Embanked river reaches in the River Rhine depositional zone – II. Rehabilitation planning

Submitted to Geomorphology

ABSTRACT

To incorporate geomorphological expertise into river rehabilitation projects, a cyclical planning procedure has been used as a framework in which stages of plan design and plan evaluation follow each other several times. The role of research in supporting planners in these stages is elaborated in two case studies on the embanked River Rhine depositional zone. In the first case, covering a major part of this zone, river rehabilitation priorities were derived from historical reference situations, and the suitability of river reaches for the associated geomorphological processes was examined. Measures are required that trigger or mimic the original dynamics of the river system, such as the creation of secondary channels to rehabilitate former shallow channel habitat dynamics, and the lowering of the floodplain surface to reconnect the river's channel and floodplain again. This information was applied in the second case, dealing with the landscape of the smaller Gelderse Poort area. Inspired by the differences between river reaches, two land use scenarios could be formulated with different ecological objectives, management types and spatial strategies. Insight into the varying impacts of fluvial processes was an aid in the examination of the compatibility of rehabilitation targets and the other river and land use functions and resulted in spatial layout proposals. The feasibility of measures and the effects on vegetation and fauna species were evaluated using the landscape ecological LEDESS model. During the planning process, research activities gradually changed from monodisciplinary to interdisciplinary. The results demonstrate that at least two scales should be investigated to attain a realistic plan. They also draw attention to the following: (1) the geomorphology of the river system has degraded throughout the last century, (2) contemporary river reaches still vary dramatically in both landform patterns and processes, and (3) a geomorphological analysis can help in setting realistic goals for rehabilitation.

KEYWORDS
Floodplain ecology, Geomorphology, River rehabilitation, Secondary channels, River Rhine, the Netherlands
INTRODUCTION

Rehabilitating the integrity of river systems requires space for geomorphological and ecological processes and their associated natural landforms and riparian vegetation. However, increasing the area designated for nature may have serious impacts on functions such as flood defence and navigation. Enlarged areas vegetated by natural floodplain shrubs and forests will increase the flow resistance of the floodplain and may raise the water stages during high discharge events to unacceptably high levels. Removing bank protection structures, or re-creating secondary channels, may result in deposition and an unacceptable shallow depth of the main channel. River rehabilitation thus requires a careful balancing of multiple uses of floodplain land and water resources. Addressing the conflicting interests has become one of the main challenges of modern, integrated water management in the late 1990s.

The solution to many problems can be found in an integrated planning process, in which the various land use claims are assigned to those parts of the river system that are most suitable. Such a planning process can follow a cyclic procedure (Fig. 8.1), in which plan design and plan evaluation alternate (Harms et al., 1993). Plan design is a creative activity, often resulting in one or more scenarios for future land use. Baseline information, rehabilitation priorities and spatial concepts are the building blocks of the planner in this stage. Plan evaluation is a more analytical procedure in which the effects of the scenarios are investigated. Usually, models are used in this assessment. The results of the evaluation may lead to a new and more detailed planning cycle (Fig. 1.1). The cyclic procedure was applied successfully in the planning of both large and small areas (400,000–12,000 ha), and thus may be used at various spatial scales.

Generally, scientists supporting the planning process will raise the following four questions where nature is concerned (Klijn and Harms, 1990): (1) Are there reference

![Fig. 8.1.](image-url)  
The cyclic planning procedure
situations for nature rehabilitation? (2) What conditions must be fulfilled to realise such situations? (3) Which areas are suitable for successful rehabilitation? (4) What measures must be part of the spatial layout? Answers to these questions should be based on sound knowledge of the disciplines involved, one of which is geomorphology. The role of geomorphology in river rehabilitation is, however, only beginning to be addressed (Brookes, 1995a; Boon, 1997) and certainly requires further development in a spatial planning context with which most geomorphologists are not familiar. This paper provides a framework for integrating geomorphological expertise in the process of river rehabilitation planning. The aims are: (1) to indicate the type of studies involved in the design and evaluation stages, and (2) to demonstrate that at least two scale levels should be investigated to attain a realistic plan.

As an example, two related case studies are presented which build on the results of the study described in Chapter 7 on the historical geomorphology of the River Rhine depositional zone (Fig. 8.2). The first case covers the major part of this zone. At the level of river reaches, rehabilitation priorities are identified (design stage) and the contemporaneous suitability of the various reaches explored (evaluation stage). The results are applied in the second case, dealing with the landscape of a much smaller area, the Gelderse Poort. Different land use scenarios are formulated and implemented in a spatial layout at the landform level (design stage), and the feasibility of proposed measures is analysed (evaluation stage). First, the connections between geomorphology and river rehabilitation policies, ecological concepts and planning instruments are outlined.

