effects of excavation and change in roughness are in the same order of magnitude for all stretches considered, except the stretches IJsselkop-Driel and IJsselkop-Dieren. Here the effect of measures is relatively large, because the water level slope is large during design discharge. On the other hand, the effect is attenuated relatively fast in upstream direction.

In order to apply table 3.8 successfully, something must be known about the expected changes in vegetation and the related changes in hydraulic roughness. This roughness is expressed in the Chézy value (C-value), and is a function of the water depth and the roughness value of Nikuradse (k-value). In figure 3.2 the C-values are given for a number of clusters of ecotopes, based on the k-values that were used in the decision support system for the Rhine branches (RWS/RIZA *et al.* 1999b).

Table 3.7 and figure 3.2 can be used to make a quick estimate of the effects on water levels of a project. Suppose that along the Midden-Waal (Nijmegen-Tiel) a floodplain is lowered by 2 meters over an area of 100 ha. Due to changes in the vegetation, the C-value at design discharge is reduced from 40 (grassland) to 25 $m^{1/2}$/s (tall vegetation). The maximum reduction in the design water levels then is calculated thus:

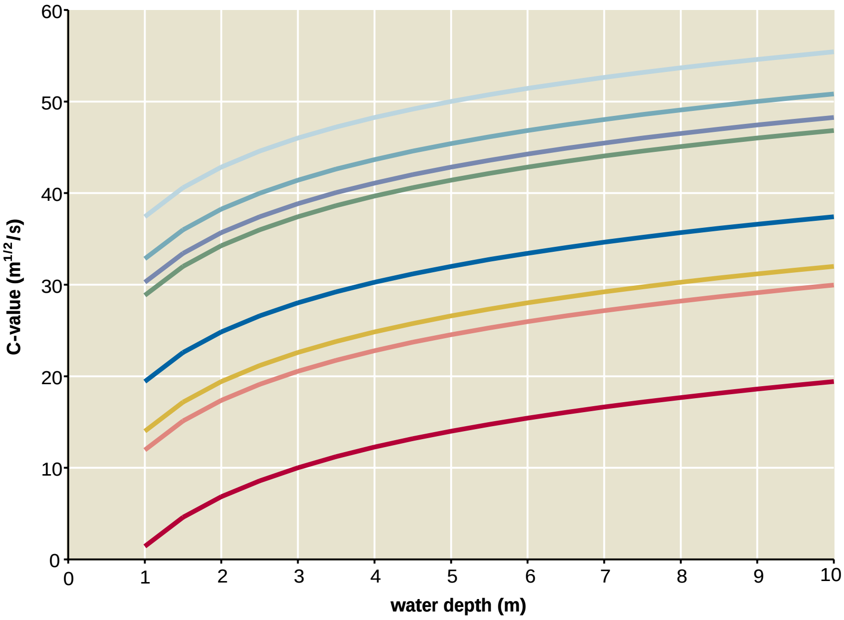
Reduction by excavation:
100 ha x 10.000 m^2/ha x 2 m / 1.000.000 x –39 mm = –78 mm

Increase by increased roughness:
100 ha x 0,01 km^2/ha x (40 – 25) $m^{1/2}$/s x +3 mm = +45 mm

Net effect: = –33 mm

Figure 3.2
Changes in hydraulic roughness (C-value in $m^{1/2}/s$) dependent on water depth in several clusters of ecotopes.

grassland
forest
shrubs
open water
built-up areas
water/marsh (80-20)
water/grass (50-50)
forest/shrubs (10-90)



As indicated above the depth of the excavation and the area are interchangeable, within certain limits. From the example it can be concluded that for safety it is better to design an excavation that is twice as deep (4 m), over only half the area (50 ha). The reduction of design water levels by the excavation is the same, but the increase by increased roughness of the vegetation is only half as big.

A second approach for the development of guidelines for the effects on design water levels is to use the results of the plan study Room for Rhine Branches. For this project the hydraulic effects were calculated of a large number of fictitious reconstruction plans. Per plan the following five versions were considered:

1. *Excavation.* The original reconstruction plan is excavated deeper, as far as the desired ecotopes allow.
2. *Surplus excavation*. Further excavation of version 1, resulting in more open water and marsh areas.
3. *Excavation and management of the vegetation*. Version 1 with a more intensive management of the vegetation, resulting in a lower hydraulic roughness.
4. *Excavation and agriculture.* Per floodplain the remaining agricultural area of version 1 is excavated to such extent that only 60 % of the agricultural use value is preserved.
5. *Surplus excavation and nature.* Compared to version 2 the area of the floodplain outside the planned measures is excavated too and made into a nature area.

In total about 130 plans with 5 versions each were calculated (RWS/RIZA *et al.* 1999a). From these calculations a number of indicators can be derived regarding the efficiency of floodplain excavation. In table 3.9 the volume of soil is given that must be excavated to bring about 0.10 m reduction of the design water levels. Here the assumption is that the relation between the volume of excavation and the resulting reduction of the design water level is linear. From table 3.9 it can be concluded that floodplain excavation is most effective along the IJssel and least effective along the Bovenrijn and Waal. The reason for this is that in the IJssel during design discharge a relatively large percentage of the discharge flows through the winter bed (40 to 70 %); in the Waal this is only 20 to 50 %. From table 3.8 it can also be concluded that for most of the river stretches the effect per cubic metre of excavation is larger along the IJssel than along the Waal.

Table 3.8
Required floodplain excavation per 0.10 m reduction of design water levels.

River stretch	Excavation (million m^3)
Bovenrijn	3,5 – 4,0
Waal	3,5 – 4,0
Pannerdens Kanaal	2,0 – 2,5
Nederrijn / Lek	2,5 – 3,0
IJssel	1,5 – 2,0

In the plan versions mentioned above not only excavation is considered, but also a change in vegetation, resulting in an increase of the hydraulic resistance. The separate effect of these two parameters cannot be calculated with the available data. Therefore the data in table 3.9 implicitly include the surplus excavation that must be realised to compensate the increase of the roughness.

Effect on design water levels per measure

Although in many respects it is useful to distinguish between the various measures, this is the case only to a limited degree when considering the effects on the design water levels. Stagnant water bodies and flowing secondary channels can be considered as special cases of floodplain excavation, and their effects can be estimated with the use of table 3.8 or 3.9. One may expect a somewhat larger contribution from a secondary channel than from a standard floodplain excavation, because secondary channels are usually oriented parallel to the flow direction.

The effect of the complete or partial removal of minor embankments on water levels cannot be estimated with the use of the indications above. Minor embankments induce a local energy loss, resulting in an increase of the water levels. The partial removal of a minor embankment therefore hardly has any effect on the design water levels, because the energy loss at the rest of the embankment is not affected. When removing minor embankments, it is useful to make a distinction between minor embankments parallel to and perpendicular to the main flow direction. The damming effect of an embankment parallel to the flow direction is negligible, but these embankments do have a function in the guidance of water flow during floods lower than design flood. Removal of minor embankments parallel to the flow direction is therefore not advisable. The effect on the water levels is largest when minor embankments perpendicular to the flow direction are removed. In table 3.9 the comparative effect of the various situations are indicated.

Table 3.9
Relative effect of removal of minor embankments on design water levels.

Orientation of the minor embankment	partial removal	complete removal
Parallel to the flow direction	no	small
Perpendicular to the flow direction	no	large

Spatial optimisation
So far the assumption was that measures are taken in the part of the floodplain where water is actually flowing during floods. An optimisation can be made by making a spatial distinction between flowing and storing parts of the floodplain. Riverine forest in principle has a damming effect, but not so if it is located in a part of the floodplain where flow velocities during floods are low. The other way round, floodplain excavation is most effective where flow velocities are highest. Although it is not possible to mark a clear borderline, from calculations with WAQUA an indication can be obtained on whether a given part of a floodplain has a discharging or mainly a storing function. A systematic elaboration of the suitability of parts of floodplains for measures that either increase the discharge capacity or impound the flow, based on the streamline patterns, can be found in WL/Delft Hydraulics (1999). In this study an investigation was made of the locations in the floodplains along the Rhine branches, where during design discharge the specific discharge (m^2/s) is relatively low (the ‘q-criterion’). In these areas an increase of the hydraulic resistance has little effect. In a second round of calculations all floodplains were excavated 1 meter, except pools, elevated areas and minor embankments. Subsequently the locations were identified where the strongest relative increase of the specific discharge was calculated. These locations are most suitable for excavation projects. The general conclusion from these calculations is, that excavation works are most effective in the vicinity of the main channel and that an increase of the hydraulic roughness causes the least effects on water levels when these are located near the winter embankment. Of course many exceptions can be found on this general rule, dependent on the local situation. For example, excavation in the leeward side of an elevated area makes little sense, and riverine forest at the base of a embankment immediately next to the river has a relatively large effect on the water levels.

Analogous to the orientation of minor embankments to the flow direction, also the damming effect of a rectangular patch of riverine forest depends on its orientation to the flow direction. With the longer side parallel to the flow direction the effect is smaller than with the longer side perpendicular to it.

These guidelines are meant to be used as a first indication of the effect of measures on design water levels. With increasing precision of a reconstruction plan the need for more detailed models increases. Dependent on the phase of the project these are SOBEK for a better calculation than with the tables above, and WAQUA for the precision and the final check.

3.4 Problems of polluted soils

In the floodplains along the Meuse and the Rhine branches significant amounts of micro pollutants are present (see paragraph 1.4.2). When reconstructing a floodplain and planning the related earthmoving, the designer is confronted with this problem. In the first place by the rules and instructions (‘what is and what is not allowed’), in the second place from the ecological risks (‘how can one treat the polluted soils in order to reduce the risks optimally’). This latter point is regulated less strictly; it is left to a larger extent to the planner to solve this problem.

At the moment a project is running to define the soil quality in the whole of the river area in so-called soil quality maps.

Active soil management in the river bed
The policy, what is and what is not allowed, is defined in the Law on Soil Protection. This law stipulates that in case of severe pollution, cleaning is required. In reconstruction projects in the river floodplains, in most of the cases the soils are heavily polluted. This forces the planner to draw up a plan, describing how and when and to what resulting quality the soil will be cleaned. This stringent policy is now under discussion, mainly because the cleaning of all heavily polluted locations is financially impossible.
A second point is that sometimes the remedy is worse than the disease. This might be the case if irreparable damage is inflicted on nature, geo-morphological or archaeological values. Cleaning can be pointless when renewed pollution by newly deposited sediments is expected.

The search is now for a more pragmatic approach, which still is sensible with respect to the environmental risks. This approach that is aimed more at functions and cost effectiveness than the former approach, and that takes the future use of the soil into consideration, is described in the document 'policy approach for Active Soil Management in the River Bed'. This approach will be further elaborated in rules for the floodplains.

The basis for these rules are:
1. a preferred order of area-oriented use options (soil remains soil; soil becomes building material; reuse after processing; storage in sand pits; removal to controlled storage facilities);
2. a function-oriented approach, based on risks (see below);
3. a cost-benefit analysis on project level.

Function-oriented approach
In measures in the river area aimed at nature development, a minimisation of the risks caused by pollutants for ecological effects is essential. Three types of ecological effects are discerned:

Direct effects: compounds have a direct toxic effect, leading to increased mortality, disruption of growth, reproduction or behaviour. This happens in the beginning of the food chain and may lead to the disappearance of species or a lower production in the area.

Indirect effects: for example: because of the disappearance of species (as a result of toxic substances), less food is available, or because of a reduced rate of degradation accumulation of detritus takes place.

Secondary effects: by accumulation and passing on of compounds in the food chain high concentrations are found in predators. This is for example the case for PCB's from fish to cormorants and otters, and for cadmium from earthworms to owls and badgers.

So it is important to plan the reconstruction of an area in such a way that the chance of direct or indirect exposition of organisms to the pollutants is minimised. 'Risk-reducing measure' is the key word here. Because the present system of standards, on which the classification for aquatic soils is based, often has no direct relation to the risks for the ecosystem, a more specific approach is needed. How this can be arranged is indicated in the document 'Active Soil Management in the River Bed: risks for nature'.

In this approach four steps are proposed, with each step zooming in more on the implications of pollutants for the function nature; from a general to local or species level.

The four steps are:

Step 1: Present standard system. Check of the measured concentrations on the present standards and classification. This results in a signal, asking for further diagnosis.

Step 2: Definition of risk limits. Check of the measured concentrations to species-specific toxicity data. This results in a better perception of the risks, defined as 'the chance of negative effects by long-term exposition'.

Step 3: Specific nature goals. Define the risks for the chosen species, representing the desired types of nature, with the help of toxicity data (which are often not available) or with the help of a vulnerability analysis (in which multistress has an important role).

Step 4: Biological availability. Various circumstances, such as age, earth removal or changes in land use, can lead to a higher or lower availability of the toxic compounds for organisms, thereby increasing or decreasing the risks.

How these steps can fit into the reconstruction planning is indicated in the scheme in figure 3.3. If this four-step approach for some reason is not feasible, the use of the guidelines (see box) may be of help.

Measures

With several measures in the river area situation might arise in which pollutants cause increased ecological risks:

- cutting into old, heavily polluted sediments;
- changes in land use (dry soil becomes wet or the other way round); this may lead to increased mobility and increased availability of compounds;
- water level dynamics; this too may lead to mobilisation and increased availability of compounds;
- earth moving; the moving around of soil may lead to (temporary) increased mobility of compounds.

Measures for which this can be important are: excavation of secondary channels, creeks, clay pits, floodplain channels, marsh development using polluted sediments, etc.

Rules of thumb for the reduction of risks by exposition to pollutants when reconstructing a floodplain

Metals:

- risks less under water than in dry conditions
- local conditions (pH, Ca) influence the intake by organisms

PAH:

- risks are decreased in the long term by degradation under dry conditions with oxygen
- availability is usually lower than would be expected from the total contents (conclusion: not all class 4 soils result in risks)

PCB:

- hardly any degradation, nor under wet nor under dry conditions

Top isolation with clean top layers decreases contact chances for organisms

Concentration to a smaller surface (for example in downward direction) decreases contact chances for organisms

Calcium containing soils have a buffering effect, which reduces the risks of mobilisation of metals by decreasing pH

Excavation and dry storage of anaerobic soils leads to a (temporary) increase of the availability of metals

A general impression of the **risks for nature** can be obtained by comparing problematic substances with permissible risk levels for nature.

From: document Active Soil Management of River Beds - Risks for Nature

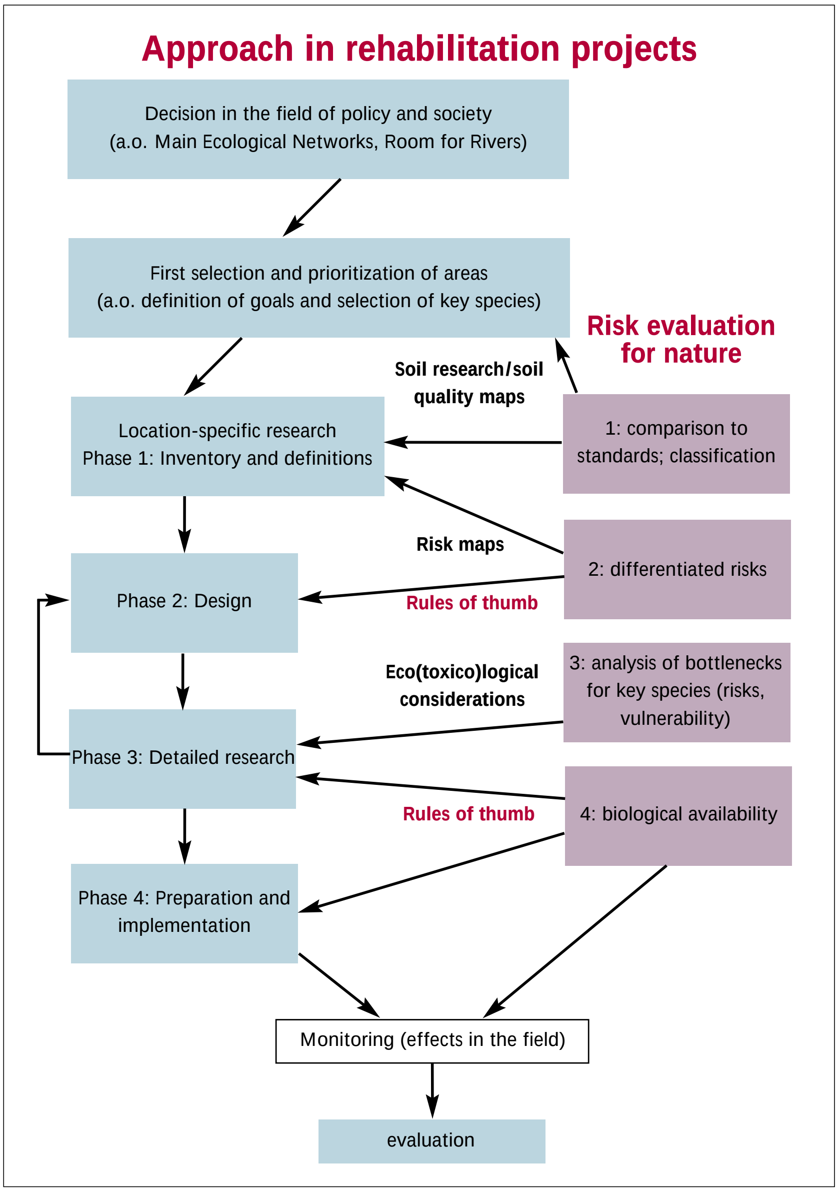


Figure 3.3
Interconnections in the planning of a reconstruction project and dealing with polluted soils.

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4 Stagnant water bodies

Tom (A.D.) Buijse, Frank C.J.M. Roozen, Rob E. Grift &
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Contents

4 Stagnant water bodies

4.1 Definitions and natural processes

In the ecotope systems for rivers, two types of stagnant water bodies are discerned: 'floodplain channel/clay pit' and 'pool' (Rademakers & Wolfert 1994). Floodplain channels and clay pits are subdivided into connected, isolated and stagnant floodplain channels and subsequently into seepage channel and brook channel if the floodplain channel is fed or influenced by seepage or brook water. Pools, based on their degree of hydrodynamics, are subdivided into linked and isolated sand- and gravel pits. Van der Molen *et al*. (2000), in the classification for aquatic components of river-floodplain systems, do not name the stagnant waters, but make a distinction based on depth, inundation frequency, soil type and presence of vegetation. The reason for this is the presumed determination of the ecological developments by these factors, rather than the origin of the water body.

The tidal creek keeps the middle between flowing and stagnant water and is also addressed in this chapter. In the following text attention is given to water bodies in floodplains that develop by natural processes: floodplain channels, scour holes and tidal creeks. Apart from that shallow pools are discerned. The appearance of stagnant water bodies is determined by age, location, shape, size and biotic interactions.

Floodplain channels form a phase in the succession series of the isolation of a former channel from the main channel. A secondary channel develops into an isolated floodplain channel; initially it is still connected to the main channel on one side, later this is only the case during floods. Then the development tends towards a slow but steady encroachment of the water by land and vegetation, to a degree that the channel can even temporarily fall dry.

Figure 4.1
The floodplain channel near Ewijk along the Waal. Floodplain channels are elongated stagnant water bodies i.e. old river channels that became disconnected from the main channel (photo Tom Buijse).

Scour-holes are caused by breaches of embankments or natural levees during floods; they are relatively deep and have steep banks.

Figure 4.2
Scour-holes develop where during floods the water flows with great force into the floodplains or through a dike. They are small, circular, deep water bodies. On this map they are located behind the embankments, a result of dike breaches in the past (from: Wolters-Noordhoff 1998).

Tidal creeks are strongly bifurcated creek systems. They form sharp and steep dynamic transition zones between land and water, under influence of the tidal movement. They can be freshwater, brackish or marine depending on their position along the longitudinal axis of river.

Figure 4.3
Tidal creeks, here shown in the Biesbosch, are usually strongly bifurcated (from: Wolters-Noordhoff 1998).

Shallow pools can have many shapes (from circular to elongated) and develop in the active floodplains behind natural levees.

The stagnant water bodies in floodplains show a wide variety in characteristics. Within close range from each other, clear and turbid waters can be found, with or without vegetation, in permanent connection to the main channel or isolated during the greater part of the year. The following main types can be discerned: clear water with or without vegetation, and turbid water by algae or by silt. Depending on size and shape, within one water body combinations are possible: e.g. turbid open water, surrounded by a zone of clear water with vegetation along the banks. This diversity is an important feature of a natural river landscape. The present appearance of stagnant waters is on one hand determined by the long-term succession, on the other hand by the spatial lay-out, the location within the floodplain, and the biological processes within that water body.

Depending on the location in the floodplain, upward or downward seepage may influence the hydrodynamics and trophic state of the water bodies. A gradient can often be discerned, as a function of the distance to the main channel. Also the influence of the wider surroundings may be important, such as seepage flows from elevated areas at some distance. Due to the limited size of many water bodies in the floodplains (from 0.1 to some tens of ha), biotic processes can have a substantial influence. For example: fish may hamper the development of aquatic vegetation by stirring up silt, especially if silt is supplied during floods. All these are natural processes, together resulting in a wide variety of water types in the floodplains.

4.1 Hydrology, morphology en ecology

4.2.1 Hydrological functioning: dynamics, sources

Stagnant waters in the nowadays active floodplains differ from water bodies behind the dikes by the irregular, seasonal floods, the so-called ‘flood-pulse’ (see chapter 1).

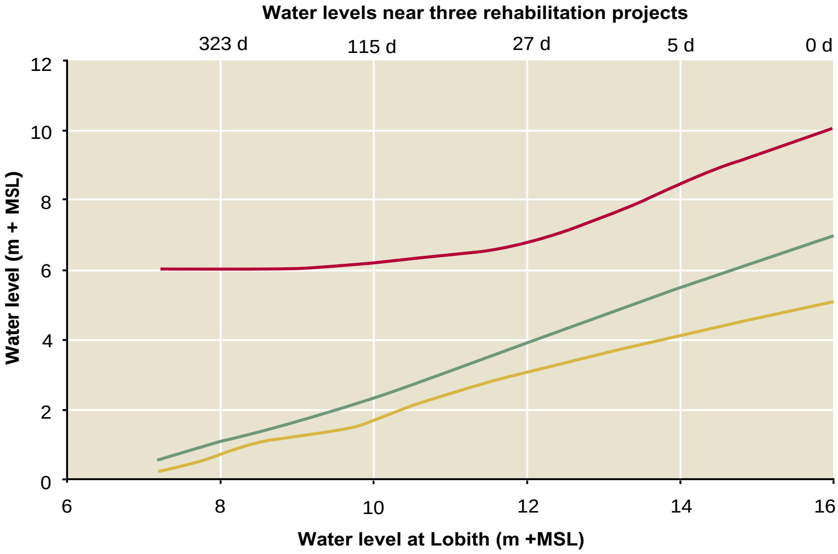
In stagnant waters the following hydrological notions are relevant: inundation frequency, level fluctuations, dam-regulated or free-flowing river, tidal movement, presence of oligotrophic ground water.

The frequency and duration of floods determine how often and for how long the water quality is equal to that of the river. Floods enable the inoculation of plant seeds, plankton and macroinvertebrates, as well as migration of fish. If the flooding occurs with force, the soil can be scoured and the old silt layers washed away. Floods upstream carry coarser sediment than those downstream of the river.

Level fluctuations that are not high enough to cause inundations, still lead to water level fluctuations in the stagnant waters. These fluctuations determine, together with the slopes around water bodies, the extent of the dynamic land-water transition zone, where pioneer communities dominate. Level fluctuations are indicators of the interaction of the water bodies with the ground water. Although the ecological effects of this phenomenon are not yet fully known, it is believed that this has consequences for the water quality, because aerobic and anaerobic conditions alternate. When this even leads to complete desiccation, fish and other organisms that depend on water of course cannot survive.

The question if a river stretch is regulated by weirs has wide consequences for the water levels. For example: a water level increase at Lobith of 4 m results in only an increase of 80 cm near the ‘Blauwe Kamer’ near Wageningen on the Rhine, but in an increase of 2.3 m near the Duursche Waarden on the IJssel and an increase of 2.7 m near Gameren on the Waal. Further downstream the fluctuations diminish and gradually get more influenced by tidal movements, or by the level fluctuations of lake Ketelmeer (at the mouth of the IJssel).

Figure 4.4
The influence of the water level at Lobith near 3 floodplain rehabilitation projects (Gameren near Zaltbommel on the Waal; Blauwe Kamer near Wageningen on the Lower Rhine; Duursche Waarden near Wijhe on the IJssel). The figures indicate the number of days per year that this water level is exceeded.



Apart from floods, the river also causes seepage fluxes. These fluxes are increased if in the floodplain deep sand- or gravel pits are present. Seepage influences both the hydrodynamics and the water quality. The hydrology on its term influences strongly the chances for aquatic vegetation to develop, by way of fluctuations, turbidity and chemistry.

Often a gradient, determined by the river, can be discerned. Human-induced elevated levels of nutrient and chloride decrease with increasing distance from the main channel, just as the level fluctuations (figure 1.1). Especially as a result of nutrient concentrations, turbid waters are usually found close to the main channel while clear waters are at a greater distance. Apart from that, increased chloride concentrations may hamper the development of aquatic vegetations, while level fluctuations determine their possibilities.

The importance of river water decreases at greater distance from the main channel, and locally also by the effect of upward seepage fluxes originating from the hilly glacial deposits. Examples of this can be found near the Gelderse Poort, along the north banks of the Lower Rhine and along parts of the IJssel. Along the Meuse, upstream of Nijmegen,

Figure 4.5
Fringed water-lily can deal very well with the large level fluctuations along the Waal (photo's Tom Buijse).

seepage runs from the elevated terraces of the Meuse into the valley. Deep seepage fluxes supply the floodplains locally with nutrient-poor groundwater. This increases the possibilities of clear water and typical, often imperilled species of aquatic vegetation and macroinvertebrates.

Strong hydrodynamics result in relatively broad transition zones between land and water, the more so when combined with gentle slopes on the sides of the water bodies. The alternation between wet and dry years result in shifts in the vegetation, making room for pioneer communities, both aquatic and terrestrial.

Centuries ago already embankments strongly reduced the extent of the active floodplains. Therefore, the water bodies with the lowest hydrodynamics have disappeared. Possibly nowadays, the water bodies behind the dikes, connected to the river only through groundwater, fulfil the functions that formerly the most remote parts of the floodplains had. Comparison with low-dynamic water bodies elsewhere along other, more natural European rivers might lead to a better understanding.

Figure 4.6
Seepage from the Wageningse Berg, a glacial relict, supplies the floodplains locally with nutrient-poor groundwater (photo Tom Buijse).

4.2.2 Morphological functioning: sedimentation

The stagnant water bodies in river floodplains will gradually aggradate, are hardly subject to any erosion, and eventually will become terrestrial components. This is a natural process, a result of the low flow velocity of the water over the floodplain. Floods induce a net inflow of sediment, which is finer with decreasing flow velocity. Erosion hardly plays a role in stagnant water bodies, except for those situated at locations where during floods the water enters the floodplain with high velocity. Newly excavated water bodies initially can have a sandy soil, but gradually this sand will be covered by silt. This process influences the level fluctuations in the water body in reaction to the groundwater table fluctuations. The silt layer has a higher resistance to groundwater flow than a sand layer, and will therefore reduce level fluctuations.

Hydro- and morphodynamics together result in rejuvenation of stagnant water bodies and its banks. During the growing season differences of the water level may amount to meters, from year to year. In relatively wet years the aquatic communities can spread, in dry years the terrestrial ones. The dynamic transition zone between land and water is the domain of pioneer species. This should be taken into account in the design of rehabilitation measures, by choosing gentle bank slopes. The inflow of sediment can hamper the development of vegetation, especially during the growing season. On the other side sedimentation can increase the process of becoming land; in shallow pools the opportunities for plant growth are better. The net aggradation of the whole floodplain and its water bodies means that the contribution of the floodplain to the reduction of design water levels gradually diminishes in time.

