EUROPEAN COMMISSION

Ecoflood Guidelines

HOW TO USE FLOODPLAINS FOR FLOOD RISK REDUCTION

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Table of Contents

Acknowledgements 7

Executive summary (*Edward Maltby, Martin Blackwell*) 9

PART I – Introduction 15

About these guidelines (*Martin Blackwell, Edward Maltby*) 17

What are the objectives of this publication? 17
Who should use these guidelines? 17
What is the scope of the guidelines? 18

PART II – Background 19

Flooding in Europe *(Evalyne de Swart)* 21

Why do we need to do something about flooding? 21
Why has flood risk and vulnerability increased? 22

Restoration of flooding on floodplains *(Martin Blackwell, Edward Maltby)* 24

Why should we restore flooding on floodplains? 24
How have floodplains been impacted? 24

Flood risk management (*Evalyne de Swart*) 27

What are flood risk and risk management? 27
What approaches can be taken to flood risk management? 27
What problems are associated with technical flood risk reduction measures? 30
What is a natural flood defence? 30

Floodplain processes, functions, values and characteristics (*Edward Maltby, Martin Blackwell*) 33

What are floodplain processes and functions? 33
How can we benefit from restoring naturally functioning floodplains? 34
What is floodplain rejuvenation? 34

The main characteristics of naturally functioning floodplains (*Evalyne de Swart, Tomasz Okruszko, Hubert Piórkowski*) 36

What are the interactions between river channels and floodplains? 36
Which factors shape floodplains? 36

PART III – Guidelines 39

Natural flood defences can contribute to flood risk management (*Tomasz Okruszko, Erik Querner*) 41

What are the main hydrological functions of naturally functioning floodplains? 41
What hydrological factors should I consider when implementing a natural flood defence scheme? 46
How can I determine the effectiveness of different measures? 46

Naturally functioning floodplains affect water and soil quality (*Carlos Hoffmann, Martin Blackwell*) 46

What are the main functions and processes performed by floodplains that affect water and soil quality? 48
What should I consider with regard to floodplain biogeochemistry when restoring floodplain functioning? 55

Floodplain restoration contributes to nature conservation (*Maarten Platteeuw, Wiktor Kotowski*) 60

How do plants and animals respond to natural river dynamics? 60
What has been lost and why? 64
What should I consider with regard to nature conservation when restoring floodplain functioning? 64

The roles of floodplains from a socio-economic perspective (*Ellis Penning, Alwin Gerritsen, Erik Querner, Evalyne de Swart, Marjolijn Haasnoot, Imke Leenen*) 71

How can I assess the socio-economic values of floodplains? 71
How can I assess the socio-economic consequences of changing floodplain use? 71
What should I consider with regard to socio-economics when restoring floodplain functioning? 74
What should I consider with regard to floodplain landscape when restoring floodplain functioning? 74
What should I consider with regard to human health when restoring floodplain functioning? 79

Organising a floodplain restoration project (*Ellis Penning, Maarten Platteeuw, Carlos Hoffman*) 83

Where do I start? 83
What are the main things I should do? 86
What are the main obstacles I am likely to encounter? 90
How can I fund a floodplain restoration project? 90
What are the characteristics of a successful floodplain restoration scheme? 93

Existing international policy and floodplain management? (*Maarten Platteeuw, Tomasz Okruszko, Edward Maltby*) 94

What are the consequences of conventional sectoral policies? 94
How does floodplain restoration relate to EU Directives? 95
What role can floodplain restoration play in IRBMPs? 95

PART IV – What next? 99

Gaps in knowledge (*Martin Blackwell, Edward Maltby*) 101

What are the roles of forests on floodplains? 101
What are the roles of wetlands in catchment hydrology? 103
What is the role of land management upstream of floodplain limits? 103
What is the role of floodplain management in estuarine/intertidal regions? 103
What about pollution swapping? 103
What is likely to happen in the future with regard to natural flood risk reduction measures? 103

References 105

Case Studies (*Wiktor Kotowski, Ellis Penning, Maarten Platteeuw, Tomasz Siedlecki, Evalyne de Swart*) 111

Case studies summary 113
1. Meinerswijk, Rhine – The Netherlands 114
2. Zandmaas and Grensmaas, Meuse – The Netherlands 116
3. Gamerensche Waard, Lower Rhine – The Netherlands 118
4. Afferdens-che en Deestsche Waarden, Lower Rhine – The Netherlands 120
5. Harbourne River – UK 122
6. Skjern Å – Denmark 124
7. Brede – Denmark 126
8. Elbe River – Germany 128
9. Odra River – Poland 130
10**. Łacha River – Poland** 132
11. Regelsbrunner Au, Danube – Austria 134
12. Upper Drava River – Austria 136
13. Tisza River – Hungary 138
14. Sava River – Croatia 140

Glossary (*Evalyne de Swart*) 143

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EXECUTIVE SUMMARY

The main objective of these guidelines is to promote the use of floodplains as natural flood defence measures, while at the same time optimising other compatible functions and values through conservation and restoration. It is intended that these guidelines will be used as a tool primarily by policy-makers and decision-makers who are aware of the potential advantages of floodplain restoration and management in the role of flood control, but may benefit from comprehensive guidance on assessing, initiating, funding and carrying-out such schemes as well as information on the other functions floodplains can perform. It is also intended that they will be an accessible source of information for a wide range of stakeholders with an interest in floodplain management. Case studies are provided to illustrate the wide range of schemes that can be carried out and the degrees of success that have been achieved.

Why do we need to restore floodplains?

Natural riverine environments are dynamic, often highly productive and biologically diverse ecosystems. Channel migration and flooding are important elements of this dynamism. However, society's desire to control rivers and exploit floodplains for agricultural and industrial development has meant that today as little as 2 percent of European rivers and associated floodplains can be considered as 'natural'. It is recognised increasingly that attempts to control rivers through hard-engineering activities may be counterproductive and that more natural floodplains may offer the best return in terms of societal benefits from flood control, water quality and sustainable land use. One of the driving forces behind the recognition for the need to restore floodplain functioning has been the increase in flooding in Europe in recent years and the associated increase in economic costs. While climate change and changing socio-economic circumstances have contributed to this situation, both river impoundment and changing land use are probably the main factors behind the increased flooding. Changing patterns of rainfall have simply acted to demonstrate how fragile and vulnerable these systems have become, which under natural circumstances would evolve with the changing climatic and hydrological regimes.

What is a natural flood defence?

While structural measures will be essential tools in some places for protecting property and goods, it must be borne in mind that this type of flood protection is never infallible. Natural flood defences generally offer a more efficient and long-term, sustainable solution to flood hazards. A natural flood defence is an area in which a specific set of measures has been taken to reduce flood risk and at the same time support or enhance natural floodplain functioning. Natural flood risk reduction measures are non-technical measures that contribute to the restoration of the characteristic hydrological and geomorphological dynamics of rivers and floodplains and to ecological restoration. In general, these measures aim to enlarge the discharge capacity of river channels and the storage capacity of floodplains. The protection of existing naturally functioning river and floodplain systems can



Figure 1. Example of how European rivers have been impacted: a dam across the Sava River, Croatia
Photo: M. Haasnoot/WL Delft Hydraulics



Figure 2. Example of natural flooding on the floodplain of the River Danube, Romania
Photo: E. Penning/WL Delft Hydraulics

also be regarded as an important natural flood risk reduction measure.

How can we benefit from restoring naturally functioning floodplains?

Often, the functions performed by natural floodplains provide benefits to society but their value is dependent on their actual perception by society. Functions performed may include the provision of goods (e.g. wood, plants or fish) and services (e.g. flood control, of water quality regulation and food chain support), while at the same time possessing attributes such as biodiversity and cultural heritage. These benefits may be expressed in either economic terms or in more abstract ways such as in terms of cultural uniqueness or biological rarity.

How do naturally functioning floodplains help control flooding?

One of the key hydrological functions performed by floodplains is that of floodwater detention. This is the temporary storage of water entering a floodplain either by overbank flow from a river or from adjacent hillslopes as surface or sub-surface runoff. The storage of water from these two sources delays and reduces river peak discharge. Reducing peak discharge decreases the probability of the occurrence of floods.

The types of measures that can be implemented in floodplains in order to influence the hydrology of a river (i.e. reduce peak flows and reduce downstream flooding), can be divided into two general groups:

1) Increasing water storage capacity of a floodplain. This can be achieved by:
   – increasing floodplain area,
   – increasing floodplain depth,
   – increasing storage time of water on a floodplain e.g. by increasing floodplain roughness.
2) Safe conveyance of water through a floodplain. This can be achieved by:
   – increasing floodplain area,
   – decreasing floodplain roughness.

The natural process of storing excess water during floods and its slow re-distribution during periods of low flow is key to a number of hydrological (and ecological) functions that are performed by naturally functioning floodplains.

How do floodplains affect water and soil quality?

There is a range of functions and processes that occur in naturally functioning floodplains that can affect soil and water quality. Generally these involve the import, transformation, export and/or storage of chemicals or particulate matter. Processes that involve the transformation of chemicals from one form to another are known as biogeochemical processes, and these can play a significant role in the regulation of nutrients heavy metals and other contaminants. Few biogeochemical transformation processes are unique to wet floodplain soils, but the combinations and particular dynamics of biogeochemical cycles and processes operating within them generally are restricted in ecosystems other than wetlands. Processes that involve the regulation of sediment are generally physical



Figure 3. Natural flooding on floodplains not only reduces flood discharge peaks, but supports diverse habitats
Photo: Grontmij

processes such as erosion, transportation (usually by water but sometimes by wind) and deposition or sedimentation. The main benefits that arise as a result of these various processes are water quality improvement and nutrient regulation. The restoration of wet floodplain soils as opposed to dry floodplain soils is most significant with regard to biogeochemical functions. The key functions performed by floodplain wetlands are:

– nutrient export
– nutrient retention
– carbon retention
– dissolved organic carbon regulation
– trace element storage
– trace element export

When a floodplain habitat located between upland and a river acts to improve the quality of water draining the upland and discharging into the river, it is often referred to as a buffer zone. These can be highly significant ecotones for the maintenance of good water quality in a catchment.

How does floodplain restoration contribute to nature conservation?

The dynamics of natural river systems strongly influence floodplain habitats, resulting in very specific complexes of ecosystems and habitats. The biodiversity of any given area depends upon the diversity of the physical and chemical environment and is thus enhanced by the presence of as many gradients as possible. The differentiation of the landscape by naturally functioning river systems enhances biodiversity on both the landscape and the local scale. Along physical gradients (e.g. altitude and soil composition), specialised communities and species of plants and animals have evolved through close interaction with physical factors.

In a European context, up to 80 percent of all the existing species of wild plants and animals are, at least in part, associated with river-influenced landscapes. River regulation has resulted in the widespread loss of many of these important and now rare habitats. Also, the fragmented occurrence of these habitats means that natural riverine corridors for migration of various species have been lost. Restoration of natural flooding on floodplains can result in the restoration of diverse habitats and migration corridors.

What are the roles of floodplains from a socio-economic perspective?

In today's European market economy, the fact that flooding is a vital part of a natural river system is usually ignored and floodplains are used for economic functions ranging from intensive agriculture to industrial development and housing. Flooding is often not acceptable or at best regarded as a severe hazard or nuisance, limiting human activities in an area. It is important to distinguish between flood management in floodplains that are not used intensively and flood management in highly developed floodplains because the socio-economic aspects of these two extremes are quite different. In floodplains with minimal human uses ((semi-) natural systems), the likelihood that costly damage will occur is much lower than in highly populated areas, while flooding in intensively used floodplains is likely to result in much greater damage and economic loss.



Figure 4. Diverse habitats along the Sauga River, Estonia
Photo: E. de Bruin/Grontmij

There are many functions performed by floodplains that have clear socio-economic values such as recreation, tourism, flood mitigation, agriculture and water supply. Valuation is a process that gives insight into the trade-offs of different functions of a river floodplain, both tangible and intangible. In order to be successful in implementing a natural flood defence scheme it is necessary to show the 'added value' of a proposal. Cost benefit analyses should include both tangible and intangible costs. A good example of added value is the fact that properties adjacent to newly created natural flood defences can increase in value, because of the increased attractiveness of the area.

Landscape is an important element in the public perception of a floodplain restoration project. To a large extent it determines the aesthetic perception of a project and relates to direct use values such as recreation and tourism as well as the appeal of living in a specific area. Landscape also has an existence value (non-use value) and therefore is an important feature from a socio-economic point of view. Both man-made landscapes in modified floodplains and the natural landscape of unmodified floodplains have their own values. In man-made landscapes cultural and historical elements and elements that reflect the history of occupation often are regarded as being of high value. It is a combination of these elements along with the current land use and regional folklore that gives people an emotional connection to a landscape.

Are there any potentially negative impacts from floodplain restoration schemes?

While many health benefits can arise from floodplain restoration schemes (e.g. the use of recreational areas, improved water quality etc.) it is important to consider that some aspects of floodplain restoration can potentially be deleterious to human health. Generally health threats arise because of the association of water with water-borne diseases. The nature of the threats varies depending on the potential type of restoration scheme proposed and the associated likely causes of poor health. In addition, problems can arise from the encouragement of 'nuisance' species to an area, such as mosquitoes, which not only can be annoying to the public but in some situations can be associated with specific health risks.

Many of the processes described in this document provide numerous benefits in addition to that of natural flood defence. However, it must be acknowledged that in some circumstances, while practices may alleviate certain problems, they can actually generate different problems. For example, the removal of nitrate from surface waters by the process of denitrification is generally seen as a beneficial process with regard to water quality. However, under certain conditions the main product of denitrification is nitrous oxide which is a greenhouse gas. Also, wetlands are one of the largest natural sources of methane, another greenhouse gas, and therefore consideration must be given to pollution swapping effects when implementing natural flood defence schemes.

Organising a floodplain restoration project

Organising a floodplain restoration project can be a difficult and complex task. Although several guidelines on how to initiate and implement such projects have been published most are applicable only to small streams or focus on impacts arising specifically from dam construction. The guidelines presented here aim to be applicable generally, providing practical guiding principles derived from existing knowledge on how to carry out successful natural flood defence schemes.

Integration and communication are vital when organising floodplain restoration schemes. Plans should be incorporated into spatial planning processes in order to ensure the involvement of all stakeholders, who can be local and national-level decision makers, local inhabitants, farmers, fishermen and nature conservationists. Additionally the inclusion and integration of all relevant disciplines (e.g. hydrology, geomorphology, water and soil science, ecology and socio-economics) will ensure optimal solutions are found to any problems encountered. The participation of stakeholders in water management issues is one of the means prescribed in the EU Water Framework Directive for achieving the required quality standards for water bodies. Involving stakeholders contributes to gaining a sound social basis and early participation is essential to allow people to understand the problems, to search for solutions and to participate in drawing conclusions. Without early and comprehensive involvement of stakeholders, floodplain restoration projects are likely to fail.

How does existing international policy affect floodplain management?

Although the greatest impacts on rivers and floodplains have been experienced within the last 200 years, due largely to increasing technology and engineering capacity, this has been accelerated within the last 50 years by inappropriate national and EU policies which are the most important driving forces affecting floodplain use. These policies have promoted largely sectoral exploitation of rivers and floodplains, resulting not only in the degradation of these systems but also their sub-optimal use. One of the key policy factors affecting the sectoral exploitation and degradation of floodplains has been the Common Agricultural Policy (CAP), affecting two-thirds of the European Union's land area. Historically this has promoted intensification of production through mechanisms such as fertiliser usage, land drainage and protection from

flooding, all of which have significantly impacted floodplains. Despite recent changes to the CAP for environmental benefits, many floodplains are still in a state of severe degradation.

The most important piece of recent legislation that affects the restoration and conservation of floodplains is the Water Framework Directive (EC/60/2000), although it does not explicitly address natural flood defence. Indirectly, however, the issue of flood management is included, since the Directive requires that no further deterioration of river systems is to be allowed. Reduction of flood impact is a stated goal of the Water Framework Directive, though precautionary measures are not specified.

The Water Framework Directive and the 11 water related Directives associated with it provide a mechanism for the implementation of floodplain restoration for the purposes of natural flood defence, and support not only hydrological values (e.g. flood reduction), but also many of the additional benefits a naturally functioning floodplain can deliver through promotion of good ecological status of wetlands (and floodplains).

Gaps in knowledge and the future

Despite increasing knowledge of the role floodplains play in catchment hydrology, particularly flood defence, and the many other values and benefits they can provide, there are a number of areas in which knowledge is still lacking. Further scientific research is required into the hydrological role of forests on floodplains despite some already detailed reports such as those arising from the FLOBAR Projects (Hughes, 2003), the hydrological role of wetlands, best management practices upstream of floodplain limits and floodplain management in estuarine/intertidal zones.

The factor that is most likely to impact natural flood defence schemes in the future is global change. Predictions for changes in climate vary widely, but inevitably changing patterns of rainfall and sea level rise will impact the need for flood defences, and the ways in which flooding is managed.

Increasingly, tools such as 'The Planning Kit' (Van Schindel, 2005) and the WEDSS (Modé, et al., 2002) must be used to help understand how ecosystems are functioning and the implications of different measures with regard to natural flood defence. Additionally, application of the Ecosystem Approach (Maltby, 1999) will assist in developing the processes which can lead to the most appropriate balance of natural floodplain dynamics against other social and economic priorities.

In the future it is likely that the need and demand for natural flood defences will increase. Already the construction of housing and other developments is generally forbidden or restricted on floodplains in recognition of the problems it can cause. If our rivers are to be managed in a sustainable way, it will be necessary to manage them in as natural a way as possible, and natural flood defence schemes, when managed and undertaken in the correct fashion, can form part of a holistic solution to the sustainable management of flood risk, nature conservation, water quality and economics.



Figure 5. The role of floodplain forests in natural flood defence is still unclear. (Sauga River, Estonia)
Photo: E. de Bruin/Grontmij

PART I

Introduction

ABOUT THESE GUIDELINES

What are the objectives of this publication?

The primary aim of these guidelines is to stimulate the restoration of floodplains that protect against floods and provide opportunities for the re-establishment and development of highly valuable habitats, along with other benefits delivered by naturally functioning floodplains. These guidelines provide up-to-date, state of the art information on why and how to go about such restoration projects. In addition, they provide information on why we should conserve natural floodplains already providing these functions. The Ecoflood guidelines aim to make scientific information accessible to practitioners, policy-makers, decision-makers and stakeholders, providing an over-arching framework of guidance. They bridge the gap between science and practice by means of concise case studies and by providing information on practical opportunities and constraints that might be encountered. Guidance is given on the technical, financial and social engineering aspects of floodplain restoration schemes, while recognising the existence of knowledge gaps among the research fields relevant to floodplain restoration.