![Fig. 8.2.](image_url)
Locations of the two study areas within the River Rhine depositional zone
ROLE OF GEOMORPHOLOGY

Rehabilitation policies

At present, river rehabilitation policies in the Netherlands are an important source of inspiration for many scientists. The prospects for applied geomorphology have been growing steadily since the late 1980s, induced by developments in river ecosystem management, spatial planning and flood control (Table 8.1).

Large amounts of toxic chemicals were released into the River Rhine during a fire at the Sandoz chemical factory near Basle, Switzerland, in 1986. It caused the death of enormous numbers of fish and focussed attention on the ecological function of the river. Although international cooperation to improve water quality began in 1950s, the accident triggered the formulation of additional policies to improve the situation for migratory fish and increase the diversity of species (Van Dijk et al., 1995). In 1987, the Rhine Action Programme was published, followed by an Ecological Master Plan describing how the targets agreed upon by the Rhine countries are to be achieved by measures encompassing both the channel and the floodplain areas (Schulte-Wülwer-Leidig, 1991).

Meanwhile, a new strategy for nature conservation in the Netherlands has been introduced. As the Netherlands is one of the most densely populated countries of Western Europe, increasing urbanisation and the associated needs for infrastructure are seriously threatening the values of Dutch landscapes (Vos and Zonneveld, 1993). It was recognised that nature conservation policies alone cannot safeguard these values, and a more offensive approach was advocated. Aspects of the new strategy are separation of the high-dynamic land use functions of rural areas (e.g. agriculture, infrastructure) from low-dynamic land use functions (e.g. nature, recreation), and the creation of relatively large areas for both categories so that they can develop more independently (De Bruin et al., 1987; Sijmons, 1990). The new ideas on rural land use planning were elaborated in the Nature Policy Plan. The central element in this plan is the National Ecological Network: a network of natural areas that are connected with each other by smaller stepping stones, enabling migration of species (Ministerie van Landbouw, Natuurbeheer en Visserij, 1990). For its realisation, various rehabilitation projects have been proposed. Within the 29,000 ha of Rhine floodplains, the 8000 ha designated for nature at present are to be enlarged by another 8000 ha by 2018. These areas mainly include riparian grasslands and wetlands.

Major floods in the German and Dutch parts of the River Rhine system occurred in 1993 and 1995. In January 1995 more than 200,000 people had to be evacuated from the area adjacent to the embanked river floodplains. These floods raised awareness once again that the discharge of water and flood protection will remain the first priority river function. Moreover, studies on the impact of future climate change indicate a 5% increase in peak discharges during winter and early spring, which may be expected around 2050 (Kwadijk, 1993; Haasnoot et al., 1999). In the light of this information, policy making and the implementation of integrated rehabilitation plans were speeded up considerably. As a result, rehabilitating the integrity of river systems has become a major issue in forthcoming national and regional policies for spatial planning (Waterloopkundig Laboratorium, 1999; Ministerie van Verkeer en Waterstaat, 2000).
River ecosystem concepts

Ecological concepts describing the functioning of the river system are crucial for river rehabilitation (Townsend, 1996; Lorentz et al., 1997). Following such concepts, rehabilitating geomorphological processes and patterns is essential to the success of rehabilitation policies. The most fundamental and most widely applied concepts are the River Continuum Concept (Vannote et al., 1980) and the Flood Pulse Concept (Junk et al., 1989).

The River Continuum Concept emphasises the longitudinal gradient within temperate river systems. Associated with the increase in discharge and channel dimensions in the downstream direction, various biologically important features – such as availability of light, water temperature and food resources – change as well. This results in a continuum of habitat types. The river continuum is related to the establishment of an equilibrium river profile and is maintained through the transport and downstream fining of sediment and organic matter. Depending on the geological setting, these processes result in various river reaches, each with characteristic landform patterns and related habitat conditions.

The Flood Pulse Concept emphasises the function of flooding events in the exchange of nutrients and species between the river channel and the various floodplain habitat types. The flood pulse is associated with the processes of erosion and deposition, which are essential to rejuvenating the floodplain ecosystem. The storage of sediment results in an important lateral zoning in process dynamics, to which the river biota are adapted. Restrictions imposed by the flow and sediment transport decrease away from the channel, but restrictions imposed by flooding increase with decreasing height of floodplain landforms.