Resuspension of sediments has consequences for the light climate and the possibilities for the development of aquatic vegetation. There are three important factors that may cause resuspension: wind, shipping and fish that stir up the soil. Wind is only of major importance in large water bodies and shipping only in water bodies that are connected to the main channel. The influence of wind and shipping therefore can be directed to some extent by a proper design of the restoration measures, either by limiting the size of the water bodies or by avoiding the connection of water bodies to the main channel. The influence of fish is much more difficult to direct. It is clear that fish choose their preferred locations during floods, because they are not evenly distributed over the water bodies after a flood.

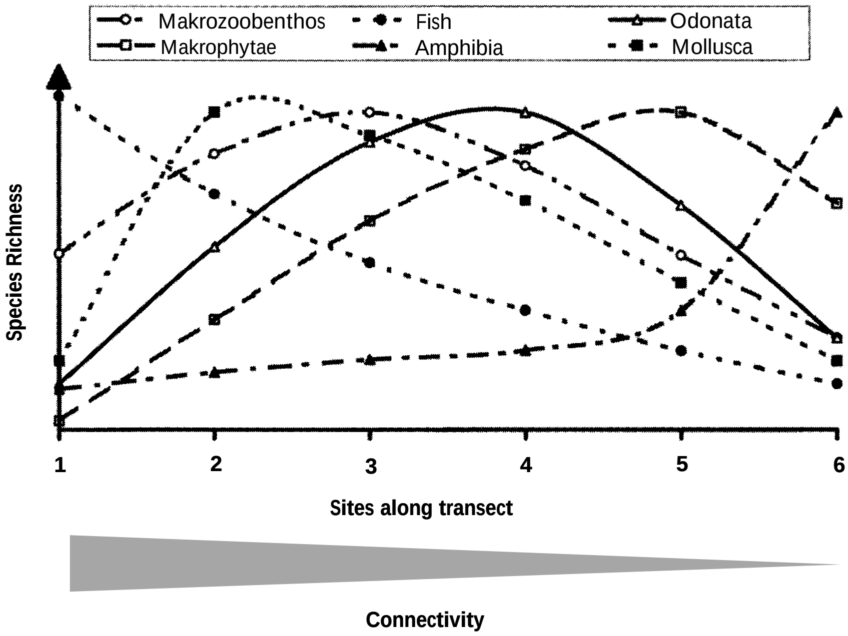
The question whether a water body becomes turbid or not seems to be the result of the opposing forces of on the one hand the development of an aquatic vegetation, that makes the water body unfit for benthivorous fish such as bream (*Abramis brama*), and on the other bioturbation by those fish, that hampers the development of aquatic vegetation. The development of aquatic vegetation itself can be promoted by the design of the water body; positive features are gentle slopes, periodically extending above the water level and a large ratio of shore length to water surface area.

4.2.3 Ecological functioning

Just like any biotope in the river area, stagnant water bodies have their characteristic communities and functions. They host a wide variety of (semi-) aquatic flora and fauna that depend on stagnant water. Fish have their largest diversity in the main channel, but species like dragon-flies, amphibians and aquatic plants have their largest diversity in stagnant waters (fig. 4.7). Fish species such as bream and white bream (*Abramis* bjoerkna) need both the main channel with its flowing characteristics and the stagnant water bodies in the floodplain to complete their life cycle. Other species such as tench (*Tinca* tinca) and crucian carp (*Carassius* carassius) depend on stagnant water bodies for their complete life cycle. Amphibians migrate from their hibernation areas to the floodplains in spring, to deposit their eggs. Dependent on the species, they stay there for some time, during which period they have their specific demands on vegetation and water quality (Creemers 1994). Aquatic plant species are hardly found in the main channels of the large rivers, like the Rhine and the Meuse. Their presence completely depends on the presence of stagnant water bodies.

On balance undisturbed floodplain water bodies have a larger biodiversity than water bodies that are not influence by rivers. This is caused by the fact that floods create 'time windows' in which dispersal, migration and recolonisation can occur. This holds true especially for species that are strictly bound to water during their whole life cycle, such as fish and molluscs, and for plants that rely on water for the dispersion of their seeds. Apart from that, floods induce gradations of hydro- and morphodynamics (which diminish with increasing distance from the main channel), which allow for the variety in characteristics and successional stages of stagnant water bodies.

Figure 4.7
The diversity of several plant- and animal groups along a gradient of hydrological connectivity (from: Tockner *et al.* 1998).



Stagnant waters show differences in biodiversity, dependent on their hydrological distance to the river. This range of water types, partly with low and partly with high biodiversity, form together the diversity of biotopes that are characteristic for floodplains. Water bodies that are at close distance to the river, but not permanently connected to it, turn out to have the lowest biodiversity. Stagnant waters that are permanently connected to the main channel often house representatives of both flowing and stagnant waters. Stagnant water bodies that are connected to the main channel frequently (more than 20 days per year) house the same species from stagnant waters, but the species of flowing water bodies cannot maintain themselves. When the influence of the river is reduced further, and the floodplain is flooded for less than 20 days per year on average, the biodiversity increases; this is partly due to the fact that aquatic vegetation can develop here, and partly to a different, more nutrient-poor water quality.

As a result of the ‘flood pulse’ (chapter 1) water bodies in active floodplains are richer in diatoms than water bodies behind the embankments. Diatoms are better adjusted to running water. The algae community counts few blue-green algae. The zooplankton in clear water bodies is dominated by other species groups than those in turbid waters or in waters that are connected to the main channel. The floods also induce an inflow of plankton, plant seeds and macroinvertebrates. For fish they offer the opportunity to migrate into and out of the floodplain.

Water bodies that are not connected permanently to the main channel, but that have a high inundation frequency, have the lowest diversity of fish species. After a long period of isolation from the main channel less species are found than shortly after an inundation period: not all species can maintain themselves. In low-dynamic water bodies, that are clear and rich in aquatic vegetation, the characteristic limnophilic fish species are found. Fish may have an important role in the turbation of water by resuspension of silt and sedimentated algae. This holds true especially in cases where large numbers of bentivorous bream are present after an inundation. Combined with the inflow of silt during floods, this might hamper the development of aquatic vegetation for a long time.

Birds use the water bodies to forage: plants, insects, fish, the bottom fauna of banks that emerge when the water level drops. These sources are mainly of interest for birds in periods with falling water levels. Because of the limited size of the water bodies, birds can locally exhaust their feeding sources to a large extent.

Floodplain lakes in their natural condition are rich in phosphates and nitrates. From these high concentrations one might expect blue algae blooms in many instances, but still this phenomenon is not often observed. The surplus enrichment by human-induced fertilizer seems not to have led to the disappearance of ecological communities in stagnant waters. However, this phenomenon probably has induced a decrease of the number of clear, vegetation-dominated water bodies in floodplains. Comparison of the present situation with vegetation maps of around 1950 shows such a trend.

4.3 Interrelations with the surroundings

The lowering of floodplains by the excavation of stagnant water bodies has a positive effect on the water levels, especially during large flood events. During floods the flow velocity can increase by the presence of such deeper water bodies. The exact size of this effect depends on the layout and on the location of these water bodies with respect to the stream lines during floods. This must be calculated for each specific situation.
For the time being one design principle is that only the upper 5 m of water body actually take part in the discharge of water and a decrease of design water levels. More depth does not lead to extra positive effects in this respect. To give an indication of the upper limit of the effects: if all floodplains are excavated to a depth of 1 m, the design water levels will decrease some 20 to 30 cm (Silva 2001).

In floodplains, including the stagnant water bodies, a net sedimentation takes place. This causes these waters to become shallower gradually, thereby slowly diminishing their contribution to the reduction of the design water levels.

For the development of stagnant water bodies the surroundings in both the near vicinity and at intermediate distances are relevant. The near vicinity comprises the banks of the water bodies and the surrounding floodplain, the wider surroundings may include higher grounds and terraces, from which seepage fluxes originate, and neighbouring stagnant water bodies from which recolonisation can take place.

Riverine forests at the banks of the water bodies cause, by their leaves, organic soils and mostly turbid waters. On the other hand such forests provide protection against the wind, thus reducing the resuspension by wind.

Grazing is a natural phenomenon in floodplains. Grazing and intensive trampling of the banks may hamper the development of the vegetation on the banks. Steep slopes result in less vegetation and less alternation of aquatic and terrestrial developments. For the time being no indications could be found that there are interrelations between the fertilizer regime on the surrounding agricultural lands and the ecological functioning; still such interrelations are expected.

The water bodies in floodplains together form an ecological network. Although this is not yet clear in a quantitative sense, it is assumed that such water bodies together are better capable of sustaining ecological communities. Nearby waters are important source populations for recolonisation. Thus ecological communities in waters that only differ in their level could master hydrological variations because the circumstances are always favourable in one of these water bodies, and recolonisation to the other waters is quick when the conditions turn favourable there. Model calculations on ecological networks show that a few large key areas are more sustainable than many small ones. This does not imply that stagnant waters should be dimensioned as large as possible, because this also changes the ratio between shore length and open water area, but rather that a larger number of water bodies must be created at close distance to each other. In other words: it is better to have in one floodplain several water bodies and in another floodplain none, than one or two water bodies in every floodplain. So far no calculations are available of minimum sizes of such key areas and of the optimal distances between them.

Apart from their ecological function and their contribution to water levels during flood events, the water bodies in floodplain now and in the future have an important function for both professional and recreational fishery.

4.4 Design of stagnant water bodies

4.4.1 Where can stagnant waters be made and where not

Along the Waal the floodplains have relatively high inundation frequencies and duration. This would plead to the design of connected water bodies here. The floodplains along the Lower Rhine and the IJssel have much lower inundation frequencies. Here mainly stagnant waters with aquatic vegetation could be developed, the more so because of the presence of elevated areas nearby supplying the floodplains with nutrient-poor groundwater. Along the dam-regulated parts of the Rhine and the Meuse the level fluctuations are reduced when the river discharges are low. This offers opportunities for aquatic plants that are sensitive to level fluctuations.

Stagnant water bodies can nowadays hardly arise from by natural morphodynamic processes, because the main river channel is fixed within groynes or because the banks are protected with rip-rap. Water bodies can only be formed naturally if erosion is permitted in the floodplains. Ideas related to this are the flood gullies along the dam-regulated Maas.

During floods the river is allowed to scour the floodplains on a limited scale. This leads to the formation of gullies and pools, which are eroded during the next flood event. No net aggradation is expected here.

As a rule, however, human interference is needed to create new stagnant water bodies. From ecological perspective it is best to link to historical maps and natural shapes and sizes. All along the Rhine branches floodplain lakes that have a natural origin can be found (Wolters-Noordhoff 1990: 3 Oost-Nederland 1830-1855). These are mainly cut-off meanders and former main channels, but also relatively small, circular deepscour holes). Few floodplain channels are still connected to the main channel on one side. The size of stagnant waters is to a certain degree related to size of the Rhine branch e.g. the largest channels and 'scour holes are found along the Waal, which discharges 70% of the total Rhine. Along the IJssel many stagnant waters are found especially between Deventer and Wijhe. The most downstream part of the IJssel shows many similarities to those of the Meuse and Waal, due to the tidal movement in the former Zuiderzee. Centuries-old cut-off channels like the 'Kil van Hurwenen' or the 'Oude Waal' near Nijmegen, are still present at several locations. Apart from that a much larger number of waters is present that were excavated for the extraction of clay and sand.

Along the Meuse the naturally formed stagnant waters, such as cut-off river bends, were mainly found along the meandering stretches between Maaseik and Neer and downstream of Mook (Wolters-Noordhoff 1990: 4 Zuid-Nederland 1838-1857). Stagnant waters that have arisen naturally are hard to find in the active floodplain of the Meuse, because they have been aggradated or, in some instances, because they are now situated behind the embankments. Along the Meuse the stagnant water bodies mainly consist of artificially cut-off bends, gravel pits and harbours. These waters are characterised by their unnatural large size and depth. Small stagnant waters are mainly present on the stretch between Lith and Hedel. The Bergse Maas is excavated; here hardly any stagnant water bodies are present.

The floodplains along the Meuse have a much lower inundation frequency and duration than those of the Rhine branches. As a consequence the stagnant water bodies along the Meuse have a much less dynamic character than those along the Rhine. The first floodplains along the Meuse are inundated at a discharge of 1250 $m^3 s^{-1}$, which is exceeded only some 3 days per year. These floodplains are located in the upstream stretches of the Meuse in the Netherlands. The remaining floodplains are inundated less often; the main part has an inundation frequency of only one day per 4 years (van der Veen pers. comm.).

The 'Maasplassen', between Maaseik and Neer, form a large system of both isolated and connected large stagnant water bodies, excavated for the mining of gravel and sand. The Maasplassen are, because of their number, size and depth, an unnatural element in the active floodplain of the Meuse, but at the same time they do have their specific ecological values. Even to the present day, water bodies of this type are being formed. It is highly desirable that these water bodies are transformed in such a way that the characteristic natural values of a river are enhanced. Reducing the depth of these waters and the steepness of their slopes enhances the natural values, and is in line with the proposed measures to design sand pits along the Rhine branches into more characteristic floodplain components. At this moment due to the still poor water quality of the Meuse also the reduction of the influence of the river water is preferred.

Before the Nieuwe Merwede was excavated and the Haringvliet was closed off, the downstream parts of the rivers had a wide diversity of tidal creeks (Wolters-Noordhoff 1990). Diversity was found in length and width and in the chloride content of the in- and outflowing water. By the excavation of the Nieuwe Merwede, and the construction of groynes and stone bank protection, in the first place the influence of the river on the Biesbosch, a large freshwater tidal area, was reduced. By the closing off the Haringvliet (1970) the tidal range was reduced drastically. As a consequence the tidal creeks lost much of their dynamic character. They differ from secondary channels further upstream, only under influence of the river, in being strongly bifurcated, showing a sharp gradient between bare and vegetated parts, having steeper banks and showing sharp gradients in the longitudinal direction: by their bifurcations they quickly become narrower and shallower (fig. 4.3). These shapes are the consequences of the force of the tide, which fills and empties these creeks twice a day.
In fact these waters are not truly stagnant, because most of the time water is either flowing in or out. Although the morphodynamical processes have now been stopped, many tidal creeks in the Biesbosch, along the Haringvliet and the Oude Maas still have their original forms, notwithstanding the fact that they are partly aggradated and that the vegetation on their shores has changed. The long-term level fluctuations, caused by the river, are reduced here. Truly isolated water bodies are relatively scarce in these parts of the river floodplains. Whenever they are present, they are similar to isolated water bodies further upstream.

Table 4.1
Suitability of the river stretches for the development of connected and isolated water bodies.

stretch	suitability for connected water bodies	suitability for isolated water bodies	explanation
Bovenrijn	high	fair	strong hydro- and morphodynamics
Bovenwaal	high	fair	strong hydro- and morphodynamics
Middenwaal	high	fair	strong hydro- and morphodynamics
Oostelijke Benedenwaal	high	fair	strong hydro- and morphodynamics
Westelijke Benedenwaal	high	fair	strong hydro- and morphodynamics
Pannerdens Kanaal	high	limited	strong hydro- and morphodynamics, lack of room
Rijn near Arnhem	limited	limited	strong hydro- and morphodynamics, lack of room
Doorwerthse Rijn	limited	limited	strong hydro- and morphodynamics, lack of room
Nederrijn/Lek	limited	high	regulated by weirs, low dynamics
Boven-Lek	limited	high	regulated by weirs, low dynamics
Boven-IJssel	limited	high	elevated, low inundation frequency
Midden-IJssel	fair	high	elevated, low inundation frequency
Sallandse IJssel	fair	high	elevated, low inundation frequency
Beneden-IJssel	high	high	elevated, low inundation frequency
Boven-Maas	high	fair	strong hydro- and morphodynamics
Grensmaas	high	limited	strong hydro- and morphodynamics
Plassenmaas	fair	high	low inundation frequency
Peelhorstmaas	fair	high	low inundation frequency
Venloslenkmaas	fair	high	low inundation frequency
Maaskantmaas	limited	limited	regulated by weirs, low dynamics
Beneden-Maas	limited	limited	low inundation frequency, lack of room
Afgedamde Maas	limited	limited	low inundation frequency, lack of room
Bergse Maas	limited	limited	low inundation frequency, lack of room
Lower stretches	high	limited	tidal movement

Retention areas can also be suitable for the creation of stagnant water bodies. Because these areas are situated further from the river they offer opportunities especially for clear water bodies with aquatic vegetation. In the document 'Room for Rhine Branches' suggestions are made for retention areas along the Upper Rhine, the Pannerdens Canal, and the upstream parts of the IJssel and the Waal.

4.4.2 Suggested dimensions

The lay-out of water bodies that are to be created should be linked to t he natural forms of floodplain water bodies. These are in the first place elongated floodplain channels, dependent on the river stretch under consideration as a cut-off bend or horseshoe-shaped. Then there are the circular scour holes, shallow pools and tidal creeks.

Floodplain channels can vary in size considerably, scour holes are usually less than one hectare in size. The elevation, inundation frequency and depth have their influence on the chances for the development of aquatic vegetation and the size of the transition zones between land and water. For shallow pools this can vary from intermittently falling dry to modestly deep. Closer to the river the hydro- and morphodynamics will usually increase, thereby promoting pioneer communities.

Large and deep sand pits are undesirable, although they offer good hiding opportunities for fish, due to the absence of flow and their large depth, and are important roosting place for waterfowl. Clay pits excavated in the traditional way are undesirable because of their steep side slopes and their unnatural, rectangular forms.

Meandering rivers are, amongst others, characterised by steep and deep outer bends and gently sloping and shallow inner bends. In the outer bend sediments are most coarse, where in the inner bend, where the water flow velocity is lowest, they are the most fine. Cut-off meanders kept those morphological characteristics, although the top-layer of sediments now consist of finer material and organic matter. Cut-off meanders are gradually filled with sediments during floods, and will consequently become shallower, and eventually altogether become land. The pace of this process depends on the situation, especially on the amount of sediment that is transported by the river; it may take from decades to centuries.

The cut-off meanders are the present-day floodplain channels. The difference between inner and outer bends is especially visible on the stretches where the river originally had a strongly meandering character, e.g. along the Waal in the Gelderse Poort and on the stretch between Tiel and Zaltbommel. In these stretches the relatively deep waters are not only present in the form ofscour holes, but also in the outer bends of channels. To some extent the deep sand pits have comparable characteristics to these natural deep waters. Of course they are much larger than scour holes and much more circular than channels, and they have much steeper slopes. However, it these sand pits are transformed for natural development they may keep some deep parts, while the rest can be give characteristics like those of natural scour holes or outer meander bends.

This sketch of the transforming man-made stagnant waters can also be used for the adaptation of the existing water bodies. Former sand- and gravel pits can be made shallower. The contribution of these pits to the discharge of water during floods and safety is limited to the upper 5 m.

Table 4.2
Isolated and one-sided connected floodplain channels: guidelines for their design.

length	250 - 5000 m; dependent on the dimensions of the main channel
width	10-100 m; possibly varying
shape	elongated, slightly curved to horseshoe-shaped
side slopes	1:10 inner bend; 1:3 outer bend
depth	slightly curved oxbow lake to 3 m (at design low water levels); horseshoe shaped floodplain channels have deep outer bends (up to 8 m) and shallow inner bends; then make a choice between 1 design depth for the whole length or increasing depth in down-stream direction (slope 1:100 - 1:1000);
location	preferably excavate clay deposits from and re-open old floodplain channels
distance to the river	one-sided connected channels: close to the river; isolated floodplain channels: on historical locations or as far from the river as possible
falling dry	these floodplain channels contain water permanently; regular falling dry of the banks is desirable
management	grazing strategies determine the development of the vegetation along the banks

Table 4.3
Scour holes: guidelines for their design.

shape	circular
area	0.1 – 4 ha
side slopes	rather steep (1:3); slopes may become gentler at the point of influx, due to sedimentation (1:10)
depth	up to 10 m at design low water level
falling dry	no
location	at locations where, during high water levels, the water flows from the river into the floodplain
ecological network	in principle 1 per floodplain
development	create the boundary conditions (e.g. locally lowering of the embankment between main channel and floodplain to allow for scouring during flood events) or excavate directly

Table 4.4
Tidal creeks: guidelines for their design.

shape	main creek with more or less perpendicular to its side creeks (possibly these have their side creeks as well); elongated, tapering
length	main creek length 100-2000 m; width of the inflow opening up to 20 m; gradually becoming narrower; side creeks with a length up to 100 m
side slopes	steep, 1:1 to 1:2
depth/falling dry	bottom slope in longitudinal direction: permanent water containing at low tide in the main creek (up to 2 m depth) and parts of the side creeks (up to 0.5 m depth). Falling dry at the ends of the main creek and the side creeks at low tide.
location	connected to the main channel; the main creek runs parallel to the main channel, side creeks are more or less perpendicular to it
ecological network	maximum 1 per floodplain; the number of branches determines the dimensions

Table 4.5
Shallow water bodies: guidelines for their design.

shape	diverse: circular, ellipse, curved
area	0.1 - 10 ha
side slopes	gentle 1:5 - 1:20; when up to 2 m depth a gentler slope (1:20) than at deeper parts (1:3-1:5)
depth/falling dry	the whole range from completely falling dry to max. 5 m depth with only the shore zones that emerge with low water levels
location	in principle in the whole floodplain; much water level fluctuation, relatively deep and close to the river will result in mostly turbid waters, while limited water level fluctuation, shallow and distant from the river may result mainly in clear waters with submerged vegetation
management	grazing determines the development of the vegetation on the shores
ecological network	more water bodies in one floodplain; possibly interconnected at medium water levels

Furthermore water bodies can be (re-)connected to the river. If they are not connected to the river permanently and have a high inundation duration (more than 20 days per year), they turn out to have a low biodiversity. Even more this type of water is highly over-represented at the moment. Clay pits, that often have almost vertical slopes, can be given gentler slopes. The clay in the direct surroundings of existing water bodies can be excavated following the contours of the underlying sand deposits, thereby restoring some of the natural transition zones between land and water.

4.4.3 Management and maintenance

The need for management and maintenance is determined by the functions that are assigned to the water bodies. From ecological perspective the management and maintenance activities must be kept as limited as possible in order to enable the long-term natural development and succession. The Rhine and Meuse should both have a diversity of water bodies in various stages of succession. Other functions, such as recreation and safety, may have demands with respect to, for example, access or storing capacity, which has its impact on management and maintenance.

Another option might be in the management of floodplains. Because of the erosion of the main channel and the sedimentation on the floodplains the transition zones have become sharper and narrower. Floodplains are flooded less frequently and shorter than prior to regulation. About all floodplains have embankments, which separate them from the main channel. Almost all are equipped with small sluices, which now serve to fill the floodplain before those embankments are overtopped and to drain the floodplain with falling river water levels. These sluices could be used, by keeping them closed after a flood, to increase the inundation duration of the floodplain (cf. Galat *et al*. 1998). This system was used in earlier centuries for example in Hungary, where it is called the ‘fok’-system (Zsuffa 2001). One might call it controlled flooding. It is one of few options to create on a large scale and on a long term semi-aquatic conditions in the floodplains. Especially amphibians and fish could profit from such a system for spawning. Of course this depends on the present land use; floodplains that now have a function for nature development are the first to consider.

Grazing is a natural phenomenon in floodplains. Grazing and intensive trampling of the banks can however hamper the development of a shore-line vegetation. The development of a shore vegetation along stagnant water bodies can be expected in a zone of maximally 1 m depth at standard low river water level. The development of submersed aquatic vegetation can take place to a water depth of maximally 2 m. Although compartimentation is not seen as a viable solution, it may sometimes be necessary to fence off the banks to enable the settling and development of a vegetation there. Where this is the goal and a negative impact of cattle is expected, the cattle should not be allowed closer than 1 m from the water.

Do's:
- use natural forms and dimensions
- use the distinctions in hydro- and morphodynamics between the Rhine and the Meuse and between the branches and stretches of these rivers
- differentiate within river stretches; the inundation duration is now not very discriminative.
- conserve existing water bodies with low dynamics
- use seepage flows with nutrient-poor groundwater from the upland fringe
- make shallow shore areas with dynamic land-water transition zones
- create a high ratio of shore length to water surface area
- connect floodplains with high dynamic characteristics to the river; one-sided or as secondary channel
- create gradients in grazing intensity
- consider the possibility of water retention or controlled flooding through management of sluices in the embankments in between main channel and floodplains

Don'ts:
- new deep sand-mining pits
- steep slopes
- 'one size fits all' solutions

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5 Flowing secondary channels

Luc H. Jans

Contents

5 Flowing secondary channels

5.1 Definition and natural development of secondary channels

A secondary channel is defined here as a channel, situated parallel to the main channel, in which the water flows during a large part of the year. It is mainly this flowing character that makes the distinction between secondary channels and other types of floodplain water bodies, such as pools and floodplain channels.

In natural river systems, continuous changes in the morphology of the river are quite common. Because of the large fluctuations in discharge and sediment load of the river, continuous erosion and sedimentation take place. Due to erosion of banks, the natural river can become ever wider and shallower, which may cause local reduction of the flow velocity and the development of a point bar. When such a point bar develops into an island, also a secondary channel is created; see figure 5.1. This natural process of island and channel formation will only take its course when the width of the main channel is at least 100 times larger than its depth (Schoor & Sorber 1998; Wolfert 1998). In the present Rhine branches and the Meuse in the Netherlands this ratio nowhere is higher than 50, making natural island and secondary channel formation impossible. Before 1850, there were still plenty of opportunities for these processes in the Netherlands. Secondary channels were primarily found along the weakly meandering river stretches, and mainly in the downstream part of the floodplain.

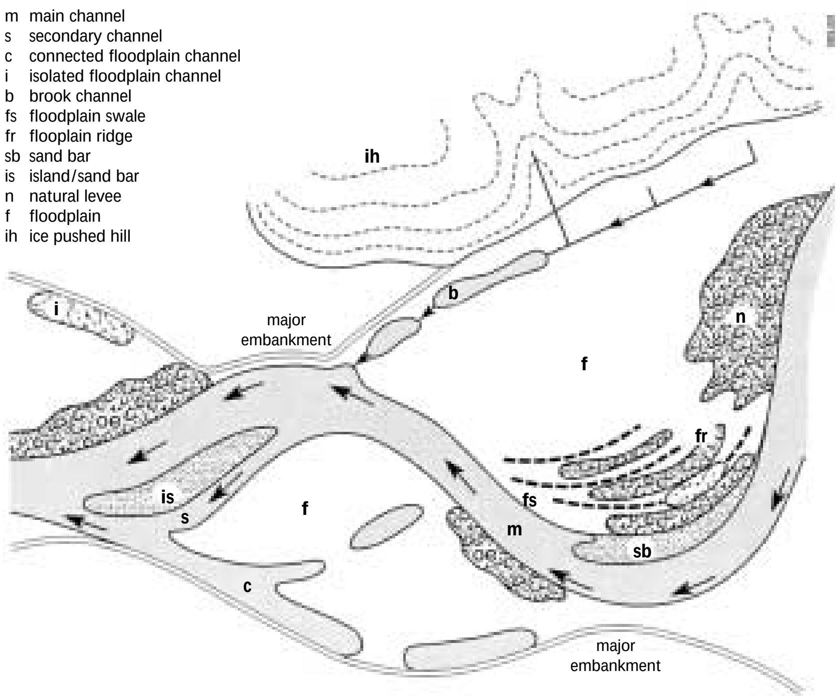


Figure 5.1
Morphological elements in a floodplain; pay attention to the secondary channel, and the difference with floodplain channels as discussed in chapter 4 (from: Wolfert 1998).

Normally secondary channels will slowly silt up at the upstream end, thereby transforming into one-sidedly connected floodplain channels that only during floods take part in the discharge of water.

Because secondary channels are often characterised by a small water depth and a low flow velocity as compared to the main channel, secondary channels offer suitable conditions to many species of fish and macro-invertebrates that are dependent on flowing water, but find the main channel too dynamic. Because of the limited water depth and the continuous connection to the main channel, secondary channels can also be important for species that need shallow, flowing water conditions only during part of the year. If the secondary channel is active from a morphological point of view, new pioneer situations are created permanently, thereby restarting the succession process. Nevertheless natural secondary channels will show a tendency towards ever further silting up, and become ever stronger vegetated with an ever more permanent vegetation.