Who should use these guidelines?

It is intended that these guidelines will be used primarily as a tool by policy-makers and decision-makers who are aware of the potential advantages of floodplain restoration and management in the role of flood control, and may benefit from comprehensive guidance about assessing, initiating, funding and carrying out such a scheme. A large number of case studies are included, and it is hoped that these will prove useful to policy-makers and decision-makers in raising awareness among sceptics and the unaware of the benefits that can be delivered by floodplain restoration schemes. More generally, they can provide information to a wide range of stakeholders and practitioners.



Figure 6. Floodplains can store large quantities of water during floods, reducing downstream flooding
Photo: Grontmij



Figure 7. Policy- and decision-makers contribute to the production of these guidelines at the Ecoflood Stakeholder Workshop (Delft, January 2004)
Photo: E. Penning/WL Delft Hydraulics

What is the scope of the guidelines?

These guidelines have been developed specifically for European rivers. They apply to a river's middle reaches, but not estuaries or headwaters.

The upper limit is defined as the point on a river upstream of which there is no capacity to store significant amounts of water in the floodplain.

The lower limit is defined as the tidal limit of a river, and therefore does not include the restoration of intertidal saltmarshes through managed realignment of sea defences. It is anticipated that this topic will be covered in a future project.



Figure 8. Example of a typical lowland floodplain on which water can be stored during floods (River Ottery, Southwest England)
Photo: M. Blackwell/SWIMMER

Part II

Background

FLOODING IN EUROPE

Why do we need to do something about flooding?

Floods are high water events that can cause damage by inundating normally dry areas. Worldwide there has been an increase not only in the number of floods but also in the number of people affected by them and in economic losses resulting from them. In the nine years from 1990 to 1998 the number of recorded flood disasters was higher than in the previous three and a half decades (Kundzewicz, 2002). Currently flooding causes over one-third of the total estimated costs of natural disasters and accounts for two-thirds of people affected by them. The worldwide increase in the occurrence of flooding is reflected in Europe as demonstrated by the recent widespread flooding on many Central European rivers in 2002 such as the Elbe and the Danube (Box 1). According to Munich Re (2003), the economic cost of flooding in Europe in 2002 was greater than in any previous year. Despite the fact that large floods such as those seen on the Elbe and Danube are spectacular and cause widespread damage, many smaller flood events that do not make the headlines also contribute to the growing cost of flooding.

Box 1 – Recent Major Flooding in Europe

In the winters of 1993 and 1995, Belgium, France, Germany and the Netherlands were inundated by floods in the catchments of the Rivers Rhine and Meuse. In the Netherlands the River Meuse flooded towns in the southern region and from areas along the River Rhine more then 50,000 residents were evacuated. Economic losses from the two events were estimated 1 billion and 3 billion USD respectively (Hausmann and Perils, 1998).

Two years later, in July 1997, extremely heavy rainfall caused severe flooding in the catchment of the River Oder affecting extensive areas in Germany, Poland and the Czech Republic. The highest floodwater levels exceeded all those that had previously been recorded. In addition the flooding was exceptional because of its long duration. To give an idea of the magnitude of the flooding: in Poland alone, in the basin of the Rivers Vistula and Oder, more than 5000 km^2 was flooded, more than 70,000 buildings, 3,800 bridges, 1,400 km of roads and 675 km of embankments were damaged or destroyed.

More recently major flooding events occurred across Europe in August 2002, affecting Austria, Czech Republic, Germany, Russia, Romania, Spain and Slovakia, with economic losses exceeding 15 billion Euro. The flooding was caused by torrential and long lasting rainfall. During these events numerous small and medium sized rivers flooded in Austria, Germany and the Czech Republic. In response the water level in the larger rivers such as the Danube, Elbe, Moldau and Mulde also began to rise rapidly. During the floods several major cities were flooded, for example Salzburg, Prague and Dresden. The town of Grimma was devastated by the River Mulde. During the flooding, some 60,000 residents were evacuated in Austria, a total of 200,000 in the Czech Republic and more than 100,000 in Germany's New Lands region alone. Some 4 million residents in Germany were affected and 100 fatalities were recorded, most of which occurred during flooding events near the Black Sea coast in Russia (communication from www.swissre.com).



Figure 9. Map of the area affected by the August 2002 floods
Source: Swiss Reinsurance Company, map data GfK Macon

Why has flood risk and vulnerability increased?

The observed increase in flood risk and vulnerability can be attributed to a combination of changes in the climate, terrestrial and socio-economic systems of the world, all of which are contributing towards the degradation of naturally functioning and highly valuable floodplain habitats (Kundzewicz and Menzel, 2003).

What are the effects of climate change on flooding?

The current extent and rate of climate change will probably exceed all natural climatic variations occurring in the previous millennium (EEA, 2004). There is evidence that most of the observed recent warming is attributable to human activities, particularly the emission of greenhouse gases (originating from burning fossil fuels) and land-use changes. Climate change has already expressed itself in the form of changing patterns of precipitation.

In recent times annual precipitation has increased in northern and central Europe, but decreased in southern and south-eastern Europe. These patterns of change are expected to continue into the future.

The annual discharge of many European rivers has changed over the past few decades, and the spatial variation of these changes is linked partially to the changes in patterns of precipitation described above. In southern and south-eastern Europe river discharges have been seen to decline, while in northern and north-eastern Europe they have increased. These patterns of change of river discharge are expected to continue along with the changing patterns of precipitation, resulting in a decline in annual discharge in southern and south-eastern Europe and an increase in almost all parts of northern and north-eastern Europe. It is also predicted that the contrast between summer and winter discharges will become more significant in all areas. It is foreseen that periods of intense precipitation will increase in frequency, especially in winter. This will increase the likelihood of flooding events. In addition, winter precipitation will fall more often as rain rather than snow as a result of higher temperatures, resulting in rapid run-off (due to saturation of the soil) and a greater risk of flooding (IPCC, 2001). In delta areas the expected sea level rise (expectations vary from 9 to 88 cm by 2100) will make it difficult for rivers to drain into the sea, resulting in greater risk of flooding in these areas.



Figure 10: Drainage of agricultural land can result in increased runoff and flooding
Photo: M. Blackwell, SWIMMER

What are the effects of land use change on flooding?

Land use affects runoff rates, and consequently any changes in land use can induce changes in hydrological systems and result in increased flood risk (Kundzewicz and Menzel, 2003). Deforestation, drainage of arable land, urbanisation and loss of wetlands affect the water storage capacity of a catchment and increase runoff. This results in less water retention within a catchment and higher river discharge and flood peaks.

Urbanisation has influenced the flood hazard in many catchments by increasing the amount of impervious area (*e.g.* roofs, yards, roads, pavements and car parks). Consequently increased rates of runoff occur and during intensive precipitation events the time to peak discharge of rivers decreases. The drainage of agricultural land has a similar effect (Figure 10). In mountainous areas the development of hill-slopes increases the risk of landslides and debris flows. At the same time river regulation (channel straightening and shortening, construction of embankments and reduction of the floodplain area) has increased discharge peaks especially in the lower reaches of river systems. The regulation of rivers often is stimulated by the desire to use floodplains more intensively for purposes such as agriculture or housing development.

What are the effects of socio-economic change on flooding?

The impact of floods on society has grown substantially as a result of changes in socio-economic systems. For example, a large number of incorrect decisions have been made on the location of housing developments, resulting in the establishment of settlements in flood-prone areas. Floodplains attract development because of their flatness, high soil fertility, proximity to water and availability of construction materials. Population growth, shortage of land and faith in the safety of flood protection schemes has resulted in densely populated floodplains. As a result of consequent large capital investment in floodplains (Figure 11), the economic loss potential as a result of flooding increases. At the same time much of the natural flood storage potential of floodplains is lost and riparian and floodplain habitats are destroyed.



Figure 11. Large investments connected to river systems
Photo: Grontmij

Box 2. Populations on floodplains

In the USA approximately 7% of the land surface is designated as having a 100 year flood risk, and approximately 10% of the population live in this zone. A similar proportion of people in the UK live in areas of similar flood risk, but in Japan approximately 50% of the population and 70% of the total assets are located on floodplains, which cover only about 10% of the total land surface of the country. However, the percentage of flood-prone area in Bangladesh is much higher. In 1998 flooding inundated two thirds of the country's area. In less developed countries informal settlements in floodplains surrounding cities are very common, usually established by poor people from the countryside seeking employment in towns.

Reference: Kundzewicz and Menzel, 2003

RESTORATION OF FLOODING ON FLOODPLAINS

Why should we restore flooding on floodplains?

Natural riverine environments are dynamic, highly productive, biologically diverse ecosystems. Channel migration and flooding are important processes contributing to the development of river/floodplain systems and a key part of the Flood Pulse Concept (Box 3). They are part of the natural dynamics which maintain functions such as habitats and fisheries support, but often conflict with human uses of these systems such as transport or agricultural development.

Throughout history societies have tried to control rivers and associated flooding through actions such as the construction of dams and embankments and river channelisation. Such actions largely have ignored the multiple benefits which natural riverine environments can supply (Box 4). These include regulation of water quality, provision of food supplies, biodiversity and natural flood control. The impact has been so great, especially during the last 200 years, that today as little as 2 percent of European rivers and associated floodplains can be called 'natural'. It is recognised increasingly that attempts to control rivers through hard engineering activities may be counter-productive and that more natural floodplains may offer the best return in terms of societal benefits from flood control, water quality and sustainable economics. One of the driving forces behind the recognition for the need to restore floodplain functioning has been the increase in flooding in Europe in recent years and the associated increase in economic costs. While climate change and changing socio-economic circumstances have contributed to this situation, both river impoundment and changing land use are probably the main factors behind the problem. Changing patterns of rainfall have simply acted to demonstrate how fragile and vulnerable these systems have become, which under natural circumstances would evolve with the changing climatic and water regimes.

How have floodplains been impacted?

Throughout history there has been a tendency towards isolating rivers from their floodplains, river regulation and overexploitation (Petts, 1984). Natural

Box 3. The Flood Pulse Concept

The Flood Pulse Concept is a conceptual framework for river-floodplain interactions. The floodplain is considered as the source for the majority of nutrients and provides much of the habitat in the river system, while the main channel is considered as little more than a transportation corridor through which fish and other organisms can access the channel margin resources. Floods provide the connection between the river and the resources derived from the floodplain. The Flood Pulse Concept applies to rivers where floods are predictable, occurring on a reliable schedule, and have a significant duration. The chemistry of floodplain waters is often different to that of the main channel and this can provide special habitats or resources for organisms. The ability to access floodplains during floods allows fish and other organisms to benefit from and adapt to the resources and environmental conditions found on floodplains (Junk et al. 1989).

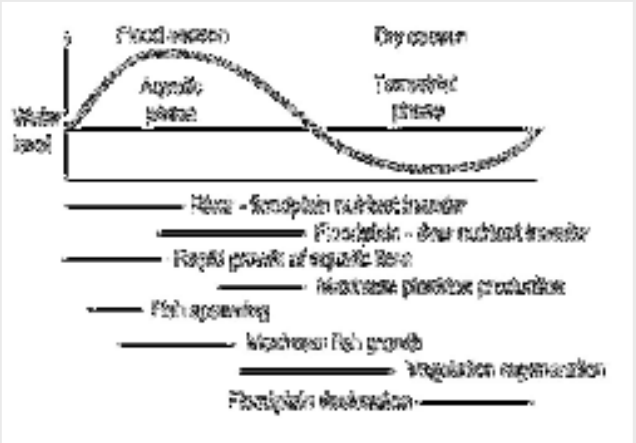


Figure 12. Generalised floodplain water level and its relationship to floodplain processes
Source: After Junk et al., 1989

flooding and migration of rivers across floodplains means development in these areas is risky and so a global culture of river confinement has developed, and in doing so, natural river evolution has been restricted. Floodplains have been routinely drained and developed to make easier the construction of routeways across valleys, allow agricultural production and human settlement and to reduce the risk of waterborne diseases such as malaria and vectors such as water snails, commonly associated with wet floodplain backswamps (Reiter, 2000).

The impacts on rivers and floodplains by humans can be of either a proximal or distal nature (WWF, 2000). Proximal impacts include those that result directly in the modification of channel form or hydrology, such as channelisation, embankment, dam construction and river water abstraction. Distal impacts originate mainly from catchment land use and other activities that affect runoff and pollution. The first large scale river regulation projects were carried out by the Ancient Egyptians, and it was their ability to regulate the waters of the River Nile that is one of the principal reason for the success of their civilisation over four thousand years ago (Baines, 2002). In Europe, deforestation of large areas of land between 4500 and 3000 years ago resulted in impacts such as changes in flow regime,

Box 4. Main reasons to restore flooding on floodplains

- *Natural patterns of flooding on floodplains can help reduce downstream flood peaks, and so contribute to flood risk management.*
- *Naturally functioning floodplains can help improve water quality and reduce the effects of diffuse pollution.*
- *Many important and sometimes rare habitats occur on naturally functioning floodplains.*
- *Floodplains are naturally dynamic systems, and need to be able to change in order to adapt to the impacts of climate change. Without the ability for adaptation, catastrophic events are more likely to occur.*
- *Naturally functioning floodplains often are important for the development of fish and other natural resources used by humans.*
- *Natural floodplains provide many other benefits that often are of very high economic value.*

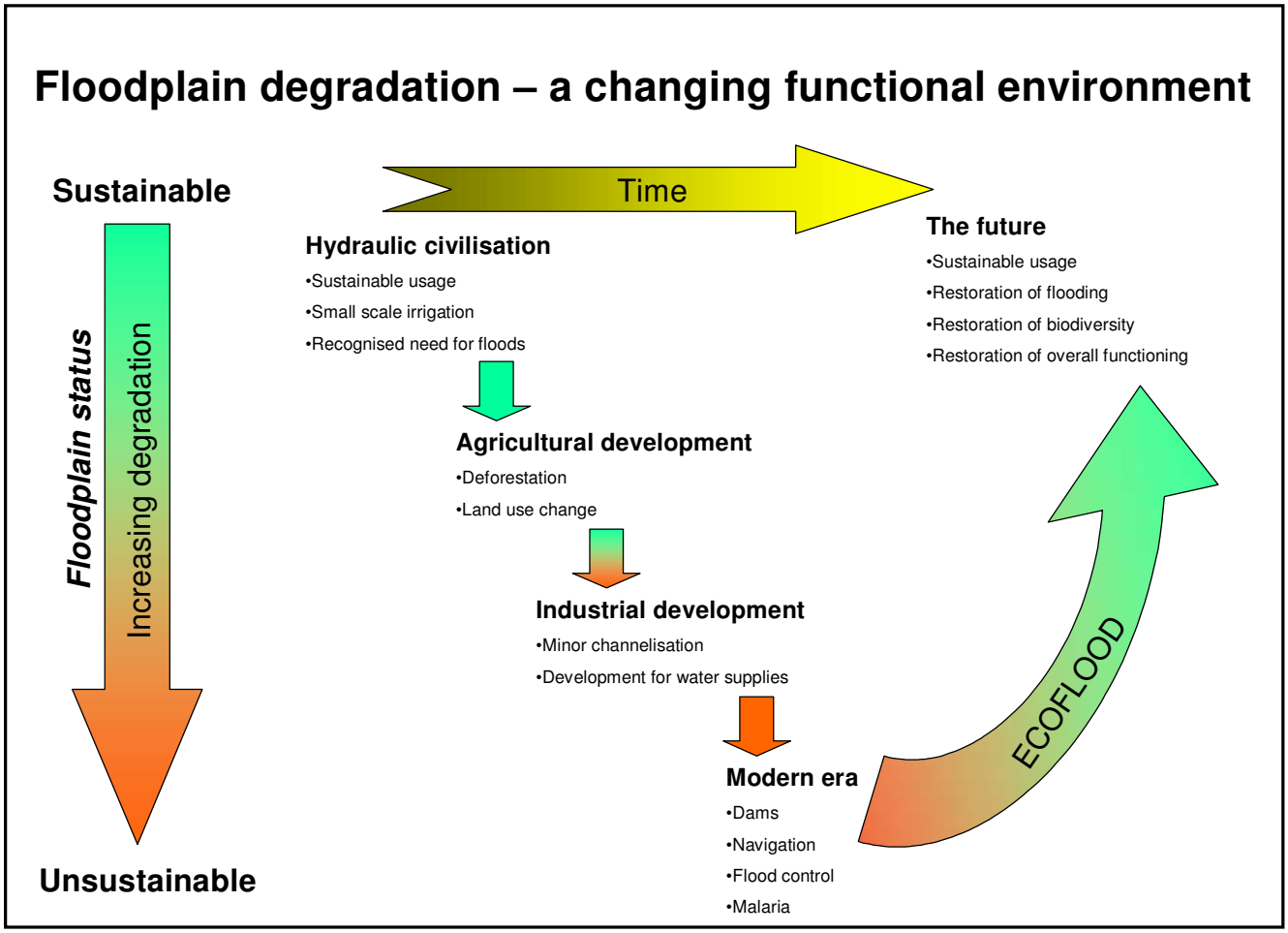


Figure 13. The impacts of humans on riverine environments and the way forward
Source: Maltby and Blackwell, 2003

discharge, increased sediment load and altered patterns of erosion and sedimentation (Gregory et al., 1987; Starkel et al., 1991). Subsequent intensification of direct channel works was, in part, a response to the changes in channel morphology resulting from this deforestation (Leach and Leach, 1982). Initially these works were primitive, mainly for the provision of local water power and flows. Subsequently, larger scale changes occurred to improve the navigability of rivers, prevent flooding and reclaim floodplains, largely in response to a developing commercial environment (Darby, 1983). The 19th century saw a boom in river regulation activities, driven by three main factors; a need to create more agricultural land to provide food for rapidly growing urban populations, a need to control the breeding grounds of malaria-carrying mosquitoes and a desire to control increased flooding. Already by the end of the 18th century dam building technology was well established, but the peak period of construction was 1950-1980 (Petts, 1989). The end of this period coincides with the realisation that environmental damage was resulting from these activities, and today there is a perceived need to return rivers and floodplains to a more natural, sustainable state.

FLOOD RISK MANAGEMENT

What are flood risk and risk management?

Flood risk is a function of probability of flooding and damage resulting from flooding. Flood risk management deals with low probability flooding events and their effect is measured by the damage they cause. However, it should be considered that flood risk management does not only involve minimising the actual risk, but also deals with the perceived risk as well. Often there is a difference between the two. The goal of flood risk management is the minimisation of flood risk through the implementation of measures that can most efficiently reduce risk. This can be done by reducing the probability of flooding, minimising potential damage or a combination of both (Hooijer et al, 2002).

What approaches can be taken to flood risk management?