System classification and modelling

Generally, the planning process starts with a resource inventory to gain sufficient knowledge of the various land units and associated potentials (Peck, 1998). A resource inventory implies the use of a classification system, enabling the collection and presentation of information in a systematic way (Lotspeich and Platts, 1982). It provides a common language for scientists and planners as well as a basis for setting up rules in landscape ecological models. As a consequence of its role in ecological concepts,
geomorphology is among the most essential aspects in any system classifying natural resources of rivers. In the Netherlands, geomorphology has been incorporated into the River Ecotope System, which has been developed as an integrated classification system to be used in policy oriented research and rehabilitation planning in large river systems (Rademakers and Wolfert, 1994). The land and water units distinguished are called ecotopes, defined as spatial ecological units at the landscape level. The composition and development of ecotopes are determined by specific combinations of abiotic, biotic and anthropogenic conditions (cf. Leser, 1976). Following the Flood Pulse Concept, the three most important disturbance factors able to set back the vegetation succession have been selected as classification criteria (Table 8.2): morphodynamics (encompassing flow velocity, erosion and sedimentation rates); hydrodynamics (timing, frequency and duration of flooding) and anthropodynamics (land use and management). Morphodynamics are reflected in the landform configuration and hydrodynamics in the floodplain relief. Accordingly, most ecotopes may be identified and mapped by means of delineating ecologically relevant landforms. In the landscape ecological

<table>
<thead>
<tr>
<th>LAND UNIT</th>
<th>CLASSIFICATION CRITERION</th>
</tr>
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<tbody>
<tr>
<td>Physiotope</td>
<td>Ecotope</td>
</tr>
<tr>
<td>Deep sand-bed channel</td>
<td>Deep sand-bed channel</td>
</tr>
<tr>
<td>Shallow sand-bed channel</td>
<td>Shallow sand-bed channel</td>
</tr>
<tr>
<td>Secondary channel</td>
<td>Secondary channel</td>
</tr>
<tr>
<td>Slough</td>
<td>Slough</td>
</tr>
<tr>
<td>Sand bar / shoreface</td>
<td>Sand bar / shoreface</td>
</tr>
<tr>
<td>Natural levee</td>
<td>Levee ruderal vegetation</td>
</tr>
<tr>
<td></td>
<td>Levee hardwood forest</td>
</tr>
<tr>
<td>Floodplain flat</td>
<td>Floodplain grassland</td>
</tr>
<tr>
<td></td>
<td>Floodplain softwood forest</td>
</tr>
<tr>
<td></td>
<td>Floodplain ruderal vegetation / macrophyte marsh</td>
</tr>
<tr>
<td>Abandoned channel</td>
<td>Abandoned channel aquatic vegetation</td>
</tr>
<tr>
<td>Gravel-pit lake</td>
<td>Gravel-pit lake</td>
</tr>
<tr>
<td>Built-up terrain</td>
<td>Built-up terrain</td>
</tr>
</tbody>
</table>

Table 8.2.
Excerpt from the River Ecotope System
In rehabilitation strategies, measures usually aim at mitigating human interference or restoring natural situations from the past. The effects are often assessed by means of models, either to anticipate on failures and success of such measures, or even as part of an environmental impact assessment. Among the instruments used in the Netherlands, is LEDESS—Landscape Ecological Decision Support System (Roos-Klein Lankhorst, 1991; Harms et al, 1993). LEDESS is a deterministic knowledge-based system, that simulates the spatial and temporal development of vegetation and fauna. An operations model of LEDESS is shown in Fig. 8.3. Its two main functions are: (1) checking the ecological feasibility through confrontation with the geomorphological and hydrological conditions, and (2) determining the developments in vegetation and fauna. The River Ecotope System is incorporated in LEDESS when it is applied to river systems. Vegetation types are determined by physiotope, management and time required to reach a certain stage in the vegetation succession, eventually leading to the target vegetation, i.e. the vegetation type desired when implementing measures. Subsequently, vegetation determines the area suited for breeding, foraging or refuge of fauna species. Information on the succession of plant communities and habitat requirements was derived from the literature. Data on the actual situation and on the planned developments are stored in a grid-based geographical information system (GIS).
RHINE DEPOSITIONAL ZONE

Historical reference situation

The inspiration for river rehabilitation may be derived from descriptions of past situations or from relatively pristine river systems elsewhere, revealing the existence of more natural landscapes and biologically more diverse ecosystems (Bisseling et al., 1994). For instance, the international agreement to restore habitats of migratory fish in the River Rhine (Schulte-Wülwer-Leidig, 1991) refers to 19th century information about changes in channel and bar formation and about salmon, which was sold in large quantities on the markets of towns along the river. Comparing reference situations with the river system to be rehabilitated enables investigation of which phenomena and processes have been degrading through time and, consequently, the identification of the direction of change that has to be pursued (Kern, 1994; Pedroli et al., 1996). Accordingly, more comprehensive scientific data on such reference situations are useful in the rehabilitation planning process.