The term secondary channel is in a certain way a combined name for various water types. Under this name sometimes only permanently flowing channels are understood, and sometimes also the periodically flowing channels. These intermittently flowing channels fall dry during low discharge periods on at least part of their course, over their whole width, thus making flow impossible. Along the Meuse so-called flood channels are being planned. These are in fact one-sidedly connected channels that only take part in the discharge during floods, and are then connected to the main channel on both ends. Their ecological and morphological functioning therefore shows more parallels to one-sidedly connected channels (discussed in chapter 4) than to secondary channels.

In the plans for the Rhine branches the possibilities for so-called green rivers are discussed. These are periodically discharging channels, which contain water at such a low frequency that a permanent vegetation is present in their bed.

5.2 Hydrology, morphology and ecology

Because secondary channels can no longer develop by their own account in the present-day Dutch rivers, they will only develop if helped by human hand. Over the past decade five secondary channels were made in the Netherlands, all of them along the Waal (figure 5.2). The following text is to a large degree based on the experiences gained in these secondary channels.

5.2.1 Hydrological functioning

Because secondary channels are almost permanently connected to the main river, their water levels are about equal to those in the main channel. As a consequence the level fluctuations over the year and from year to year are large. Related to this, also the flow velocities vary strongly. These are as a general rule lower than those in the main channel, because the energy slope is smaller and the hydraulic resistance higher because of the reduced water depth.

Practice has proven that the direct influence of shipping on flow velocities in the secondary channel can be quite large. At low water levels the effect of suction and pushing up by ships can cause the flow velocities in the

Figure 5.2
The locations of five excavated flowing secondary channels along the Waal, in the Heesseltsche Waard near Opijnen, in the Leeuwense Waard near Beneden-Leeuwen and three secondary channels in the Gamerensche Waard.

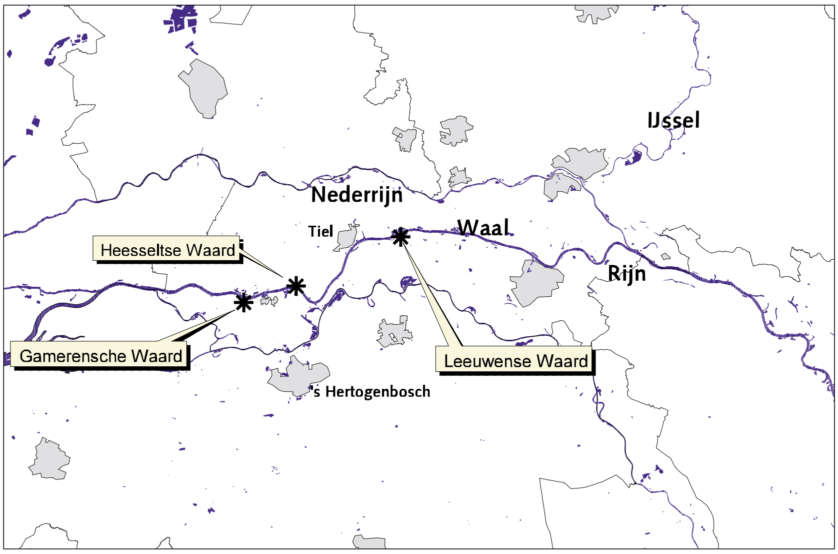
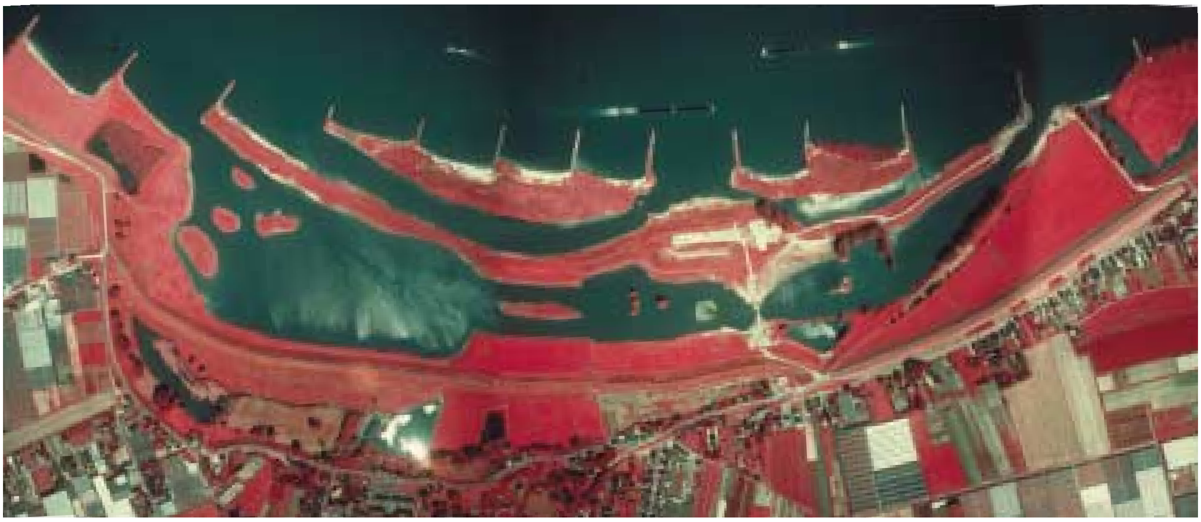


Figure 5.3
The Gamerensche Waard with three secondary channels (false colour aerial photo June 2000).



secondary channel to vary greatly. Sometimes the flow direction is even reversed. This can be accompanied by level fluctuations of several decimetres. The effects of ships are smaller with increasing length, depth and discharge of the secondary channel.

The construction of secondary channels brings about the presence of surface water closer to the winter embankment. This will cause stronger seepage flows from the river to the polder, which can have influence to several hundreds of meters from the major embankment, dependent on the properties of the soil profile.

5.2.2 Morphological functioning

The flowing character of the water brings about strong morphodynamics in secondary channels. The first experiences with secondary channels on one side indicate erosion of the banks and on the other side sedimentation in the streambed of the channels. By these processes, small steep slopes (little 'cliffs') are formed continuously, as well as new bare point bars in the gullies.

By the creation of secondary channels the sediment balance of the river may change; the main stream discharges less water, while probably the sediment load is not decreased in the same ratio. This will cause sedimentation in the main channel.

The erosion in secondary channels mainly occurs as bank erosion, but locally also the channel bed may be eroded. This can be expected especially in and directly downstream of narrowings, often as a result of vortices. In wider parts and in inner bends the water flow is slower; here point bars may be formed. Also directly after the intake sand deposition is expected, because the flow velocity in the secondary channel is lower than in the main channel.

5.2.3 Ecological functioning

Vegetation
The large level fluctuations and the continuous water flow in secondary channels are the reason why only a few plant species can possibly find a place in the secondary channel; an example is Loddon pondweed. Experience so far even points towards the complete absence of aquatic vegetation.

For the bank vegetation secondary channels can be important. This goes especially for pioneers of emerging soil, such as mudwort, brown galingale, needle spike-rush and willows. Due to the fluctuating water levels and flow velocities in secondary channels, continuously new conditions are formed. The succession of the vegetation is constantly set back. As a consequence, for pioneers there are favourable conditions ever again, and not only once. Of course from year to year the composition of the pioneer vegetation will differ significantly, dependent on the water levels during

Figure 5.4
Trees on the banks of the secondary channel near Opijnen (photo L.Jans).

essential periods for settling, germination and growth. The first experiences in the Gamerensche Waard indicate a surprising completeness of the pioneer vegetation (Jans *et al*. 2001). During the summer season the aquatic vegetation will be thin or even absent in the then shallow water. This means that there are only few possibilities for aquatic fauna that depends on vegetation. An exception can be trees; several tree species can cope with large water level fluctuations (figure 5.4).

Macro-invertebrates
Because the water in secondary channels flow slowly, these channels offer opportunities for several species of aquatic macro-invertebrates, that have difficulties in finding favourable conditions elsewhere in the river area. This concerns mainly species that need a continuous current in order to feed. Often these species need a firm substrate to attach themselves to. Research in the Gamerensche Waard shows that on firm substrate (stones, firm clay banks) the densities of rheophilic species are highest. It was also found that in the secondary channels there is a wide biodiversity in mosquito larvae, living in the soil. Probably also vegetation, both on its leaves and on its wood, offers many possibilities for these rheophilic species.

Wood, dead or alive, in secondary channels can add significantly to the ecological value of a river, because of the wide biodiversity of the macro-invertebrates living in it. Trees in and along secondary channels cause fewer problems for shipping than along the main channel. They can form a habitat that is suitable especially for macro-invertebrates and fish, and that has all but disappeared.

The strong fluctuations in flow velocities caused by shipping can affect the macro-invertebrates in the secondary channel. These effects are reduced with increasing size of the secondary channel. The exact effect on the macro-invertebrates is still not known, but it is assumed that at least part of the macro-invertebrates community cannot cope with the quick changes in flow velocity and direction.

Secondary channels can also be of some importance for terrestric macro-invertebrates, earthworms and many kinds of insect larvae. The periodical emergence of the soil often brings about a regression in succession. The species of the aquatic environment die and terrestrial species colonise the new parts. As a result the terrestrial macro-invertebrates of the banks and bed of secondary channels always are in some kind of pioneer phase. This means often that only a limited number of species are found, though sometimes in high densities (Lammertsma *et al*. 2001). Under such circumstances the land that is being uncovered also offers feeding possibilities for birds that feed on terrestrial macro-invertebrates, especially for waders. For the time being, however, the pioneer conditions in the Dutch river area do not seem to lead to high densities of terrestrial macro-invertebrates, probably due to the limited possibilities for colonisation within the time frame of the accessibility of the new habitat (Faber *et al*. 1999).

Fish
Secondary channels can have an important function for rheophilic fish species (Grift 2001). From research in the new secondary channels along the Waal it is concluded that these channels can be important especially for the growing stage of fish. Of some species that have become scarce in

the Netherlands, such as barbel and ide, considerable numbers of young fish were found during samplings. A function as spawning area has not been observed yet.

Birds
Because of the fluctuating water levels in secondary channels waders can make use of the presence of emerging silt banks and shallow flowing water. Of course the significance of secondary channels in this respect depends on the area of suitable habitat that is found during the waders' presence in the river area, in the late summer and autumn. If the slopes are gentle, a large area of just inundated banks will always be present somewhere, independent of the water level.

In secondary channels some special conditions can be found that have become scarce elsewhere in the river area. For example small cliff banks can be present, offering nesting opportunities to sand martins and kingfishers. During periods of severe cold, the still flowing water in the secondary channel can offer feeding possibilities for water fowl.

5.3 Interrelations with the surroundings

If one wants to excavate a secondary channel somewhere, a close look must be given to the possible consequences for safety against floods and shipping.

5.3.1 Interrelations with safety

The construction of a secondary channel can add to the safety against floods, because it increases the discharge capacity of the winter bed of the river. Because the water in the secondary channel can flow fast during floods, it may add much to the lowering of the design water levels.

The flowing water can also cause erosion of the banks of the secondary channel. Erosion processes are valuable aspects of a natural secondary channel. In order to allow erosion, some room is required along the secondary channel. It is therefore better to keep the secondary channel at a distance of at least 100 m from the major embankment.

5.3.2 Interrelations with shipping

Shipping can be affected negatively by secondary channels because these can change the sediment loads of the river, which may have consequences for the navigability. Also transversal flow near the intake and outlet of the secondary channel may cause problems for shipping.

In the Rhine branches minimum dimensions for the shipping lanes have been adopted. These dimensions are valid for the river water level that has an exceedance frequency of 95 %. If part of the discharge is diverted from the main channel to the secondary channel, the flow velocity in the main channel is reduced. This can cause deposition of sand and consequently reduction of the water depth in the main channel. Because of this, secondary channels are designed in such a way that computer models predict a maximum sand deposition of 0.2 m. The first experiences with the secondary channels in the Gamerensche Waard indicate lower rates of sand deposition than predicted. As yet no final conclusions can be drawn on this point.

With respect to the other possible adverse effect for shipping, the transversal flow near intake and outflow, it is remarked that so far no negative effects have been experienced.

Both the rate of sand deposition in the main channel and the transversal flow velocity can be kept within limits by a proper design. By construction of thresholds or regulation works in the secondary channel, the withdrawal of too large a fraction of the discharge by the secondary channel can be avoided.

5.3.3 Interrelations with land use in polder areas

The construction of a secondary channel may increase the seepage flow from the river towards the polder areas during floods. This flux depends on a number of factors; calculations must determine how strong this effect will be. If a strong increase of seepage is expected, this might call for the necessity of improvement of the draining system in the polder area directly behind the embankment. On the other hand, nature areas behind the embankments might profit from the increased seepage flux.

5.4 Construction of secondary channels

5.4.1 Where can secondary channels be constructed

Secondary channels belong to lowland rivers and therefore they might be appropriately planned in all of the Dutch parts of the Rhine and Meuse basins. In practice, however, it does not make sense to try to realise secondary channels in stretches where hydrodynamics are not strong enough. Therefore the stretches of the weir-regulated Nederrijn/Lek and the weir-regulated parts of the Meuse are not taken into consideration, with an exception of possible weir passages (see text box).

Secondary channels as weir passages?

In weir-regulated river stretches secondary channels make no sense because the hydrodynamic conditions are reduced too much here.
What does offer opportunities, however, are secondary channels parallel to the weirs themselves. Here a water level difference is always available, guaranteeing water flow. Of course, the discharge here must be regulated strictly in order not to undermine the function of the weir itself.
This regulation must be ensured by a construction at the intake of the secondary channel.

A secondary channel of this type bears much resemblance to a fish passage, but if it is given much room and freedom it can surely make a contribution to ecological rehabilitation. A special point of interest here is the water flow that is needed to draw the fish to the downstream end of the secondary channel.

The flow velocity in the secondary channel can increase beyond standards during low discharge periods, because of the big level difference over the weir. To avoid this the secondary channel must be made very long, or be equipped with obstacles or thresholds. An example is the secondary channel near the weir in the Nederrijn near Driel, now under construction.

The Bovenrijn and the Waal are the most suitable river stretches for the construction of secondary channels. This notwithstanding the fact, that in the Waal the amount of sand transported by the river is the largest of all branches, increasing the risk of fast sand deposition in the secondary channel. In this respect the Boven- and Midden-IJssel have the advantage that their ratio of width to depth is so small that the risk of sand deposition in secondary channels is reduced strongly (Wolfert 1998).

On river stretches where at present the navigation channel is only just wide and deep enough, which is the case on the Midden-Waal, the construction of a secondary channel will quickly lead to problems for shipping. Then the amount of water that can be diverted to the secondary channel may become so small, that frequent interruptions of the water flow through the secondary channel will result. From the view of practical feasibility it may be better then to try to realise secondary channels in stretches where the demands of shipping are less restrictive.
Another important feature is the exact location of the secondary channel in the river stretch. A secondary channel in a floodplain in an inner bend will silt and sand up faster than in an outer bend (figure 5.5).

Because of their water flow and constant connection to the main river, secondary channels are easy to be found by many different organisms. Dispersion and colonisation processes are fast here. From the idea of

Figure 5.5
An excerpt of the maps that depict the rate of sand deposition on the banks of the Rhine after a flood event (Sorber 1997).

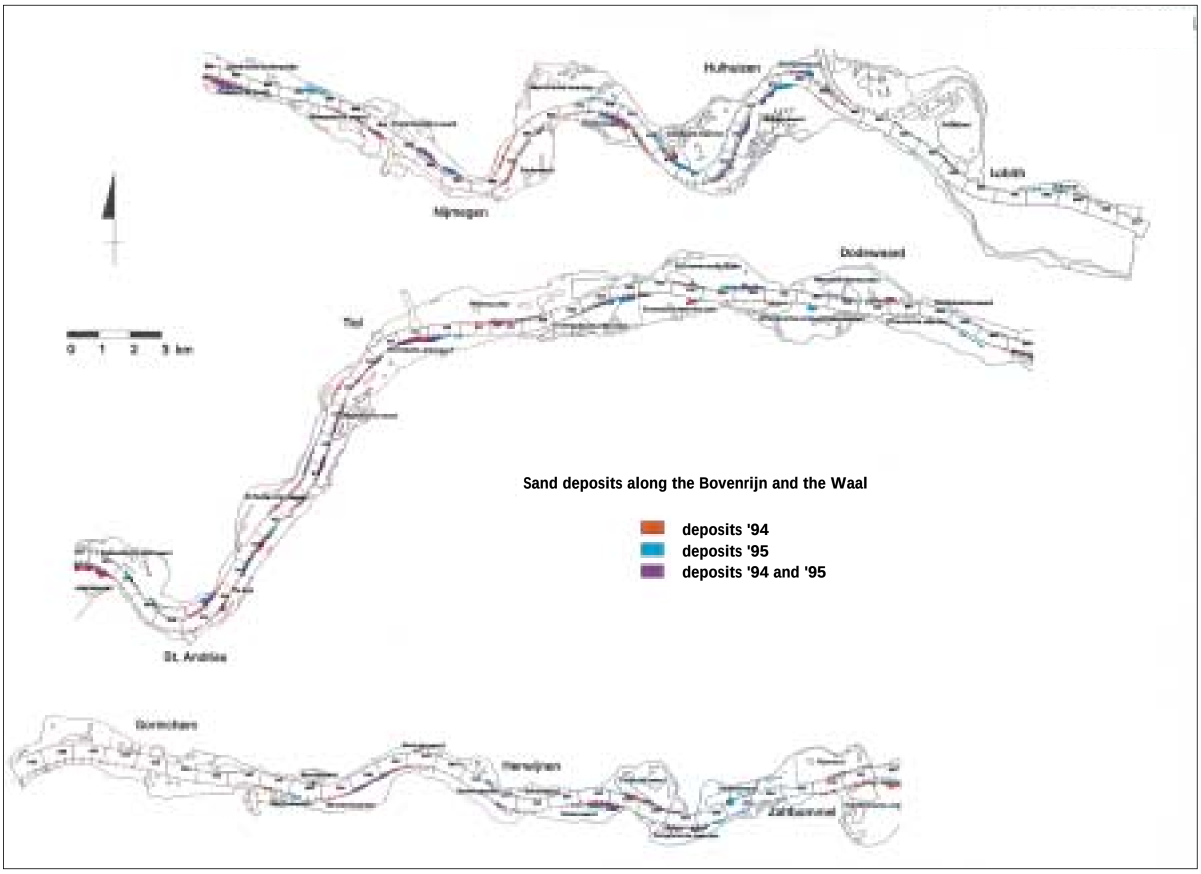


Table 5.1
Suitability of the river stretches for the development of connected and isolated water bodies.

stretch	suitability for connected water bodies	suitability for isolated water bodies	explanation
Bovenrijn	high	fair	strong hydro- and morphodynamics
Bovenwaal	high	fair	strong hydro- and morphodynamics
Middenwaal	high	fair	strong hydro- and morphodynamics
Oostelijke Benedenwaal	high	fair	strong hydro- and morphodynamics
Westelijke Benedenwaal	high	fair	strong hydro- and morphodynamics
Pannerdens Kanaal	high	limited	strong hydro- and morphodynamics, lack of room
Rijn near Arnhem	limited	limited	strong hydro- and morphodynamics, lack of room
Doorwerthse Rijn	limited	limited	strong hydro- and morphodynamics, lack of room
Nederrijn/Lek	limited	high	regulated by weirs, low dynamics
Boven-Lek	limited	high	regulated by weirs, low dynamics
Boven-IJssel	limited	high	elevated, low inundation frequency
Midden-IJssel	fair	high	elevated, low inundation frequency
Sallandse IJssel	fair	high	elevated, low inundation frequency
Beneden-IJssel	high	high	elevated, low inundation frequency
Boven-Maas	high	fair	strong hydro- and morphodynamics
Grensmaas	high	limited	strong hydro- and morphodynamics
Plassenmaas	fair	high	low inundation frequency
Peelhorstmaas	fair	high	low inundation frequency
Venloslenkmaas	fair	high	low inundation frequency
Maaskantmaas	limited	limited	regulated by weirs, low dynamics
Beneden-Maas	limited	limited	low inundation frequency, lack of room
Afgedamde Maas	limited	limited	low inundation frequency, lack of room
Bergse Maas	limited	limited	low inundation frequency, lack of room
Lower stretches	high	limited	tidal movement

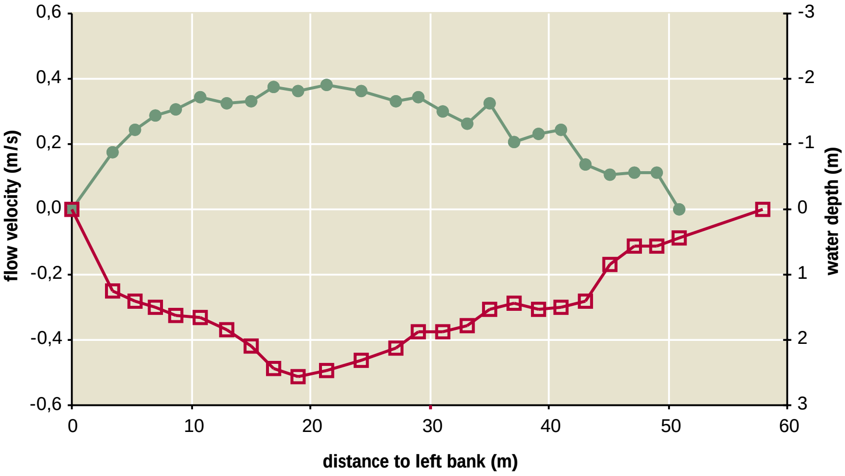
ecological networks not only the interrelations between separate secondary channels are important, but also the interrelations between a secondary channel and the shallow and moderately deep water zone of the main channel. Assuming that these zones are not rendered unfit everywhere for aquatic organisms by shipping or dredging, fragmentation is not expected to play an important role here.

5.4.2 How can secondary channels be constructed

As was pointed out before, secondary channels can no longer develop on their own account in the Dutch river area. An exception is the Grensmaas, where maybe by measures such as addition of extra sediment, 'natural' development of secondary channels is still possible (Liefveld *et al.* 2000). In general one can state that if secondary channels are desirable, they must be excavated. In the design of the secondary channel, account can be taken of the ecological demands of organisms and the boundary conditions from safety and shipping in several ways.

The discharge in the secondary channels can be regulated by means of constructions. The amount of sand that is transported into the secondary channel can to some degree be regulated by the construction of a threshold in the intake. These two aspects, discharge and sediment load, determine to a large degree the flow velocity, erosion and sedimentation, that in their turn are important for the possibilities the channel offers to different types of organisms.

Figure 5.6
Variation in depth of the secondary channel induces variations in flow velocity. Example of a measurement perpendicular to one of the secondary channels in the Gamerensche Waard. From: Jans *et al.* 2001.



The rate of erosion depends on the amount of water flowing through the secondary channel. Model calculations indicate only limited erosion of the silt that is deposited during low discharge periods. This erosion will not prevent net sedimentation in the channel. Only by the construction of a sand and silt trap at the upstream end of the secondary channel net sedimentation can be prevented (van Wijngaarden 1998).

Results from the Gamerensche Waard show that in bank channels (secondary channels between the main channel and the minor embankment) sand deposition during floods dominates the development of the channel. Due to their location close to the river much sand is transported into the channel. Closing off of the intake will take place here much quicker than in secondary channels that enter the floodplain (figure 5.7).

5.4.3 Management and maintenance

Because limits are usually put on the permissible rate of erosion and sedimentation in secondary channels, maintenance measures such as dredging or defending banks can be necessary. It is practically impossible to design stable secondary channels while taking all preconditions into account.

Figure 5.7
Sedimentation of sand in an intermittently discharging secondary channel in the Gamerensche Waard (photo L. Jans).

Chances are that the secondary channels tend to be closed off by sand or silt. If the aim is to make sure that the secondary channels take part in the discharge during floods, dredging is necessary. In the secondary channel the sediment has a chance of being polluted, as a result of erosion of banks with older and more severely polluted sediment. This depends on the location of the channel in the floodplain and on the soil layers that were cut. The deposition processes of sand in secondary channels are still being studied. It is considered a possibility that during extreme floods the secondary channels are opened up again.

Because secondary channels, at least locally, cause erosion (figure 5.8), erosion might happen on sites where this is not allowed, for example near winter dikes, infrastructure or heavily polluted areas. In such cases defending the banks with stones may be necessary. Monitoring is then needed.

Figure 5.8
Bank erosion near the intake of one of the secondary channels in the Gamerensche Waard (photo L. Jans).

Another type of management that must be mentioned here is grazing. Because secondary channels are often also constructed because of their effect on design water levels, it might be wise to make sure that the floodplain does not develop a tall vegetation or even forest, because that would completely undo the effect of the secondary channel. One way of preventing tall vegetation to develop is by grazing. In this respect one must be aware of the fact that when a secondary channel is made, automatically an island is created, which has consequences for the accessibility of the area by cattle.

5.4.4 Recommended characteristics and dimensions

Do's:

- make use of the specific properties of the location under study
- make sure that the secondary channel has enough room to allow the connected processes of erosion and sedimentation to follow their natural course (or at least as much as possible).
- allow for variability in depth, width, side slope in the channel
- allow for sufficient flow in a considerable part of the channel
- make sure that the developments in the channel are monitored and reported

Don'ts:

- planning of secondary channels only because they are ‘en vogue’
- ‘one size fits all’ solutions
- wide, deep channels with limited discharge and too low flow velocities

Table 5.2
Recommended characteristics and dimensions for the construction of secondary channels.

length	no restrictions. However, the length of the secondary channel should not become too large with respect to the length of the main channel, because of the minimum water level slope needed to secure truly flowing conditions in the secondary channel (see flow velocity).
width	to reduce the influx from the main channel into the secondary channel, at least part of the secondary channel must have a width that does not exceed 10 meter. Elsewhere the secondary channel may be wider. Differences in width automatically induce differences in flow velocity, which is seen as a positive feature.
depth	in order to make sure that the secondary channel discharges more or less continuously, the ridge must be constructed at a level lower than the level with an exceedance frequency of 95 %. For aquatic organisms it is essential that even at extremely low water levels in parts of the channel the water depth is at least 0.5 m.
side slopes	in order to obtain banks that are interesting from an ecological view-point, the side slope must be not steeper than 1:10 (preferably 1:30). This results in more border and pioneer vegetation, more and better spawning opportunities for fish and an increase of the feeding area for waders. Gentle slopes will, however, induce an increase of sedimentation of silt.
sand	in order to reduce the sedimentation of sand in the secondary channel it may be wise to construct a sand trap at the upstream end of the secondary channel. Sometimes a former sand pit can be given this function.
location in the winter bed	• in order to reduce the sedimentation of sand in the secondary channel, a secondary channel in the outer bend is the best choice. A second reason for this choice is the discharge of water, as related to safety. • avoid secondary channels at locations where much sand is deposited presently; the amount of sand sedimentation will increase anyway, after a secondary channel is created. • in order to avoid problems with the stability of the winter dike, a distance of at least 100 m must be kept to it.
subsoil	for most of the river stretches in the Netherlands a subsoil of sand or clay is expected. Only at the upstream stretches of the Rhine in the Netherlands and in the Grensmaas secondary channels with a subsoil of gravel are possible.
angle of inflow with respect to the main channel	the larger this angle, the smaller the discharge and the smaller the sedimentation of sand in both the secondary and the main channel.
flow velocity	to reduce the risk of erosion it is recommended to design the secondary channel in such a way, that the flow velocity in the larger part of the year is not higher than 0.3 m/sec. For aquatic organisms mainly the spatial variability in flow velocity is relevant. Each species and each phase will then find its favourable conditions. The range to keep in mind here is between 0.1 and 1.0 m/sec.
distance between secondary channels	in order to enable the exchange of organisms that are reliant on secondary channels for their survival, the distance between secondary channels should not be too large. However, this critical distance differs per species. Also important is, if the next secondary channel is located up- or downstream.