There are five basic approaches that can be taken to flood risk management:

i) Runoff reduction measures
ii) Preventive flood risk reduction measures
iii) Preparatory measures
iv) Incident measures
v) Post-flooding measures

i) Runoff reduction measures
These measures are focused at land use management in the run-off generation areas of river systems, namely upstream catchment areas (Figure 14). Land use management measures are aimed at reducing the



Figure 14. Retaining water in headwaters as a runoff reduction measure
Photo: Y. Wessels/Grontmij

effects of land drainage, deforestation and urbanisation on peak flows in the river system. These types of measures are most effective in small (local or regional) catchments and when implemented over a large proportion of it. Land use management measures are most effective for the reduction of low to medium peak flows. However the effectiveness is strongly dependant on the characteristics of precipitation and antecedent conditions. For prevention of extreme flooding events in large rivers these types of measures are less effective.

ii) Preventive flood risk reduction measures

Preventive flood risk reduction measures include flood control, spatial planning and raising awareness. This actually involves a wide range of categories including technical measures (flood storage, dams, embankments, walls) (Figure 15), regulatory measures/instruments (e.g. spatial zoning), financial measures/instruments (burden sharing, subsidies, financial compensation) and communicative measures/instruments (brochures, role-plays, seminars etc.). Preventive flood risk reduction measures are aimed at both reducing the probability of flooding and minimising potential damage. Technical measures are, for example, the construction of dams, embankments and river channel normalisation, while natural flood defence measures are directed at enlarging the resilience of the river-floodplain system. These include measures such as restoration and enlargement of floodplains by setting back embankments and floodplain excavation (Figure 16), reconnecting side channels, reconstruction of meanders and the removal of minor embankments. All of these measures contribute to the restoration of the characteristic hydrological and geomorphological dynamics of rivers and floodplains. This is the focus of the information provided in these guidelines.

Spatial planning can be an effective way to minimise the potential damage caused by flooding and is expected to become increasingly important as awareness grows that some degree of flooding is inevitable (Box 5). By using spatial planning instruments such as regulations and hazard-zoning, authorities can discourage investment in flood prone areas and ensure that the resilience strategies for river systems are feasible as activities in floodplains decrease. In the Netherlands the 'Room for Rivers' regulation imposes considerable restrictions on building activities in the floodplains of large rivers (Box 6).



Figure 15. Dams are a technical solution to flooding but environmentally insensitive
Photo: J. Matthews



Figure 16. Lowering the floodplain provides more storage for flood water.
Photo: Grontmij

Box 5. Resilience strategy

Present day preventative flood risk management is aimed at fully controlling floods, mainly through technical measures such as embankments. However there is growing awareness that this strategy may cause fundamentally unpredictable flooding in cases of discharge above the design capacity. For example embankments in the Netherlands are designed to deal with events that occur once every 1250 years. If however, the river discharge is larger than this design capacity there is a chance of embankment failure and subsequent uncontrolled flooding. This will cause widespread damage to densely populated areas behind the embankments. The resilience strategy consists of a set of measures aiming to minimise the effects of flooding, rather to control or resist them. Measures such as setting back of embankments and the creation of new floodplains/wetlands and watercourses are included in this strategy. This requires land use changes and multiple land use in certain parts of floodplains.

iii) Preparatory measures
These measures include flood forecasting (Figure 17), warning and emergency plans. Components of these measures are identification of the likelihood of flooding events, forecasting future river stage/flow conditions, the issuing of warnings to the appropriate authorities and the public about the extent, severity and timing of floods, dissemination of warnings and the responses by the public. These measures are aimed at minimising flood damage.

iv) Incident measures
These measures include crisis management, evacuation of the population in areas threatened by flooding and local emergency protection in these areas (improvised or supportive flood defence measures). These measures aim to minimise flood damage.

v) Post-flooding measures
These measures include aftercare, compensation and (if applicable) payment of insurance money. They bring relief to those affected by disasters. Other post-flooding measures include the reconstruction of damaged buildings, infrastructure and flood defences, post-flood recovery and regeneration of the environment and economic activities in the flooded area, reviewing of flood management activities to improve the process and planning for future events.

Flood risk management strategies are sustainable if they provide sufficient safety both at present and in the future. Additionally they must provide an acceptable balance between the restriction imposed by flood risk reduction measures on the one hand and the conditions needed for economic, social and environmental development in areas at risk of flooding on the other hand. The ideal sustainable management strategy is not the same for every region as they may differ in economic, physical, cultural and ecological characteristics.

Box 6. Room for Rivers regulation

The Room for Rivers regulation is a regulation of the Dutch Ministry of Transport and Water and the Ministry of Health, Spatial Planning and Environment. It was designed after the floods of 1993 and 1995 in order to strictly regulate all building activities in the floodplains of large rivers. A key element of the regulation is that building activities are only allowed if it is not possible to locate the activity outside the floodplain and the activity has been shown to impose no substantial restriction on the enlargement of (future) river discharge capacity. If these requirements are met the activity has to be constructed in a way that local water level rise in the river system is minimal and compensation of this minimal effect is guaranteed.

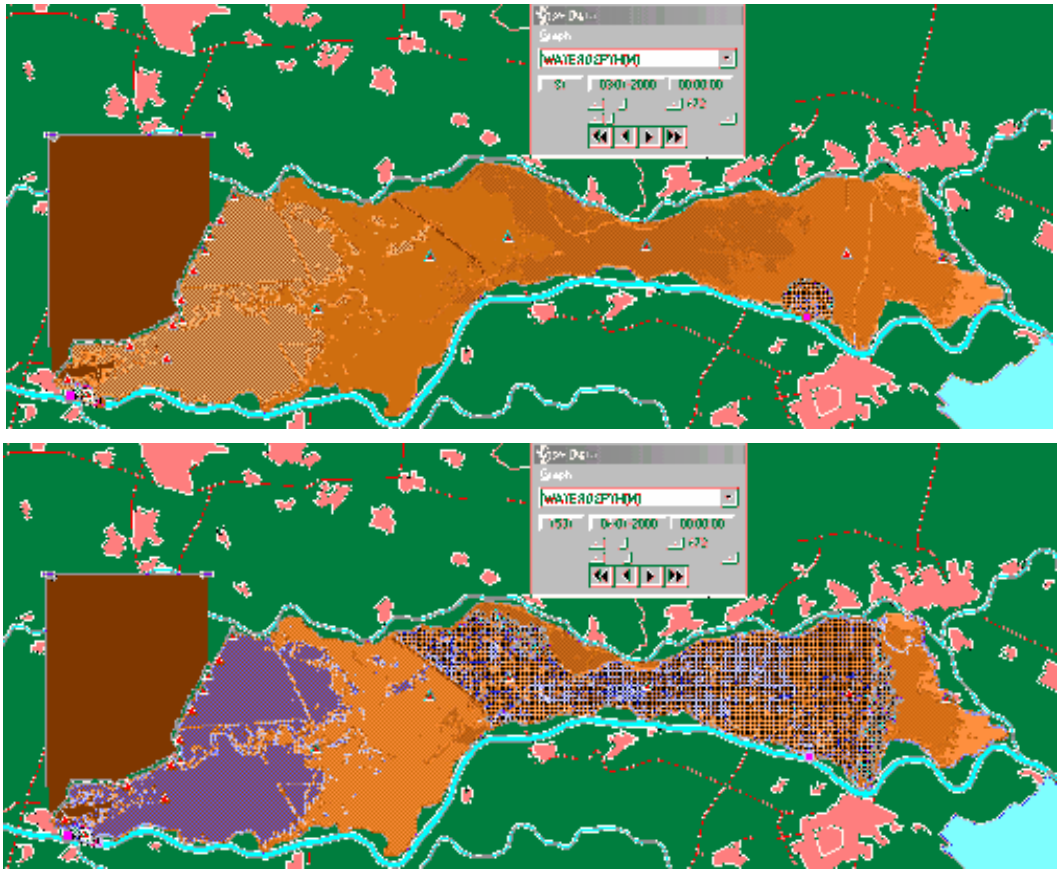


Figure 17. Two flood forecast maps simulating embankment failure. These can help prepare for the consequences of flooding. *Source: Grontmij*

Box 7. Summary of approaches to flood risk management

Individual approaches to flood risk management will not provide a solution. In practice a whole suite of tools is required to deal with the effects of inevitable flooding, and these will include:

- ***Runoff reduction methods** - minimising the probability of flooding through appropriate land use management.*
- ***Preventive flood risk reduction methods** – flood control via technical and more natural methods (e.g. floodplain restoration), spatial planning and raising awareness.*
- ***Preparatory measures** – flood forecasting, dissemination of warnings and emergency plans to minimise damage.*
- ***Incident measures** – crisis management strategies, evacuation strategies and local emergency protection full stop.*
- ***Post flood measures** – aftercare, compensation, reconstruction, regeneration (both environmental and economic) and strategic planning for future events.*

Flood risk management strategies must provide an acceptable balance between the restriction imposed by flood risk reduction measures and the conditions needed for economic, social and environmental development in areas at risk of flooding.

What problems are associated with technical flood risk reduction measures?

Recent flood events have shown the vulnerability of technically oriented flood risk reduction measures. The most important technical measures are artificial embankments, dams and barrages and channel normalisation. The following problems are associated with technical flood protection measures:

- **Channel normalisation.** This measure includes channel straightening, lining (usually with concrete), narrowing and deepening. During this process islands and sand banks are removed and meanders are cut off. Locally this leads to an increase in the discharge capacity of the main river channel. However this causes higher discharge peaks and raises the water level in downstream areas resulting in higher flood risks. Through the modification of the river channel natural river dynamics and morphological and sedimentological processes are altered, and degraded.
- **Construction of embankments.** The construction of embankments leads to protection of land behind embankments but also to confinement of river floodplains. This decreases the water storage capacity of floodplains leading to a consequent increase in discharge peaks. Furthermore the construction of embankments encourages urban and industrial development in former floodplain areas protected by embankments. This leads to an increase in flood damage if embankments are breached. Another disadvantage is that embankments only provide protection up to a specific design capacity resulting in uncontrolled and unpredictable flooding events during discharges that exceed design capacity. The construction of embankments has led to both a decrease in area and the degradation of valuable and diverse floodplain ecosystems.
- **Construction of dams.** This results in changes in river dynamics and morphological and sedimentological processes in both upstream and downstream areas. Consequently river and floodplain ecosystems are altered and degraded. The negative effects of dam construction on potential flood damage in cases of failure are similar to those of embankments. Extreme precipitation, landslides and design defects can cause the failure of an earth or concrete dam. In recent decades, on average, one or two major dam bursts per year have been recorded. In Europe, one such disaster with many casualties occurred in 1963 in Northern Italy: a landslide triggered a flood wave that burst over a 265m high dam, killing more than 3000 people.

Box 8. The Tagliamento River, Italy – Conventional flood risk reduction measures threaten one of the last naturally functioning rivers in Europe

The Tagliamento River is located in north-eastern Italy. Its source is in the Alps and it flows for 178 km to the northern Adriatic Sea, connecting two biomes in less than 100 linear km; the Alps and the Mediterranean Sea. The river is one of the last naturally functioning large rivers in this part of Europe.

In November 1966 exceptional flooding, due to the collapse of dykes in the Lower Tagliamento, caused the death of 14 people, the loss of more than 5,000 properties and severe damage to around 24,000 houses in more than 50 towns. Despite this experience, urbanisation, intensive agricultural use and industrial development of riparian areas have continued along the riverine corridor.

After more than 30 years of discussions, a flood control plan prepared by the National Water Authority of the North Adriatic Rivers has been approved by the Decree of President of Ministers in 2000 and by the Government of the Friuli Venezia Giulia Region of Flood Risk Reduction. It is based on the construction of large water storage basins. These huge water reservoirs are to be located within the proposed NATURA 2000 Site (Site of Community Importance 'Greto del Tagliamento'), where the floodplain is 3 km wide and still in a near-natural condition. The proposal has been condemned by many NGOs (e.g. WWF) and stakeholders in the region.

According to WWF, political objectives and scientific facts are not being equally considered in this plan. "The Environmental Impact Assessment is being carried out by the executor of the plan after it has already been approved. The factual information on which the plan is based is of poor quality according to the international scientific community and no sound scenario studies looking at alternative options to the designed basins has been carried out" (Nicoletta Toniutti, WWF Italy).

In 2003, WWF Italy and the WWF Alpine Programme started a 'Preliminary Study' to identify alternatives to the original proposal. Experts in hydraulics, socio-economics and ecology involved in the project concluded that a different, sustainable solution is possible. They recommend:

- *location of the water retention basins closer to the areas of highest flood risk,*
- *preservation of unconstrained riparian corridors and maintenance of flow variability,*
- *setting up of an effective forecasting and alert system,*
- *a range of measures, particularly non-structural ones,*
- *a public participatory process involving all the main stakeholders, including the general public,*
- *establishment of a multidisciplinary team involving the scientific community and engineers.*

For further information see Spaliviero (2002), Tockner et al. (2003) and WWF (2004).



Figure 18. The 'natural' Tagliamento River, Italy
Photo: Nicoletta Toniutti, WWF Italy

What is a natural flood defence?

A natural flood defence is an area in which a specific set of measures has been taken to reduce flood risk and improve natural floodplain functioning at the same time. The measures are preventive flood risk reduction measures that can be aimed at both reducing the flooding probability and minimising the potential damage (Table 1). In general, natural flood risk reduction measures aim to enlarge the discharge capacity of river channels and the storage capacity of floodplains. Natural flood risk reduction measures are non-technical measures that contribute to the restoration of the characteristic hydrological and geomorphological dynamics of rivers and floodplains and ecological restoration. Changes in land use are often needed for the implementation of these measures. Therefore spatial planning and stakeholder involvement are of vital importance when implementing a natural flood defence scheme. The protection of existing naturally functioning river and floodplain systems also can be regarded as an important natural flood risk reduction measure.



Figure 19. Example of a natural flood risk reduction measure: a reconnected side channel
Photo: Grontmij

Table 1. Natural flood risk reduction measures

Measure	**Qualitative description of the measure**
Protection of existing naturally functioning river and floodplain systems	The existing storage capacity of the river system is maintained and valuable ecosystems are protected.
Flood bypasses	New river bypasses, including new floodplains with wetland or floodplain ecosystems. Also called green rivers.
Removal/lowering of minor embankments	Enlarges the effective river floodplain.
Setting-back of embankments	Enlarges the storage capacity of a floodplain and leads to enlargement and restoration prospects for a floodplain.
(Re)construction of stagnant water bodies such as isolated channels and oxbows in the (former) floodplain	Increases the storage capacity of a floodplain.
Development of manageable flood detention polders which should preferably be used as extensive grassland or floodplain forest	Increases the storage capacity of a floodplain.
Floodplain excavations	Enlarges the effective river floodplain.
Changes in land use in the catchment area (for example reforestation)	Promotes retention of water in a catchment area.
Restoration of floodplain vegetation	Increases the storage time of water on a floodplain.
(Re)construction of meanders	Increases the storage capacity of a river channel, decrease a river's slope.
(Re)construction of flowing side channels	Increases the storage capacity of a channel area and increases the water conveyance capacity through a river section.
Re-meandering the river course or allowing spontaneous river morphological development	Increases the storage capacity of a river channel.
Removal of flow restrictions	Alleviates unwanted flooding in some areas and purposefully relocates this to designated areas. Increased river flows downstream with managed storage areas used for habitat creation.
Rejuvenating or removing vegetation with a high hydraulic roughness	Only ecologically beneficial if the management of the vegetation supports the development of a stable and viable ecosystem.
Removal or lowering of groynes and other hydraulic obstacles in the river channel	Allows more dynamics in water level fluctuations, decreases a river/valley roughness coefficient.

FLOODPLAIN PROCESSES, FUNCTIONS, VALUES AND CHARACTERISTICS

What are floodplain processes and functions?

In any floodplain a number of processes may be occurring to a greater or lesser extent. These may be of a physical, chemical or biological nature. Examples of processes that may occur in floodplains are water storage, denitrification and plant uptake of nutrients. The degree to which these processes occur is ultimately dependent upon controlling variables such as temperature, hydrological regime and nutrient status. As a consequence of the occurrence of processes, a floodplain will perform ecosystem functions. The process of water storage may result in a floodplain performing the function of flood attenuation, while the processes of plant nutrient uptake may contribute to the ability to perform the function of water quality improvement through the removal of nutrients from surface water and shallow groundwater. Plant uptake of nutrients may also result in the performance of other functions such as the provision of support to the food web and habitat, demonstrating that an individual process may contribute to a variety of floodplain functions. The relationships among these are illustrated in Figure 20, and a list of the types of functions and processes that naturally functioning floodplains can perform is given in Table 2.