The geomorphological maps and description of the River Rhine in historical time, presented in Chapter 7, can be regarded as an adequate historical reference situation. It not only provides information on the various pre-channelisation landform configurations, but also aids understanding the role of fluvial processes and identifying the variables responsible for the river reach variability, such as physiographical setting and river systems history. This is why a historical approach is preferred here: not all of this information is easily transferred from other river systems since river systems can differ greatly (Hobbs and Norton, 1996). The maps were digitised, thus providing quantitative information on landform areas and changes. Following the set up of the River Ecotope System (see Table 8.2), information on ecotopes could be derived from the landform (i.e. physiotope) data, when combined with information on land use and land cover as depicted on the historical maps. The results are presented in Table 8.3.

To examine the degradation of the river ecosystem and to identify river rehabilitation priorities, the historical description is compared in Table 8.3 to the present-day distribution of ecotopes, derived from data from Silva and Kok (1996). The differences between the 18th and 19th century data can be regarded largely as the river systems’ natural variability in time. Most of the differences between the 19th and 20th century data, however, are the result of the late 19th century channelisation, which resulted in a decline of natural values, indicating which of these phenomena and processes are to be rehabilitated. The construction of groynes and revetments resulted in some major changes in channel dynamics and floodplain aggradation.

As a consequence of the channelisation works the main channels decreased in width – and increased in depth – and all secondary channels disappeared. As a result, fauna communities depending on tranquil flowing, shallow water have been reported to be degrading too (Admiraal et al., 1993). The present river ecosystem lacks islands and recently deposited sand bars, where bar formation once triggered the establishment of vegetation pioneer communities. The decrease in softwood floodplain forest cover is partly the result of this development. On the other hand, the shoreface of the main
channel is more dynamic now, which is reflected in the wide, sandy beach and the local presence of aeolian river dunes and small, sandy natural levees along the River Waal.

In the floodplains, sloughs and abandoned channels, and their associated marshes and reedlands decreased in size. The decrease of vegetation types characteristic of riparian wetlands has continued in the last few decades (Van den Brink et al., 1991; Jongman, 1992) and is considered here to be the result of lower water levels, caused by the main channel bed degradation. The intensified use of floodplain land resulted in a decrease in area of natural grasslands and a strong increase in deep sand and gravel pits and built-up areas.

Suitability of river reaches

In ecosystem rehabilitation, it is common sense to follow the philosophy of ‘design with nature’ (McHarg, 1969; Nunnally and Keller, 1979), in which natural processes are preferred as tools to achieve rehabilitation targets. In turn, it makes sense to assess the contemporaneous suitability of river reaches for reinstating geomorphological processes which were characteristic in the historical period, such as island formation, point-bar accretion and overbank deposition. Pre-conditions for the development of fluvial landforms underlying dynamic ecosystems of the Rhine distributary system have been identified in Chapter 7. It is assumed here that the very same conditions have to be fulfilled in the present-day regulated river system.

The contemporaneous values of the predictors of island formation and bar

<table>
<thead>
<tr>
<th>ECOTOPES</th>
<th>UPPER-IJSSEL</th>
<th>MIDDLE-WAAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1750 (%)</td>
<td>1840 (%)</td>
</tr>
<tr>
<td>Deep/shallow channel</td>
<td>10.42</td>
<td>10.36</td>
</tr>
<tr>
<td>Secondary channel</td>
<td>0.16</td>
<td>0.00</td>
</tr>
<tr>
<td>Slough</td>
<td>2.40</td>
<td>0.56</td>
</tr>
<tr>
<td>Sand bar/ shoreface</td>
<td>0.40</td>
<td>0.25</td>
</tr>
<tr>
<td>Levee/dune dry ruderal vegetation</td>
<td>3.03</td>
<td>2.88</td>
</tr>
<tr>
<td>Levee/floodplain softwood forest</td>
<td>3.27</td>
<td>2.20</td>
</tr>
<tr>
<td>Levee/floodplain hardwood forest</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Floodplain softwood timber forest</td>
<td>0.71</td>
<td>0.76</td>
</tr>
<tr>
<td>Floodplain grassland</td>
<td>63.05</td>
<td>66.53</td>
</tr>
<tr>
<td>Floodplain pasture</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Floodplain moist ruderal vegetation / macrophyte marsh</td>
<td>0.24</td>
<td>0.31</td>
</tr>
<tr>
<td>Abandoned channel with aquatic vegetation</td>
<td>1.43</td>
<td>1.45</td>
</tr>
<tr>
<td>Gravel-pit lake</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Arable floodplain land</td>
<td>14.22</td>
<td>14.12</td>
</tr>
<tr>
<td>Built-up area</td>
<td>0.36</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 8.3. Historical and contemporaneous occurrence of ecotopes in the floodplains of the Upper-IJssel and Middle-Waal river reaches