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6 Lowered floodplains

Albert J. Remmelzwaal & Maarten Platteeuw

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6 Lowered floodplains

6.1 Reference situation

The ecological reference situation of a lowered floodplain is the floodplain of a natural river, which constantly changes its course. This floodplain has sandy banks with high dynamics close to the river and lower dynamics with clayey soils further from the river.

Due to the embankments the present day floodplains are covered with a layer of clay or sandy clay. The original diversity in altitude and soil type has disappeared. Frequency and duration of flooding is the same in the whole floodplain. Lowering of floodplains can lead to rehabilitation of sandy ecotopes and to increased differentiation in duration of inundation.

Before the normalisation of the rivers sandy banks were found in large areas, partly as point bars that only fell dry with low river discharge. These sandy banks and point bars formed a dynamic system. Inundation and emergence interchanged, erosion and sedimentation changed the situation continuously.

Figure 6.1
Reference of sandy, dynamic ecotopes under natural conditions, here along the Loire (photo: J. Backx).

The sandy banks are characterised by bare soil and pioneer vegetation. Locally river dunes may be formed by the wind. Depending on the situation the succession of the vegetation is set back from time to time, thus keeping the pioneer character alive, or sedimentation and succession of vegetation occur. The dynamics of the river lead to natural changes in soil types and relief, thus influencing the vegetation development significantly.

The pioneer conditions are characterised by an open vegetation. The soil cover is low and annual plant species and species that can survive adverse conditions by forming rhizomes form a large fraction. Dependent on the

elevation of the terrain this can refer to species from wet or dry conditions. In moist locations willows can develop in large densities. In open pioneer vegetation specific groups of insects are found, which are not present in clayey, densely vegetated floodplains. From the part of birds, species such as the little ringed plover use the open locations as nesting area.
Many waders feed in the open conditions on the transition from land to water.

These conditions have become scarce in the Netherlands. Directly along the main channel, bare soil is present between the groynes. The area is too small, however, and the dynamics of water level and wave action is usually so strong that only high-dynamic sandy banks are present, with limited chances for ecological development. Without complete restoration of the original river dynamics, possibly part of the natural values of a river can be restored. Floodplain lowering can provide the conditions of a low, sandy bank where processes of water and wind can follow their course.
Of course, further lowering of the floodplain can lead to the development of marshes and water bodies. These measures are considered in other chapters.

6.2 Hydrology, morphology and ecology

6.2.1 Hydrological functioning

Lowered floodplains are likely to be flooded more frequently and longer than other floodplains. When no minor embankments are present the lowered locations are inundated earlier than higher locations. In embanked floodplains water is retained for a longer period after floods.

When the clay layers are completely removed, the open water in the floodplain can react quickly to changes in river water level, even if no direct inundation occurs (flow pulse). This is due to the highly permeable sandy subsoil.

6.2.2 Morphological functioning

After a floodplain is lowered, sedimentation can cause a gradual restoration of the original situation. Directly along the banks of the river sand can be deposited during floods. This also happens without floodplain lowering, but the lower the floodplain the more often inundation occurs and the faster the rate of sand deposition. During each flood, some centimetres to decimetres of sand are deposited at locations where the water enters the floodplain (see chapters 1 and 8). The 'Ewijkse Plaat' along the Waal is and example of a floodplain that aggradates gradually after excavation, as a result of sand deposition. In seven years the level has increased some 30 to 40 cm; most of this sand was deposited during the extreme floods of 1993 and 1995.

At longer distance from the main channel silt is deposited during floods. The mean annual deposition rate ranges from some tenths of millimetres along the Rhine branches, some millimetres along the Zandmaas, to some centimetres along the Grensmaas (see chapter 1). The deposition rate is determined by the inundation frequency, the flow velocities, the content of suspended matter, the presence of minor embankments, and, to a lesser degree, the thickness of the water layer that remains in the floodplains with falling water levels in the river.

When floodplains are lowered, the silt deposition rates are expected to increase. The degree to which this will be the case depends on a number of factors. In lowered floodplains where the minor embankment is removed simultaneously, the sedimentation rate could increase tenfold, leading to sedimentation rates of centimetres per year.

If floodplain lowering is combined with measures that increase the flow rates in the floodplain significantly, silt deposition can be kept at a low level and even erosion can occur locally. Here one might think of complete or partial removal of minor embankments (where erosion is expected only where the embankments are removed, while elsewhere sedimentation is increased), and the excavation of secondary channels. Stimulation of erosion and reduction of sedimentation help in maintaining the pioneer situation in lowered areas over a longer period.

6.2.3 Ecological functioning

When floodplains are lowered the topsoil is removed, together with the existing vegetation, the seed bank and the soil fauna. A pioneer situation is created. Apart from that, in many cases the removed top layer consists of clay and the new surface of sand. Therefore often major changes in the root zone are induced, resulting a.o. in a reduction of nutrients and an increased chance of wilting during the summer on the higher locations. Finally the depth, duration and frequency of inundations increase. When only parts of a floodplain are lowered, this brings about a wider variety in abiotic conditions in the area.

Vegetation

Lowered parts of floodplains in their first years have an open vegetation with a large share of annual species. In low parts that only emerge in the course of the summer wet pioneer species such as mudwort can be found. At locations that emerge a little earlier in the season, large amounts of willows can germinate. The higher parts are characterised by a.o. several species of goosefoot.

From the pioneer vegetation, other succession stages of vegetation can develop that are dominated by perennial species. The development of these is hampered by inundation, erosion and sedimentation, wilting and lack of nutrients. Also grazing and trampling can add to a longer duration of the pioneer phase. The exact duration of this vegetation therefore depends on the situation.

Without grazing, a large fraction of the permanent vegetation can consist of willows and tall vegetation; with grazing a vegetation develops in which grassland is present, possibly interchanging with tall vegetation and scrubs.

Macro-invertebrates

Together with the topsoil of a floodplain all terrestrial fauna, consisting of insects, worms and spiders, is removed. For these groups of organisms too lowering of floodplains implies the creation of a pioneer situation.
On the sandy soils of lowered floodplains the recolonisation by terrestrial macro-invertebrates such as earthworms and leatherjackets is found to be a slow process (Faber *et al*. 1999, 2000). The soil type and the duration and frequency of inundations seem to be the main obstacles for a quicker recolonisation. For birds that prey on these species, little food is available during the pioneer stages.

Figure 6.2
The types of terrain that develop after removal of the clay layer of a floodplain. On the left the situation directly after the implementation is shown, on the right the situation after a few years. It is shown that pioneers and tall herbs colonise the area, but that the open character can be preserved for a number of years (photo's: A.J. Remmelzwaal).

For insects living on the surface the lowering of a floodplain results in interesting changes in the species composition. In the first years after the excavation these areas are inhabited by some specific species of wasps, beetles en spiders. On one hand these are species that prefer dry, sandy locations with scarce vegetation and on the other hand species of humid, bare riverbanks. Many of these species have declined considerably in numbers in the Netherlands over the last decades, a result of the ever-ongoing reduction of dynamic conditions (Faber *et al.* 1999, 2000).

Small mammals

In relatively high floodplains with much grassland the field vole is the most common mammal. In lowered floodplains, however, the wood mouse dominates. Floodplains in general and lowered floodplains in particular are inundated regularly. These areas must therefore be recolonised after each inundation. The rate with which this occurs depends a.o. on the vicinity of elevated areas. Floodplains can show quite low densities of mice as a consequence, making them unattractive for birds of prey. This holds true even more for lowered floodplains, because of the more frequent inundation and because wood mice are less important for birds of prey than common voles.

Birds

Floodplain lowering initially leads to the destruction of breeding opportunities of some characteristic species of the Dutch river area, such as the corncrake and the corn bunting. The same goes for the species that breed in tall vegetation, hedges and thickets and for so-called meadow birds that are found in floodplains (but do not have their major strongholds here). Dependent on the development of the vegetation, for some of these species a new suitable breeding area will form in the course of years.

On the other side of the balance the possibilities for water-bound species and pioneer breeding species are clearly increased. Species such as little ringed plover and shelduck show a marked preference for the lowered areas, while migrating species such as northern lapwing, black-tailed godwit and many other species of waders make ample use of the increased areas of shallow water and the openness of the area.

The slow recolonisation of lowered areas by organisms living in the soil, such as worms and leatherjackets, seems to be reflected in the numbers of waders that hunt by touch. These numbers remain low in the first two or three years after lowering, although the terrain seems suitable for them. Species that hunt by sight, such as northern lapwing and other plovers, forage on macro-invertebrates that live on the soil and increase their numbers quicker after an excavation.

Ecological developments on the long term
As a result of silting up and succession of the vegetation, the sandy pioneer situation can slowly change its character. If large numbers of willows germinate, changes can occur quite rapidly. River dynamics and grazing can slow down this development, or even completely prevent it. How long a pioneer vegetation can hold out, strongly depends on the circumstances and grazing management. No general predictions can be made.

6.3 Interrelations with the surroundings

The order of magnitude of the reduction of the design water levels by floodplain lowering is indicated in chapter 3.3. The effects on a given location must always be considered in the spatial context in which the lowering will take place, and in coherence with other measures. Computer simulations of the water flow are necessary tools here. The total effect of a number of measures can be different from the sum of each one separately.

A possible side effect of floodplain lowering is that the stability of the major embankments is endangered. To avoid this, excavation works should not be considered at a distance of less than 100 m from the embankment.

As a result of floodplain lowering projects, in which in certain locations the covering clay layers are removed completely, seepage fluxes can develop or be increased. With high river water level the seepage from the river to the embanked areas is increased. When floodplains are bordered by ice-pushed hills (e.g. along the Nederrijn/Lek), the seepage flux from these elevated areas to the floodplain may increase, leading to lower groundwater tables in the higher areas. Locations where the seepage flux reaches the root zone often have a special water quality and vegetation types. To these opportunities and problems near ice-pushed hills due attention must be paid.

If as a result of floodplain lowering the discharge through the floodplain is increased significantly, this may lead to a decrease of the flow velocity in the main channel, and to the deposition of sand. When the floodplain is lowered while the minor embankment remains intact, the sand deposition in the main channel will not be significant. If on the other hand the floodplain is lowered where no minor embankments are present, or if these are removed, the effects will be larger, and may have consequences for the navigability of the main channel.

Important factors in the ecological interrelations of lowered areas and their surroundings are the opportunities for migration of several species and the presence of the different habitats that species need during their life cycle. It is important to realise that there are interrelations within a floodplain, in the longitudinal direction of the river system, and in the transversal direction; separate floodplains are no isolated units.

6.4 Application of floodplain lowering

In the previous paragraphs it has been made clear that lowering of flood-plains can have positive effects on both safety and ecology. Of course certain preconditions must be regarded. This paragraph deals with the practical aspects of the application of the excavation and lowering of floodplains. Implicitly the assumption is that the excavation is not so deep that permanent open water bodies result from it.

6.4.1 Where can floodplain lowering be applied

Floodplains can be lowered in virtually all stretches of the winter bed of the Dutch river branches. The effect of lowering on design water levels are largest where the highest increase in flow velocities is expected (see par. 3.3), especially where bottlenecks are present. In the parts of the flood-plain with low flow velocities lowering has no effect on the design water level; where the winter bed is wide, the effect is limited.

From the viewpoint of landscape and ecology it is important not to affect existing valuable elements. By a proper choice of layout, shape and size of the areas to be lowered these elements can be saved and even enhanced.

Important ecological values that are not easy to replace are often linked to a certain degree of isolation from the river. Especially the existing grasslands on natural levees must be mentioned. Other examples are some elevated areas and isolated water bodies, with an inundation duration of less than 20 days per year. These elements must be preserved as much as possible. Dynamic areas with long to very long inundation

Figure 6.3
When the lowering is performed along a steep slope (photo on the left) the transition from land to water is sharp during most of the time; gentler slopes and preservation of some micro-relief leads to a wider transition zone. In general this second option leads to a wider ecological variety (photo's: A.J. Remmelzwaal).

durations (more than 50 days per year) can have specific values too. As these areas are already situated in the lower parts of the floodplain, they are usually not the most feasible locations for further excavation. Generally speaking the areas to be lowered can be planned best at the expense of the periodically inundated areas, with an inundation duration between 20 and 50 days per year. At present these areas are most common and have the least specific ecological values.

The lowering of floodplains leads to wetter conditions. The character of these areas depends on the characteristics of the river branch where they are situated. In the free discharging upper and middle stretches of the Dutch parts of the rivers, lowering of floodplains can lead to dynamic terrains with pioneer characteristics. These areas are inundated during large parts of the winter and spring, and emerge in the course of the summer. In the weir-regulated and downstream stretches, lowering of floodplains will lead to marsh-like conditions, because here the summer water levels will not drop too low. Table 6.1 gives an overview of the river stretches that offer opportunities for dynamic and for marsh-like ecotopes. While looking at this table, one has to keep in mind that the so-called 'vertical room' for creation of these ecotopes decreases along the river. For example: an excavation of 3 m along the Boven-Rijn results in 35 % of open water in the floodplain (on average), while an equally drastic measure along the Waal near Zaltbommel results in more than 60 % open water (Klijn & de Vries 1997).

Figure 6.4
Aerial photo of the Afferdensche en Deestsche Waarden in 1997, one year after the excavation of clay in the central part. The lowered area can be discerned clearly.

6.4.2 Recommended dimensions

Hydraulic and hydrological aspects
The effects of the lowering of a specific floodplain on the design water levels depend on the location within the floodplain, and of the shape and depth of this lowered area. As was indicated in paragraph 3.3 however, the main point is the total volume of the excavation (provided this excavation is executed in parts that contribute to the discharge during floods). The exact layout comes second to this.

When during the design phase more details are needed, model calculations to determine the exact effects are needed, especially if floodplain

Table 6.1
Possibilities for the development of dynamic and marshy ecotopes as a result of floodplain lowering in the Dutch river stretches of Rhine and Meuse.

stretch	frequently flooded areas emerging in the course of the summer	frequently flooded areas marshlands
Bovenrijn	yes	no
Bovenwaal	yes	no
Middenwaal	yes	no
Oostelijke Benedenwaal	yes	no
Westelijke Benedenwaal	limited	limited
Pannerdens Kanaal	yes	no
Rijn near Arnhem	limited	limited
Doorwerthse Rijn	no	yes
Nederrijn/Lek	no	yes
Boven-Lek	limited	limited
Boven-IJssel	yes	no
Midden-IJssel	yes	no
Sallandse IJssel	no	yes
Beneden-IJssel	no	yes
Boven-Maas	yes	no
Grensmaas	yes	no
Plassenmaas	no	yes
Peelhorstmaas	no	yes
Venloslenkmaas	no	yes
Maaskantmaas	no	yes
Beneden-Maas	limited	no
Afgedamde Maas	limited	limited
Bergse Maas	limited	limited
Lower river stretches	no	yes

lowering is combined with other measures. Modelling one floodplain can be of help to determine the optimal design for a desired reduction of design water levels. In many cases calculations for river stretches are needed as well.

General hydraulic guidelines for the location and design of lowered floodplains are linked to the principle that in a floodplain as many as possible unhampered flow lines must be created. This implies that floodplain lowering in the leeward side of elevated areas is not useful. In general the most obvious layout is an elongated shape, parallel to the main channel.

Another item is the change that can be expected in seepage patterns. The closer the lowered area is to the main channel, the smaller the effect on seepage fluxes will be. If the embanked polder area adjacent to the lowered area is low, seepage may increase there. In most cases this increase is limited, and can be compensated with simple measures. If a floodplain is bordered by ice-pushed hills, the seepage from these hills into the floodplain can be increased; the effects on groundwater levels, water quality and vegetation must then be calculated carefully.

Ecological aspects
For the opportunities for ecological development after a floodplain lowering the most important items are: the soil type that comes to the surface, the relative elevation, the relief that is created and the interrelations with the surroundings.

In general an excavation to the sandy subsoil can be recommended, because sandy soils are scarce in the floodplains, and because they have specific ecological values. The presence of sandy soils in the near vicinity of clay soils will enhance the diversity of abiotic conditions, resulting in enhanced biodiversity.

The elevation after excavation in the first place determines the mean frequency and duration of inundations. Every inundation zone in the floodplains has its own specific values. Scarcely vegetated wet conditions, on the transition zone between land and water, are scarce at this moment. Dependent on the water level fluctuations and the layout of the floodplain, these locations are situated in different elevation zones in the course of the year. Exactly these dynamic conditions of inundation and emergence are valuable, a.o. for wet pioneer vegetations and foraging waders.

It is important to design the excavations in such a way that with all possible water level fluctuations a significant area of sodden soil is present during the summer. In practice this means that an excavation must have a significant level difference, dependent on the water level fluctuations, and a very gentle slope. In this gentle slope some micro relief can be introduced. This brings about an alternation of small pools and dry patches, adding to the diversity of the floodplain.

The depth of the excavation depends on the situation in the floodplain and on the river stretch where the floodplain is located. The latter determines the 'vertical room' available (see paragraph 1.4, figures 1.4 and 1.5).

Excavation that removes the complete clay cover can in principle be performed in two ways: following the contours of the underlying sand layer, or uniformly to a defined depth. From an ecological viewpoint this distinction is not relevant, as long as the right abiotic conditions are created. From the viewpoint of the history of development of the area it might be interesting, however, to restore the former relief.

Looking at the level of a floodplain, a good rule is to try to reach a situation with a complete gradient from permanent water to elevated areas that are hardly ever flooded. Then under all circumstances a land-water transition zone is present, which is of great value. After a flood recolonisation can start from the elevated areas, while during low discharge the open water will secure survival for aquatic organisms.
Of course the exact design must differ from one floodplain to the next; no uniform landscape must be created.

Safety versus ecology
From the viewpoint of safety against floods it may be desirable to plan a deeper excavation than would be optimal for ecological values. This will lead to a shift towards more aquatic communities and riverine species, at the cost of terrestrial groups and the communities of isolated water bodies. If the area of permanent water becomes large and its depth greater, no increase of ecological value is to be expected.

Table 6.2 gives an overview of the most important recommendations.

6.4.3 Management and maintenance
Due to the combined effect of the succession of vegetation and sedimentation of sand and silt, the effect of the excavation will gradually diminish. In order to slow down or even set back periodically the succession of the vegetation, in the first place it is important to have hydro- and morphody-

Table 6.2
Points of interest when planning the lowering of a floodplain by excavation.

safety	ecology
surface level with respect to the river water level	
the main point is that the design river water level be reduced; the effect must be calculated for each floodplain using mathematical models	the determining factor is the mean inundation duration. Especially the frequently inundated zone (50 to 150 days per year inundated) often results in valuable additions to existing values
layout	
first comes the volume of the excavation; second its shape. Elongated, interconnected shapes;not under the lee of elevated areas. The excavated areas must be part of areas where the water actually flows during floods.	diversity in level is important, in order to create wet and dry areas under all circumstances. To make sure that the transition zones between wet and dry areas are sufficiently wide, gentle slopes (appr. 1:100) and the presence of micro-relief are required.
stability of the embankment	
the excavation must be planned in such a way, that erosion cannot threaten the major embankment (min. distance 100 m) and that no seepage fluxes of dangerous intensity develop (to be calculated for each location).	
landscape	
from both points of view the projected works must be made to fit in the landscape. This involves preservation of existing values (cultural, historical, landscape and ecological values); this involves excavations on locations where this adds to safety; this involves creating a coherent system of ecotopes, offering good living conditions for the species of the river area.	

namics that are strong enough. The layout plays an important role in obtaining these dynamic conditions. Even with an optimal layout, however, in most cases additional maintenance measures will be necessary. For vegetation management the first option is grazing. Grazing can counteract or even prevent the development of rough vegetation, scrubs or forest, dependent on the grazing density. Instead, a vegetation dominated by grass may develop, while on sandy soils even pioneer situations can be maintained over prolonged periods. If willows germinate and grow in large numbers, grazing may have to be complemented with occasional removal of shrubs and trees.

In order to compensate for the effects of sedimentation, it may be necessary to excavate the floodplain again after some period. In this chapter it was already mentioned that the rate of sedimentation depends strongly on the situation in the area. Consequently it is difficult to indicate the time span after which renewed excavation would be needed. Apart from that, both ecological and safety arguments can be of influence. An ecological argument is the covering up of the sandy soil by clay layers. From the point of safety the main point is the reduction of the hydraulic cross section. The ecological argument is important even when the deposited clay layer is thin, the safety argument only after this layer has reached some considerable thickness.

The renewed excavation brings about costs, and a renewed interference in the ecosystem. This interference does not necessarily have to be considered as being harmful, however; periodically renewed excavation can be considered as a human replacement of some of the lost natural river dynamics.

6.5 Research

In several floodplains lowering has already been applied, on large or small scale. RIZA researches the ecological effects of floodplain lowering in the Afferdensche en Deestsche Waarden en de Stiftsche Uiterwaarden floodplains along the Waal. This research is combined with research of the effects of grazing management. The field work will end in 2001, in 2002 the reports will be written.

In the framework of IRMA-Sponge research is carried out into the opportunities and boundary conditions for so-called cyclic rejuvenation. By this term the process is meant of putting back periodically the spontaneous succession and landscape formation (i.e., the level increase) of the floodplains, after the floodplain was lowered. This research tries to answer questions such as: can cyclic rejuvenation take over the role of river dynamics? How often and over what kinds of areas must the measures be renewed, in order to simulate natural processes and in order to guarantee safety at the same time?

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7 Removal of minor embankments

Albert J. Remmelzwaal & Max H.I. Schropp

Contents

7 Removal of minor embankments

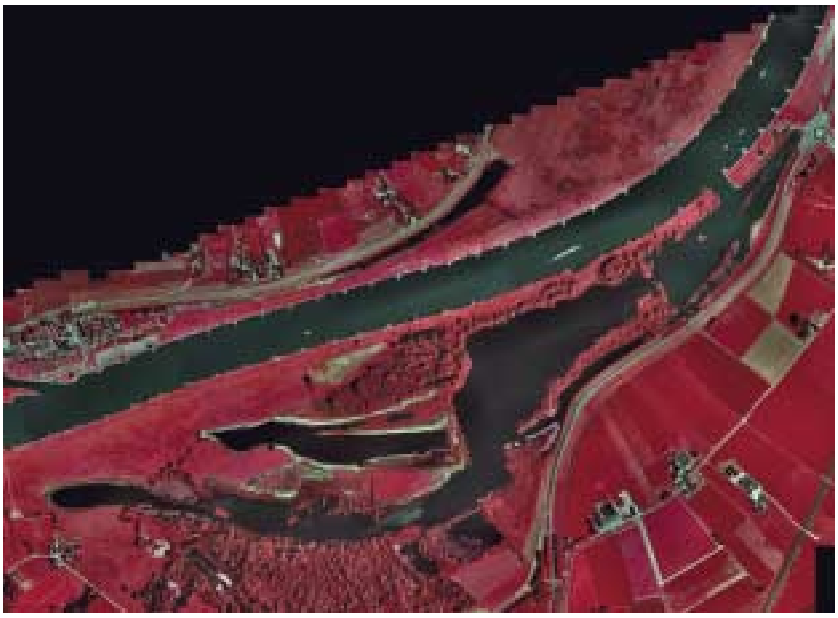
7.1 Definition and presence of minor embankments

The construction of embankments of the main rivers in the Netherlands started in the eleventh century. By about 1450 the construction of embankments was more or less completed (Middelkoop & van Haselen 1999). Only the Limburg part of the Meuse has never been embanked. Along the better part of the rivers, a system was introduced of minor and major embankments. The major embankments protect the area behind them against floods, and are designed to withstand water levels during design discharge. Minor embankments reduce the inundation period of the floodplains, making the floodplains more suitable for human use. Inundation of embanked floodplains virtually only occurs in the winter period, as summer floods are quite scarce.

Embankments cause local energy loss when they are overflowed. As a result the partial or complete removal of embankments can cause a reduction of the design water level, thus increasing safety against flooding. By removing the minor embankments the floodplain will be inundated with a higher frequency and a longer duration. This affects the options for use of the floodplain, and the ecological potentials.

The ecological reference situation for measures regarding the minor embankments is given by the natural river, without embankments or regulation. The natural river landscape has a wide variety of ecotopes. This variety is caused by the variation in space and time of the river dynamics. The construction of minor embankments has only favoured the low-dynamic forms of riverine nature. Removal of them can restore some of the natural dynamics. However, the situation after this measure will still differ strongly from the natural situation, because of flow regulation

Figure 7.1
Aerial photograph in false colour of the partially removed minor embankment in the Duursche Waard along the IJssel.



works, the unnatural high level of the floodplains and especially the influence of the major embankments. Only if these would be removed, the situation would resemble the natural situation.

7.2 Hydrological, morphological and ecological effects in the floodplain

7.2.1 Hydrological effects

If the minor embankments of a floodplain are removed, the inundation frequency will increase. Water levels that are higher than the surface level of the floodplain, but lower than the top of the minor embankment will now lead to inundation too. In figure 7.3 this is a flood between the moments D and E. The degree to which the inundation frequency is increased, depends on the level of the original embankment and the surface level in the floodplain. The increase is therefore not equal in the whole floodplain.

Figure 7.2
Minor embankment with inlet during flood (photo: Henk Wolters).

In this approach the assumption is that sluices, if present, are kept closed when the water level is rising. Sluices in practice are opened when they can still be reached, which is usually earlier than when the embankment is actually flooded.

Not only the inundation frequency is increased, but also the inundation duration. This is a consequence of the increased frequency and the earlier start of inundations during floods: when the river water level reaches the floodplain surface level instead of the level of the top of the embankment. In figure 7.3 this period is indicated by A-B. When the sluices in the minor embankment are not opened timely with falling water levels, or when their discharge capacity is small, the removal of the minor embankment may induce a shortening of the inundation duration at the end of a flood wave (shift of point C in figure 7.3).

For the Stiftsche Uiterwaarden along the Waal, calculations were made to define the effect of the removal of minor embankments. These calculations were carried out with water level data of the years 1901-1990. Figure 7.4 and 7.5 show the results; a surface level of 6.0 m NAP and a level of the embankment of 7.5 m NAP were assumed. Figure 7.4 shows that the

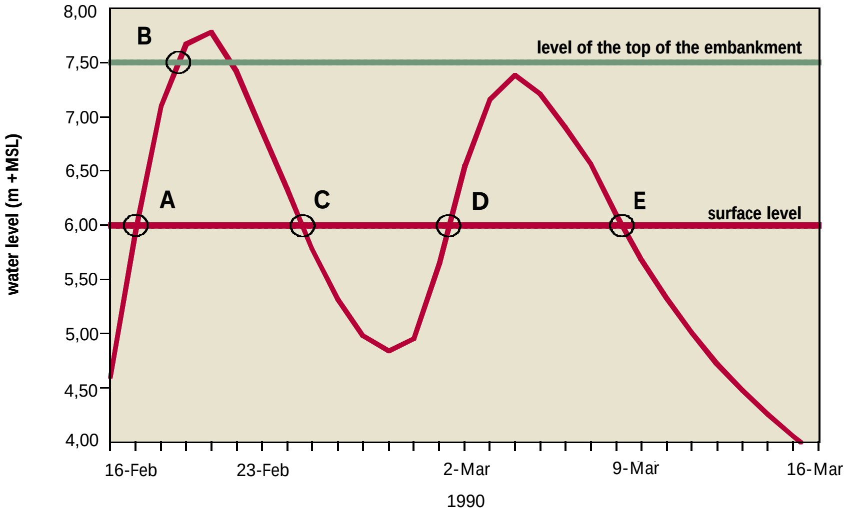


Figure 7.3
Illustration of water level fluctuation, relevant moments for inundation.
For explanation: see text.