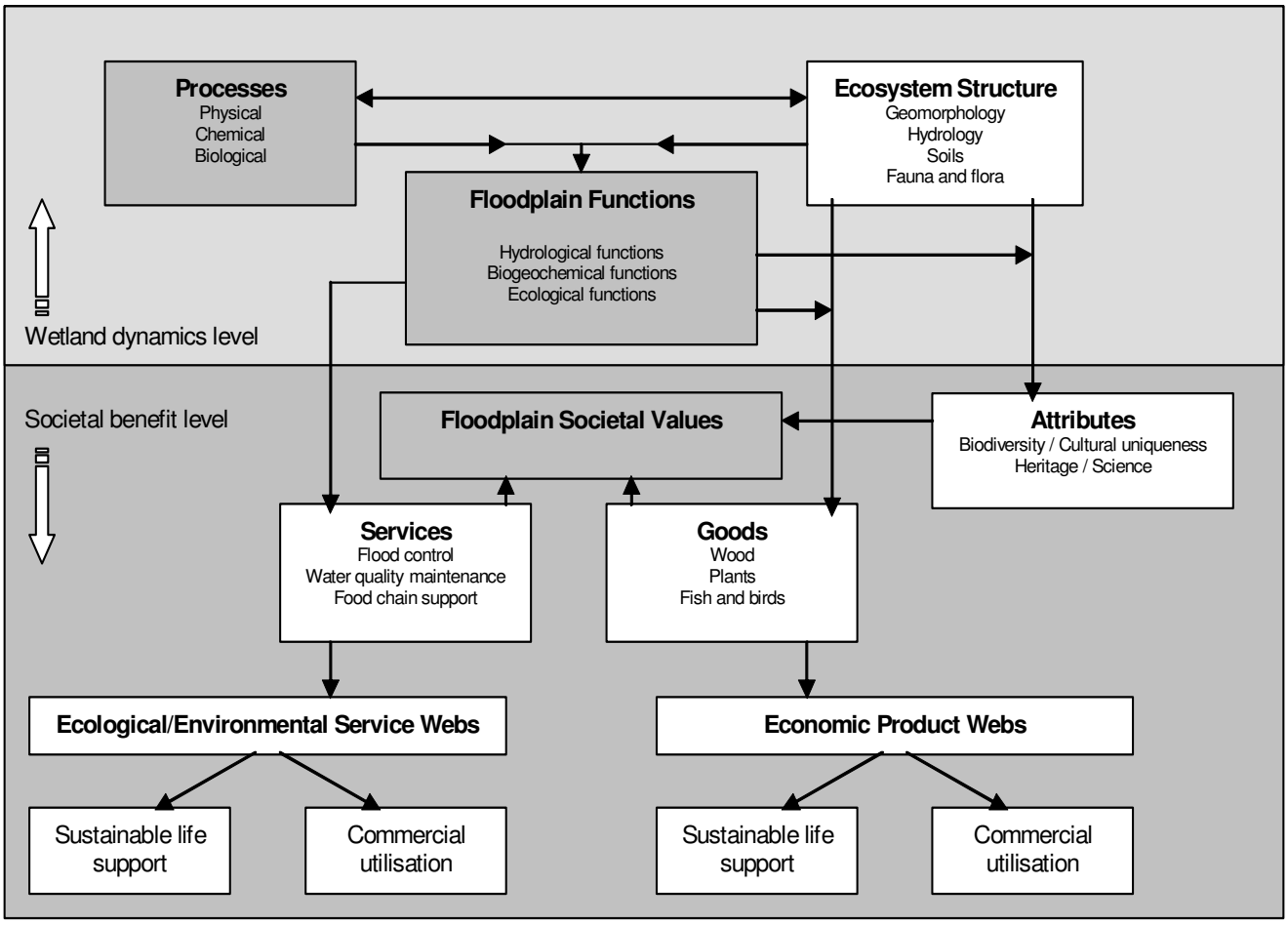


Figure 20. Relationships among floodplain processes, functions and values
Source: After Maltby et al., 1996

Table 2. Floodplain functions and processes

FUNCTIONS		PROCESSES
Hydrological functions *(Water quantity-related)*	Flood water regulation	Flood water storage Increase in river discharge capacity
	River base-flow maintenance	Groundwater discharge
	Sediment retention	Sediment deposition and storage
Biogeochemical functions *(Water quality related)*	Nutrient retention	Plant uptake of nutrients Storage of nutrients in soil organic matter Adsorption processes in soil Precipitation Retention of particulates
	Nutrient export	Gaseous export of N (denitrification and ammonia volatilisation) Vegetation harvesting Soil erosion
	Carbon accumulation	Accumulation of organic matter and formation of peat
Ecological functions *(Habitat related)*	Ecosystem maintenance	Provision of diverse habitat Provision of habitat microsites
	Food web support	Biomass production Biomass import Biomass export

Source: Maltby et al., 1996

How can we benefit from restoring naturally functioning floodplains?

The functions performed by naturally dynamic floodplains provide benefits to society but their value is dependent on the actual perceived extent of these benefits. This may be expressed in either direct economic terms (Box 9) or in more indirect ways such as in terms of cultural uniqueness or biological rarity. Functions are performed by an ecosystem with or without the presence of society, usually as part of a self-sustaining ecosystem, whereas floodplain values are determined by the particular views of society or individual stakeholder groups. These will vary over time and space while the functions performed by ecosystems may not.

What is floodplain rejuvenation?

Natural floodplain vegetation (e.g. scrub and trees) generally has a higher hydraulic roughness coefficient than agricultural land (e.g. grassland and arable crops). This means that water will not flow as rapidly over naturally vegetated floodplains as it will over agricultural land. If the natural vegetation comprises mainly woodland the hydraulic roughness will be very high and in some circumstances can result in the detention of significant quantities of floodwater and lowering of flood peaks downstream. However, two main impacts may occur in an area of forest during a flood. Firstly, flooding of land adjacent to the forest can occur due to the backing-up of water within the woodland. Secondly, damage to vegetation can occur and in some cases large tracts of woodland can be swept away leaving exposed soil on the floodplain when the flood recedes. These areas will become re-vegetated fairly rapidly, and this process is known as floodplain rejuvenation (Duel et al., 2001; Baptist et al., 2004). In areas where undesirable flooding occurs regularly as a result of the floodwater retention properties of a floodplain forest, parts of the forest can be selectively felled in order to mimic natural floodplain rejuvenation. This has both hydrological and ecological benefits, in that it enables flooding to be managed both in the vicinity of the forest and downstream, as well as increase biodiversity.

Box 9. Societal values of floodplains

Example 1 – The Charles River catchment, USA.

As a result of the ability of floodplain wetlands in the Charles River catchment, U.S.A., to detain precipitation and run-off, flood damage was reduced by an estimated 60-65% due to the lowering of river flood discharge peaks. A 40% reduction of the wetland area would result in an estimated $3million worth of flood damage per annum (Sather and Smith, 1984). Floodplains possessing a similar ability to reduce downstream flooding in a less populated or less intensively farmed catchment would not be perceived as having the same value despite performing the same functions to a similar degree, as less damage would result from their loss. This demonstrates how position in the landscape can affect the value given to a particular function.

Example 2 – Global values of different ecosystem services

In the chart below the value of selected renewable services provided by various ecological systems are compared (Costanza et al., 1997). The services include those that contribute both directly and indirectly to human welfare. It can be seen that floodplains and swamps have by far the highest value for the services included in this study, the major values arising from disturbance regulation (capacitance, damping and integrity of ecosystem response to environmental fluctuations, e.g. storm protection and flood control) and water supply (the storage and retention of water). When considering these services the value of floodplains and swamps is estimated at nearly $19,000 per hectare per year.

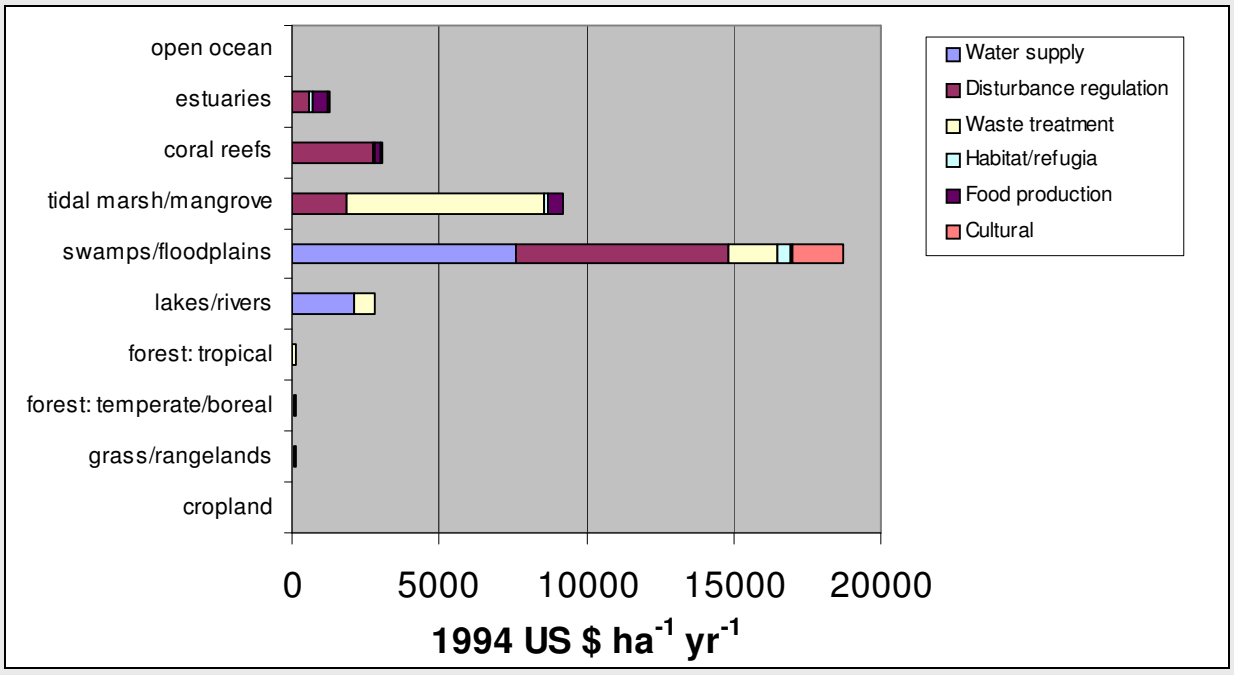


Figure 21. Average global value of selected annual ecosystem services
Source: After Costanza et al., 1997

THE MAIN CHARACTERISTICS OF NATURALLY FUNCTIONING FLOODPLAINS

What are the interactions between river channels and floodplains?

Natural floodplains are among the world's most biologically productive and species rich ecosystems. Floodplains in temperate climate zones once had the same importance with regard to biodiversity as the tropical rainforests do today for biodiversity in the tropics. Up to 80% of all kinds of bird, grass, herb, shrub and tree species of European lowlands could be found in the floodplains of middle and eastern Europe.

The number of habitats within a floodplain reflects the geomorphological dynamics and sedimentological diversity (Richards et al., 2002). Geomorphological processes such as erosion and sedimentation are connected to the hydrological dynamics of rivers and floodplains. These hydrological dynamics result from changes in river discharge and are expressed in variations of flow velocity, water level and floodplain inundation. At high discharges floodplains will be inundated and perform the function of water storage.

Which factors shape floodplains?

The geomorphological processes of sedimentation and erosion shape the morphological elements that can be distinguished within a river and floodplain. In river channels morphological elements such as pools, riffles, bars and islands are found. Another important morphological characteristic of the river channel is its pattern (e.g. straight, meandering, braided or anastomosing). Floodplains contain morphological elements such as alluvial ridges (with natural levées and river dunes), oxbows and cut-offs, side arms, backswamps and plains (with variable sedimentary composition). The morphological characteristics of the river-floodplain cross section results in highly variable topography. Factors such as climate, geology, morphogenesis, hydrological regime, relief and catchment area affect the morphological elements along a longitudinal gradient. Sedimentological diversity is affected by these factors in a similar fashion. Generally the texture of sediment decreases along the river from the headwaters to the mouth. Furthermore, there is a gradient across a floodplain with sandy deposits at the river banks (natural levees and dunes) and finer materials as distance from the river increases. In parts of the floodplain where water has stagnated and terrestrialisation processes occur (for example in oxbows or backwaters) peat can sometimes be found.

The diversity of sedimentation patterns, geomorphology and hydrology in floodplains makes them highly biodiverse ecosystems. The number of habitats within a floodplain reflects its geomorphological dynamics and sedimentological diversity. The species richness

Box 10. Definitions of river and floodplain

Rivers and floodplains are both part of a river system. A river system can be defined as the system of connected river channels in a drainage basin (Bridge, 2003). The drainage basin (or catchment) is the area that contributes water and sediment to the river system, and is bounded by a drainage divide.

*A river valley cross-section generally can be divided into the main river channel and the floodplain. Both of these units can be subdivided into various morphological elements. The **river channel** is distinctive in that it has a finite width and depth, a permeable boundary composed of erodible sediment and a free water surface (Church, 1992). The word channel implies that it contains continuously or periodically moving water. The **floodplain** is the strip of land that borders the river channel and that is normally inundated during seasonal floods (Bridge, 2003).*

In these guidelines a distinction will be made between parts of a floodplain that were formerly flooded before being modified by human activities that preclude flooding and currently active floodplains which are still subject to flooding. The first will be referred to as former floodplain and the second will be referred to as floodplain.

of areas in turn reflects the number of habitats in a region and the number of species per habitat (Whittaker, 1960). Besides species richness, diversity of age structure is an import feature with regard to biodiversity. In geomorphologically dynamic environments like floodplains, erosion and sedimentation processes will locally destroy older vegetation and create new surfaces for colonisation by pioneer species (Richards et al., 2002). More specifically the dynamics of channel migration and floodplain renewal constitute an important control of the ecological diversity of river corridors. Floodplain restoration initiatives should address the causes of degradation by reinstating these dynamics rather than the symptoms of floodplain biodiversity decline.

Another important factor affecting the characteristics of floodplain ecosystems is 'management'. This includes mowing and grazing. In natural floodplains the presence of grazers/browsers such as deer, elk, beavers, wild horses and geese are of vital importance for diversity of vegetation. In combination with variations in flooding frequency, depth and duration they create conditions for vegetation that are highly varied in structure and species composition. Typically this comprises a mosaic of grassland, shrub and forest on a floodplain (Figure 23).



Figure 22. The Bug River, Poland: an example of a meandering river with broad floodplains containing slacks and dunes
Photo: F. Vliegenthart/Grontmij



Figure 23. Example of a floodplain comprising a mosaic of habitats (Pechora River, Russia)
Photo: M. Haasnoot/WL Delft Hydraulics

Part III

Guidelines

NATURAL FLOOD DEFENCES CAN CONTRIBUTE TO FLOOD RISK MANAGEMENT

If flooding is to be dealt with in a natural, sustainable way, a change of thinking is required. Technical and structural solutions must be replaced by softer, natural solutions that aim to manage flood risk and we must learn again to live with flooding. Whilst structural measures will in some places still be essential tools for protecting property and goods, it must be borne in mind that this type of flood protection is never infallible and can generate a false sense of security. By using the inherent ability of floodplains to store floodwater and consequently delay and reduce river peak discharges, flood frequency can be reduced. Natural flood defences generally offer a more efficient and long-term, sustainable solution to flood hazards than technical solutions.

What are the main hydrological functions of naturally functioning floodplains?

Rivers and their floodplains comprise one of the most important components of the hydrological cycle and together perform economically and environmentally valuable functions related to the regulation of water quantity. The two main hydrological functions they perform are floodwater retention (Figure 24) and the recharge and discharge of groundwater.

i) Floodwater retention

Water that is temporarily stored in floodplains during flood events generally originates from two main sources; overbank flooding from a river or surface and/or sub-surface runoff from land adjacent to a floodplain. Sometimes overbank flooding will be the dominant source because flooding can occur downstream in 'dry' areas where there is little or no runoff, as a result of heavy rainfall higher in the catchment. The interaction of these two water sources impacts the way a floodplain delays and reduces river peak discharges. If there is negligible inflow from adjacent land most of a floodplain's storage capacity will be available for the storage of overbank flooding resulting in the lowering and delaying of flood peak flows. Alternatively, if there is a significant input from adjacent land, the storage capacity of a floodplain will be reduced resulting in less reduction and delay of flood peak flow.



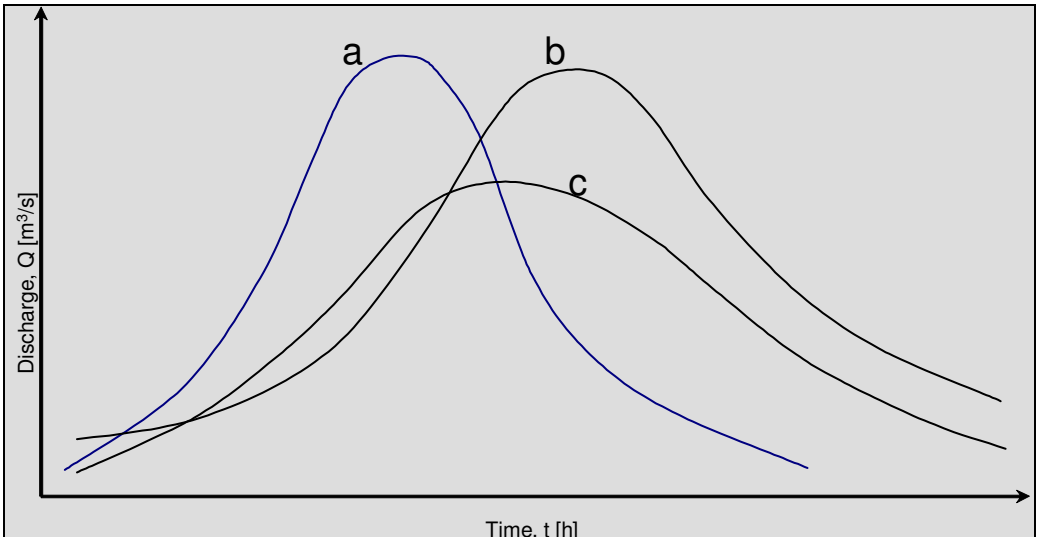
Figure 24. The Biebrza River Valley, Poland, storing water during a flood event
Photo: T. Okruszko/SGGW

Reducing peak flows decreases the probability of downstream flooding. Even reductions in peak discharge heights of only a few centimetres can be beneficial as it can prevent overtopping of flood defences which is often associated with high levels of damage. While reducing peak flows reduces the likelihood of flooding, delaying the time to peak flows can also be useful. It can provide more time for flood damage prevention measures to be implemented such as the evacuation of people from areas at risk from flooding (Figure 25).

The role of wetlands in floodwater retention has been reviewed by Bullock and Acreman (2003). Most of the studies they reviewed (82%) claimed that floodplain wetlands have a significant capacity to reduce or delay flood peaks. The amount of time that floodwater is detained in a floodplain (short-term = less than a week, long-term = a week or more) will affect the type of physical, chemical and ecological processes (including sedimentation and nutrient removal), which result in the provision of additional services by floodplain wetlands.

The impact of a floodplain on the flood process depends on the presence of different floodplain and river channel morphological elements (Table 3). Figures 26a-d illustrate the typical sequence of hydrological processes that occur on a floodplain during a flood event and give an idea of how particular landscape elements can control, guide or modify floodwater within a river valley. It is important to emphasise that although the basic role of each floodplain landscape element can be defined in general terms, natural floodplains differ in size, morphogenesis and climate and different landforms react individually to each flood event. These factors affect flood duration, flood extent, relative stability of ephemeral landforms and also the capacity of a floodplain to store ground or surface water.