1 derived from: Silva and Kok (1996)
development and the historical data on the River Lek were calculated by Lambeek and Mosselman (1998) according to the methods described in Chapter 7. The width–depth ratio and the Shields parameter were calculated for the discharges (Q) occurring in 95%, 75%, 35% and 10% of the time, at various locations in the three Rhine distributaries. Envelopes of values related to these discharges are given in Fig. 8.4 and compared with historical data. This indicates the differences between past and present suitability for island and bar formation. The suitability changed dramatically since the width–depth ratio values strongly decreased due to the river regulation works. The suitability for point-bar formation, though, still varies among the river reaches. High point bars can be formed in the uppermost and lowermost reaches of the River Waal.

Fig. 8.4.
Present-day possibilities for island formation and point-bar accretion in the three Rhine river distributaries, compared with the situation before channelisation (partly adapted from: Lambeek and Mosselman, 1998)
Fig. 8.5, especially during low discharges when width-depth ratio values are relatively large and the Shields parameter value is high. These point bars, however, are not stable features: when discharges increase the width-depth ratio values decrease while the Shields parameter values remain high, indicating high transport rates and the breakdown of the bar. Only in the Lower-Waal reach, which is slightly tide-influenced, the width-depth ratio values remain constant so that a stable high point bar may develop there. In the River IJssel no point bars can develop at all, except in its lowermost reach, which is suitable for the formation of low point bars in bends.

Similarly, the suitability for sloughs, abandoned channels and marshes has been explored (Fig. 8.5). Sloughs may remain connected to the main channel along the River Waal as a result of the higher flow velocities over the floodplains during inundation. Elsewhere, the future presence of abandoned channels is guaranteed by a relatively low flooding duration where floodplains are inundated at Q 10% water levels or less, such as along the Upper-IJssel and Middle-IJssel reaches. In contrast, floodplain channels tend to silt up relatively fast in the Lower-IJssel reach and (parts of) the channelised River Neder-Rijn/Lek, because of the relatively long flooding duration there - flooding already starts at Q 35% water levels. This, and the extremely small fluctuations in water levels, make these reaches very suitable for the development of marsh vegetation.

Rehabilitation measures

Historical reference situations may help to set directions, but cannot be simply seen as
targets for river rehabilitation plans (Bal et al., 1995). With changing socio-economic circumstances, functions such as navigation, flood control and fresh-water supply gained in importance during the last century, and this is not likely to change in the near future. Moreover, the return of some of the original fluvial processes will be hampered because of irreversible effects of human influences on the river and its floodplains (e.g. Amoros et al., 1987). Bed degradation, for instance, is difficult to undo. A totally natural river system, therefore, is generally acknowledged to be an unrealistic option (Brookes, 1995b; Hobbs and Norton, 1996; Pedroli et al, 1996). Consequently, reintroducing the patterns and processes of the former river ecosystem as much as possible is the challenge of the planner. In addition, artificial measures may be required to create new circumstances that trigger or mimic the original dynamics of the various river and floodplain ecosystems. As indicated by the historical reference situation and the contemporaneous suitability of river reaches, two such measures are acknowledged to be especially relevant for the river rehabilitation process in the River Rhine distributary system: creating secondary channels and lowering of the floodplain surface.

The creation of secondary channels is an objective of various large river rehabilitation projects (e.g. Bernhart, 1992; Harberg et al., 1993; Marchand, 1993). In the Netherlands, secondary channels have been proposed as an alternative means to rehabilitate the former shallow aquatic environments with year round, tranquil water flow (Cals et al., 1998), thereby re-introducing important habitats for fish and invertebrates. Whereas groynes and revetments prevent any pronounced bar development in the main channel, secondary channels may even provide space for the development of small bars, provided that the width–depth ratio is relatively large.

The artificial lowering of (parts of) the floodplain surface is seen as a method to reconnect the river's channel and floodplain again (Van de Kamer et al., 1998). A lowered floodplain surface will increase rates of natural levee formation, which may rehabilitate the morphodynamics of the former sand and gravel bar environment. It will certainly increase flooding duration, which will lead to the rehabilitation of the former wetland environments. Both types of measures will not only increase habitat diversity, but will also decrease the hydraulic roughness of floodplains.