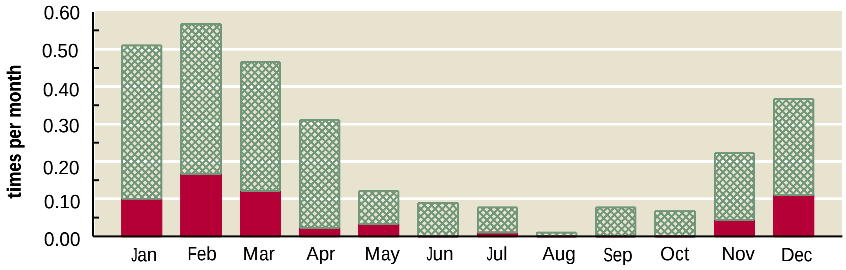


Figure 7.4
Calculated increase of the inundation frequency of the Stiftsche Uiterwaarden as a result of the removal of the minor embankment (calculation period: 1901-1990).

present (6.00-7.50)
increase low floods

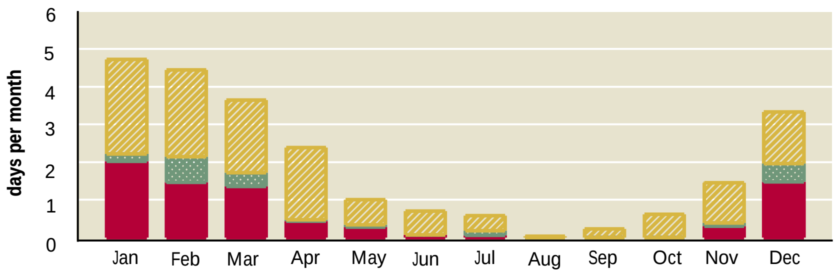


Figure 7.5
Calculated increase of the inundation duration of the Stiftsche Uiterwaarden as a result of the removal of the minor embankment (calculation period: 1901-1990).

present (6.00-7.50)
increase by longer high floods
increase by low floods

inundation frequency is increased sharply. In terms of the mean number of inundations per month this effect is the strongest in the winter period, but the relative increase is strongest in summer and autumn.

Figure 7.5 shows the increase of the inundation duration. Here a distinction is made between the lengthening of the inundation duration caused by high floods and inundation during lower floods. Here too the conclusion is that the effects in absolute sense are largest in winter, but in relative sense in summer.

With increasing surface level of a location in a floodplain, the effect of removal of minor embankments becomes less outspoken; locations higher than the former top of the embankment are not affected at all.

7.2.2 Morphological effects

Because the inundation frequency of a floodplain increases due to the removal of the minor embankment, the amount of silt transported into the floodplain increases as well. The sedimentation rate is expected to increase by a factor 2 to 3. Combined with floodplain lowering, this might even be as much as a factor 10, resulting in sedimentation rates of some centimetres per year. So for large-scale reconstruction projects the choice on whether or not to remove the minor embankments can be crucial for the future sedimentation. Model calculations of the effects of floodplain reconstruction on silt sedimentation along the Rhine branches show that the increase is only a few percent if the minor embankments are maintained, while their removal leads to an increase of almost 50 % (Asselman 1999).

Sedimentation could lead to the development of sandy natural levees at the locations where the river water overflows the bank, thus adding to the diversity of the floodplain. Where high flow velocities are expected, some erosion might occur. This leads to the conclusion that the removal of minor embankments can help in the restoration of some of the natural dynamics.

7.2.3 Ecological effects

The changes in frequency and duration of the inundations influence the ecological functioning of a floodplain. The most important changes are caused by inundation in spring and summer.

Increase of the inundation frequency in spring and summer means that the breeding opportunities for many bird species are affected. From research in the Afferdensche and Deestsche Waarden and in the Stiftsche Waarden floodplains it was found that in years with prolonged inundations in spring the density of species breeding or foraging on the ground or in the lower parts of the scrubs declines. For greylag goose a postponement of breeding was observed. When floods occur after the beginning of the breeding season, clutches may be lost. On the other hand the increased inundations may increase the breeding and foraging opportunities for water birds, if in a floodplain water bodies and marshes are present.

For small mammals and terrestrial insects some similar results are found as for birds breeding on the ground. Inundation in spring and summer induces a risk for propagation and survival. This also affects the foraging opportunities for species that feed on these mammals and insects, such as birds of prey.

The effects for the vegetation are expected to be of limited nature, because the plant species that are sensitive to inundations are not found at levels below the former top of the minor embankment.

If in a floodplain no low sections (water bodies and marshes) are present, the increased inundation frequency may have negative effects for ecology, especially if the species that are present in the floodplain depend on a terrestrial environment. If low sections are present, the increase of inundation frequency could have positive effects for species that are bound to the aquatic environment or to the land/water transition zone.

When the morphological dynamics is increased considerably, it may create pioneer conditions on both sandy and clayey substrates. This type of dynamics is typical for the natural river system. Room is made for specific species of plants and insects, and even birds if sufficient area is available.

A final point is the effect on the water quality of the open water bodies in the floodplain. When these waters are inundated by river water only incidentally, a mesotrophic system might develop, with clear water and aquatic vegetation. If such water types are inundated more often as a result of the removal of the minor embankment, the load of nutrients and silt will increase. This may lead to the disappearance of the species that depend on clear water. So for clear water bodies the removal of minor embankments could have negative effects.

The conclusion is that the removal of minor embankments will lead to a more natural system, but that this may cause loss of existing ecological values. Additional measures could increase these natural values; especially floodplain lowering must be mentioned, because this can increase the fraction of wet ecotopes and pioneer conditions.

7.3 Interrelations with the surroundings

Minor embankments influence their surroundings because they induce a local energy loss, resulting in an increase of the water levels. The partial removal of a minor embankment therefore hardly has any effect on the design water levels, because the energy loss at the rest of the embankment is not affected. When removing minor embankments, it is useful to make a distinction between minor embankments parallel to and perpendicular to the main flow direction. The damming effect of an embankment parallel to the flow direction is negligible with very high water levels, but these embankments do have a function in the guidance of water flow during floods lower than design flood. Removal of minor embankments parallel to the flow direction is therefore not advisable. The effect on the water levels is largest when minor embankments perpendicular to the flow direction are removed. In table 3.10 the comparative effect of the various situations are indicated.

Table 7.1
Relative effect of removal of minor embankments on design water levels.

Orientation of the minor embankment	partial removal	complete removal
Parallel to the flow direction	no	small
Perpendicular to the flow direction	no	large

The removal of a minor embankment might affect the morphological processes in the main channel. Increase of the discharge through the floodplain during floods automatically leads to a decrease of the discharge through the main channel. This might cause sand deposition in the main channel. However, problems are expected only if the discharge through the floodplain is increased very significantly indeed. This could be the case, for example, if in the floodplain large, deep open water bodies are situated. Moreover, this effect will only occur if large sections of the minor embankment are removed.

Removal of the minor embankment brings about a partial restoration of the natural interrelations between a river and its floodplains.
The migration opportunities for organisms, sediment and nutrients increase. What the final outcome of these opportunities is, and if the result can be judged as positive, depends on the local situation. In many cases the removal of minor embankments should preferably be combined with other measures.

7.4 Application of minor embankment removal

7.4.1 Where can minor embankments be removed

Minor embankments may be removed wherever they are present. Reasons not to do so can be the present land use or the presence of ecological values that depend on a certain degree of isolation from the river (low dynamics, good water quality). The combination of the removal of the embankments with floodplain lowering or the excavation of secondary channels may lead to enhanced ecological rehabilitation, because open water bodies and marshes are developed.

7.4.2 Recommended dimensions

To avoid the danger of local high flow velocities, the breach in the minor embankment should not be designed too small; one should think of a breach of at least 100 m. In order to maximise the effect, the floodplain must take part in the discharge, so also an outlet opening should be provided. Elements that obstruct the water flow, such as access dams, forests and elevated areas can reduce the flow. The additional lowering of the floodplain will increase it.

Table 7.2
Overview of the most important points of attention for the design of measures to remove minor embankments.

river hydraulics	ecology
Size and location	
Minimum length 100 meters; both an inlet and an outlet must be made. No removal of embankments parallel to the main stream, because these help in guiding the flow during less-than-design floods.	
Lay-out	
It is important to have continuous flow between inlet and outlet. If possible, obstacles should be removed.	Combination with floodplain lowering or the excavation of secondary channels can increase the ecological values considerably
Safety and hindrance	
For reduction of the design discharge, only the complete removal of embankments perpendicular to the flow direction is effective. One should take account of the risk of sand deposition in the main channel. This is only a real risk if the discharge that is diverted to floodplain is increased significantly	
Landscape	
From both viewpoints the measures must be designed to fit into the landscape. This involves preservation of the existing culture-historical, landscape and ecological values, removal of the embankment at locations where this adds to safety, and making a coherent design of a combination of measures.	

7.4.3 How to deal with polluted soils

In the floodplains a lot of polluted sediments are present. The minor embankments themselves were almost exclusively built before 1900, so little pollution is to be expected in them. The removal of minor embankments is therefore not expected to cause problems in this field.

Because after the removal of the embankments increased flow velocities can occur locally, the resulting erosion can spread polluted soils if these are present at or near the surface. If this risk is present and if it calls for measures must be judged specifically for each situation.

7.4.4 Management and maintenance

In most cases the removal of minor embankments will be carried out only if the agricultural use of the floodplain ends. In nature areas the management must be aimed at the prevention of forest development, in order to keep up the discharge capacity of the floodplain. Grazing can be used as a tool. In specific situations periodical maintenance, in the form of removal of sediments, can be necessary, especially in pools in low-lying areas.

7.4.5 Research

In some nature rehabilitation areas minor embankments have been removed (a.o. in the Blauwe Kamer and the Duursche Waarden floodplains).
In these areas a broad ecological monitoring plan is carried out. These monitoring programmes show the developments in these areas, but not to what extent these are caused by the removal of the minor embankment. RIZA researches the effects of floodplain lowering and the development of floodplain waters in relation to a.o. the degree of isolation from the river. Although these research projects are not aimed specifically at the effects of the removal of embankments, they provide us with fundamental knowledge about floodplain ecology, which can also be used to predict the consequences of the removal of minor embankments.

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8 Natural levees

Margriet M. Schoor, Esther Stouthamer & Anne M. Sorber

Contents

8 Natural levees

8.1 Definition and natural development

Natural levees are sandy parts of riverbanks with a relatively high surface level. They are formed by sand sedimentation during floods. If the floodplains are flooded, the flow velocity of the water above the riverbank is reduced sharply. The sand that is transported by the water is deposited on the bank. The lighter silt is transported further from the river, where the water has a flow velocity of less than 50 cm/s. The sand deposition is found in a strip of some tens of m wide along the river, and builds up a sort of wall there (figure 8.1). This natural levee is further heightened with each flood, with a rate ranging between millimetres to tens of centimetres per event. This rate is reduced with increasing elevation of the natural levee.

Natural levees are quite common in the river area. Most floodplains, if not disturbed by excavation for brick industry or sand, are higher near the river than near the embankment. Active formation of natural levees is not found everywhere (see paragraph 8.2). The recent natural levees are much narrower than those formed before the construction of the embankments. Those old natural levees were the natural, elevated areas in the floodplains, where the first human settlements were found. They were some hundreds of m wide and one to two m high. The natural levees often became inhabited directly after their formation, and remained so until the present day, except some natural levees of western stretches of the rivers in the area near the coast. Here peat formation started after the coast was closed, some 4000 years ago. These areas were abandoned because of frequent changes of the river bed. The natural levees were covered by peat. After the construction of the embankments, which in the river area was finished by the 14^{th} century, the natural levees of the present-day rivers were not inhabited any more.

Figure 8.1
Natural levee near Hurwenen along the Waal (photo: W. ten Brinke).

Figure 8.2
Sand deposition in the Bizonbaai, along the Waal near Nijmegen, in 1995.

If the river cuts into an old bed, a Pleistocene river dune, an ice-pushed hill or a river terrace, this brings about extra uptake of sand by the river and increased sand deposition on the natural levees just downstream of this point.

8.2 Hydrology, morphology and ecology

8.2.1 Hydrological and morphological functioning

In the present situation the formation of natural levees is still going on. After the floods of 1993 and 1995 the sand depositions along the Rhine branches and the Meuse were mapped with the use of aerial photographs and field measurements. It was found that most of the sand was deposited on the banks along the Waal (figure 8.3 and 8.6). Significant differences were found between separate floodplains too. In all river branches it was found that most of the sand is deposited in the inner bends; more sand is available for deposition in the inner bend than in the outer bend (figure 8.2 and 8.4). This is caused by erosion of the outer bend, after which the sand is transported to the inner bend by the helicoidal flow over the river bottom.

Bolwidt *et al.* (2000) have calculated the increase of the natural levees of the Rhine branches over a period of 100 years, assuming that on the average three times per decade a flood occurs during which sand is deposited on the natural levee. Thus a level increase was calculated of ca 65 cm over the whole length of the Waal, on both sides in a strip of 50 m wide. The floodplains along the Waal are heightened by 5 to 16 mm per year, according to Middelkoop (1997). Over the last century this was about 0.2 to 10 mm per year. This rate would lead to a total increase of 50 to 160 cm per century, and 20 to 100 cm over the last century. The level increase of the natural levees is therefore more or less parallel to that of the floodplains.

Along the IJssel the natural levees are heightened by about 0.5 cm per flood. This results in a level increase of about 15 cm per century.

If the sedimentation rate is expressed per meter bank length, it is highest along the Waal. Next come the Pannerdens Kanaal, the Bovenrijn, the IJssel, the Nederrijn and Lek and the Merwede. Along the IJssel and the Nederrijn the sedimentation rate is about 8 times lower than along the Waal. In all river stretches considered, the sedimentation rate in the inner bends is at least twice that of the outer bends.

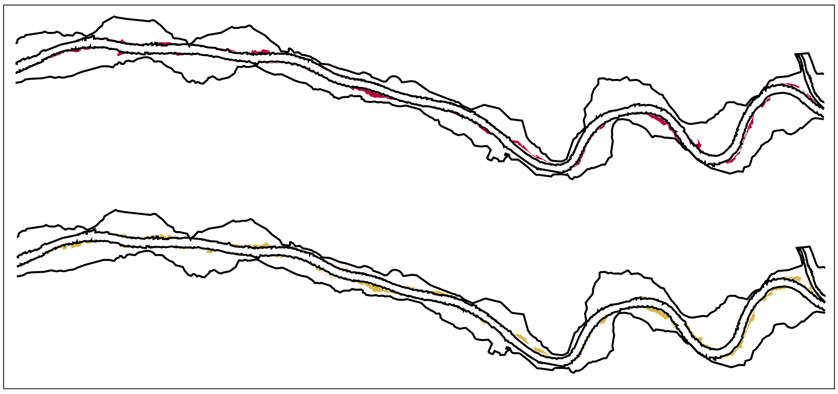
Sedimentation on the natural levees occurs when they are inundated. According to Bolwidt *et al.* (2000) no direct relation can be found between the duration and volume of the river discharge and the volume of sand deposition on the natural levee. A relation between the inundation depth and the height of the natural levee could not be demonstrated. During a relatively low flood a thin layer of sediment is deposited; the same during a relatively high flood. The sedimentation rate on the natural levee probably depends on the flow velocity over the natural levee, because with high flow velocity the water can transport and deposit more and coarser sand. So far no relation has been observed between the sedimentation rate on a natural levee and the size of the floodplain behind it.

The concluding assumption is, that during each flood the same amount of sediment is deposited on the natural levees (table 8.1 and figure 8.3). The frequency with which these floods occur is important to determine the total volume of sand depositions on the bank of the river.

Table 8.1
Sand deposition on natural levees, along various Rhine branches, in m^3 (Bolwidt *et al.*, 2000).

deposition (m^3)	**Bovenrijn**	**Waal**	**Pannerdens Kanaal**	**IJssel**	**Nederrijn/Lek**
Per flood event during which the natural levee is inundated	3400	179600	8200	33000	26000
Yearly average	1000	53900	2400	9900	7800

Figure 8.3
Sedimentation of sand on the banks of the river Waal after the floods of 1993 and 1995.



The spatial differences in sedimentation patterns along the Waal are caused by the flow patterns of the river water. The formation of natural levees is mainly found at locations where the water enters the floodplains from the main channel (figure 8.5). Such locations can be expected where the floodplain is low and no minor embankment is present, or where the floodplain becomes wider because the major embankment deviates from the main channel. This means that the construction of the embankments and other human interventions greatly affect the formation of natural levees.

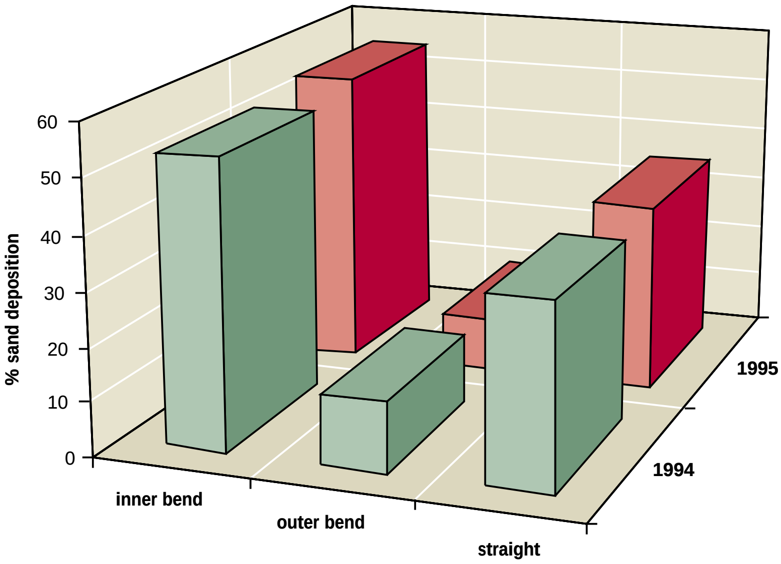


Figure 8.4
Sand deposition in 1994 and 1995, divided into locations in inner bends, in outer bends and in straight stretches.

Along the Meuse, little formation of natural levees is observed. As a result of river normalisation and canalisation, few morphological processes can occur. Apart from that, intensively grazed grasslands and steep banks covered with riprap characterise the Meuse. During the inventory of sand depositions along the Meuse and Rhine branches after the flood of 1995, relatively few sand depositions were found along the Meuse.

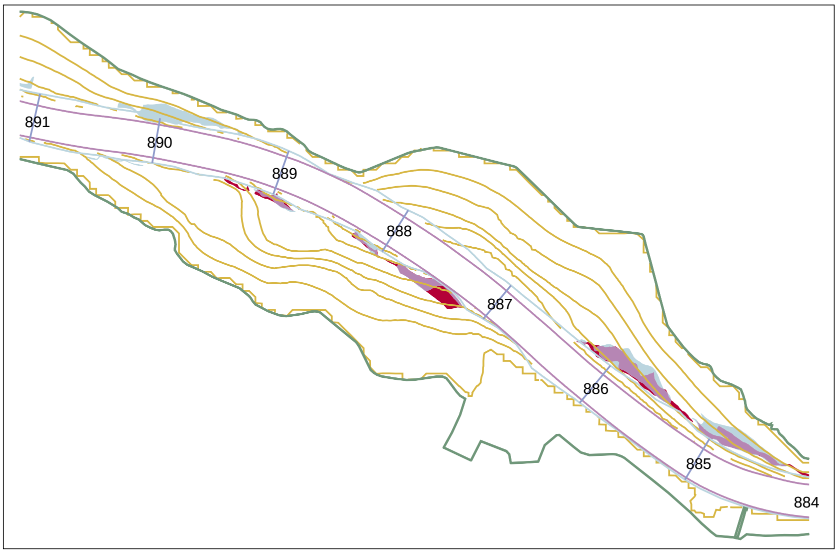


Figure 8.5
Flow patterns in some floodplains along the Waal with the locations where natural levees were formed in 1993 and 1995.

sand deposition 1994
sand deposition 1995
sand deposition 1994 and 1995
stream lines with discharge at Lobith of 15000 m^3/s

8.2.2 Ecological functioning

On low natural levees, with inundation durations between 20 and 50 days per year, the conditions are highly dynamic; they are inundated often and each time the vegetation is covered by a layer of sand. Under such conditions only pioneer species can survive. Low natural levees can be important as breeding ground for pioneer breeders like plovers and terns, especially because of their sparse and low vegetation.

High natural levees, with inundation durations between 2 and 20 days per year, are inundated less frequently and are characterised by dry, oligotrophic and sandy conditions, which may make them suitable for flower-rich grasslands of natural levees. These types of grasslands can only survive on high natural levees (with an inundation duration of less than 3 days per year) and with a grazing regime (with low stocking rates). The exact type of grassland that can be expected if these conditions are met, still depends on such factors as the availability of seeds, soil characteristics and the exposition. The combination of thin vegetation and prevailing dry conditions make high natural levees suitable for some very characteristic and scarce species of insects and spiders; amongst them beetles, spider wasps, wasps and spiders (Faber *et al.* 1999).

8.3 Interrelations with the surroundings

Because natural levees are relatively high, promoting their development does not add to reduction of design water levels. Their development is a slow process however, which occurs only during floods. As it involves only a narrow strip in the longitudinal direction, parallel to the main channel, the negative effect of natural levees on design water levels is small.
By their shape they can have a positive function in guiding a larger part of the flow through the main channel, just like minor embankments.
The presence or development of natural levees has no consequences for navigability.

The safety standards that must be regarded impose no or hardly any restrictions on the locations where the development of natural levees can be allowed or stimulated. The combination of a narrow shape parallel to the flow direction and a low rate of increase will make sure that hardly any effect on the design water levels can be noticed.

On low natural levees the most characteristic ecological communities of flora and fauna consist of typical pioneer species of high-dynamic conditions. Usually these species are not very sensitive to fragmentation of their habitats and they can reach and occupy favourable locations in short time. As a result these ecological communities have no special demands, in terms of the ecological network approach, to locations, dimensioning or spatial coherence of low natural levees. At the most a single natural levee could be too small to offer sufficient area to certain species with high demands. This may be the case for some typical insect species on very short (less than 50 m) natural levees.

On high natural levees vegetation types of less dynamic conditions could develop. Dependent on the stage of succession and management practices, flower-rich grasslands of natural levees or even hardwood riverine forest may develop. The absence of management usually leads to tall vegetations (and possibly the degradation of flower-rich grasslands of natural levees), shrubs and trees, but not necessarily to the establishment of hardwood riverine forest. As a consequence some type of grazing management should always be applied on small natural levees, where no hardwood riverine forest is expected.

With regard to ecological networks, grasslands of natural levees resemble natural levees to some degree, although the rate of recolonisation is probably somewhat lower for natural levees. This implies that the proximity of other stretches of grasslands of natural levees is important for the chances of reoccupation. In order to support a hardwood riverine forest of a size sufficient for the maintenance of key populations, the size of the natural levee is important too. This would involve areas of some hundreds of ha.

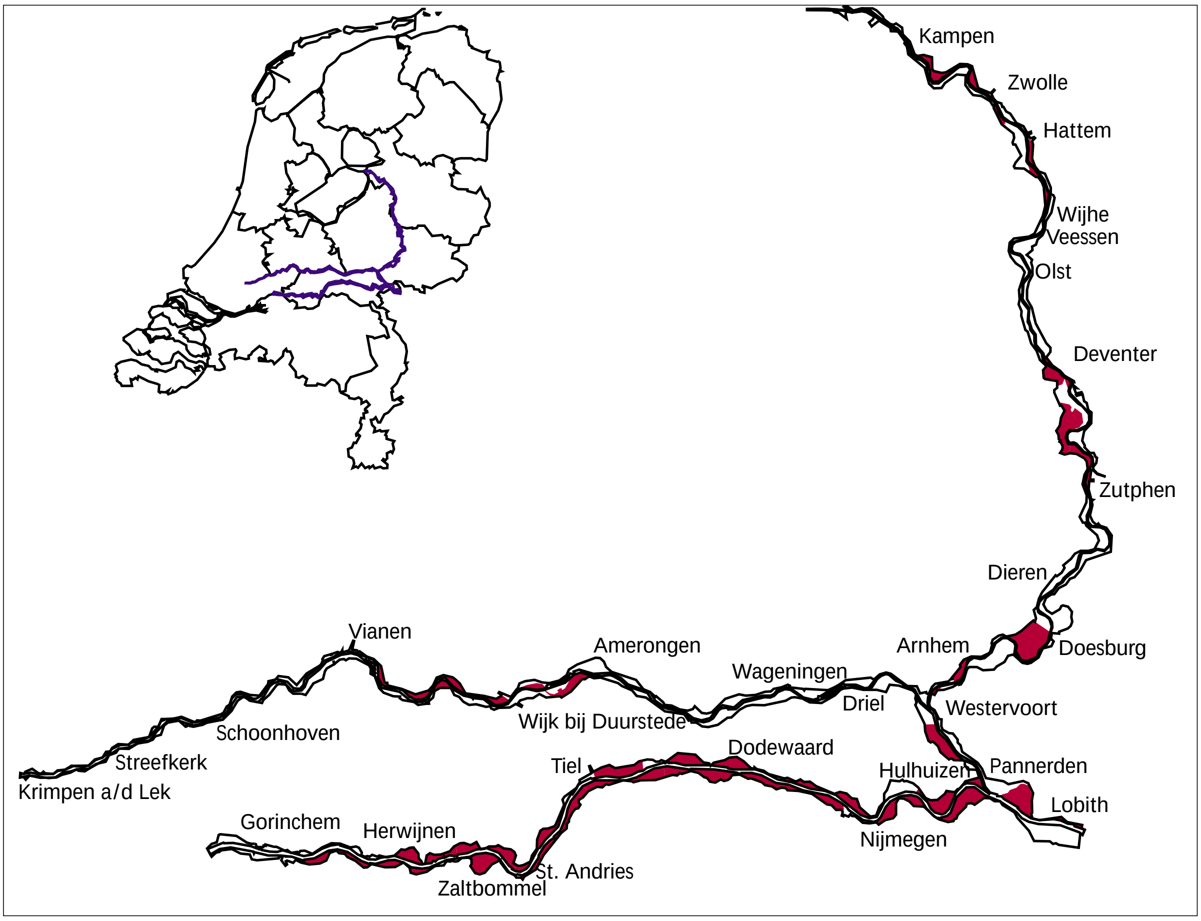
As natural levees are relatively high elevation with respect to the surrounding area, they may have an important role during floods as a resort for terrestrial species from the lower parts of the floodplain. This implies that the presence of a natural levee is more important in a wide floodplain than in a narrow one. However, these resorts will never be of crucial importance for species, because natural levees are inundated during extreme floods too, and recolonisation must be started from embanked areas.

8.4 Measures to encourage the development of natural levees

8.4.1 Suitable locations for the formation of natural levees

Figure 8.6 shows the floodplains in which more than 1000 m^3 of sand was deposited during the flood of 1995. In 1993 this map was almost identical. These floodplains hold the most promise for development of natural

Figure 8.6
Map of the floodplains where during the floods of 1995 more than 1000 m^3 of sand was deposited.



levees. Most of the sand is deposited on the banks of the Waal. Along the IJssel much less sand is deposited, and along the Nederrijn and Lek, the Meuse and the Merwede hardly any sand is deposited at all. The difference is associated with the ratio of width to depth of the main channel. This ratio is an indication of the morphological activity of a river. A larger ratio means that more sand is deposited on the banks. By consequence in the present situation the development of natural levees is found mainly along the Waal and Bovenrijn, which have a larger width to depth ratio than the other river branches.

Along the IJssel, the development of natural levees is found at locations where large water bodies are located close to the main channel and in the inner bend in the Zalkerwaard floodplain. Along the IJssel, most of the banks have been fixed by riprap. This probably counteracts the uptake of sand and subsequent sedimentation on the natural levee. In the Zalkerwaard floodplain the bank is not defended, and here sedimentation on the bank is found.

8.4.2 Recommended measures

Measures that cause the floodplain to be inundated more frequently will enhance the process of growth of natural levees. Such measures are the lowering of floodplains directly next to the main channel, or the removal of minor embankments.

8.4.3 Management

After floods landowners often remove the sand. If this happens no longer, more natural levees could develop. Fertilisation of the natural levee is not recommended, because this has a negative influence on the natural process by promoting the wrong type of vegetation. If no fertilisers are added, the difference between the natural levee and the rest of the floodplain will become clearer. Moreover, most of the species of flower-rich grasslands of natural levees are put at a disadvantage.