During periods of base-flow (Figure 26a) only part of a floodplain usually contains water and this is restricted mainly to permanent water bodies such as the main river channel, side meanders and oxbows. When floodwater enters the floodplain by flowing over or through the alluvial ridge, erosive flows are generated and subsequent deposition of eroded material occurs in oxbows, cut-offs, drainage channels, side arms and backswamps (Figure 26b). During flood peaks, water covers the whole floodplain and water flows down the valley in a broad, shallow channel (Figure 26c). Flow velocity is relatively high in zones of flow convergence and low in expanding flow zones. As the water level in the river decreases, part of the floodwater flows back into the main channel through side arms and crevasse channels but some will remain in floodplain depressions (Figure 26d). This natural process of storing excess water during floods and the slow re-distribution of it during periods of base-flow is important for the maintenance of hydrological (and ecological) functions performed by naturally functioning floodplains.



a = typical hydrograph for a channelised river; a rapid rise to a high flood peak discharge
b = hydrograph shows a delayed rise to flood peak discharge, providing more time for flood damage prevention measures to be implemented
c = hydrograph shows a reduced flood peak and a delayed rise to flood peak, meaning that flooding is less likely and more time is available to implement flood damage prevention measures

Figure 25. Hydrographs of three river flood discharge scenarios

Table 3. The impact of floodplain characteristics on the flooding process

Landforms		PROCESSES OCCURRING DURING DIFFERENT FLOOD EVENT STAGES		
		Initial stage	**Advanced stage**	**Final stage**
River channels	pools	Deceleration of water flow.		Accumulation of relatively fine sediment.
	riffles	Acceleration and distribution of water flow: a driver for water distribution in a main river channel.	Modification of flow patterns; source of coarse (sand and pebbles) suspended material.	Coarse sand and pebble accumulation resulting in formation of bars.
	bars	Partially blocks water flow; acceleration and diversion of water flows into cross-bars, chutes or crevasse channels; initiation of accumulation of sediment and other particles.	Modification of flow patterns; source of coarse (sand and pebbles) material.	Sediment accumulation and landform stabilisation and intensification of stream bed erosion creating new bar channels.
Alluvial ridge	islands	Acceleration and diversion of water flow into cross-bars, chutes or crevasse channels; accumulation of coarse particulate material.	Roughness of vegetation obstructs water flow; acceleration and modification of flow patterns; stimulation of lateral erosion; diversion of water towards floodplain	Sediment accumulation and enhancement of lateral/bank erosion.
	cross-bar channels	Blocks and accelerates water flow; stimulation of erosion; diversion of water towards floodplain.	Acceleration of flow and modification of flow patterns.	Stream bed and bank erosion enhancement
	levees	Protects floodplain from rising river waters; natural embankment.	Acceleration of water flow at the crest of the levee; restricts flood extent in a flood basin.	Sand accumulation; trapping of floodwater in the flood basin; controls flood duration.
	crevasse channels	Natural sluice gates to floodplains, sporadically operational in initial stage.	Distribution of floodwater onto floodplains.	Assists natural gravity return flow at the beginning of the terminal stage.
	crevasse splays	Occasional redistribution of river water.	Distribution of floodwater; intensive fine sand or silt accumulation.	Accumulation of fine sediments (silt, loam).
Flood basins	silt/loamy plains	Occasional storage of alluvial ground water.	Provide floodwater storage in the floodplain; reduction of peak flow; deposition of fine sediments.	Low permeability of sediments supports seasonal, dynamic wetlands with short term stagnant water tables; enlarges water storage capacity of the floodplain.
	clayey plains		Provide floodwater storage in the floodplain; reduction of peak flow; deposition of fine sediments.	Extremely low permeability of sediments supports seasonal, dynamic wetlands with long term stagnant water tables; enlarges water storage capacity of the floodplain.
	oxbows and cut-offs	Storage of lateral or alluvial ground water.	Distribution and storage of floodwater; reduction of water flow; deposition of fine sediments.	Assists return flow; enlarges water storage capacity of floodplains.
	side arms	Storage of lateral ground water.	Distribution and storage of floodwater; reduction of water flow; deposition of fine sediments.	Assists return flow to the main channel.
	back swamps	Storage of lateral ground water (soligenuous fens located at the edge of floodplains) or alluvial ground water (fluviogenous fens beside alluvial ridges)	Storage of flood water and fine sediments (typically organic); due to morphology significantly decelerate flow (almost stagnant water bodies).	Storage of large amounts of flood water in organic material (slightly decomposed peat) provides additional water storage capacity.

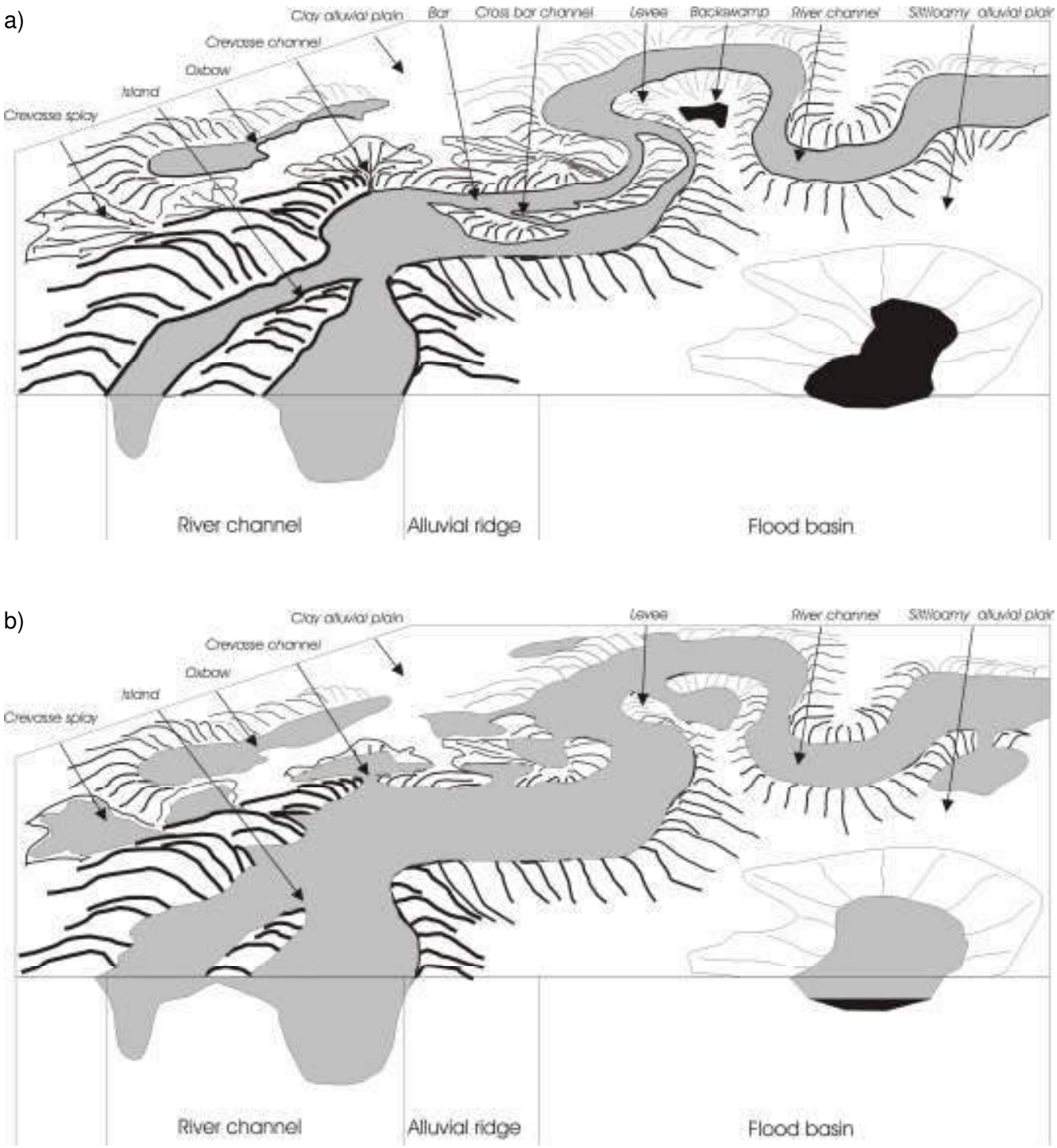


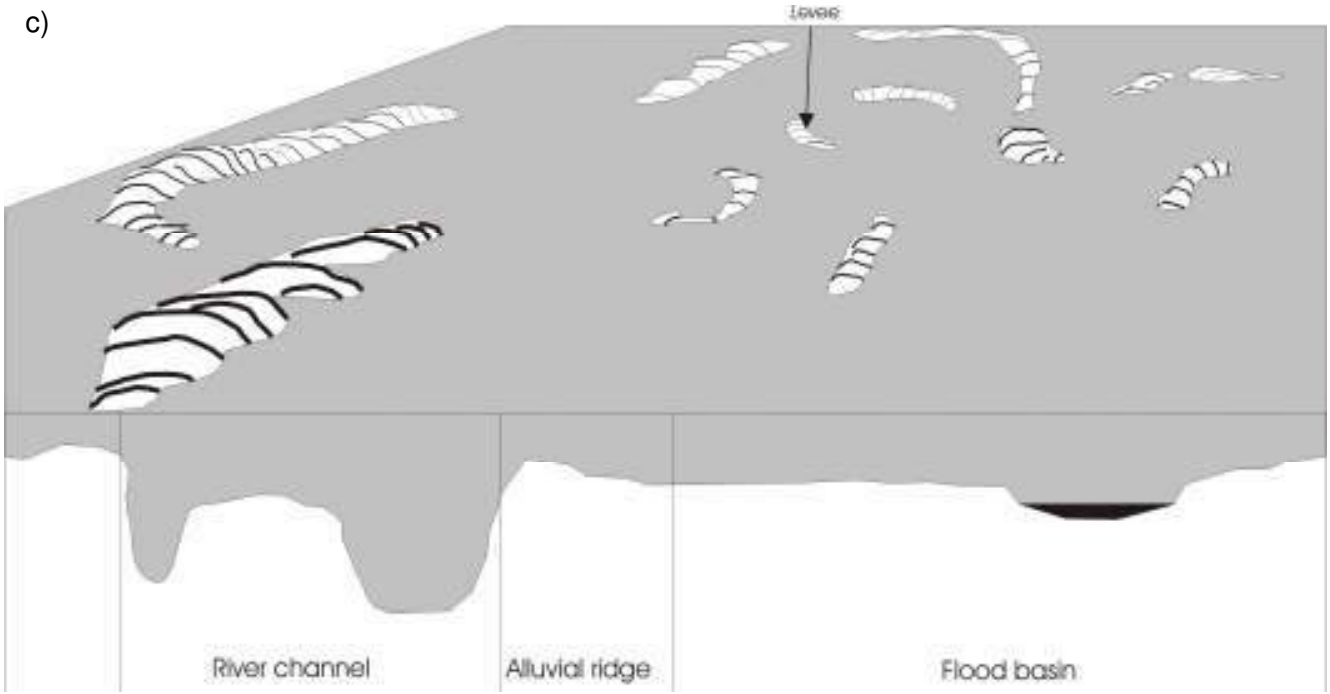
Figure 26. Stage of flood: a) base-flow stage, b) initial stage, c) advanced stage, d) final stage

ii) Groundwater recharge and discharge

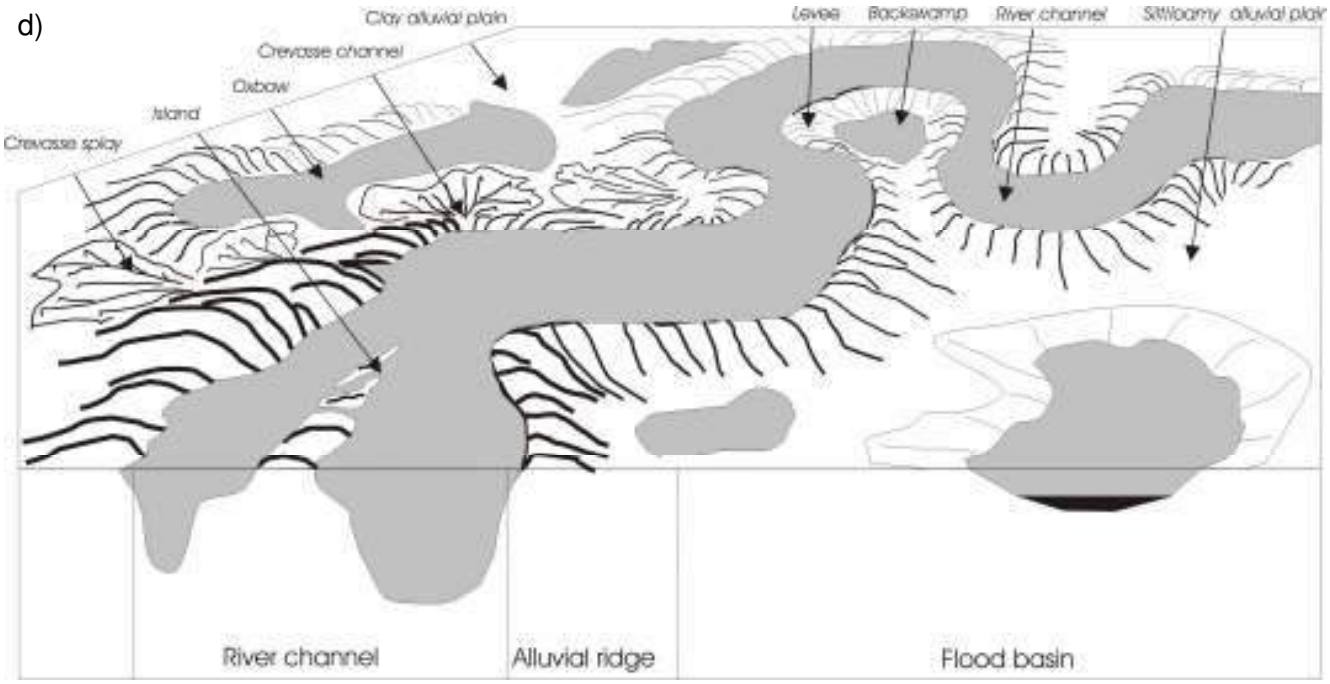
There are various ways by which flood water that is detained on a floodplain can leave the floodplain. Transpiration and/or evaporation processes return water to the atmospheric phase of the hydrological cycle. The amount of water leaving a floodplain in this way varies seasonally, depending upon temperature and stage of plant development. The flow of water from floodplains back to a river channel is controlled by morphological features on a floodplain. If there are no obstacles such as levees, water flows back into the river as soon as river levels are less than bank-full. This process is still a part of the flood-flow (Figure 26d). In other cases, due to the presence of natural or artificial barriers, water can only leave the floodplain slowly through infiltration into the ground. In such cases it will either support the baseflow of a river or re-charge a groundwater body.

The amount of groundwater recharge that occurs depends on local conditions such as geology and the current hydrological condition of the aquifer. Geological structures determine if the water stored in a floodplain can reach groundwater aquifers. The presence

c)



d)



of an impermeable layer isolates shallow or more often deep aquifers from contact with shallow subsurface or surface waters. There are also dynamic relations between waters of different origin. Different flow directions occur depending on the relationships among the height of water in a river, floodplain and aquifer. Groundwater recharge occurs when an aquifer has a low piezometric level (water table) and is not isolated by an impermeable geological layer.

Groundwater discharge occurs in a floodplain when there is an upward seepage of groundwater to the soil surface. This occurs if a recharge area is hydrologically connected to a floodplain via an aquifer. A number of factors can restrict this process including the presence of an impermeable layer, low permeability of subsoil or bypass drainage. Groundwater discharge in a floodplain is important because it promotes the saturation of the soil profile and affects its biochemical and ecological status. In some cases high evapotranspiration rates of wetland plant species mean that water discharged into a floodplain wetland never reaches the river. However, if discharge from a wetland is high enough it can become an important source of water for baseflow in a river during periods of low-flow.



Figure 27. Groundwater-fed Alder Carr at the valley edge (Biebrza marshes, Poland)
Photo: T. Okruszko, SGGW

What hydrological factors should I consider when implementing a natural flood defence scheme?

The types of measures that can be implemented in floodplains to influence the hydrology of a river (i.e. reduce peak flows and reduce downstream flooding), can be divided into two general groups:

1) Increasing the water storage capacity of a floodplain. This can be achieved by:
– increasing floodplain area,
– increasing floodplain depth,
– increasing storage time of water on a floodplain eg. by increasing floodplain roughness.

2) Safe conveyance of water through a floodplain. This can be achieved by:
– increasing floodplain area,
– decreasing floodplain roughness.

The first group of measures result in the reduction of flood risk in areas downstream of a natural flood defence scheme through the storage of floodwater and consequent reduction of peak flood height. The second group of measures, namely the safe conveyance of water through a floodplain, decreases the risk in areas adjacent to a defence scheme as well as downstream. Details of the most popular natural flood reduction measures are described in Table 1.

Generally the roughness of a floodplain is associated with its vegetation cover. Tall vegetation such as trees and bushes reduce flow and increase water, but the precise effect depends on additional factors such as vegetation density and strength. Short vegetation such as natural grassland and pastures have considerably less impact on flowing water and promote the rapid conveyance of water through a floodplain. Morphological features on floodplains such as oxbows and levees also impact the roughness of a floodplain, as do artificial features such as bridges and walls, and all must be taken into account when considering floodplain roughness. However, the most important single factor that should be considered when implementing a natural flood defence scheme is the ratio between stored water and river discharge. Given that a discharge of 1 $m^3 s^{-1}$ over the period of one day can inundate an area of 1 ha to a depth of almost 9 m, it can be seen that the storage areas required to reduce flood peaks generally will be quite large and must reflect the size of river on which they are situated.

How can I determine the effectiveness of different measures?

There is a significant difference between the qualitative description of the processes involved in flood formation and reduction and quantitative assessment of proposed measures to assist with the selection of the best approach to flood defence in a catchment. In order to make these decisions it is necessary to determine decision criteria and calculation methods. These decision criteria should be used to develop optimum solutions by multi-criteria analysis (MCA), taking into account ecological, economical and sociological issues. MCA techniques have the advantage over other techniques in that they can assess a variety of options according to a variety of criteria that may have different units of measurement (e.g. €, kg, km etc.), and which may be both quantitative and qualitative (Table 12).

Determining the hydrological impact of measures proposed for a particular section of river/floodplain requires the calculation of outflow from the valley section and/or the amount of water stored. The likely changes in river flow due to proposed measures can

be calculated using flow routing methods – the hydrological one is based on a continuity equation only while hydraulic ones use both momentum and continuity equations. If the amount of stored water is of concern, various GIS tools are used in order to identify the space available for water retention. These methods can be combined to form various management tools such as 'The Planning Kit', developed at Delft Hydraulics, The Netherlands (Box 11). Another more generic tool that can help with scenario testing is the Wetland Evaluation Decision Support System, developed during a series of EU projects, and produced during the EVALUWET Project (EVK1-CT-2000-00070, see Box 24).

Box 11. The Planning Kit: a decision support tool for the Lower Rhine

The 'Planning Kit' is a river management decision support tool designed specifically for the distributaries of the Rivers Rhine and Meuse in the Netherlands. It enables the investigation of the impacts of various combinations of measures (relating to ecology, landscape and cultural heritage) and generates an overview of the costs. It can be used by people with a non-technical background and is based on existing numerical models for the Rhine distributaries. The output can comprise sketches, aerial photos and other visual outputs for each type of measure considered.

Users with a non-technical background are provided with a simplified version of the 'Planning Kit' named 'Water Manager' which uses the same database but presents the output in a qualitative way and omits the specific details. Developed by WL | Delft Hydraulics and the Government of The Netherlands, the Planning Kit has a simple structure that can be also applied to other rivers. It can help resolve problems when a large number of options have to be evaluated.