GELDERSE POORT AREA

Rehabilitation scenarios

River rehabilitation planners are confronted by interests and land use claims from other sectors (urbanisation, navigation, recreation, agriculture, etc.) which often conflict with nature. The prospects and expected future developments in these various sectors is uncertain. Scenario studies are believed to be useful tools for dealing with this uncertainty in the decision-making process (Schoute et al., 1995). A scenario is a description of (1) the current situation, of (2) a possible or desirable future situation, as well as (3) a series of events that could lead from the current state of affairs to this future situation. Scenario studies usually comprise more than one scenario, since the
combined impacts of external factors and scenario building assumptions generally leads to different series of events, and therefore to different future states. It is not the ambition of the scenario approach to predict the future, but to explore possible futures or the feasibility of desired futures.

One of the river rehabilitation projects in which a scenario approach was adopted was the Gelderse Poort project. The Gelderse Poort area is situated in the eastern part of the Netherlands (Fig. 8.2) at the apex of the River Rhine depositional zone. Here, the River Rhine splits up into two distributaries: the River Waal and the River Neder-Rijn. Due to its position, the area was designated as one of the core areas of the National Ecological Network (see section 2.1). Its 1000 ha of nature reserves will have to be extended by approximately 3000 ha in the near future. The Province of Gelderland started a rehabilitation planning project in which the emphasis has been on nature, but other river and land use functions were also involved, namely outdoor-recreation, agriculture, river management and sand and clay extraction. Although plans have been made for the entire area, which encompasses 12.000 ha, this paper concentrates on the 3500 ha of floodplains.

An important impetus for the formulation of the scenarios in the process of plan design was given by historical reference situations concerning the Upper-IJssel and Middle-Waal river reaches (Chapter 7). The differences in fluvial style described helped the authorities, N G O s and other stakeholders to order their thoughts on the future of nature in the Gelderse Poort area. As a result, two scenarios were formulated in which different ecological objectives could be coupled to different types of nature management and to different spatial strategies for nature rehabilitation: the Macrogradient scenario, and the River Dynamics scenario (Table 8.4; Fig. 8.6).

The Macrogradient scenario aims at diversity of species and species communities. Important ecosystem gradients are emphasized, not only within floodplains, but also between the riverine environment and the land protected by embankments. The Upper-IJssel reach is the reference situation, which is a low dynamic fluvial environment in which many types of wetlands can occur, partly influenced by seepage water coming from nearby ice-pushed ridges. Accordingly, in the Gelderse Poort area only half of the 3000 ha of new nature will be developed in the floodplain area.

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>HISTORICAL REFERENCE SITUATION</th>
<th>ECOLOGICAL OBJECTIVE</th>
<th>NATURE MANAGEMENT</th>
<th>SPATIAL STRATEGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrogradient</td>
<td>Upper-IJssel; Low dynamic</td>
<td>Bio-diversity; variety of ecosystems</td>
<td>Maximum variation in management</td>
<td>Integrating and zoning of land use</td>
</tr>
<tr>
<td></td>
<td>environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Dynamics</td>
<td>Middle Waal; High dynamic</td>
<td>Natural processes; self-sustaining</td>
<td>Little interference</td>
<td>Segregating land use</td>
</tr>
<tr>
<td></td>
<td>environment</td>
<td>ecosystems</td>
<td></td>
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</tr>
</tbody>
</table>

Table 8.4.
Characteristics of the two rehabilitation scenarios for the Gelderse Poort area
Biodiversity is to be improved by a spatial strategy of integration and zoning of land use functions, and maintained by a maximum variation in management. The result will be a landscape with a great variety of wooded plots, shrubs, hedges, grasslands and marshes. Agricultural practices in the floodplain will be reduced, both in area and in intensity. There will be space for outdoor recreation and forestry. Clearly, the objective of the Macrogradient scenario is intermediate between traditional nature conservation and the new strategy of nature rehabilitation.

The River Dynamics scenario, however, emphasises the nature rehabilitation strategy. It focusses on natural ecosystem processes, and it concentrates on the river floodplains. This scenario is based on the historical reference situation of the Middle-Waal reach, which describes a highly dynamic environment, largely controlled by the river itself. Rehabilitation of an ecosystem that is functioning as naturally as possible requires segregation of land use and excluding dynamic land use functions, such as agriculture, from the floodplain area. Human interference through nature management will be reduced to a minimum. The resulting landscape will consist mainly of floodplain forests and wetlands in which climax vegetations can develop.

**Impacts of fluvial processes**

Development of these two scenarios into a spatial layout proposal was based on a comparison with the area’s physical and socio-economic structure. The geomorphological input to the spatial layout was strongly guided by the impacts erosion and deposition were expected to have on the various river and land use functions in the Gelderse Poort area. Insight into fluvial processes, derived from the historical reference situation, made it possible to anticipate the effects rehabilitation measures were likely to have. These processes are not restricted to the location of a particular measure, but may have implications further downstream or upstream, which
complicates the design. During the design stage, however, it was shown that the benefits and restrictions from nature rehabilitation measures vary considerably within the Gelderse Poort area, so that enough space remains where nature and other functions are compatible. This will be exemplified below for two measures: creating secondary channels and lowering the floodplain surface aimed at an increase in the rates of natural levee formation.