Recommendations:

- claim room for the development of natural levees in restoration projects
- claim room on natural levees for the development of their specific ecological values
- when drawing up the management plan of the area, take account of the question if high vegetation on the natural levee is allowed or not
- take account of the irregular growth speed of natural levees; on the average, only once in 3 years the level is increased.

Table 8.2
Points of attention for stimulation of the development of natural levees.

height	maximum up to mean high water level
width	50 to 100 meters
development can be promoted thus:	the main thing is to increase the inundation frequency of the floodplain. This should be done especially at locations where the sand load of the river water is high, so in the inner bend. In the outer bend also sand is deposited, but less than in the inner bend. The inundation frequency can be increased by removal of the minor embankments or by excavation of the floodplain.
management	when the objective is grassland on natural levees: • no use of fertilisers • no removal of the sand • extensive grazing • development period: 10 to 20 years when the objective is riverine forests: • large units (up to some hundreds of ha) • no use of fertilisers • no removal of the sand • no or very extensive grazing • development period: ca 10 years for softwood forest, minimal 50 years for hardwood forest

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9 River dunes

Margriet M. Schoor, Esther Stouthamer & Anne M. Sorber

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9 River dunes

9.1 Definition and natural development

River dunes are dunes located along the river banks. They develop by accumulation on the river bank of wind blown sand from a dry river bed, a process that is quite different from that forming natural levees. In river dune formation it is not the river but the wind that transports the sand. Still, natural levees and river dunes are often difficult to distinguish. Processes may alternate: development of natural levees during floods and subsequent river dune formation during low discharges. Immediately following high flow, the bare sand on the river banks can be blown by the wind, forming river dunes. This activity is short-lived, however, since the sand is limited in amount and soon becomes covered with vegetation. The formation of river dunes requires a long-term source of sand. In the existing situation, this source can be formed by the groyne field beaches that are exposed at various times of the year, depending on their elevation and the water level.

In the Netherlands during the last ice age ideal conditions for river dune formation prevailed. In that era the Rhine and the Meuse were braided rivers with wide and shallow beds that fell dry during the winter. A strong wind from predominantly southwestern directions was present. The river dunes that developed in that time are now called '*donken*'. These are now for a large part covered by younger river sediments, but here and there they are still found at the surface. These *donken* are found in the Alblasserwaard, the Land between Meuse and Waal, Northern Limburg, the Maaskant, the Liemers, the Krimpenerwaard, the Bommelerwaard and the Land of Heusden and Altena.

On historical maps river dunes are sometimes indicated. For example the river dune complex in the Vreugderijkerwaard, nowadays no longer active, can be found on 18th century maps. These dunes were located on a wide bank in an inner meander of the IJssel.

Figure 9.1
River dune along the Volga. This is a good example of a river dune in its natural situation. The photo gives an indication of the width of bank that is required to let a river dune develop (photo: M. Schoor).

9.2 Hydrology, morphology and ecology

9.2.1 Hydrological and morphological functioning

The Millingerduin

Currently, the Millingerduin area along the Waal near Nijmegen is the best-developed river dune area in the Netherlands. Although it has frequently been excavated in recent decades, it has continued to replenish itself. Great quantities of sand are also deposited in the Millinger floodplain during floods. This means that a certain amount of natural levee formation is taking place. However, considering the size and shape of the levee, river dune formation is also very evident. In contrast with natural levees, dunes can reach elevations higher than those of the highest water levels. The Millinger dunes will be inundated only during extremely high floods. Dune formation in the Millinger floodplain can be explained by the presence of wide beaches with a favourable orientation to westerly winds.

Figure 9.2
The Millingerduin (photo: Roel Doef).

Groyne fields and on the wind

In many groyne fields wind erosion can be observed. This can also be concluded from the formation of small dunes and desert pavements, formed by the drifting of sand. There are more natural levees on which sand is deposited by the wind, but nowhere does this lead to such well-developed river dunes as those in the Millingerduin. Additionally several more groyne fields with wide beaches and a favourable orientation to the wind can be found along Dutch rivers, especially along the Waal. At these places the most important conditions for dune formation have been met, so there is the possibility that dunes will form. Whether this will actually occur depends on other factors such as particle size and existing vegetation.

Wind erosion of recently deposited river sand is mainly taking place in autumn, during low discharges, and under the influence of western winds. Favourable locations for the development of river dunes are inner bends of the rivers, where as a result of the helicoidal flow sand is deposited. The chance for river dunes to prevail is greater when the dunes develop on higher locations on the river banks.

Figure 9.3
Groyne field with small dunes and desert pavement (photo: Pim Jungerius).

Meuse
Nowadays along the Meuse no active river dunes are found. As a result of weir construction and river normalisation, little morphological activity can be identified. Moreover, intensively grazed grasslands and steep banks covered with riprap are characteristic for the Meuse, as they are for the IJssel. This makes active river dune formation impossible. Along the Meuse many Pleistocene river dunes are found, which locally are eroded by the river.

9.2.2 Ecological functioning
Vegetation plays an important role in river dune development. It holds the sand in place and prevents further erosion, thus enabling the growth of the dune. However, as long as some sand continues to disperse, part of the dunes will remain bare. This exposed, relatively highly elevated sand is hot and dry in the summer. Such conditions are rather exceptional in the river area. It attracts very specific species of plants and animals, such as soapwort (figure 9.5), hyssop-leaved tick-seed and the nodding thistle, the Natterjack toad and various species of insects and spiders (cf. Faber *et al.* 1999).

In later stages of succession, a softwood or even hardwood riverine forest can develop on the river dune. In such cases the ecological functioning of the river dune cannot be distinguished any longer from that of comparable forests on sandy soils with a different morphological background.

River dunes have an important function in the floodplains during floods, as a resort for terrestrial species of insects and small mammals.

9.3 Interrelations with the surroundings

Because river dunes are highly elevated, stimulation of their development does not contribute to reduction of design water levels. Consequently, the only goal of the promotion of river dune formation in rehabilitation plans is to increase natural values. Compensation of the effect on the design water levels can become necessary; this must be determined with the help of model calculations.

Figure 9.4
Detail Millingerduin: fixation by the vegetation (photo: Roel Doef).

Figure 9.5
Soapwort on the Millingerduin (photo: Margriet Schoor).

In practice it is found that the spontaneous development of river dunes is only possible in a very strictly limited number of locations, because the scale and degree of dynamics are limiting factors (see paragraph 9.4).

River dunes form no obstacle for the navigability of the main channel.

If no grazing management is imposed, river dunes have a special function for the ecosystem only during the early stages of their development. The ecological communities that are characteristic for these stages are pioneers, with a large capacity for dispersion and little sensitivity to fragmentation of their habitats. As a result, the young river dunes have no clear function in ecological networks. From an ecological viewpoint, older river dunes often have a function as riverine forests.

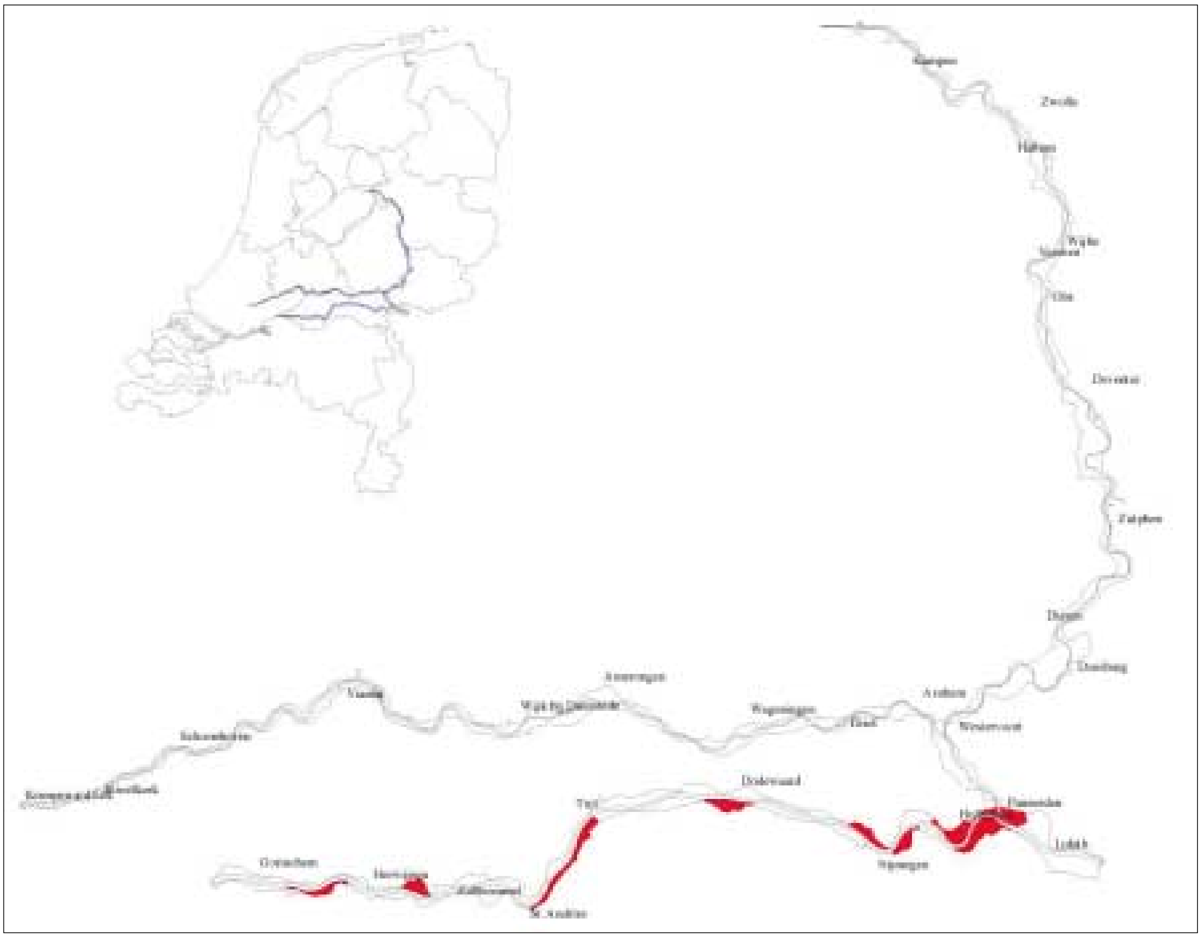
If grazing management is imposed (with low stocking rates), grassy vegetation will develop quite quickly. Such vegetation may develop further into a flower-rich grassland of natural levees, which is characterised by species that only grow in relatively hot, dry and often lime-rich locations. Occasional supply of fresh drifting sand with high lime content and grazing are prerequisites for the survival of these grasslands in the long term. Due to the lack of real river dunes in the Netherlands, (fragmented) flower-rich grasslands of natural levees are now mainly to be found on embankments and high natural levees.

9.4 Measures to stimulate the development of river dunes

9.4.1 Where can these measures be applied

Based on the river bank width and the exposure of the beaches between the groynes, a map with promising locations for river dune formation was made. Only in some floodplains along the Boven-Waal such promising locations could be identified. In the Millingerwaard there is no need, as a river dune is present here.

Figure 9.6
Map of promising locations for the development of river dunes.



The most promising locations are floodplains where a number of connected beaches between the groynes are present. These are along the Waal: the Klompenwaard, the Millingerwaard, the Gendtse Waard and the Oosterhoutse Waarden floodplains.

9.4.2 Recommended measures

Measures that stimulate river dune formation are increasing the size of the groyne beaches, counteracting the development of vegetation on the river bank by grazing, and removal of gravel and obstacles from the groyne beaches. Floodplains with a large number of connected groyne beaches and a favourable orientation towards the westerly winds are the most suitable.

If these measures are considered, one has to bear in mind that river dunes only develop their own specific character if sand drift is actually occurring. A river dune is more than a shape in the landscape; transportation of sand by the wind and fixation by the vegetation also make up part of it.

Table 9.1
Points of attention when promoting the development of river dunes.

character	it is an essential property that a river dune should be allowed to drift. Therefore the fixation of sand by planted vegetation must be avoided.
area	0.1 to several ha
height	under natural circumstances up to 20 m above the surrounding area. Present active dunes are not higher than ca 5 m.
to be promoted by:	• increase of the area of the sandy beach of the river, in order to increase the fetch of the wind over the bare sand. The best way to achieve this is to interconnect several groyne beaches behind the groynes, with the right orientation to the prevailing wind direction. • avoidance of the development of vegetation on the river banks. • removal of gravel and obstacles from the beach.
location	the locations in the Netherlands where river dunes can develop are rather scarce; a map is included in the text.
interrelations with the river area	limited. No influence is expected on the navigability; the influence on the design river water levels is only of local importance, and should be calculated individually.

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10 Reedmarshes

Hugo Coops & Frederike I. Kappers

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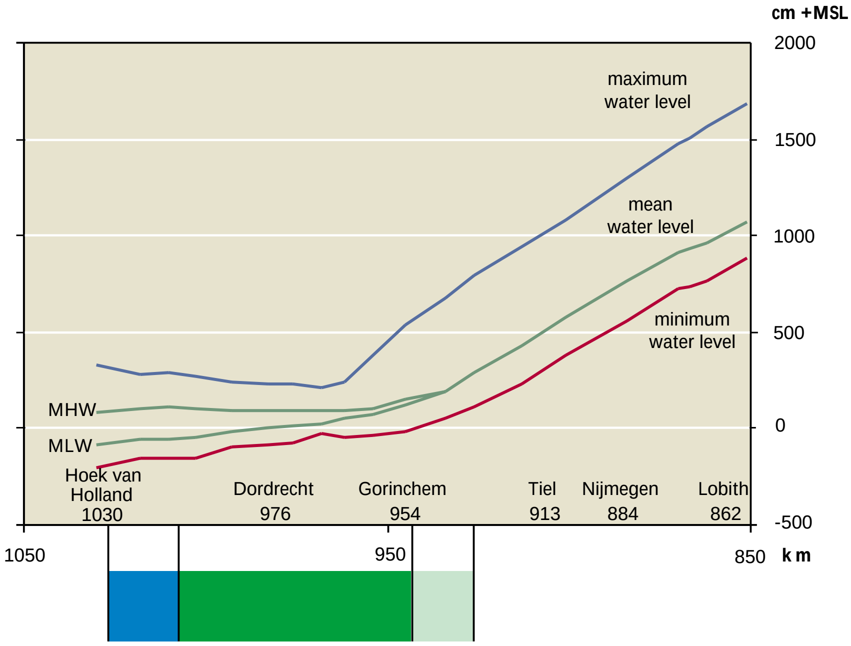
10 Reedmarshes

10.1 Reference situation

In the river area, reedmarshes are defined as the ecotopes that have almost constant water levels up to or above soil surface level, and that are dominated by tall helophyte vegetation or by vegetation of tall forbs.
In the present situation these types of terrain are mainly found near the mouths of the large rivers (figure 10.1). More upstream marsh ecotopes have become scarce close to the main channel, mainly because the conditions near the river have become either too dry or, during inundations, too wet. This is a result of the construction of the embankments. With the scarce marsh areas or wetlands that are left, important conservation values are associated: for example about 25 % of the bird species that appear on the red list have their distribution centred in reed marshes.

Figure 10.1
Optimal presence of reed marshes along the hydrodynamical gradient from the Boven-Rijn, Waal, Merwede, Oude Maas and Nieuwe Waterweg.
Blue = brackish marshes,
green = reed-covered banks,
light green = fragmented reed stands.



The key area for marshes in the river area is the freshwater tidal area. In optima forma this area has survived only in the river branches with a relatively large tidal movement (average fluctuation of more than 1 m): the Oude Maas, Nieuwe Maas, Hollandsche IJssel and Lek. In the south rim of the estuaries of the Rhine and Meuse the tidal amplitude has been reduced sharply due to the enclosure of the Haringvliet; nowadays here the tidal movement is only a few decimetres vertically. The freshwater tidal areas have markedly changed their character. Silt banks and mudflats that once were inundated and drained twice a day are now permanently inundated, clubrush stands were eroded, reeds and willow vegetations have shifted towards a more ruderal vegetation. From east to west there used to be a transition from freshwater to brackish conditions, and then to the salt marshes of the coastal area. After the enclosure of the Haringvliet in 1970, these brackish former salt marsh areas have become more ruderal. Many characteristic areas have been replaced by a reed vegetation with relics of brackish conditions, and by wet grasslands.

Upstream along the large rivers, reed and clubrush dominate in ecotopes with relatively small hydro- and morphodynamics, because they cannot cope with extreme conditions such as desiccation and deep inundations. Originally these areas were the backswamps and the old, isolated floodplain channels, where helophytes play a key role in the process of transition from water to land. Nowadays the key areas for these types of marshes are found in embanked areas (for example in the Rijnstrangen area), along the floodplain channels in floodplains with high minor embankments (for example the Kil van Hurwenen along the Waal), in weir-regulated river stretches (for example the Nederrijn/Lek), and near the mouth of the IJssel. In fact also the peat area in Holland with its marshes was developed in the sphere of influence of the large rivers under reduced river dynamics. These marshes however do not fit in the framework of ecological restoration of the Dutch river area, and are not considered further.

10.2 Hydrology, morphology and ecology

10.2.1 Hydrological functioning

The presence of marshes along the lower river stretches is mainly determined by the properties of the daily tidal water level fluctuations (figure 10.2). In the northern part of the estuary of Rhine and Meuse this tidal amplitude is still more than a meter locally (for example 140 cm in the Oude Maas, figure 10.2). In the southern part of the estuary however only a small amplitude was left after the enclosure of the Haringvliet; on the average 30 cm in the Brabantse Biesbosch.

The vegetation on the riverbanks in the intertidal zone is influenced directly by the tidal movement. The most important parameters are: the mean high water level, the mean low water level, the tidal amplitude and the exceedance frequencies of high water levels. The combination of these parameters determines the width of the bordering zone in which reeds and clubrushes can develop.

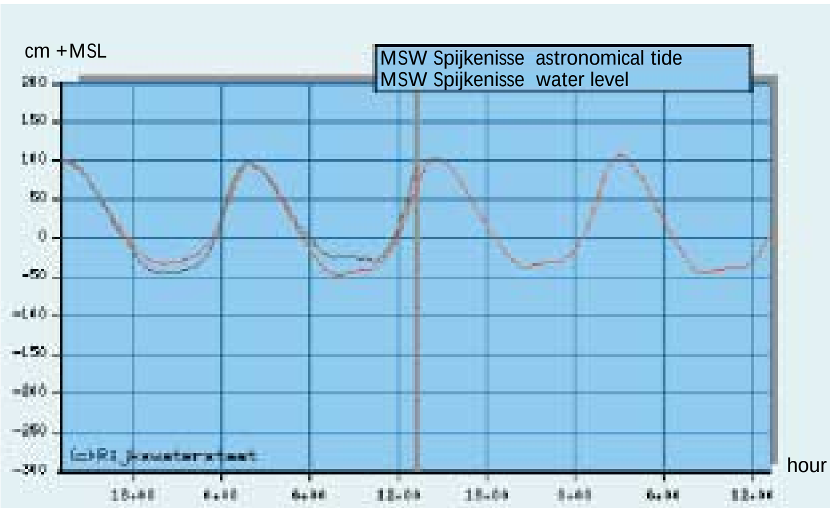


Figure 10.2
Tidal cycle in the freshwater tidal area of the Oude Maas. The mean tidal amplitude is 140 cm, the mean high water level is 1 m +MSL.

The slope of the riverbank is quite important: the gentler this slope, the higher the chances that a reed vegetation of some size develops. The vegetation above the mean high water level has a lower inundation frequency and is consequently influenced much more by groundwater table fluctuations. The tidal movement is sharply reduced in the groundwater. Because of this fact, the upper limit of the reed is found higher above mean water level if the tidal movement is reduced; this effect is called the 'telescope effect' (Zonneveld 1959).

The distance from the open water at which the tidal movement in the groundwater can be considered negligibly small depends on the hydrological properties of the soil. In clay soils this distance is only a few meters, in sandy soils no more than some tens of meters.

In riverbank complexes the tidal movement is also reduced as a result of the limits of the capacity of the draining system; this is all the more the case if embankments are present. In earlier coppice, reed and bulrush cultures the water level was manipulated with culverts and weirs; the operators tried to inundate these areas late and drain as early as possible in the tidal cycle. Such a principle was used in the restored Stormpoldervloedbos. Due to negligence, most of these culvert-embankment systems no longer are operational.

Further upstream in the river area, reed marshes can only develop where the water level dynamics are relatively small. In a large part of the floodplains of the upstream river stretches these dynamics are too strong.

10.2.2 Morphological functioning

Reed marshes make up an intermediate stage in the development of dry land from open water. The freshwater tidal area has obtained its form and functioning to some part due to heavy inundations by the sea, after which an inland sea was formed, which started to develop towards land again by the influx of silt and the development of vegetation (figure 10.3). Characteristic for these areas is a slow transition of the landscape, with intermittently a return to earlier conditions as a result of heavy floods.

The siltation process in areas with low flow dynamics and wave action leads to the first occupation by clubrushes, once the soil is level with the intertidal zone. When a closed vegetation has developed, it leads to deposition of silt with increased rates, while it prevents erosion. The soil level is aggradated further by the rhizomes, which grow upwards in constantly renewing layers. When the surface level has increased to almost mean flood level, the inundation duration is reduced to such extent that the establishment of common reed is possible. This causes even faster siltation rates because of its dense structure and high litter production. In principle a change in vegetation towards the development of willow scrub and forest will start as soon as the surface level becomes higher than mean high water level. In practice however, in the Biesbosch the reed stage was prolonged artificially by low embankments and drainage. Because of the effect of soil compaction, the process of level increase was slowed down.

The net surface level increase in the former Biesbosch proceeded with a rate of a few centimetres per year, with strong local variations. In a creek on the island of Tiengemeten, a rate of up to 15 centimetres per year was measured; in the lee of dams rates of a few centimetres per year are possible. The siltation rate is difficult to predict in general terms, although some rough estimates can be made with the help of computer models for water and silt transport. The tidal movement, in which a flow reversal takes place, and the degree of consolidation of the deposited silt are the causes of the unpredictability of the sedimentation process.

The development of helophytes increases the siltation rate, but if this process proceeds too fast the vegetation will not be able to maintain itself. Other causes for poor vegetation development are erosion or insufficient influx of nutrients in the silt. Still, once vegetation has developed, it can stay there for a long time under marginal growing conditions.

In low-dynamic floodplains and backswamps also organic soil development will play a role in the gradual heightening and desiccation of the soil. In the extreme situation with stagnant water even peat development can be observed. In such conditions the helophyte stage will last at least some decades.

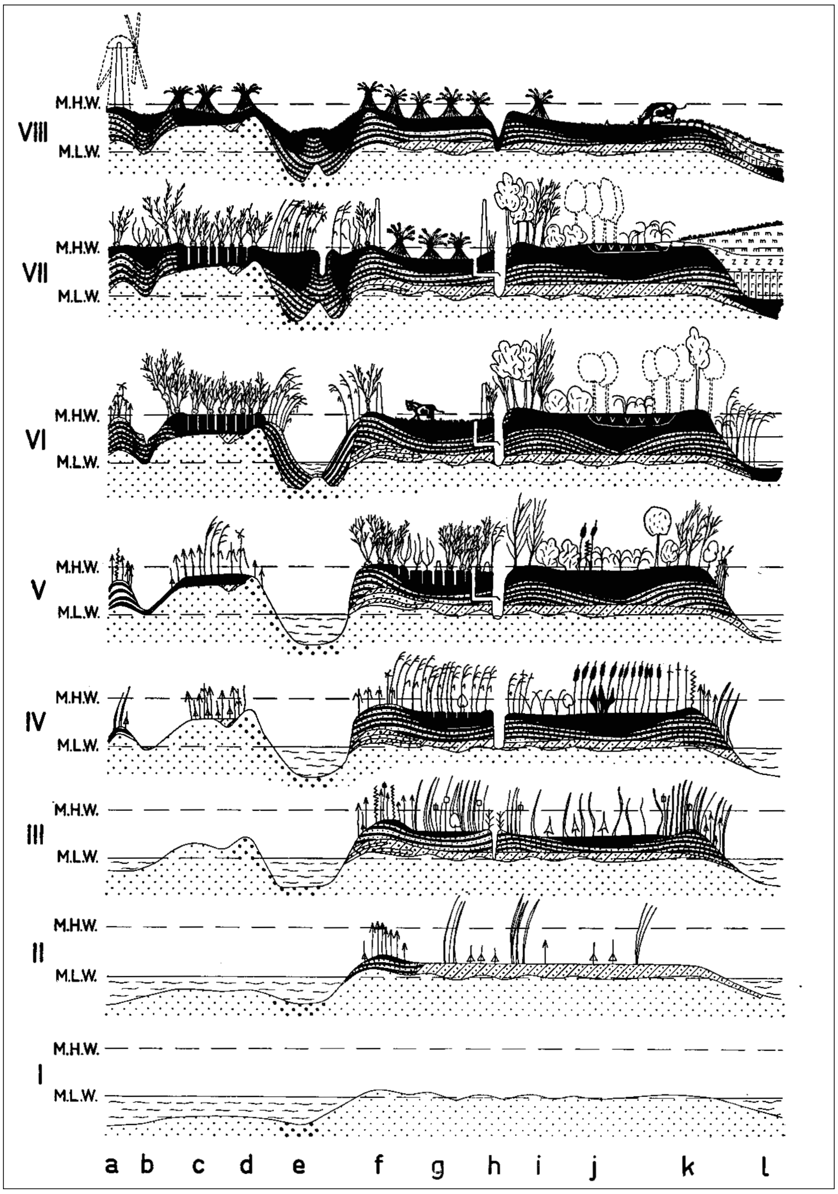


Figure 10.3
Schematic presentation of the historical development of silt banks in the Biesbosch. If a silt bank has grown to above mean low water level, clubrushes will establish; on sandy natural levees this is mainly sea club-rush, on silty backswamps mainly common clubrush. Once a clubrush vegetation is established, it increases the siltation rate, thus increasing the surface level; finally reed and reedmace will settle. Reed and willow cultures are favoured artificially during the next stage by the construction of ditches and embankments; in the ever further isolated waters, peat formation starts. Finally the surface level starts to subside again after the construction of embankments and the installation of a drainage system. Summarised after Zonneveld (1959).