Reference: "The Planning Kit, a decision making tool for the Rhine Branches", S.A.H. van Schijndel, WL | Delft Hydraulics, Delft, Netherlands



Figure 28. Example of output from the Planning Kit

NATURALLY FUNCTIONING FLOODPLAINS AFFECT WATER AND SOIL QUALITY

High nutrient, heavy metal and sediment concentrations in water are associated with poor water quality and environmental degradation. On the other hand minimum concentrations of some chemicals are required to maintain surface water bodies at optimum environmental quality, and sediment deposition on soils can help maintain fertility and soil development. Floodplains can have the ability to regulate these properties in a variety of ways, and consequently can perform soil and water quality improvement functions.

What are the main functions and processes performed in floodplains that affect water and soil quality?

There is a range of functions and processes that occur in naturally functioning floodplains that can affect soil and water quality. Generally these involve the import, transformation, export and/or storage of chemicals or particulate matter. Processes that involve the transformation of chemicals from one form to another are known as biogeochemical processes, and these can play a significant role in the regulation of nutrients and heavy metals. Processes that involve the regulation of sediment are generally physical processes such as erosion, transportation (usually by water but sometimes by wind) and deposition or sedimentation.

How do biogeochemical transformations affect water quality?

The type and rate of biogeochemical processes that occur in floodplain soils depends largely upon their hydrology. Well drained soils generally are aerobic, that is they contain considerable amounts of oxygen and water passes rapidly through them, often providing little opportunity for biogeochemical transformations to take place. On the other hand poorly drained soils typically are anaerobic, containing little or no oxygen, have high organic matter content and the residence time of water often is long, providing plenty of opportunity for biogeochemical transformations to occur. For this reason most of the water and soil quality functions and benefits that occur in floodplains take place in the wetter soils found within them, and these soils will form the focus of the information provided here.

Few biogeochemical transformation processes are unique to wetland soils, but the combinations and particular dynamics of biogeochemical cycles and processes operating within them generally are not found in many other ecosystems. Wetland or hydric soils often have unique distributions of oxygen rich and oxygen depleted zones resulting in sequences of transformations of nutrients and metals that cannot occur in other ecosystems. The combination of biological, chemical and physical processes that occur in wetlands result in biogeochemical interactions that can mobilise, immobilise, transform and even remove completely from the wetland/aquatic system a wide range of compounds and elements. A generalised diagrammatic representation of the wetland biogeochemical cycle is shown in Figure 29.

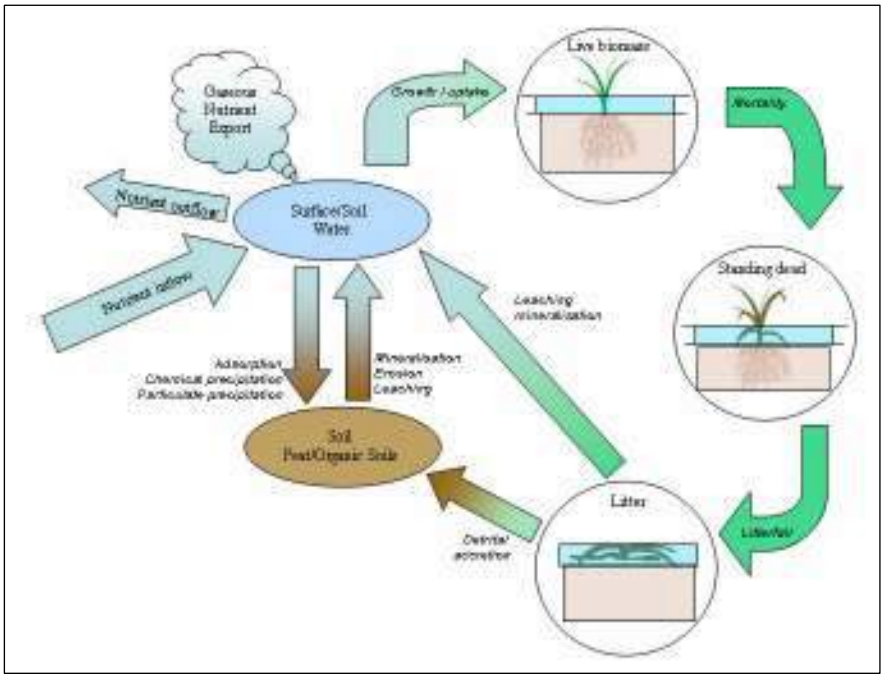


Figure 29. A generalised view of the wetland biogeochemical cycle
Source: After Kadlec and Knight, 1996

Many of the transformation processes within wetlands are con-

trolled by the oxidation or reduction (redox) potential in the soil. When flooding occurs, oxygen becomes rapidly depleted because oxygen consumption by micro-organisms continues, but the rate of diffusion of oxygen into the soil is greatly reduced. Following inundation, oxygen depletion can occur at a rate of anything from a few hours up to a few days, during which a well recognised sequence of transformation processes occurs. The nature and rate of these transformations are fundamental to the rate and types of many of the biogeochemical functions performed by wetlands. The main chemical cycles associated with soil and water quality are N, P, C and trace elements.

What are the key nitrogen related biogeochemical processes occurring in floodplain wetlands?

The most limiting nutrient for plant growth in wetland soils often is N (Gambrell and Patrick, 1978). The key transformation processes for N that occur in wetlands are mineralisation, adsorption, plant uptake, nitrification, denitrification and fixation. Important gaseous phases comprise part of the cycle, and are of particular significance in some wetlands with regard to their ability to export N from the wetland system.

What are the key phosphorus biogeochemical related processes occurring in floodplain wetlands?

Phosphorus is one of the most important chemicals in many ecosystems as it is vital for plant growth, and like N, often it is the limiting nutrient in wetlands. Also like N, it is subject to a wide variety of transformations in wetlands depending upon the particular conditions that prevail. Unlike the N cycle, it is commonly accepted that there is no gaseous phase in the P cycle, although evidence is growing that in some systems gaseous phosphine could be a significant pathway (Devai and DeLaune, 1995). Commonly, a large proportion of P in wetlands is tied-up in organic matter and inorganic sediment as a consequence of either precipitation under aerobic conditions, adsorption or inclusion in organic matter through plant uptake. Oxygen depleted conditions can result in the mobilisation of previously precipitated and immobilised P.

What are the key carbon related biogeochemical processes occurring in floodplain wetlands?

Carbon also is a crucial element and subject to transformation processes within wetlands. Biodegradation is limited in wetlands by the characteristically oxygen poor conditions that exist, which lead to accumulation and formation of organic soils such as peat. However, several anaerobic processes such as fermentation and methanogenesis can result in organic matter degradation. Carbon compounds are important for the biochemical transformation of many other elements in wetland systems as commonly they provide a respiration substrate for bacteria, and consequently are degraded in association with the transformation of other elements.

What are the key trace element related biogeochemical processes occurring in floodplain wetlands?

Many trace elements, in small quantities, are vital to the health of flora and fauna, and consequently are commonly referred to as micro-nutrients. However, trace elements (including micronutrients) can reach toxic concentrations in soils and surface waters. The most toxic are Hg, Cd and Pb, for which no biological function is known. Four major mechanisms operate in wetlands which enable them to interact with trace elements. These are adsorption, precipitation, sediment retention and plant uptake, although some



Figure 30. Peat mining in Harju County, Estonia
Photo: E. de Bruin/Grontmij



Figure 31. Heavy industry in Eastern Europe has resulted in heavy metal pollution of floodplains *Photo: Grontmij*

metals, especially mercury and selenium, do have gaseous pathways. Problems associated with heavy metals in the environment particularly are of concern in Eastern Europe, where the use of measures that can reduce trace metal mobility such as liming of agricultural soils have been greatly reduced in the last decade (Várallyay, 1993). There are numerous sources of trace elements in the environment, including fertilisers, manures, industrial waste as well as natural sources such as metalliferous rocks and degraded peatlands.

How do sedimentation processes affect water quality?

Sedimentation takes place when the velocity of water transporting sediment is reduced, and this typically occurs when river water spills onto floodplains during flood events. The removal of sediment from river water can provide water quality benefits by removing nutrients, trace elements and other pollutants associated with particulates. At the same time the quality of the floodplain soil can be degraded if too many pollutants or nutrients are deposited. However, throughout history many areas have relied on regular flooding events to deposit nutrient rich sediments in order that crops can be produced in a sustainable way. In some regions of Europe floods are still welcome for this reason, such as in the lower reaches of the River Danube. If these natural patterns of flooding are degraded, for example by the construction of dams or embankments along the river, the resulting changes to the natural functioning of river systems and loss of flooding can severely impact agricultural production (Pinay et al., 2002a).

As well as being dependent on a regular sediment supply to maintain their natural fertility, floodplains can also offer an instantaneous improvement in water quality through the deposition of sediment. In particular, the deposition of particle bound substances such phosphorus is particularly important.

Soil erosion is the source of sediment and therefore also the first step in the sedimentation process. Various factors affect the delivery of sediment to a river. Land use may change both the quality and the quantity of sediment, and it is of particular interest when considering the land use of downstream floodplains, which may receive sediment during flooding events. The amount of sediment deposited during over-bank flooding events is generally high and may account for a substantial amount of the total annual sediment load in a river (Table 4).

Phosphorus (usually in the form of phosphate) is often attached to particulate matter, especially small sized particles which may be carried far into floodplains before they are deposited. Table 4 gives some examples of phosphorus deposition rates. Generally phosphorus compounds deposited on floodplains originate from processes of erosion in uplands and consist of calcium, iron and aluminium compounds or clay silicates. Sometimes particulate-associated phosphorus can become dissolved and mobilised, although much of it is thought to remain more or less permanently bound to particulates. Sedimentation of particulate nitrogen in floodplains is not as significant as that of particulate phosphorus, because nitrogen species are found mostly in the dissolved phase e.g. nitrate, ammonia or dissolved organic nitrogen. Nevertheless, some studies show that particulate nitrogen may be trapped in floodplains (Table 4).

Table 4. Examples of sedimentation and associated nutrient deposition rates

Experimental area	Rate of sediment accretion g m^{-2} y^{-1}	Percent of total river sediment load	Phosphorus deposition g P m^{-2} y^{-1}	Nitrogen deposition g N m^{-2} y^{-1}	Reference
21 various floodplains, UK	400-12,200	39.5-48.8	1.3-11.6	N/A	Walling, 1999
Single floodplain, River Gjern, Denmark	4,600	5.6-23.9	11.8	N/A	Kronvang et al., 1999
Single floodplain, riparian zone, France	28,898	N/A	N/A	64.5	Brunet, et al., 1994
Single floodplain, riparian zone, France	N/A	N/A	12.7	N/A	Brunet and Astin, 1998
Bottomland hardwood wetland, USA	800	14	N/A	N/A	Kleiss, 1996
10 km stretch of floodplain, River Danube, Austria	25,000	50	N/A	N/A	Tockner et al., 1999
Single floodplain, France	N/A	N/A	9.0	N/A	Fustec et al., 1995
Riparian forest levee	7,840	N/A	8.2	52.4	Johnston et al., 1984
11 various floodplains, USA	N/A	N/A	1.46	14.6	Johnston, 1991

Although sedimentation on a floodplain is a natural process occurring during flooding events, sometimes it is necessary to remove sediment deposits if, for example, a water quality problem may arise if pollutant re-mobilisation occurs. One strategy involving removal of sediment deposits, called cyclic floodplain rejuvenation, has been developed with the additional benefits of flood risk management and nature restoration in mind. Essentially, the floodplain is lowered by excavation and secondary channels constructed or reconstructed to give more space for water and thereby reduce flooding risks. At the same time ecological rehabilitation of the floodplain takes place. As the conditions will change with time due to the hydrological, morphological and ecological processes it is important to have a strategy for sustainable cyclic floodplain rejuvenation.

Sedimentation often is an important process with regard to the retention of trace elements and persistent organic pollutants (POPs). For example, in areas where heavy industry and mining have occurred such as in the catchment of the River Elbe, Germany, floodplain sediments can contain high concentrations of trace elements. The significance of sedimentation (and potential remobilisation) of trace elements is discussed below.

How do floodplains retain nutrients?

The retention of nutrients in floodplains can have significant impacts on the quality of water draining from them, and is widely considered to be one of the most important functions they perform. There are several processes by which nutrients can be retained in wetlands, including storage in plant material and soil organic matter (Box 12). Some forms of N and P may be chemically precipitated under certain soil environmental conditions, or if attached to or included in particulate matter, they may be retained through sedimentation. Retention processes do not result in permanent removal of nutrients from a system, but temporary storage, which can exist for a range of periods. For example, nutrients taken-up by woody plants may be stored for tens or even hundreds of years, depending on the life cycle of the plant, before plant mortality releases the nutrients back into the system. Following mortality organic material may become incorporated into soil, and if conditions prevail that permit the accumulation of soil organic matter or even the development of peat, storage of nutrients taken-up by either woody or herbaceous plants can last for thousands of years.

Box 12. N and P processes and transformations in floodplains



Figure 32. Nitrogen processes and transformations



Figure 33. Phosphorus processes and transformations

Source: Hoffmann, 1998

How do floodplains export nutrients?

Nutrient export occurs through one of three principal processes: gaseous emission, harvesting of vegetation (see Figure 34) or erosion. The nutrient export function is particularly significant, because like nutrient retention it provides mechanisms for potentially improving the quality of polluted water, but unlike nutrient retention, it represents a permanent removal of nutrients from the system and with no risk of remobilisation should conditions in the wetland change. Some of the processes that enable the export of nutrients, such as denitrification and ammonia volatilisation, respectively can result in the export of harmful compounds like nitrous oxide, which is a greenhouse gas, or ammonia, which can be deposited on nutrient sensitive environments, resulting in ecological degradation, as well as contribute to acid rainfall (Box 13).



Figure 34. Harvesting reeds provides a mechanism for the export of nutrients from a floodplain wetland
Photo: Albert Beintema

How do floodplains retain carbon?

The carbon balance in wetland ecosystems primarily is controlled by environmental conditions, especially hydrology. Carbon contained in organic matter accumulates where the annual input of plant litter exceeds the annual breakdown. Accumulation is favoured by low temperatures, high acidity, low nutrient status, and perhaps most importantly, waterlogging. The slow diffusion of oxygen in saturated soils exerts severe limitations on the rate of decomposition of organic matter in water saturated environments. Organic-rich wetland soils and peats can have considerable environmental, ecological, socio-economic and archaeological significance (Box 14).

Why is organic carbon important in surface waters?

Control of the amount of organic carbon in surface waters is important as not only can it be an important source of energy for an aquatic system, but it can impact the quality of water in several ways. It can affect the turbidity of surface waters, have a strong influence on pH and act as a strong complexing agent, affecting the transport of many chemicals, especially trace metals. Excessive concentrations can cause problems in the treatment of water for human consumption.

How do floodplains store trace elements?

Trace elements in the environment can be highly toxic to a wide range of organisms, but floodplain wetlands provide a potential sink for them. The sustainability of this function depends on many factors, but in particular on the nature of the processes responsible for the performance of the function. For example, if the storage process predominantly is through contaminated sediment retention, the sediment storage capacity of any wetland is finite, and eventually will be exceeded. Performance of this function also incurs potential hazards, whereby accumulation of heavy metals in a wetland system can eventually result in degradation of the system itself. As with nutrient retention, trace element storage represents only a temporary storage of potential pollutants, and if conditions within a wetland change, remobilisation and possibly toxic flushes are always a possibility.

Box 13 – Greenhouse gas emissions and pollution swapping

While many of the biogeochemical processes occurring in floodplain soils can contribute to the improvement of water quality, it must be remembered that in some cases, while solving one pollution problem, they may be causing another. One good example of this is the process of denitrification, which potentially can remove nitrate from surface water by converting it to harmless nitrogen gas (N_2). However, under certain conditions the process may be incomplete resulting in the production of nitrous oxide which is a greenhouse gas, and therefore while limiting the pollution of water by nitrogen fertilisers, we may simply be swapping a relatively local pollution problem for the global problem of climate change (M. Hefting et al. 2003). Which of these is the more important problem depends on individual perspectives. Also, wetlands are one of the largest natural sources of methane, another greenhouse gas, resulting from the storage and subsequent transformation of carbon compounds. Consideration must be given to pollution swapping effects when implementing natural flood defence schemes.

Box 14. Significance of organic soils and peatlands

- ***Biodiversity -*** *The variation in trophic status and pH across the range of peatland types results in enormous variation in vegetation and community assemblages. The distribution of invertebrates and higher animal species is frequently linked to this spatial variation of plants across hydrogeomorphic gradients, and commonly results in highly biodiverse faunal and floral populations.*

- ***Palaeoenvironmental information and heritage -*** *Wetland and especially peat-forming ecosystems often uniquely preserve a sequential record of their own development together with a record of features and events in their contemporary environment. The combination of conditions conducive to preservation (e.g. waterlogging, acidity, low microbial activity, relatively small temperature fluctuations), and the incremental patterns of accumulation of organic matter and/or sediment make many wetlands exceptionally efficient at recording environmental changes at local and wider scales. Studies of pollen, macrofossils, human artefacts and cultural remains (e.g. the Sweet Track, Somerset, UK), preserved in peats and wetland soils have contributed greatly to our knowledge of vegetation and landscape history, the nature and speed of change of past climates as well as changes in human society. Early human communities often depended on wetlands for economic prosperity or even their survival. Some traditional uses still remain, such as cutting of Phragmites for thatching, late-summer grazing of fen meadows, small-scale peat digging, hunting of wildfowl and fishing. Strong cultural traditions are often associated with such uses giving rise to distinctive human communities and landscapes in different parts of Europe.*



Figure 35. The Sweet Track – an example of preservation of archaeological remains in peat
Photo: English Heritage: Somerset Levels Project

How do floodplains export trace elements?

The permanent removal of trace elements from surface waters is highly dependent upon their form within the wetland.

Trace elements incorporated into vegetation can be removed by management processes such as harvesting, and this enables controlled removal. Trace elements incorporated into sediments may be exported by physical erosion by either water or wind (Figure 36), or by biogeochemical remobilisation and export in solution by water. Changes in environmental conditions, such as fluctuations in acidity or redox potential can cause releases of trace elements, and result in wetlands formerly acting as sinks to act as sources.