Creating secondary channels is typical of the River Dynamics scenario. When creating such a channel, the influence of the river flood pulse will increase considerably because the minor river dikes within the floodplain will have to be lowered as well. Consequently, flooding duration and flow velocities will increase not only in the vicinity of the new channel, but also in more distant parts of the floodplain. Various factors are involved in the allocation of new secondary channels. First, the intensive use of the river for navigation hampers the development of secondary channels. New secondary channels will divert part of the water flow from the main channel, where reduced flow velocities will probably result in in-channel deposition of sediment. Such a measure thus runs the risk of contradicting the international agreement on navigation, which guarantees a minimum 2.5 m depth of the river when discharges are small. Moreover, narrowing the main channel to compensate for the loss in flow velocities is not a realistic solution in the River Waal due to its many bends, which already impose constraints on navigation by modern barges and tow-vessels. Second, the safety of embanked areas is at stake, since the creation of secondary channels is often combined with the desire to establish a greater area of floodplain hardwood forest. A floodplain forest will increase the roughness of the floodplain considerably, but this could be compensated for by excavating a new secondary channel in the same river reach. Nevertheless, in general, forests are not likely to develop where the floodplains are narrow and flow velocities during inundation are relatively high. The highest flow velocities are found along the River Waal. Third, the nature management costs have to be considered. The historical analysis showed that many secondary channels in the River Waal were blocked by sandy deposits. Until they were replaced as a habitat by younger channels downstream, the life cycle of these channels lasted for approximately 30–50 years. As the river Waal is still transporting large quantities of sand, it may be expected that the new secondary channels will need to be maintained by dredging every now and then, which is rather expensive. In contrast, the secondary channels in the River IJssel were much more stable features, a situation which is more or less comparable with the present state of the River Neder-Rijn. As a result of this analysis, two secondary channels were proposed in the Gelderse Poort area, to be situated along the rivers Rhine and Neder-Rijn.

Lowering the floodplain surface to increase the rates of natural levee formation, relies on the knowledge that levee sedimentation rates decrease as the height of the levee rises. Moreover, a broad river shoreface is known to increase the aeolian dynamics as well, and will result in small aeolian dunes on top of the levee. As this measure involves the excavation of a zone along the main channel, which will not have much impact on the remainder of the floodplain, it fits into both the Macrogradient and the River Dynamics scenario. Two factors were relevant in the planning of this measure. First,
Fig. 8.7.
The contemporaneous landform configuration in the database of LEDESS (A) and the rehabilitation measures proposed in the River Dynamics scenario (B)
excavating part of the floodplain may be financed by selling the extracted sand and gravel to the nearby construction industry or specifically for use in the dike reinforcement projects in the Gelderse Poort area. The most appropriate parts of the floodplains are likely to be found in the former point-bar environments along bends of the River Waal. Second, the success of the measure requires the availability of large quantities of sand stored in a broad, gently sloping, sandy river shoreface. These circumstances occur in the upper part of the River Waal and are related to its potential for forming low point bars. For these reasons, the stimulation of natural levee formation was proposed on various locations along the River Waal (Fig. 8.7).

Feasibility of measures and effects

The LEDESS model was used to evaluate the feasibility of the spatial layout proposal and to give an impression of the consequences of the different scenarios chosen (see section 2.3). The procedure (Fig. 8.2) started with the construction of a grid-based physiotope map with 250 m x 250 m cells (Fig. 8.7 and Fig. 8.8, A and B). Information on landforms and morphodynamics in the Gelderse Poort area was derived from historical maps and existing geomorphological and soil maps on a scale of 1:50,000. Information on hydrodynamics was derived from daily discharge data for the period 1901–1985, stage-discharge relationships for several points along the river and from information on the elevation of the floodplain surface and minor dikes within the floodplains (cf. Knotters et al., 1993). Drawing on an understanding of the relationships between vegetation and landforms, the proposed layout could be compared with the physiotope map. Where proposed land use functions were not possible under the present-day abiotic conditions, additional measures had to be proposed or the proposed layout had to be changed. The anticipated measures clearly differ in the two scenarios chosen (Fig. 8.8, C and D) and resulted in new physiotope maps indicating the conditions after measures are executed.