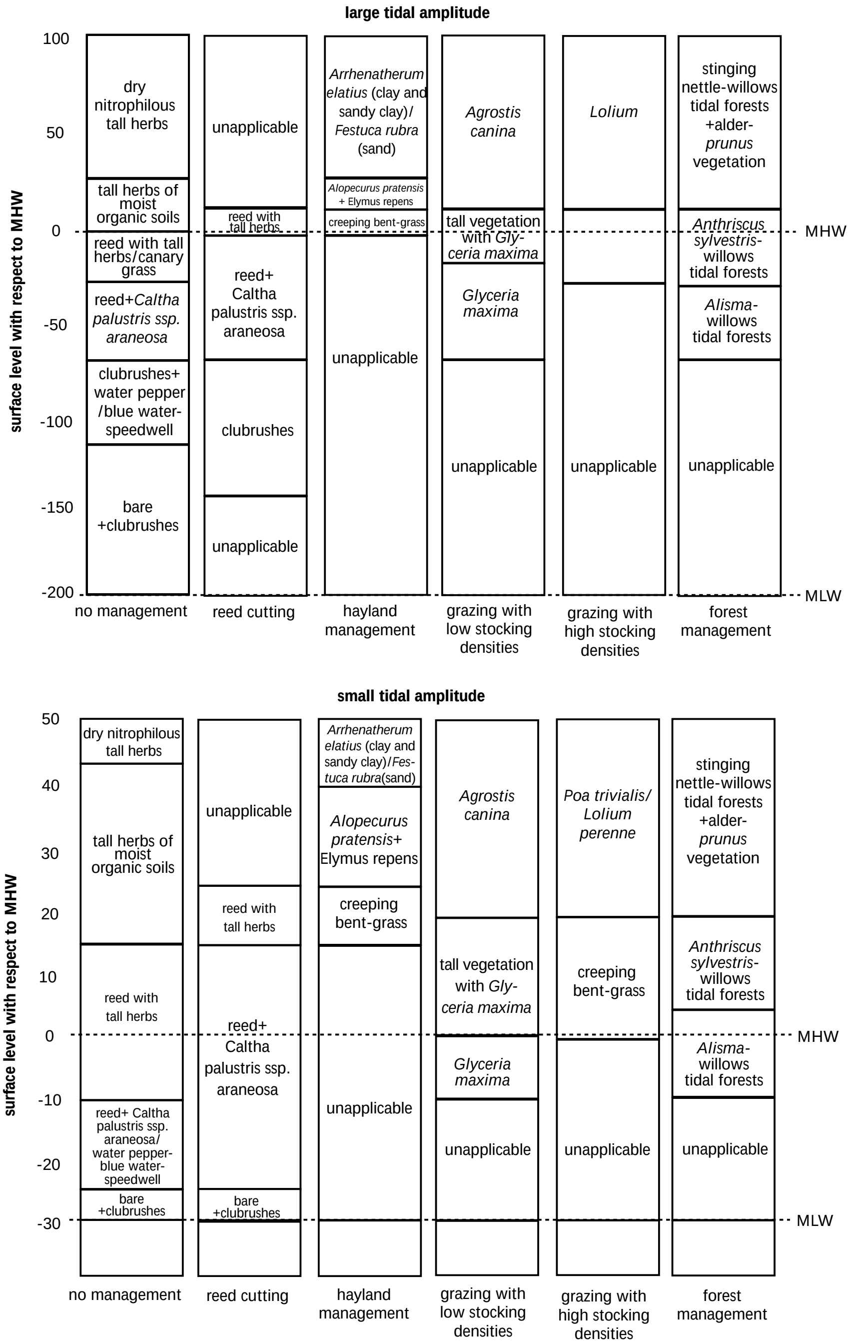
10.2.3 Ecological functioning

Zoning of the vegetation in freshwater tidal marshes
In the freshwater tidal area a number of ecotopes can be distinguished that are relevant for marsh development (Maas 1998). These ecotopes are: tidal creek, unvegetated bank and former saltmarsh. Linked to these ecotopes are a series of vegetation types; see table 10.1. The potential development of various vegetation communities is indicated in figure 10.4, expressed relative to mean high water level. For the establishment of a desired type of vegetation one also has to observe other factors.
A remark to be made here is that many reed and clubrush fields were used by man from early days on, and that their continuity and presence to a great extent have been shaped by man. Such vegetation can remain where they are for long periods, even when the conditions are suboptimal; these conditions are no indications of the chances of new establishment of a new vegetation. Moreover increased wave attack, irregular water level fluctuations and foraging waterfowl are important factors determining restoration success. These factors can be kept under control during restoration only to a limited extent.

Table 10.1
Presence of vegetation types and characteristic species in the ecotopes of the freshwater tidal area.

ecotope	vegetation type	characteristic species
tidal creeks	unvegetated tidal creek	–
	aquatic vegetation	fennel pond-weed, pond-weed, yellow water-lily, arrow-head, and other aquatic plants
unvegetated banks	unvegetated silt or sand bank	–
	Pioneer vegetation of water pepper and blue water-speedwell (Polygono-Veronicetum anagallis)	water pepper, blue water-speedwell, *Rorippa nasturtium-aquaticum, Callitriche* spp.
former saltmarsh	vegetation of common clubrush (incl. grey clubrush vegetation)	common clubrush, grey clubrush, hybrid clubrush, *Callitriche* spp.
	clubrush vegetation with *Bolboschoenus maritimus* (Alismato-Scirpetum maritimi)	*Bolboschoenus maritimus*
	clubrush vegetation with triangular clubrush (Alismato-Scirpetum scirpetosum triquetri)	triangular clubrush, *Bolboschoenus maritimus*
	clubrush vegetation with *Caltha palustris* ssp. *araneosa* (Alismato-Scirpetum calthetosum)	common clubrush, *Caltha palustris* ssp. *araneosa*, common water-plantain, arrow-head, *Callitriche* spp.
	vegetation of lesser reemace (Typho-Phragmitetum typetosum angustifoliae)	lesser reedmace
	reedland with *Caltha palustris* ssp. *araneosa* (Typho-Phragmitetum calthetosum)	reed, *Caltha palustris* ssp. *araneosa*
	tall sedge vegetation, vegetation of reed sweet-grass, vegetation of greater reedmace, vegetation of canary grass tall reed vegetation	several helophyte species *Leucojum aestivum, Senecio fluviatilis, Angelica archangelica, Elymus caninus,* and others
	tall herbs of moist organic soils	stinging nettle, greater dodder

Figure 10.4
Zoning of the vegetation in the freshwater tidal area of the Rhine and Meuse according to the model EMOE. The scheme for the large tidal amplitude indicates the original situation; amplitude 200 cm. The small amplitude of 30 cm is the situation in the southern part of the estuary after the enclosure of the Haringvliet.



Explanation of the vegetation zones:
bare banks + clubrushes: mosaic of bare banks and tussocks of clubrushes. This class is the first pioneer stage of silting banks. On the open parts *Vaucheria dichotoma* often dominates, scattered patterns of pioneer species such as blue water-speedwell, *Rorippa nasturtium-aquaticum* en water pepper are found. Dynamics are strong (deep inundation, silting up, wave attack), making the vegetation variable.
clubrushes + waterpepper/water-speedwell: this is the well-developed part of the previous zone. Several vegetation zones in mosaic a) low pioneer vegetation of mudflats of water pepper en blue water-speedwell (Polygono-Veronicetum anagallis). b) clubrush fields. The natural vegetation of clubrushes can be subdivided into several types
reed + Caltha palustris ssp. araneosa: Reed saltmarshes within the reach of tidal movement are characterised as Typho-Phragmitetum calthetosum, and have a spring dominance of *Caltha palustris* ssp. *araneosa*, a giant form of the *Caltha palustris* with special adaptations to the tidal conditions. With reduced tidal movement this type can maintain itself if the reed is mowed.
rough reeds: With further surface rising the reed fields roughen; other tall herbs enter the reed. On exposed locations reed grasses dominate, while greater reedmace can dominate on locations where much litter is accumulated. On still higher, better drained locations tall herbs of moist organic soils are found, in which *Filipendula ulmaria*, great willow-herb and common meadow-rue can dominate. Finally on well-drained former saltmarshes dry **(nitrophylic) tall vegetations** develop. By mineralisation of organic material here nitrophilic species, such as stinging nettle, dominate.

The intertidal zone of the freshwater tidal area consists of a sharp zoning of vegetation types, which are highly characteristic by their species composition, the presence of a number of unique taxa, and the high productivity of the vegetation. Of special interest are the vegetation types of reed and clubrush. These are mainly found between mean high water and low water level. Based on many vegetation mappings in the mouths of the Rhine and Meuse, the prediction model EMOE has been developed, which generates the spatial distribution of vegetation types, based on elevation in the tidal zone, salt content and management methods.

10.3 Interrelations with the surroundings

Hydraulic aspects
The main precondition for river managers is that the discharge capacity of the winter bed during design discharge is not affected. Compared to short grass vegetations a high helophyte vegetation has a high hydraulic roughness. This may be important in the calculation of the resistance of floodplains, and in addressing the question if marsh development should be compensated for by extra excavations elsewhere.

In the estuary enlargement of the winter bed has a minimal effect on the discharge capacity; here the hydraulic roughness of the vegetation is no point of interest. Increase of the area of marshes here will mainly have effects on the storage in the floodplain.

The hydraulic resistance is a point of interest when water flow occurs during design discharge. This is the case in the upstream parts of the rivers. Helophytes form a dense cover within which only limited discharge is possible. During a flood, substantial flow through reed marshes will only be possible when the vegetation cover is completely inundated, and the water can flow over the vegetation or through open patches of the vegetation.

A number of aspects are of interest for the resistance that helophytes pose to the discharge under extreme conditions:

1. Marsh vegetations are often located in low-dynamic parts of the floodplain, which during floods have rather a storing than a discharging function.
2. Helophytes grow on low parts of the floodplain, e.g. on the banks of pools and pits. Under design circumstances this vegetation will then be flooded completely.
3. The horizontal profile of the vegetation is determined by the thickness, length and density of stems. In table 10.1 a number of key figures for helophytes are given. In mixed and tall vegetations the horizontal profile will be higher.
4. The flexibility of the vegetation and the parting of leaves and stems as caused by flow. Taking into account the stiffness of dead reed stems and the moderate flow velocities in the floodplains, bending is not expected to have an important part in the roughness of the vegetation. The assumption is that dead biomass behaves just like in stagnant water, and is not washed out. For dynamic locations this is a conservative assumption.
5. The phenological situation during design circumstances is always the winter situation in the Rhine and Meuse basins. This situation differs significantly from the growing season.

Table 10.2
Hydraulic relevant properties of some plant species of marsh vegetations.

	mean length (winter) m	mean thickness (m)	stem density (n)	cross area perpendicular to flow m^2m^{-2}	rem.
reed freshwater tidal area	3.0	0.008	80	0.70	
reed floodplains	2.5	0.0075	80	0.64	1
rough reed:				0.30	2
reed	2.5	0.005	30		
tall vegetation	0.5	0.003	20		
low vegetation	0.1	irr.	irr.		
rough vegetation in marsh	0.1	irr.	irr.	0.01	3
yellow flag	0.5	0.015	10	?	
reedmace	1.5	0.025	20	0.04	4
common clubrush	depends on water depth	0.004	100	0.06	5
canary grass	1.0	0.003	200	0.23	6
reed sweet-grass	0.2	irr.	irr.	0.10	7
sedge	0.3	0.006	200	0.28	8

rem. 1:
The estimation is that about 25% of fully covering reed vegetations in the winter consist of flat lying litter, with a thickness of 0.1 m.
rem. 2:
Rough reed vegetations will consist of a mosaic of dominant species
rem. 3:
For rough marsh vegetations in the winter situation, a very small structure above ground may be assumed.
rem. 4:
For reedmace a strongly clustered structure with 50% bare soil may be assumed.
rem. 5:
For common clubrush a clustered structure with 50% bare soil may be assumed.
rem. 6:
For canary grass a clustered structure with 25% bare soil may be assumed.
rem. 7
For reed sweet-grass a clustered structure with 50% short grass may be assumed.
rem. 8:
For sedges a strongly clustered structure with 25% litter layer, thickness 0.1 m, may be assumed.

Figure 10.5
Vegetation structure of reed in winter.

Water quality aspects
If marshes are flushed strongly, the sedimentation of silt in the marsh may lead to water quality differences between the marsh water and the river water. This difference is enhanced by the chemical changes in the marsh water: the content of organic acids increases, giving the water a dark colour, nutrients that are bound to silt are deposited, and nitrogen disappears by the denitrification process. The size of the marshes in the Rhine-Meuse estuaries is not enough to demonstrate these effects clearly, but in more natural areas it can be seen clearly sometimes.

The fixation of nutrients by the vegetation is hard to determine. On one hand there is the passive fixation by silt sedimentation. On the other hand the helophytes take up nutrients from the sediment and use it in the build up of biomass. The order of magnitude of the yearly biomass production of reed is 10 to 25 tonnes of dry weight per ha, 3 to 5 % of which is N and 0.1 to 0.3 % P. Apart from that, in the root zone nitrate is transformed into nitrogen, which disappears as a gas. Rules of thumb are available to estimate the cleaning efficiency of heavily loaded cleaning marshes, but these rules cannot be used easily in natural systems because the average contents are much lower and the environmental conditions fluctuate strongly.

An additional quality factor is the strong accumulation capacity of metals as arsenic, cadmium and lead in the biomass of fast-growing helophytes and rough vegetation species. What happens to these compounds after degradation of the organic matter is not yet fully understood.

10.4 Measures to develop marshes

10.4.1 Development of helophytes
In many cases, a vegetation will settles spontaneously, in which after some years reed and clubrush will begin to dominate the wet and shallow zone. The developments are determined by the water level fluctuations, the wave dynamics, the soil type, grazing strategies and terrain management practices.

water level fluctuations and establishment of vegetation
For the establishment of many helophytes a quiet environment of water levels in or just above (max. a few centimetres) soil surface is needed. Only then seeds can germinate and seedlings can survive the first growing period. During the first year the plants must be able to accumulate sufficient reserves in the rhizomes in order to survive the next year.

The demands for the germination stage differ per species: reed plants germinate on just wetted soil, complete inundation is poorly tolerated by the plants. Reedmace and common clubrush on the other hand germinate best in shallow water, and especially clubrushes germinate well in a tidal area, presumed no strong water currents occur. Possibly soil algae (e.g. *Vaucheria*) play an important role in the stabilisation of the soil surface, enabling seeds to germinate and seedlings to grow up in relatively protected conditions.

Usually helophyte stands grow vegetatively. In this way especially reed is able to extend along the tidal gradient downwards. Reeds are then sometimes found beneath mean low water levels. Spreading can also take place vegetatively, in which process flooding can be important. Washed out parts of reed may be found in all sorts of locations, independent of suitable germination conditions. The *Caltha palustris ssp. araneosa*, a species that is unique for the freshwater tidal area, even has special adaptations for this type of spreading, because after flowering new plants develop on the stem, which can detach from the mother plant and reach other places floating in the water.

Vegetative establishment is being simulated since old times by planting economically interesting plants like reed and common clubrush. In this way in certain favourable locations a quick and complete vegetation cover can be obtained.

wave action and flow dynamics
Wave action and flow dynamics have important influence on the chances of development of the plant growth, and thus on the natural values of the intertidal zone. In the first place the water movement has an indirect effect, because it influences the soil development. In sheltered, low-dynamic sites fine silt is deposited and silty banks develop; on exposed banks the fine silt is eroded and the coarser sand remain or are deposited. On exposed banks the vegetation has to cope with the mechanical forces of waves and water flow, low contents of nutrients in the soil and the washing out of dead organic matter. The succession on low-dynamic banks follows other lines than that of high-dynamic locations: by the faster rate of soil elevation and accumulation of litter, a reed vegetation can become rough in a relatively short span of time, in which the domination by reed is succeeded by that of rough marsh vegetation species, such as great hairy willowherb and stinging nettle.

soil
It has been stated earlier in this chapter that the natural composition of the soil reflects the dynamics of the environment. Because in bank development projects often soil is excavated or added, after the completion of the project strong erosion can occur. This hampers the first development of a vegetation. This holds true also as a risk for the planting of vegetation on banks that were made artificially with silt out of the river: if the silt is washed out too quickly the plants can not grow further. On the other hand, a dense vegetation can quickly cover the whole area and stop erosion. Complete exclusion of erosion again is not an optimal option, because this implies quick sedimentation and succession, and probably a short duration of the desired type of ecotope.

In the Biesbosch at several locations experiments have been carried out with permeable constructions on banks and groynes, such as permeable groynes in which sediment containing rhizomes of reed is added. Moreover, research has been carried out to the root penetrability of geotextiles and various sizes of riprap.

grazing
In several situations grazing is a determining factor in the development of the vegetation. The most important natural grazers are geese. Because geese are found in large numbers mainly in large-scale, open areas, their impact on the development of reedmarshes sometimes is considerable. Plantings of clubrushes in the Haringvliet and neighbouring areas had disappeared after only a few years, despite the use of exclosures that prevented grazing during the first year. Successful plantations can be

found too, however, most of them in the somewhat less open parts of the area.

The development of a helophyte marsh is difficult to combine with grazing cattle. With cattle present, helophytes can only survive in remote, extensively grazed areas.

10.4.2 Restoration and development of freshwater tidal marshes

For restoration of freshwater tidal marshes, a design that is aimed at maximalisation of the intertidal zone is important. This will enable the restoration of the complete gradient, including intertidal creeks, mudflats and salt marshes. If possibilities can be found to promote local erosion and gully formation too, these should be used. Because in a large part of the area the tidal amplitude is much reduced, a complete development of the gradient is not possible and an adapted zoning must be used.

Because shipping has increased, the banks along the rivers have been eroded. The main cause of this was a concentrated wave attack in a narrow bank zone, where the vegetation was not very vital. A halt has been called to most of this erosion by the implementation of a large-scale program of bank defences. At the same time these bank defences created sheltered areas, with great potential for the development of marsh vegetation. As was found out however, spontaneous increase of these vegetation does not or hardly happen; additional measures are needed. The causes are: foraging geese, cliffs, unsuitable germination conditions, and an unsuitable substrate for roots.

INTERMEZZO: PREVENTION OF NUISANCE CAUSED BY MOSQUITOS

During public participation meetings in the planning process, inhabitants often express their fear for the development of nuisance caused by mosquitos as a result of the planned restoration measures. The planners can prevent these problems by including some rules regarding the ecology of relevant mosquito species in their design

Important factors

For the development of mosquito nuisance these factors are relevant:

1. sufficient size of the larvae population;
2. highly synchronized emergence period, which is promoted by a uniform water temperature and large scale, uniform ecotopes;
3. Wind speed and direction. With strong winds, no large swarms are formed. The wind direction is relevant to determine if the mosquitoes can reach the locations where they cause nuisance.
4. presence of landmarks. Mosquito swarms develop at landmarks, which probably has a function as orientation point. Developed imago's look for a suitable place to mate. Usually they look for such a location close to the breeding area; they have no urge to cover large distances. This happens only if they cannot find suitable mating areas near their breeding grounds

Which mosquito species cause nuisance

Most of the nuisance from the past was caused by species of the families of chironomids and culicids. The chironomids nuisance was caused by a quick change in environmental conditions after the closing off of estuaries;

this nuisance disappeared after establishment of a new ecological equilibrium. The highest densities of culicid larvae are found in temporary soaked conditions with pools and ditches, and in forested areas with depressions or ditches. These larvae can also be found in pools in grasslands, in roof gutters, and other ephemeral pools with a low pH.

Guidelines

The starting point is: prevention of large concentrations of mosquitoes, prevention of a suitable habitat for them. The following measures can be considered:

1 Avoid a continuous line of scrubs from the area to housing areas, these could form a corridor for mosquitoes..
2 Distance and orientation of the plan area to the housing areas. A planning area in down wind direction and large distance will cause least problems. Most mosquitoes do not wander further than a few hundreds of meters from their breeding grounds.
3 Potential breeding grounds can be isolated by high vegetation or plantations. Mosquitoes avoid open areas. By isolation of their breeding grounds with trees, which provide quiet conditions, a concentration of mosquitoes can be expected at the lee side. Wandering only happens if no suitable mating location is found nearby.
4 The chances of synchronised emergence of a species is increased by large units of one ecotope and by uniform water temperatures. Development of small units, variation of water depth which causes variation in water temperature, diminishes the chances of synchronised emergence.
5 Predators, such as fish and birds, can keep mosquito populations at low densities in the larval stage, which occurs in the water. Enabling fish to enter will help to prevent nuisance.
6 Increase of inundation frequency by the river reduces the chances of development of mosquito nuisance.

Figure 10.6
Bank defence measures prevent erosion of helophytes along the Oude Maas.

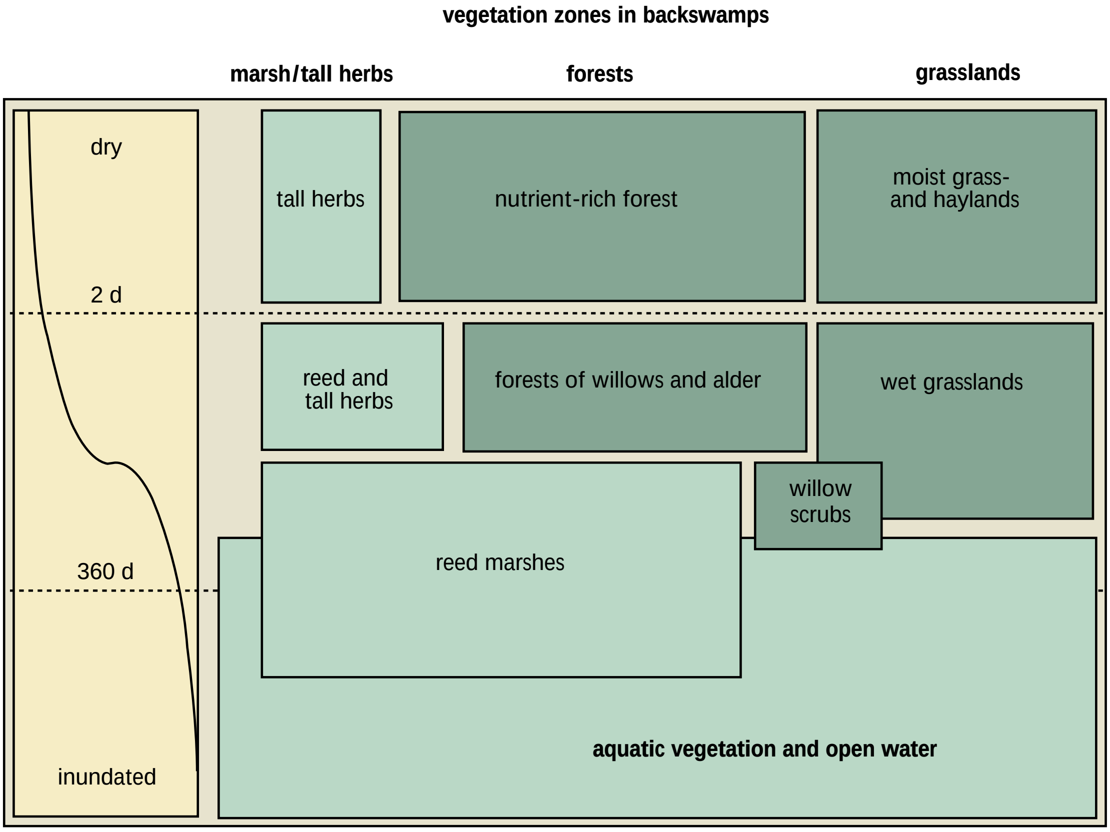
In the recent past several projects have been implemented in the south-western part of the Netherlands to develop reed and clubrush vegetation, with varying success. Planting clubrushes turned out to be successful along the Nieuwe Merwede and the Amer, but failed on the Tongplaat and Ventjagersplaten banks.

Figure 10.7
Only the exclosed clubrushes survive, one year after being planted on the Tongplaat.

10.4.3 Restoration and development of marshes in the upstream area

Reed and clubrush vegetation can dominate at certain locations along the large rivers. The water level fluctuations determine their presence. Reed and other helophytes cannot cope with complete inundation during the

Figure 10.8
Scheme of backswamps-storage area, based on reduced river dynamics with water level fluctuations during the year of approximately 100 cm.



growing season. The plants can avoid this by growing at higher locations, but there water shortage during summer (especially on sandy soils), grazing and competition with species of tall vegetation and riverine forests hampers their development. The presence of reed is then limited to those locations where the groundwater reaches to the surface during the summer, and the inundation depths during summer are not larger than 1 m. For these reasons suitable locations are found in floodplains with high minor embankments, along weir-regulated river stretches and in embanked areas.

In the floodplains, summer inundations can reduce the area of helophyte vegetations considerably. An example is the Oude Waal near Nijmegen, where a flood in July 1980 caused a very strong reduction of helophyte vegetations. These vegetations gradually recovered in the following years.

Reed marshes often have high conservation values. This is especially the case in the reed marshes in the Rijnstrangen area. Moreover they can offer a reference for nature development projects for water retention areas. In such areas with reduced river dynamics, with fluctuations of 2 m maximum, valuable marshes may develop. The hydraulic boundary conditions for such areas are now being studied by Delft Hydraulics.

10.4.4 Where can the development of marshes be stimulated

In table 10.3 an indication is given per river stretch of the suitability of the stretch for the development of marshes.

Table 10.3
Suitability per river stretch for the development of marshes.

Stretch	suitability	explanation
Bovenrijn	limited	only isolated floodplains with high summer embankments present
Bovenwaal	limited	only isolated floodplains with high summer embankments present
Middenwaal	limited	only isolated floodplains with high summer embankments present
Oostelijke Benedenwaal	fair	only isolated floodplains with high summer embankments present
Westelijke Benedenwaal	fair	only isolated floodplains with high summer embankments present
Pannerdens Kanaal	limited	the Rijnstrangen area (in the polder) offers good potential
Rijn near Arnhem	limited	
Doorwerthse Rijn	fair	just upstream of weirs is the most suitable location
Nederrijn/Lek	fair	just upstream of weirs is the most suitable location
Boven-Lek	high	
Boven-IJssel	limited	
Midden-IJssel	limited	
Sallandse IJssel	fair	
Beneden-IJssel	high	
Boven-Maas	low	
Grensmaas	low	
Plassenmaas	fair	just upstream of weirs; floodplains often too high
Peelhorstmaas	fair	
Venloslenkmaas	fair	
Maaskantmaas	fair	
Beneden-Maas	high	suitable after enlargement of the winter bed
Afgedamde Maas	high	suitable after enlargement of the winter bed
Bergse Maas	high	
Oude Maas, Nieuwe Maas, Noord, Hollandsche IJssel	high	
Ben. and Nwe. Merwede	high	
Biesbosch and Amer	high	
Harinvliet, Spui, Holl.Diep	high	

10.4.5 Attention points for the design

Table 10.4
Points of attention when developing measures.

marshes in tidal areas	
area	not relevant
most relevant water level	mean high water level and amplitude of the tidal movement.
discharge	not relevant
maximum river level and river level fluctuation	for a long period > 1 m level increase in the summer months (May – September)
location in the flood plain	not relevant
functions in the ecological network	a large interconnected area is important for the functions of migration
upstream marshes without tidal movement	
area	not relevant
most relevant water level	inundation frequency, ground water class
minimum and maximum sustainable river water level	the level of the flood plain surface determines the development. The difference between mean and minimum water level should be no more than 50 to 60 cm.
minimum and maximum inundation duration	summer inundations must be short and shallow

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11 Grazing management of floodplains

Perry Cornelissen & J. Theo Vulink

Contents

11 Grazing management of floodplains

Under natural conditions in our climate zone, grazing by large mammals in river areas is an integrated part of the system (Groot Bruinderink *et al.* 1997, Van Wieren *et al.* 1997). Grazing influences the development of types and structures of the vegetation, and thus on the presence of many plant and animal species. The aim is consequently to manage the flood-plains integrally with free ranging herds of large mammals, because then the development of the vegetation can be directed by a natural process (Grontmij 1995, Postma *et al*. 1996). The expectation is that apart from abiotic factors, such as soil composition and inundation frequency, grazing by large herbivores such as cattle and horses is one of the most important factors to determine the structure of the vegetation, and thus the hydraulic resistance of the floodplain. The use of large herbivores could then serve two goals: it helps to reduce further increase of the design water level, and it helps to create a more natural landscape.

Not only cattle and horses, but also wild herbivores such as red deer, elk, wisent, wild boar or beaver can play an important role for the develop-ment of the vegetation. In this chapter only grazing by cattle and horses will be addressed, because this method is used most frequently so far and probably in the near future.

This chapter is not going to provide advice with regard to exact numbers of cattle to be used in the management of the floodplains. This is not feasible, because the situation differs too much from one place to another to make general rules useful. For each location again one will have to find out which measures (type of grazing management and numbers) can best be used. This chapter deals with the general principles of grazing, and is based on research by RIZA. Indications are given of the effects of grazing intensities and grazing methods. Based on these general principles and the results of the research, a set of measures can be chosen. After implemen-tation, monitoring will have to provide the information as to whether or not the goals of management are obtained.

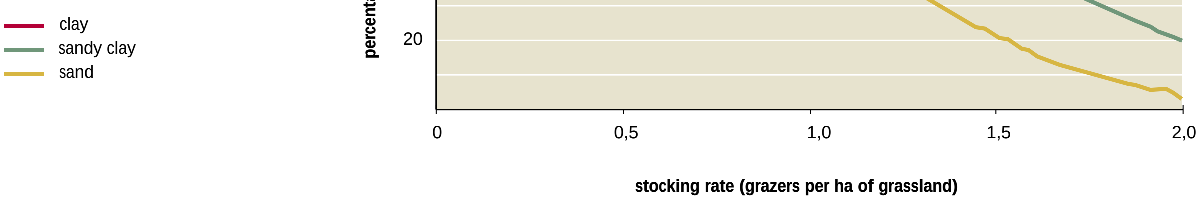
11.1 How does grazing function?