Box 15. Summary points, floodplain biogeochemistry

- *The main benefits that arise as a result of floodplain biogeochemistry are water quality improvement and nutrient regulation*
- *The restoration of wet floodplain soils as opposed to dry floodplain soils are most significant with regard to biogeochemical functions*
- *The key functions performed by floodplain wetlands are:*
  - *nutrient export*
  - *nutrient retention*
  - *carbon retention*
  - *dissolved organic carbon regulation*
  - *trace element storage*
  - *trace element export*



Figure 36. Water erosion can cause the remobilisation of trace elements. Example of water eroding sediments on the River Dinkel, The Netherlands
Photo: Y. Wessels/Grontmij

What should I consider with regard to floodplain biogeochemistry when restoring floodplain functioning?

The priority of floodplain restoration schemes in the context of this document is natural flood defence and natural flood control, but the objective of this section is to provide information on how floodplain restoration for flood defence can simultaneously facilitate the optimisation of water quality. When floodplains and riparian areas are restored in order to re-establish natural flood control functions it is tempting to assume that the function of improved water quality will automatically occur. However, it is important to focus on some of the variables controlling water quality and also consider floodplain functioning and stability with regard to water quality. It is first necessary to gather information about the catchment of which the floodplain to be restored is a part.

The information listed in Box 16 should be acquired. If the issue of water quality is used as a starting point for a restoration scheme it is necessary to assess the whole river system and develop an integrated river basin management plan in order to achieve sustainable use of the river system, which at the same time makes allowance for natural flood defence. However, more commonly it will be considered as a secondary factor to flood defence, in which case it is important to optimise the opportunities for improving water quality wherever possible.

How can river water quality be a controlling variable in the management strategy of a floodplain restoration scheme?

At an early stage it may turn out that water quality limits the re-establishment of some of a floodplain's natural (usually ecological) functions, although it will not directly affect the ability of a floodplain to be part of a natural flood defence scheme. If the river water is of poor quality that could potentially threaten valuable or important floodplain ecosystems in the event of restoration of natural flooding, it might be necessary to restrict the occurrence of flooding in some areas to extreme events only. This will limit the damage it does and also provide a flood defence function during large flood events only.

What are the key concepts with regard to floodplain biogeochemistry that should be considered when restoring floodplain functioning?

There are three key concepts related to floodplain biogeochemistry (Box 21):

1) The river continuum concept: this considers the entire fluvial system as a continuous gradient of physical conditions and associated biotic adjustments. The river continuum concept provides a unidirectional (longitudinal) perspective (Vannote et al., 1980).

Box 16. Basic information about the catchment

Information on the following variables in a catchment must be obtained if water quality improvement is the main objective of a floodplain restoration scheme:

Land use
Soil type
Urbanisation
Industrial activities
Point source pollution
Non-point source pollution
River water quality
Groundwater quality
Erosive processes
Sediment quality
Mining activities



Figure 37. Different land uses in a catchment

Source: NERI

2) The flood pulse concept: this recognises the natural interactions between a river and its floodplain (lateral connectivity). The flood pulse concept (Junk et al., 1989) emphasises the importance of alternating dry and wet phases (Ward et al., 2002). The concept of hydrological connectivity (Amoros and Roux, 1988) refers to exchange of matter and energy between different units of a riverine landscape (Ward et al., 2002). Both concepts give a lateral and temporal perspective.

3) The nutrient spiralling (or material spiralling) concept: this considers the downstream transport of nutrients as a spiralling process, where nutrients pass through a cycle and it is possible to measure the distance required for a complete cycle to take place. The shorter the distance the more nutrients can be used and the more retentive and productive the river, riparian zone or floodplain will be (Newbold et al., 1981).

What will be the likely significance of restoring wetland biogeochemical functions on river water quality?

Although water quality may be enhanced by restoring the hydraulic connectivity between the river and the floodplain not all improvements are of quantitative importance. The most significant impacts are on particle bound substances such as phosphorus compounds adhering to silt and clay particles, which are trapped on the floodplain during flooding events. In contrast, for dissolved compounds such as nitrate, retention through biological uptake or export by transformation of nitrate to dinitrogen gas (N_2) through the process of denitrification are not likely to be significantly altered by restoration of flooding. This is due to a discrepancy between the amount of dissolved compound (e.g. nitrate) present in floodwaters and the surface area of the floodplain. An example of the differences in retention of dissolved and particulate nutrients on large floodplains is given in Box 17.

However, it is important to distinguish between the removal of pollutants from floodwaters flowing from the main river channel onto a floodplain and the removal of pollutants from catchment runoff that has not previously entered the main river channel. While removal of pollutants, especially dissolved nutrients, may not be particularly significant with regard to river flood-water quality, the restoration of floodplain wetlands and riparian ecotones, including their connectivity to both upslope/catchment runoff and the river can be highly significant with regard to protecting river water quality.

In this role as 'buffer zones' (Box 18), floodplains are able remove large quantities of potential pollutants and assist with the provision of good river water quality. While the contribution of individual, small areas of floodplain may be small, in combination with similar areas throughout a catchment the effects can be highly significant.

Box 17. An example of the differences in retention of dissolved and particulate nutrients on floodplains

To illustrate the differences in retention of dissolved and particulate nutrients on large floodplains, Van der Lee et al., (2004) have calculated the retention of phosphorus and nitrogen for two of the River Rhine tributaries, the Rivers Waal and IJsel. Phosphorus retention (i.e. sedimentation) amounted to 4.6% and 18.6% of the annual load for the Waal and IJsel, respectively. Nitrogen retention (denitrification and sedimentation) was only 0.68% for the Waal and 2.7% for the IJsel (and in the latter sedimentation accounted for 2.5%). In the above example the denitrification rates used to calculate the figures were in the range 38 – 44 kg N ha^{-1} $year^{-1}$ (Van Der Lee et al., 2004), which is low compared to many groundwater fed wetlands. Tockner et al. (1999) found a significantly higher nitrate removal rate of 960 kg N ha^{-1} $year^{-1}$ or 45% of the amount entering a 10 km long floodplain area along the River Danube. Removal of nitrate from floodwater through denitrification on larger floodplains is probably also limited by the diffusion rate, as nitrate has to migrate to the anaerobic sites at the surface water-sediment interface or into the sediment. Also soil properties influence denitrification.

How should I approach problems that are associated with dissolved elements and compounds that might be problematic following floodplain restoration?

Approaches to these problems are best demonstrated by consideration of nitrogen as an example of a dissolved nutrient that could potentially cause problems. There are three basic ecological principles driving the biogeochemical cycle of nitrogen in river systems (Pinay et al., 2002b). These principles are strongly related to all the above mentioned concepts (longitudinal, lateral and vertical connectivity of the river system):

Principle 1. **The mode of nitrogen delivery affects ecosystem functioning.** Riparian areas deliver nitrogen to streams mainly as particulate matter. This is because riparian areas (under natural conditions) efficiently perform the process of denitrification (i.e. conversion to N_2). Dissolved nitrate and ammonia originating from upslope areas reach the floodplain as subsurface flow in the root zone, are taken-up by plants and upon senescence are liberated as particu-

late organic nitrogen to streams. The floodplain acts as a storage site for sediments and associated nutrients during flooding events.

Principle 2. **The area of water/substrate interface is positively correlated with the efficiency of nitrogen retention and use in river systems.** In this context the interfaces are water-sediment or wetland-upland interfaces. Increasing contact between water and soil or sediment increases nitrogen retention and processing, because a high surface to volume ratio and long contact time favours biological and biogeochemical processing (e.g. uptake, retention and transformation). It is important to be aware that the efficiency of a riparian zone in regulating nitrogen fluxes generally is not a function of the surface area of the riparian zone but more commonly a function of the length of hydrological contact between a riparian zone and the upland drainage basin.

Principle 3. **Floods and droughts are natural events that strongly influence nitrogen cycling pathways.** Biogeochemical processes are sensitive to the presence or absence of oxygen. The generic term is redox condition. Changes in water level may influence redox conditions significantly and thus biogeochemical processes, because some only take place under strictly aerobic (e.g. nitrification) or strictly anaerobic (e.g. denitrification) conditions.

What are the roles of Ecotones?

Ecotones (boundary zones, interfaces) are zones of transition between habitat types or adjacent ecological systems having a set of characteristics uniquely defined by temporal and spatial scales and by the nature of the interactions occurring within them. Aquatic-terrestrial ecotones play an essential role in the movement of water and materials throughout landscapes and generally ecological processes are more intense and resources more diverse within them. They are also zones that react quickly to human influence and changes in environmental variables (Naiman and Décamps, 1997). A series of ecotone hypotheses related to water quality and flooding issues are given in Box 19.

Box 18. Buffer Zones

A buffer zone is a vegetated area lying between agricultural land and a surface water body, and acting to protect the water body from harmful impacts such as high nutrient, pesticide or sediment loadings that might otherwise result from land use practices. It offers protection to a water body through a combination of physical, chemical and biological processes (Blackwell et al., 1999). The degree to which this protection is provided depends on a number of factors including the size, location, hydrology, vegetation and soil type of the buffer zone (Dosskey et al., 1997; Leeds-Harrison et al., 1996), as well as the nature of the impacts by which the water body is threatened.

Buffer zones can take many forms ranging from wide, purposefully constructed buffer zones, to narrow, un-cropped strips in arable fields adjacent to ditches, or even hedges or ponds. Also, they may be given many names. Some of the more common types and names are listed below, but essentially they all are able to function as buffer zones:

- *Vegetated riparian buffer zones*
- *Riparian buffer zones*
- *Buffer strips*
- *Wetland buffer zones*
- *Contour strip buffer zones*
- *Field margin buffer zones*
- *Hedges*
- *Wetland buffer zones*

For more information on buffer zones see Haycock et al. (1997).



Figure 38. A buffer zone protecting a stream from pollution from pasture upslope
Photo: M. Blackwell/SWIMMER

Box 19. Important ecotone hypotheses related to the floodplain and the riverine landscape (after Naiman et al., 1989)

- *The restoration and creation of land/inland water ecotones will promote the recovery of their ecological functions, including soil and bank stability, nutrient and sediment trapping, habitat for species conservation and regeneration, and will re-establish the process of floodplain formation and maintenance.*
- *The maintenance, restoration and creation of ecotones are efficient management tools: (1) for regulating water quality and runoff, (2) for water conservation, and (3) for enhancing amenity and recreational opportunities.*
- *In riverine landscapes, nutrient and sediment retention efficiency is positively related to the percentage of the landscape composed of terrestrial/aquatic water ecotones. This is the case in small streams and also in large rivers. Water level fluctuations are also important in riverine landscapes because retention is most efficient when riparian wetlands are flooded and water comes into contact with wetland ecotones.*
- *For smaller ecotones, nutrient and sediment retention efficiency is greatest when surface and subsurface flows are evenly distributed across the entire length of the ecotone. Retention efficiency is less when the flow of materials is concentrated in corridors such as gullies, drains, and man-made ditches.*
- *The structure and function of terrestrial/aquatic ecotones are related to the frequency of disturbance by extreme hydrological events.*
- *Sequences of flooding events affect the coupling of ecotones to adjacent ecosystems.*
- *The influence of an ecotone on adjacent systems is proportional to the length of the contact zones.*
- *The quantity and direction of water flow through ecotones directly affects the rate of exchange of dissolved and suspended solids between ecotones and adjacent ecosystems.*
- *Spatial and temporal variations in oxidation-reduction (redox) conditions characteristic of ecotones enhance the rates of certain microbial and physical processes (e.g. denitrification, methanogenesis, and phosphorus precipitation with sesquioxides). These processes proceed more slowly in adjacent ecosystems with more stable redox conditions.*

On a large scale, floodplains themselves act as ecotones between upland and rivers. On a smaller scale it is possible to identify several patches where floodplains interact with adjacent ecosystems.

Although hard to delineate, one very important part of a floodplain is the riparian zone. This can be defined as land in or adjacent to perennially flowing river channels that have soils which are normally saturated by ground water within the rooting depth of naturally occurring hydrophytic (water-loving) vegetation for at least part of the growing season, due to their proximity to the river.

For large floodplains the riparian zone acts as an area where the major proportion of sedimentation takes place during flooding events (Brunet and Astin, 1997), and improves riverbank stability (due to these functions some authors refer to these as riparian vegetated buffer strips). It is also in the riparian zone where exchange of water between a river and a floodplain takes place. In smaller streams the riparian zone acts as a link between terrestrial upland ecosystems and streams.

Some of the most important functions performed in agricultural and grazing landscapes include filtering and retaining sediment, immobilising, storing, and transforming chemical inputs from uplands, maintaining stream-bank stability, modifying stream environments and providing water storage and recharge of subsurface aquifers (Naiman et al., 1995).

Restoring natural patches between floodplains and adjacent ecosystems by removing and disconnecting man made installations and devices like drains, ditches and impoundments will improve not only water quality in the floodplain and the river but also improve the natural functioning of the whole floodplain ecosystem.

Box 20. Summary of key points to consider with regard to river water quality when restoring floodplains

- *If the issue of water quality is used as a starting point for a restoration scheme it is necessary to assess the whole river system and develop an integrated river basin management plan in order to achieve sustainable use of the river system, which at the same time makes allowance for natural flood defence.*
- *To improve river water quality in order to reduce the impacts of dissolved nutrients, particulate nutrients, metals and other substances on floodplains it is first necessary to look upstream and identify the causes of poor water quality.*
- *Restoring natural patches (ecotones) between uplands and streams can solve problems associated with dissolved nutrients. The patches are often referred to as 'buffer zones'.*
- *Man-made hydrological bypasses such as ditches and drains should be adapted to allow interaction with proposed treatment areas such as buffer zones.*
- *Restoring lateral connectivity of a river and re-meandering of streams and rivers will help reduce sediment loads.*
- *A lack of natural buffer strips may result in severe bank erosion. Bank erosion may account for more than 50% of the sediment export from a catchment (Laubel et al., 2003). In rural areas cattle fencing or forested buffer zones along water bodies will help lower erosion rates (Laubel et al., 2003).*
- *Soil erosion due to bad tillage practise in agricultural areas and a concomitant lack of buffer zones (vegetated buffer strips) may cause elevated sediment loads in streams and rivers. This can be resolved by changing soil tillage practises and improving riverbank and streambank stability by establishing buffer strips (riparian vegetated buffer strips).*
- *The restoration of natural hydrological regimes on floodplains is likely to improve river water quality during flood events with regard to sediment-bound pollutants, but will be less significant with regard to dissolved nutrients. However, river water quality can be improved with regard to dissolved nutrients by the restoration of floodplain habitats able to function as buffer zones and improve the quality of catchment runoff before it enters a river.*

FLOODPLAIN RESTORATION CONTRIBUTES TO NATURE CONSERVATION

How do plants and animals respond to natural river dynamics?

The natural dynamics of riverine systems such as water table fluctuations, erosion and sedimentation strongly influence riverine landscapes, resulting in very specific complexes of ecosystems and habitats. These natural dynamics are well explained by three concepts, namely the River Continuum Concept (Vannote et al., 1980), the Flood Pulse Concept (Junk et al., 1989) and the Flow Pulse Concept (Tockner et al., 2000). These three concepts are described in Box 21.

Because of their dynamic nature, natural river systems contribute to the existence, both temporally and spatially of many gradients such as that between water and land and those between different types of water (eutrophic and oligotrophic, fresh and saline). Since the biodiversity of an area depends upon the diversity of its physical and chemical environment and increases along with the number of gradients, the landscape diversity generated by naturally functioning river systems usually is high at both the landscape and the local scale. In a European context, up to 80% of all the existing species of wild plants and animals are, at least in part, associated with river-influenced landscapes.

What is the impact on ecology of naturally functioning rivers and floodplains at the landscape scale?

Natural river systems function as ecological corridors for the natural dispersion of plants and animals (River Continuum Concept) and make an important contribution to the ecological coherence of the landscape. Migratory fish, which often require the unrestricted connectivity of an entire catchment, present the most obvious examples of this function (Van den Brink et al., 1996; Schiemer, 2000; Grift, 2001). However, other aquatic organisms including plants also require unrestricted upstream-downstream connectivity over relatively long stretches of river to maintain sustainable populations (Ward and Stanford, 1995; Van den Brink et al., 1996). Many terrestrial animals (invertebrates as well as many species of amphibians, mammals and birds) often disperse or migrate preferentially along rivers, making the role of river floodplains as ecological corridors very important (Box 22).

Box 21. Dynamic river processes in relation to landscape and nature

1. ***The River Continuum Concept;*** *the hydrological connectivity in a river system influences conditions for plants and animals living in or along any given stretch of it (Vannote et al., 1980);*
2. ***The Flood Pulse Concept;*** *(seasonally) fluctuating discharge levels influence conditions for plants and animals living alongside the rivers (Junk et al., 1989);*
3. ***The Flow Pulse Concept;*** *also includes the (seasonally) fluctuating flows (both in direction and in magnitude) of groundwater flows, as far as these changes are caused by fluctuating river discharges (Tockner et al., 2000).*

River dynamics both shape the landscape and set the conditions within which ecosystems, habitats and flora and fauna settle. Due to the dynamics, a fourth 'time' dimension emerges when considering natural river systems over periods of several decades or more. Within such time frames, the dynamics cause significant changes in geomorphology, due to fluctuations in patterns of erosion and sedimentation. Consequently, natural rivers will change course, form new side channels, meanders or cut-off other meanders, which become oxbow lakes and then gradually experience succession towards swamps and eventually land (Wolters et al., 2001).

Box 22. Migratory wetland birds as examples of floodplain values on a landscape scale

For many migratory wetland bird species, large European river catchments traditionally delineate migration routes (Figure 39). During migration, birds rely on the presence of regular stopover sites to rest and refuel, before resuming their trip (Figure 40). These flyways have been shaped evolutionally by changes in climate and landscape over geological time (Piersma, 1994). Thus, a balance has been maintained between the distances of (riverine) wetlands along migration routes and the amount of food birds are able to consume at them in order to reach the next stopover site. Consequently, it is likely that reproductive success and population size of migratory wetland bird species are dependent upon the combination of productivity and distance of freshwater, river-related wetland sites along migratory flyways (Platteeuw, in press).