Eventually, these physiotope maps served as a basis to simulate the vegetation and fauna developments. These were calculated for periods of 10, 30 and 100 years. The results of the evaluation were expressed as the area suited for the vegetation and fauna communities considered. The calculation of the suitability for fauna species also considered chorological relationships between habitats and species. The effects of rehabilitation of the secondary channel is described as an example. The creation of secondary channels in the River Dynamics scenario results in a clear change in vegetation, both in the channel itself and in its surroundings (Fig 8, E and F). The development of softwood floodplain forest (Salicetum albo-fragilis and Salici-Populetum nigrae) fringing the channel is attributed to the higher rates in morphodynamics. Being pioneers in the vegetation succession, softwood floodplain forests can only be maintained in areas with processes of active geomorphological renewal. Development of a hardwood floodplain forest (Fraxino-Ulmëtum impatienstosum, Fraxino-Ulmëtum typicum and Fraxino-Ulmëtum alnetosum) in the surroundings of the channel is a consequence of the higher rates of hydrodynamics related to the removal of minor
Fig. 8.8. Comparison of the two scenarios: changes in physiotopes and the resulting developments in vegetation and cormorant community after 30 years in a part of the study area.
dikes. One of the animal species that clearly benefits from the secondary channel physiotope in the area is the cormorant (Fig. 8.8, G and H). The cormorant (Phalacrocorax carbo) requires open water rich in fish for foraging, and a combination of marshy woodland and open water for breeding. The cormorant is a bird species that can react quickly to changes in environment, and is therefore often found in juvenile habitats characteristic of areas with high rates of fluvial dynamics. The results of the scenarios were also compared with the situation that will exist after present developments have continued for 10, 30 and 100 years.

DISCUSSION AND CONCLUSIONS

Going through successive cycles in the planning procedure, the spatial planner will start with formulating desirable and possible futures, but in the end will aim at envisaging a probable future (De Jong, 1992). This is relevant to the activities and skills of the geomorphologists involved in the process. In the beginning of the planning process, research generally starts as a rather monodisciplinary action. From a geomorphological point of view, rehabilitation priorities can be suggested and planners can be informed of the associated processes and the places where these are likely to be an aid in river rehabilitation – or not. This is the type of study most geomorphologists are familiar with. But when possible futures are investigated, studies become more interdisciplinary in approach. The chances and risks of geomorphological processes have to be studied together with other experts, as was done in the second case study, with ecologists (nature), hydrologists (flood control), economists (sand and clay extraction), landscape architects (responsible for the design) and others. This requires insight into other sciences and a willingness among the project members to work with a common language and on common targets. It is the type of work which nowadays is generally awarded to consultants. In the domain of the probable future, planners will have to negotiate with politicians and stakeholders on the organisation of the land use changes and future management. It requires a transdisciplinary approach in which communication on the functions of the chosen geomorphological processes and the associated effects and costs of measures goes into details. The involvement of geomorphologists in this phase is still rare, but it might be an important challenge for applied geomorphology, leading to further improvement of the quality of plans.

The changing nature of research is also reflected in the amount of detail in the studies. In this study, a functional-geographical approach to geomorphology has been preferred above a realist approach (Richards, 1982; Petts, 1995). The realist approach relies heavily on high quality data for the detailed explanation of causal mechanisms operating in the smaller spatio-temporal domains. Often, the resulting models and data required are not available at the start of a planning project. Instead, the case studies presented have shown that description and classification – characteristics of the functional-geographical approach – can be adequate tools in the planning process. However, there are also limitations, which can be exemplified by the outcomes of the LEDESS model. Its results are indicated as numbers of grids of 6.25 ha, the size of
which is derived from the largest mapping scale of the soil maps available for the entire area and which can be regarded as the basic mapping unit of the GIS. Since maps are never a hundred per cent accurate, the corresponding basic planning unit, based on experiences of soil surveyors, is two to four times as large (Vink, 1963), between 12.5 and 25 ha. This implies that the results of the study should not be used for decisions on smaller areas. Realist models, therefore, gain in importance when the planning process advances into the possible and probable domains.

In this paper it has been demonstrated that geomorphological research on historical reference situations, and on the impacts of fluvial processes on the various river and land use functions, are meaningful to the design stages in a cyclical river rehabilitation planning process. The evaluation stages were shown to greatly benefit from the exploration of the suitability of river reaches for geomorphological processes and from the analysis of the feasibility of rehabilitation measures and their effects on vegetation and fauna. It has also been demonstrated that studying an area larger than the true planning area first, and on a larger spatial scale, results in information very valuable to the planning process. Applying such a framework to river rehabilitation planning processes, will draw attention to the following: (1) the geomorphology of river systems has degraded throughout the last century, (2) contemporary river reaches still vary dramatically in both landform patterns and suitability for processes, and (3) a geomorphological analysis can help in setting realistic goals for rehabilitation; thereby enabling politicians to make balanced choices for the future development of river systems.

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