Cattle and horses are typical grazers that for their maintenance and growth mainly depend on grasses, especially those of dry grasslands (Cornelissen & Vulink 2001). The habitat use of these herbivores is then determined mainly by the production of grassland, which mainly depends on the fertility of the soil. The fertility is closely related to the clay content of the soil.

At low stocking rates, the grazers can fulfil their demands almost exclusively with the available grasses (figure 11.1). In a varied landscape with grazing at low stocking rates, the diet does not consist of grasses alone. Dependent on the available grasses and on how low the stocking rate is, about 5 to 20 % of the diet consists of tall herbs, helophytes, coarse graminoids, shrubs and trees. At low stocking rates the grazers concentrate on the dry grassland. Part of the grassland is grazed intensively and remains short. The other parts of the grassland are grazed more extensively and become taller. Other vegetation types, which are less attractive to cattle and horses, are not or hardly used at all at low stocking rates, and develop into a rough vegetation. The development of riverine scrubs and forests is not prevented at low stocking rates.

At high stocking rates, the grazers can no longer fulfil their complete demands with the available grasses. They are forced to take up plant species of other vegetation types. In this case, almost the complete area of dry grasslands is kept short. The pressure on the other vegetation types is larger than at low stocking rates, and the rougher vegetation types can be transformed into grasslands. Development of scrubs and forests can be stopped at high stocking rates.

Figure 11.1
Relation between stocking rate and percentage of grasses in the diet (based on dry matter intake) of grazers such as cattle and horses, dependent on the fertility of the soil (clay content) in the area and thereby the net primary production of grassland (clay: high production; sand: low production).



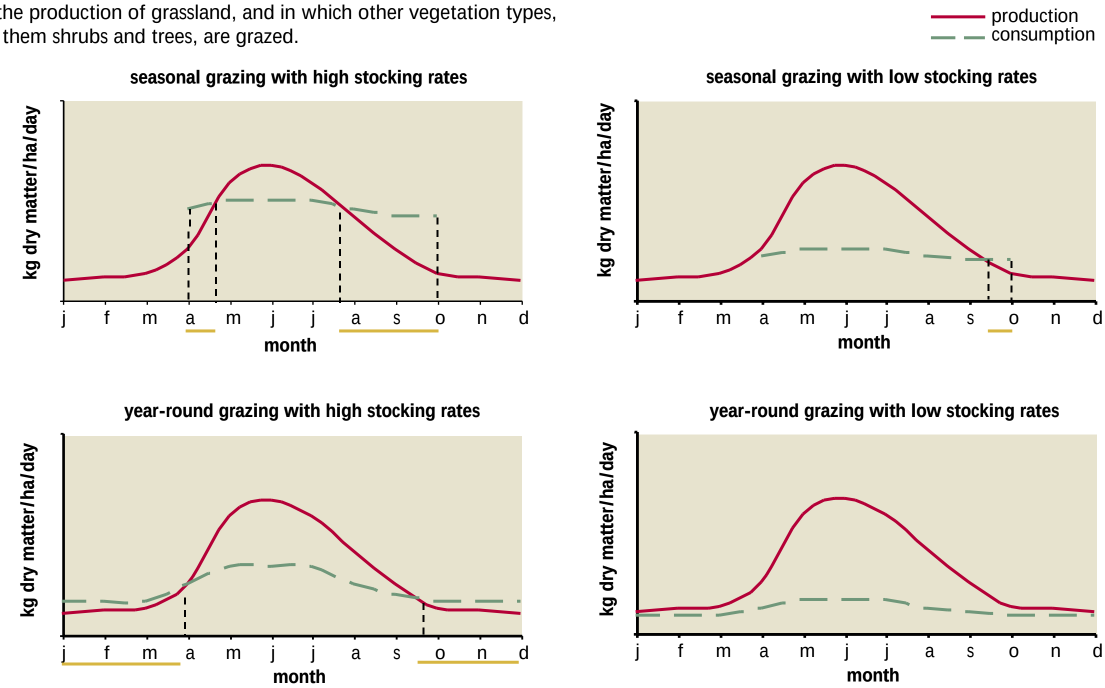
Based on the general remarks mentioned above, an estimate can be made how grazing pressure will be distributed in an area with a given vegetation type, soil type and numbers of grazers per ha. In the floodplains the grazers will mainly concentrate on the dry grasslands on the heavier and richer soils.

In rehabilitation plans often parts of the floodplain are lowered or water bodies are created. In this process, the clay is excavated till the sandy subsoil is reached. On these sandy soils vegetation types develop which are less attractive to cattle and horses than the higher grasslands.
On these sandy soils the conditions are, during the first years, quite favourable for the germination of willows; large amounts of these can germinate. At low stocking rates there is a chance that the grazers will not use this area. If that is the case, the vegetation becomes taller, and scrubs and forests can develop. To prevent that, the grazing intensity must increase to force the grazers to use the rest of their territory as well.

Increasing the grazing intensity has disadvantages too. It may counteract the development of scrubs and forests, but vegetation types that cannot withstand high grazing intensities, such as valuable floodplain meadows and helophytes, will disappear.

The net primary production of grassland during the year, in combination with the stocking rate, determines the habitat use and thus the effects of grazing (figure 11.2). Dependent on the type of grazing longer or shorter periods are found during the year, in which the consumption is higher than the production of grassland. In these periods the quantity of high quality grasses is low, which forces the grazers to use other vegetation types. Figure 11.2 shows that at high stocking rates the other vegetation types, amongst them scrubs and forests, must be grazed during 4 to 6 months in order to fulfil the demands.

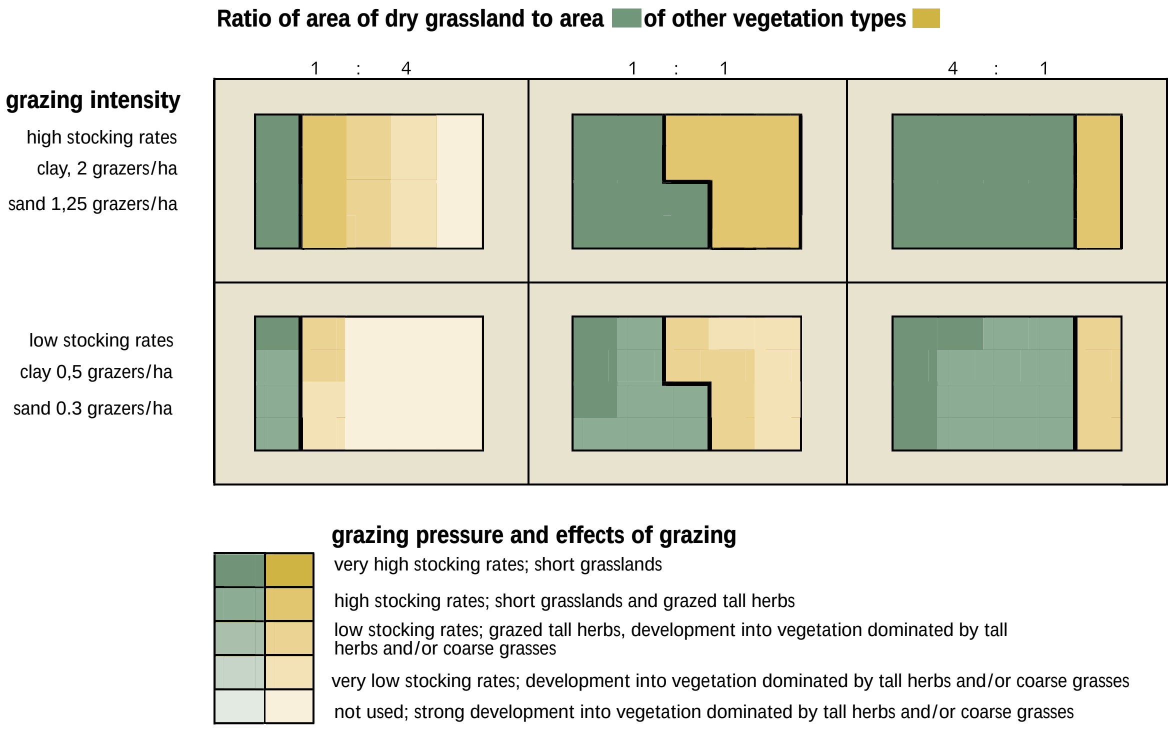
Figure 11.2
Theoretical relation between the net primary production of grassland and the consumption by cattle and horses (based on dry matter). The consumption indicates the need (maximal consumption) of cattle and horses. The horizontal grey bars beneath the months indicate the periods in which the consumption exceeds the production of grassland, and in which other vegetation types, amongst them shrubs and trees, are grazed.



The way in which in a new area the grazing pressure is divided during the first year and the following years, largely depends on grazing intensity and the ratio of area of dry grassland to area of other vegetation types (figure 11.3). Dependent on these two factors situations can develop from uniform, short vegetations to a mosaic of short vegetations, grazed rough vegetations and rough vegetations. Other factors that play a role are the variations in grazing intensity in time and the type of grazer. If grazing intensity is the same each year and grazers show the same grazing behaviour, hard limits will develop between the various structure types. If grazing intensity is reduced once every few years, certain parts of the vegetation have a chance to become taller, and gradients between the various structure types have a chance to develop.

It is possible that after rehabilitation of a floodplain the grazing pressure at certain locations is not high, while this is desirable from the point of safety against floods. In those cases the habitat use of cattle and horses must be adjusted, or additional measures, such as temporary increase of stocking rates, mowing or cutting are needed.

Figure 11.3
Schematic view of the spatial effects of grazing by cattle and horses on the structure of the vegetation, dependent on grazing intensity and the ratio of the area of dry grassland (preferred habitat for cattle and horses) to the area of other vegetation types. Grazing intensity is expressed as the number of grazers per ha dry grassland. The ratio of the areas of the vegetation types is just indicative.

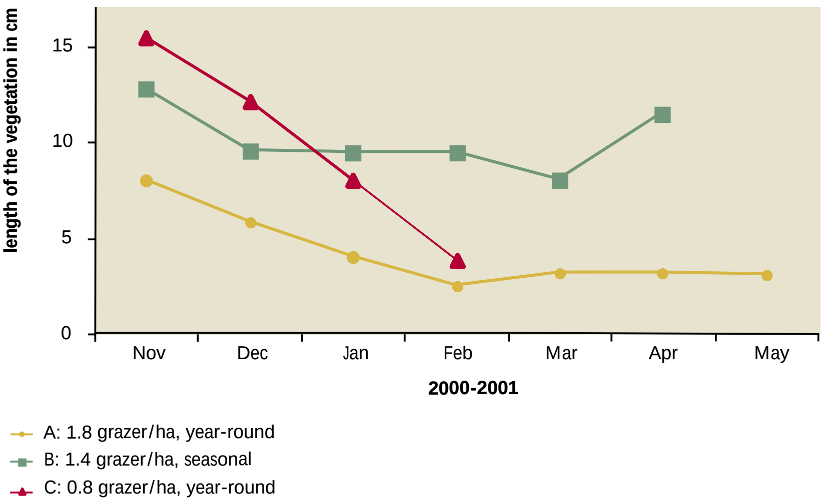


Until now the main focus has been on the consequences of stocking rates for vegetation development. The other way round stocking rates have consequences for the cattle themselves. At low stocking rates the grazers will predominantly feed on the grasses of dry grassland, which results in a high quality diet. This results in a good body condition of the grazers. At high stocking rates the grazers have to feed on different plant species as well, with a lower quality than grasses. The poorer quality of the diet can have consequences for the condition of the grazers, especially so in winter. The fertility of the area plays a role too. When determining grazing intensity, not only the desired development of the vegetation must be considered, but also the performance of the grazers, especially if the choice is on year-round grazing.

11.2 Hydrological, morphological and ecological functioning

Hydrological functioning
With the help of grazing management the hydraulic resistance of the floodplain can be reduced, because the length of the vegetation is reduced. Dependent on the grazing intensity and type of grazing management the vegetation can be grazed to various lengths (figure 11.4). Reduction of the grazing pressure by half leads to a doubling of the vegetation length (cf. year round grazing, figure 11.4A and C).

Figure 11.4
Relation between vegetation length, stocking rate and time. Stocking rate is expressed as the number of grazers per ha grassland. In area A year-round grazing is practiced with horses, during summer extra cattle are let in. In area B summer grazing with cattle is practiced. In area C year-round grazing with cattle and horses is practiced, with additional feeding during winter. Based on data of the grazing research in river areas project by RIZA.



For safety the winter situation is most important. With year-round grazing the vegetation length is reduced in the winter to its minimum. With summer grazing (from May to October) the length remains constant during the winter at the level that is reached when the grazers are taken out of the area, on average at the end of October. Summer grazing from May to October and a stocking rate of ca 1.5 grazers per ha grassland is a less desirable option from the point of safety, which asks for minimal resistance in winter. By increasing stocking rates or lengthening the grazing period the vegetation length can be reduced to a level that is acceptable for safety.

Development of shrubs and trees can be counteracted to a certain degree. Defence mechanisms of the shrubs and trees play an important role in this. Secondary plant compounds (e.g. toxins produced by elder) and defence mechanisms such as thorns (for example in hawthorn) prevent the plant from being eaten by herbivores. Development of willow forest can be prevented with the help of grazing with cattle and horses, provided the grazing pressure is high (figure 11.5). Development of hawthorn cannot be prevented by grazing (figure 11.5).

When large herbivores are left free to choose where they want and don’t want to graze, the situation might develop that short and structured vegetations or scrubs and forests develop on locations where this is not allowed from the point of safety. Adjustment of the grazing management or temporary extra measures such as mowing or using extra grazers is then needed.

Figure 11.5
Effects of grazing on shrubs and trees. At high stocking rates grazing can suppress the development of willows. Hawthorn and other shrubs and trees with secondary plant compounds or other defence mechanisms are able to survive in grazed grasslands without problems. The photograph on the left shows the situation of the development of willows within and outside of an exclosure in the Afferdensche en Deestsche Waarden floodplain (high stocking rates). The photograph on the right shows the development of hawthorn in grazed grassland in the Duursche Waarden floodplain (low stocking rates).

Morphological functioning
As a result of grazing the chances of erosion in the intensively used parts of the area with a sandy subsoil increase, because the vegetation cover is opened up (figure 11.6). In extensively used areas, which have a taller vegetation, more sedimentation occurs.
Integraal en ecotoopgericht beheer

Ecological functioning
Grazing with large herbivores is a natural process that is part of the river area. By grazing, combined with the river dynamics, a varied pattern of vegetation types and structures is developed (figures 11.7 and 11.8). Grazing also slows down or even reverses the succession of the vegetation. Because of these effects suitable habitats for many plant and animal species are created. The increase of the diversity of habitats contributes to the increase of the biodiversity in the area.

Figure 11.6
Grazing effects on sandy soils.
The photograph on the left shows a distinct reduction of the vegetation cover in the grazed area, when compared to the ungrazed section within the exclosure. The photograph on the right shows the effect of trampling, combined with that of the water level. A few weeks prior to the moment this photo was taken the water level was higher. The horses and cattle in this area moved mainly along the water line when moving from one grazing location to another. By the intensive trampling ridges are developed where the vegetation cover is destroyed and open sand comes to the surface again.

11.3 Recommendations

Grazing management can be organised in different manners. The type of grazing management depends to a large extent on the aims. In this chapter the possible choices between integral and ecotope-oriented management, between cattle and horses and between summer and year-round grazing will be considered in more detail.

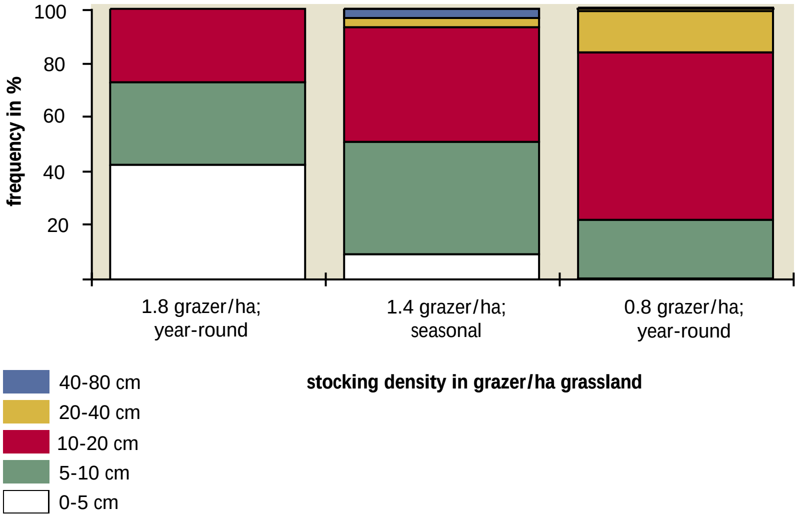
Objectives of the terrain management.
Though this may sound obvious, it is important to formulate one exact objective of management. Practice shows that often several objectives are defined, that may be contradictory to each other. As a result the aims are not obtained. For example: safety demands a clear distribution of vegetation structure, while integrated management with self-regulating herds leads to unpredictable developments, that may change in time (figure 11.9). Such developments may cause the need for additional measures to secure safety.

Figure 11.7
Changes in structure patterns, determined by grazing and river dynamics. Because of a long flood period in the spring of 1999 the grazers were forced to graze on the higher grassland more intensively. These false colour photo's show the structure of the grasslands: the dark red colour shows the taller vegetation and the pink the short vegetation. Photographs made in the Stiftsche Waarden floodplain, where summer grazing with cattle (ca 1.5 grazers per ha of grassland) is practiced.

August 1997

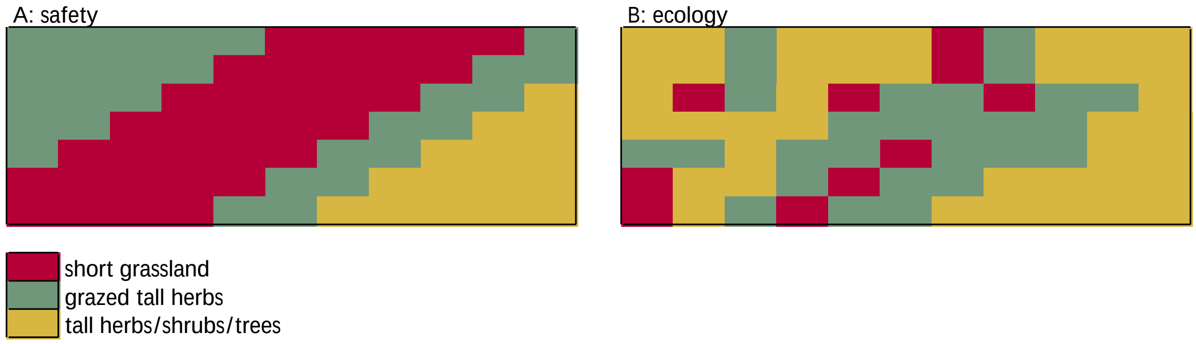
August 1999

Figure 11.8
Relation between stocking rate and grassland structure. At high stocking rates the lowest number of length classes is found, only the lower classes. About 40% is made up by short grazed grassland. At low stocking rates all classes are found, but the share of very short grazed grassland (0 to 5 cm length) at the lowest stocking rates is very low (1%). The graph is based on data of October 2000.



In larger floodplains there is no need to have a uniform goal for the whole area, because it is not a requirement that the vegetation be short everywhere (figure 11.2). This means that the floodplain can be divided into several units, each with its own goal. This does not mean that it is necessary to have several units, strictly divided by fences and each with its own type of management. Integral management is still possible, but in some units additional management measures are required, such as temporary higher stocking rates, mowing or cutting.

Figure 11.9
Desired vegetation structure from the point of view of safety (A) and ecology (B) for an imaginary floodplain. For safety the location of the ecotopes should be fixed and static, while for ecology these locations are determined by natural processes, which can change in the course of time.



Integral and ecotope-related management
The grazing management of an area can be organised integrally (one type of management for the whole floodplain) or ecotope-oriented (a specific type of management for each ecotope). Grazing is a management tool that is suited pre-eminently for integral management of varied landscapes. Integral management comes closer to natural processes of landscape formation than ecotope-oriented management. However, the possibilities to adjust the development of the landscape into the desired direction are reduced to some extent. This involves the possibilities to develop ecotopes in certain ratios, the exact locations of ecotopes and their quality.
Some adjustment is possible by regulation of the stocking rates, the period of grazing (summer or year-round grazing), the choice of the grazers and by measures that influence the habitat use by the grazers.

The choice between integral and ecotope-oriented grazing management depends strongly on the goal one has for the development of the area. If in this goal the accent is put on the development of a mosaic of ecotopes, and if the location of these ecotopes is determined by natural processes, integral management is recommended. If the location of the ecotopes is predetermined, for example for reasons of safety, ecotope-oriented management is recommended. If no factors are present to determine which method is best the general preference is given to integral grazing management, because this is a more natural form of management.

Year-round and summer grazing
In principle a choice must be made between summer and year-round grazing. According to the presently prevailing opinion, year-round grazing is a more natural form. This is only the case if both a summer and a winter

habitat are present, though not necessarily in the same floodplain. A summer habitat in the floodplain can be combined, by a proper migration route, to a winter habitat in the embanked area. If the area only consists of a summer or a winter habitat and if there are no opportunities to combine this area with other areas, summer grazing is more natural.

In summer grazing the main idea is usually a form of agricultural management, and a grazing season from May to October. This period is mainly determined by the availability of food in the grassland. Moreover in agricultural management the stocking rates is determined by economic motives; the stocking rates is often high as a result of this factor. In a more natural form of grazing management these economic motives are less important, and the grazing season can be made dependent on other factors, such as the river water levels. If in periods with high river water levels (usually in the months December to March) the grasslands are inundated the cattle are moved out, and when the water level has fallen again they are brought back again. The stocking rates can vary in summer grazing from very high to very low. This makes this form of management very suitable for both integral and ecotope-oriented grazing management.

In year-round grazing two forms can be distinguished: with and without additional winter feeding. Without additional feeding is more natural than with, assuming the area includes both a summer and a winter habitat. With additional feeding however very high grazing densities can be obtained, which makes very short grazed vegetation in spring and summer possible. Dependent on the amount and the duration of additional feeding, this form form will resemble seasonal grazing to a certain degree. With additional feeding the chances are great that the development of scrubs and forests is not counteracted enough. Without additional feeding the whole area is used by the herbivores. The cattle are forced to take up alternative sources in autumn and winter, when no grass is available, such as tall herbs and wood (twigs and bark). Experience with extensive year-round grazing without additional feeding shows that the development of scrubs and forests is still not prevented, because the stocking rates is too low (Cornelissen & Vulink 2001b). Year-round grazing without additional feeding is possible only at relatively low stocking rates, because sufficient food sources must be kept available during the winter. The stocking rates with year-round grazing with additional feeding can vary from extensive to intensive, dependent on the amount of additional feeding. As indicated before this type of grazing management will then resemble seasonal grazing, to some degree.

If year-round grazing is chosen, one or more elevated areas must be available where grazers can stay for longer periods. If no elevated areas are present within the floodplain, one can look for them in the embanked area. If the cattle should be able to reach these safe areas in the embanked area, some arrangements must be made on the dike, such as the construction of fences and grids.

Cattle and horses
Although cattle and horses have diets that are quite comparable (mainly grasses), some marked differences can be indicated in habitat use. Cattle often use a larger part of their terrain than horses (Cornelissen & Vulink 1996; Cornelissen *et al.* 1995). Horses show a stronger tendency to graze on the same locations for a longer period. Cattle will consequently spread their grazing pressure more over the whole terrain, resulting in a gradient

from very intensively to very extensively grazed parts. Grazing by horses results in very intensively grazed parts, next to very extensively grazed parts, with nothing in between. If the goal is to reach a maximum diversity in vegetation structures, a combination of cattle and horses is recommended.

Another important difference between cattle and horses is caused by the fact that cattle are ruminants and horses hindgut fermenters. As a result cattle can cope better with plant species that produce secondary plant compounds than horses, because cattle can detoxify toxins to a certain extent (Freeland & Janzen 1974). For example elder, which produces cyanogenic glycocides, is eaten by cattle, but not by horses. This can have consequences for the development of elder, if grazing is only by cattle or horses. With relatively high stocking rates the surface of the grassland will be opened by grazing and trampling grazers. This offers germination opportunities for plants. The young elder is not eaten by horses; elders can than develop and expand.

Management of cattle and horses

The use of cattle and horses in floodplains demands some efforts for their management and care. The area must be equipped with a fence that is strong enough to withstand the floods. The litter that is left in these fences after a flood must be removed, in order not to cause a damming effect during the next flood. Because cattle and horses are kept grazers, all of them must be given medical care. This implies regular veterinary attention and control. With year-round grazing this means that the grazers must be gathered once or several times a year. With seasonal grazing this requires no special efforts, as the grazers are gathered twice a year anyway when they are moved into and out of the area. Both in the case of seasonal as year-round grazing this means that a corral must be built to hold the cattle temporarily and make them manageable.

How to deal with polluted soils

In many floodplains polluted soils are found. These pollutants can end up in the herbivores by plant uptake, and accumulate there in several organs. If the herbivores are exposed to these circumstances for long periods, they might suffer adverse effects of it. Until now no cases are known of cattle of private farmers, or the cattle in nature areas in floodplains, that have experienced any problems because of the polluted soils in the floodplains. This might be related to the duration of their presence in the floodplains, or with the fact that so far no research was aimed at these matters. Cattle owned by private farmers on the average is only present in the floodplains for one or a few years, while the effects of polluted soils manifest themselves only in the long term. In nature areas the grazers remain for longer periods, but so far no research has been carried out into the effects of pollutants on them.

Table 11.1
Summary of recommendations.

Goal	Recommended management
100% safety (development of of tall vegetation, scrubs and forests is counteracted)	• Year-round or summer grazing at low or high stocking rates with additional management (mowing or cutting). • With grazing at low stocking rates a more varied spatial vegetation structure will develop than with grazing at high stocking rates, both in the case of year-round and summer grazing. • With grazing at low stocking rates more additional management is necessary than with grazing at high stocking rates. The type and degree of additional measures depend on the boundary conditions that are defined by safety.
X% safety Y% natural processes	• Definition of management units aimed at safety and nature development. • Integral year-round grazing with self-regulating populations, with an elevated area on which sufficient food is available to maintain the herds of herbivores during inundations of the floodplains. This elevated area may be situated within the floodplain, but also outside of it, as long as the grazers are free to move between the elevated area and the floodplain. • If self-regulation is not possible it is recommended to vary the numbers of herbivores in time. This simulates the fluctuations in the populations that are expected in natural populations. • Additional management is required in the units with main goal of safety only.
100% natural processes	• Integral year-round grazing with self-regulating populations, with an elevated area on which sufficient food is available to maintain the herds of herbivores during inundations of the floodplains. This elevated area may be situated within the floodplain, but also outside of it, as long as the grazers are free to move between the elevated area and the floodplain. • If self-regulation is not possible it is recommended to vary the numbers of herbivores in time. This simulates the fluctuations in the populations that are expected in natural populations.

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List of abbreviations

DLO	Directorate for Agricultural Research
EHM	Ecological Rehabilitation of the River Meuse
EMOE	Ecohydrological Model for the Bank Vegetation of Estuaries
MHW	Mean High Water level
MLW	Mean Low Water level
MSL	Mean Sea level
IRMA	Interreg Rhine Meuse Activities
LNV	Ministry of Agriculture, Nature Management and Fisheries
NUGH	Master plan for the Green Heart
NURG	Master plan for the River Landscape
PAH	Poly Aromatic Hydrocarbon
PCB	Poly Chloor Bifenyl
RIZA	Institute for Integrated Water Managament and Waste Water Treatment
RvR/RVR	Room for Rhine Branches and Room for Rivers
RWS	Directorate General for Public Works and Water Management
RWS-DLI	id., Directorate Limburg
RWS-DON	id., Directorate Eastern Netherlands
VenW/V&W	Ministry of Transport, Public Works and Water Management
VROM	Ministry of Housing, Spatial Planning and Environment
WL	Waterloopkundig Laboratorium/Delft Hydraulics

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