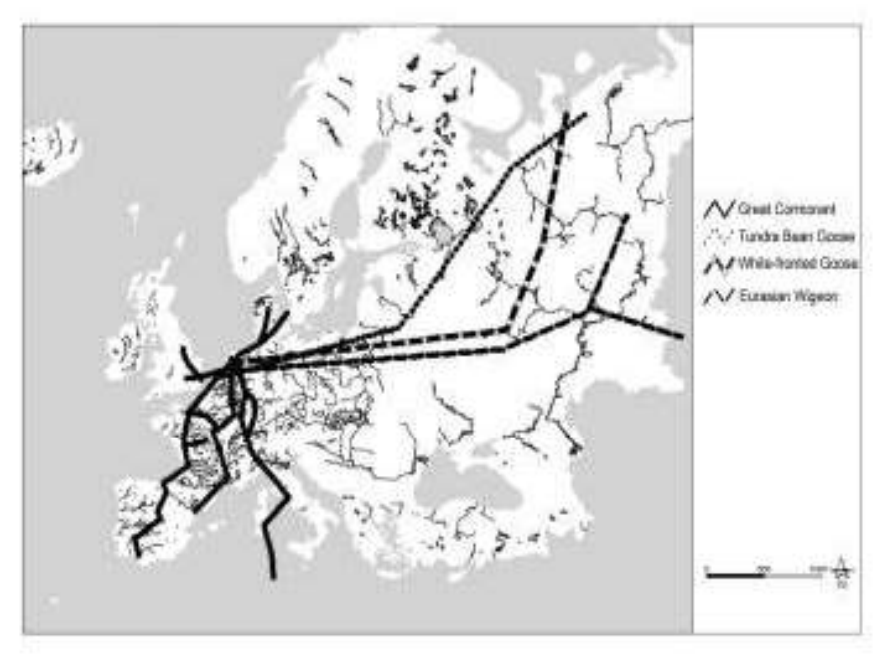
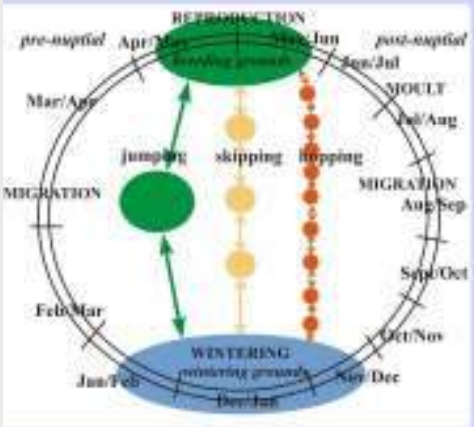


Figure 39. Examples of migration routes of four different bird species *Source: RIZA*



1. Jumping: long distances, high energy costs, few high quality stopover sites
2. Skipping: medium long distances, several medium quality stopover sites
3. Hopping: short distances, many low quality stopover sites

Figure 40. Three possible migration strategies for birds *Source: RIZA*

What is the impact on ecology of naturally functioning rivers at the local scale?

Flood and flow pulses cause large seasonal variations in inundation and/or moistness and in combination with morphology, are important agents in determining seasonal and spatial variability in habitat conditions. Temporal and spatial gradients in humidity, hydrology and nutrient status are highly variable in floodplains. Generally areas of floodplain closest to a river tend to be more eutrophic than those more distant from a river. Consequently areas receiving little riverine influence tend to be mesotrophic or oligotrophic. This applies to both terrestrial and aquatic ecosystems. Thus, a very wide variety of plant and animal species are often found in close association with river systems because of the wide range of trophic levels connected to the flooding regime.

Habitat diversity in floodplains can also result from grazing by large herbivores. The food preferences of animals, together with seasonal fluctuations in the availability of preferred food items caused by seasonal flooding, can substantially alter vegetation succession from pioneers to floodplain forests because grazing maintains parts of the ecosystem in a younger succession stage than those that are un-grazed.

What is the importance of floodplains for ecological status and biodiversity?

The temporal dynamics in naturally functioning floodplains ensures the survival of many habitats and species identified as important biological quality elements in the EU Water Framework Directive. Aquatic plant communities generally favour low dynamic conditions (e.g. in isolated oxbow lakes with relatively low nutrient loads) and are host to very specific communities of invertebrates and fish. Other species of invertebrates and fish require running water, but still benefit from seasonal flood dynamics which allows them to spawn and develop on floodplains during periods of high water.

Seven distinctive (semi-)natural landscape types are associated with floodplains, each varying in properties such as altitude, distance to the main channel, geomorphology, hydrological characteristics and anthropogenic impact. Approximately 17% of the habitat types (numbering in excess of 200) mentioned in Annex I of the EU Habitats Directive may be found in close association with river systems (Table 5), and at least 30 are also found in association with floodplains.

Many animals and plants referred to in the EU Habitats Directive are often found in floodplain habitats. For example, eight species of mammals, four reptiles, 24 amphibians and 63 fish from Annex II of the Habitats Directive (requiring the designation of Special Areas of Conservation) commonly occur in and around riverine and floodplain environments. Five of these mammal species (Pyrenean desman, beaver, two subspecies of root vole and otter), seven reptiles (three freshwater turtles and four *Natrix* snakes), as well as 46 species of amphibians and eight species of fish are also mentioned in Annex IV and numerous invertebrates and higher and lower plant taxa associated with riverine habitats are mentioned in both Annex II and IV.

Out of 194 bird species mentioned in Annex I of the Birds Directive, approximately 90 regularly occur in the seven riverine landscapes identified in Table 6. The most attractive riverine landscapes for these birds are ‘standing waters’ and ‘swamps’, where no less than 44 and 52 species respectively can be found (Box 23).

Box 23. The EU Birds Directive and floodplain landscape types

Table 5 shows the number of bird species from Annex I of the EU Birds Directive commonly occur in the natural or semi-natural landscape types identified as typical for floodplain areas (Table 6).

Table 5. Bird species associated with different floodplain landscape types

Landscape type	***Number of bird species***
Fens	18
(Semi)-natural grassland (moist/dry and wet)	26
Natural forest	28
Swamps (mineral wetlands)	52
Wet production grasslands	25
Flowing water systems (including secondary channels)	36
Standing (still) waters	44

Table 6. Landscape types and ecological and conservation values of river floodplain systems

Landscape type	Description, position and ecological values (including contribution to Good Ecological Status for Water Framework Directive)	Potential habitat types from Annex I Habitat Directive
1. Fens	Peatlands fed predominantly by groundwater, occasionally also by river water. Mostly in upper catchments and along edges of river valleys. Important nesting and feeding grounds for birds. Nutrient-poor fens often very rich in rare plant species (small sedge-brown moss vegetation). Nutrient-rich fens (e.g. tall sedge vegetation), commonly found in floodplains and important for wildlife.	1. Transition mires and quaking bogs 2. Fenno-scandian mineral-rich springs and spring fens 3. Calcareous fens 4. Petrifying springs with tufa formation 5. Alkaline fens
2. (Semi)-natural grassland (moist/dry and wet)	Present in most river valleys. Mainly semi-natural ecosystems, where vegetation succession is prevented by mowing and/or grazing, sometimes also maintained by climatic conditions or flooding dynamics. Of fundamental importance for waterfowl. Some belong to the most species-rich plant communities in Europe.	1. Xeric sand calcareous grasslands 2. Semi-natural dry grasslands and scrubland facies on calcareous substrates 3. Fenno-scandian lowland species-rich dry to mesic grasslands 4. Alluvial meadows of river valleys 5. Northern boreal alluvial meadows 6. Lowland hay meadows
3. Natural forest	The climax vegetation in most river valleys, especially in the temperate zone. Development usually impeded only in highly flooded areas or floodplains adjacent to rivers with strong flow velocities, carrying a lot of ice-float in spring. Some of the most species-rich European ecosystems and home to many rare and endangered species (especially fauna).	1. Fenno-scandian deciduous swamp woods 2. Alluvial forests 3. Riparian mixed forests 4. Riparian formations on intermittent Mediterranean water courses 5. Southern riparian galleries and thickets
4. Swamps (mineral wetlands)	Swamps and other wetlands with mineral soils occur in areas with very high water levels or/and high water level fluctuation. Typically they occur (1) in close proximity to rivers – along shores and in shallow water bays and (2) away from the main channel in (remnants of) ox-bow lakes and meanders cut-off during river regulation works. Important ecological role as breeding sites for macro-invertebrates, amphibians and fish.	1. Natural eutrophic lakes 2. Water courses of plain to montane levels 3. Rivers with muddy banks
5. Wet production grasslands	Grasslands, mainly for the production of grass for grazing, hay, etc. which may or may not be fertilised; groundwater levels relatively high, winter flooding regular; conservation values generally do not include rare flora, but do include breeding waders and/ or wintering waterfowl. Also spawning area for certain species of fish during floods, thus contributing to Good Ecological Status.	1. Alluvial meadows of river valleys 2. Northern boreal alluvial meadows
6. Flowing water systems (including secondary channels)	Flowing systems (main and secondary river channels) include highly valuable wildlife only if the water is of a reasonably high quality and channels have retained at least some elements of their natural form. Important for both aquatic and emergent plant communities and home to numerous other organisms (e.g. invertebrates and fish).	1. Fenno-scandian natural rivers 2. Alpine rivers and the herbaceous vegetation along their banks 3. Alpine rivers and their ligneous vegetation with *Myricaria germanica* 4. Alpine rivers and their ligneous vegetation with *Salix elaeagnos* 5. Constantly flowing Mediterranean rivers (2 types) 6. Water courses of plain to montane levels 7. Rivers with muddy banks 8. Intermittently flowing Mediterranean rivers
7. Standing (still) waters	In riverine landscapes mainly in the form of ox-bow lakes and old meanders cut-off by river regulation works. Some can be classified as natural eutrophic lakes. Oligotrophic lakes are scarcer in riparian areas. Important strongholds for specific communities of aquatic plants, invertebrates and fish, all contributing to the Good Ecological Status of the water body.	1. Oligotrophic waters containing very few minerals (2 types) 2. Oligotrophic to mesotrophic standing waters 3. Oligo-mesotrophic waters with benthic vegetation 4. Natural eutrophic lakes

What has been lost and why?

Often it is not known which natural values of an impacted floodplain have been lost. However, it is evident that the restriction of river dynamics resulting from the high degree of regulation to which most European rivers have been subjected has resulted in the loss of many riverine habitats and their characteristic elements of biodiversity. Natural reference sites can be used to gain information on what has been lost from a degraded floodplain.

The main causes of degradation in each of the seven main floodplain landscape types identified are summarised in Table 7. Intensive agriculture has had the greatest impact on these habitats because it promotes practices such as protection from flooding, drainage, excessive use of fertilisers (resulting in eutrophication) and the use of pesticides. River regulation, both for flood protection and for infrastructural purposes, has also greatly contributed to the loss of typical dynamic riverine landscapes.

What should I consider with regard to nature conservation when restoring floodplain functioning?

When considering floodplain restoration schemes, it is crucial to have a good understanding of the existing situation (landscapes, habitat types and plant and animal species present) and the processes supporting this condition (environmental, biological and anthropogenic). Environmental processes are mainly determined by the hydrological regime and morphodynamics. These factors generally provide the fundamental structure for the existing condition of a floodplain by determining both the hydrological condition (degree of connectivity to the main river and dependence upon groundwater) and the morphological condition (altitude, relief and soil composition).

Biological processes include 'habitat shaping' processes resulting from the presence of 'key ecological organisms' (Pastorok et al., 1997). Examples of these are:

- vegetation succession, providing different vegetation structures and thus different habitats for fauna,
- (large) grazing species, which by their grazing and trampling may locally influence vegetation succession and, thus, habitat diversity,
- beavers, which by their 'engineering' and dam-building activities may construct 'micro-wetland' habitats within the floodplain.

Another important biological process in floodplains is the functioning of the food web, which determines the biological productivity and the ecological carrying capacity for larger vertebrates, e.g. predatory fish, medium- and large-sized mammals and birds.

Table 7. Causes of decline and disappearance of natural riverine landscape types

Landscapes in river floodplains	Causes of decrease in quantity and quality
1. Fens	Largely degraded by agricultural land reclamation; mesotrophic fens, often very rich in rare plant species degraded by eutrophication (excess use of fertilisers), conservation status largely depending on the quality (trophic status) of the water; however nutrient-rich fens also becoming increasingly rare due to altered hydrology.
2. (Semi)-natural grassland (moist/dry and wet)	Natural values diminished by intensified agricultural land use, including use of fertilisers, drainage systems and loss of natural seasonal flooding.
3. Natural forest	Largely destroyed to make way for agricultural land use; typical riverine forests also degraded by loss of natural, seasonal flooding regime.
4. Swamps (mineral wetlands)	Largely reclaimed for agricultural land use; values lost because of changed and more controlled hydrology.
5. Wet production grasslands	Although not really a natural landscape type, natural values diminished by intensified agricultural land use, including use of fertilisers, drainage systems and loss of natural seasonal flooding.
6. Flowing water systems (including secondary channels)	Values lost due to infrastructural works (sluices, dams, dykes), gravel and sand industry, hydropower plants and reservoir construction, all of which have destroyed both natural habitat types (e.g. shallow running water, gravel beds) and natural connectivity between different river stretches within a single catchment area; water pollution by excess nutrients as well as chemicals (e.g. pesticides and herbicides).
7. Standing (still) waters	Disappearance due to land reclamation; degradation due to eutrophication and water and soil pollution.

Anthropogenic influences include various types of agricultural land use (arable, pasture, etc.), and associated levels of fertiliser application (resulting in eutrophication or even hyper-eutrophication), the use of pesticides and herbicides, hydraulic measures in river systems (e.g. groynes, dams, sluices, embankments, etc.) and construction of buildings and other infrastructure.

Ecological restoration targets should be formulated based on both the physical potential of an area, the ecological objectives of the Water Framework, Birds and Habitats Directives and/or national or local conservation objectives. Both historical data on the proposed restoration area (old maps, historical data on river characteristics, ecology, etc.) and data from similar, but less impacted ecosystems elsewhere may be used to determine these potential targets and to assess the likelihood of them being achieved. Finally, within the hydrological constraints of a proposed flood defence scheme, measures should be identified that will on the one hand enhance flood protection and preserve actual conservation values, and on the other stimulate the development of new values within the scope of the ecological targets. These steps are described below in more detail.

How do I assess the existing situation?

The existing condition of the proposed restoration area should be described as accurately as possible (Box 24), based on the existing spatial patterns (altitude, relief, landscape types, ecotopes, etc.) and the processes (hydromorphological and biogeochemical as well as anthropogenic) that control these patterns. One such tool that enables this assessment is the Wetland Ecosystems Decision Support System (Box 25). In addition, an inventory should be made of the conservation values of the area, including an assessment of the ecological status of water bodies in the terms required by the EU Water Framework Directive. These conservation values can be divided into local values and values of importance on an EU scale.

What are the hydrological targets, the proposed measures and the likely effects of the measures?

The hydrological targets for a floodplain restoration project (volume of water to store, area available for (temporary) flooding, mean and maximum periods and levels of flooding) and water quality (mean and maximum concentrations/loads of nutrients, particularly N and P) largely determine the set of measures suitable for the restoration. The flood management measures should be assessed with regard to their effects on ecological functions and benefits. Tools such as the WEDSS (Box 25) which enable scenario testing should be employed for this purpose.

Box 24. Assessment criteria

- *Existing distribution of landscape types (based on e.g. vegetation map, ecotope map, etc.)*
- *Geomorphological features (e.g. altitude, soil type, relief)*
- *Hydrological inputs to each landscape type (e.g. connectivity to river, inundation characteristics, groundwater tables, origin of groundwater)*
- *Trophic state of each landscape type*
- *Biogeochemistry (including possible contamination levels of soil and water)*
- *Presence of 'key ecological organisms' which contribute to habitat shaping processes*
- *Existing ecological values (e.g. ecological status of water systems according to Water Framework Directive, habitat types and or species mentioned in the Birds and Habitats Directives, Red List species, locally important habitats or species)*

What are the proposed ecological targets?

The proposed ecological targets should combine the existing conservation values and the conservation values that are likely to become re-established as a consequence of the measures carried out. The extent to which conservation values could be restored can be determined by the study of 'reference systems', which represent the original condition of proposed restoration sites, and provide an indication of the attributes that should be restored.

It is possible that some ecological targets will already exist for an area as a result of the Birds and Habitats Directive. If the proposed hydrological measures are likely to result in a system equivalent to a 'reference system', all the conservation targets are likely to be attainable, provided that all or most of the 'ecological constraints' are dealt with by the implementation of additional measures (Table 8). It must also be considered that some negative effects may arise due to the implementation of hydrological measures (Box 26).

In reality it is unlikely that any hydrological measures will result in restoration equivalent to a reference system. By estimating how much of the original hydromorphology and biogeochemistry can be restored, how many relevant source populations are still intact and up to which point the anthropogenic influences are reversible, the list of possible ecological targets can be reduced to a realistic list of likely ecological targets.

What are the realistic target landscape types and are they conducive to the ecological targets?

The potential target landscape types comprise the seven (semi-) natural landscapes that may occur in an unimpacted floodplain (Table 5). The proposed set of hydrological measures, aimed at achieving the flood management goals provides the conditions within which these landscape types must establish. Before determining whether or not these landscape types are likely to develop, potential constraints that might impede their development should be considered (Table 8). Only after taking these constraints into account, either by eliminating them or by adjusting the targets to the constraints, is it possible to predict the extent to which ecological targets identified agree with what is realistically attainable. This insight into the relationships among hydromorphology, biogeochemistry, spatial landscape patterns and ecological values will help select the most appropriate measures for combining hydrological and ecological targets. In floodplain restoration projects it is generally necessary to clearly determine the exact starting point with regard to ten possible landscape elements. These elements include the seven natural landscape types occurring in river floodplains identified previously (Table 5) and four more that are the result of anthropogenic impacts, namely degraded fens, arable land, plantation forests and urban areas.

Table 8. Ecological constraints for restoration of floodplain habitats and riverine communities and possible additional measures for alleviation of constraints

Ecological constraints for development of landscape types	Possible additional measures to alleviate constraints
Lack of available species pool	Re-introduction of target species (e.g. by spreading hay collected in target communities)
	Introduction of free-roaming large herbivores (species dispersal vectors)
	Sod cutting or topsoil removal (to activate the seedbank)
	Promote ecological corridors (i.e. restoration schemes elsewhere)
Succession of vegetation too fast and/ or leading to undesired habitat types/species composition	Introduction of more dynamics:
	More frequent flooding regime
	More or less intensive grazing regime
	Mowing regime
	Removal of topsoil
	Superficial excavation or digging (also resulting in more frequent flooding)
Succession of vegetation too slow/ desired habitat types do not develop	Removal of/ isolation from dynamics; some habitat types (e.g. the more lotic riverine oxbows, some marsh/fen types and some riverine grassland communities) do not develop quickly enough to emerge between subsequent flooding events and therefore need to remain relatively isolated from the main riverine dynamics.
Biogeochemistry unfavourable:	
Nutrient levels in soil too high	Topsoil removal
Levels of chemical pollution in soil too high	Frequent mowing and removing biomass
Nutrient levels of feeding water too high	Maintain isolation from main river channel and/or maintain connection to high quality groundwater input
Levels of chemical pollution in hydrological inputs too high	Maintain isolation from main river channel and/or maintain connection to high quality groundwater input
Desiccation during dry, growing season	Removal of drainage system (i.e. ditches)
	Retention of river water
	Retention of ground water
	Removal of highly degraded top soil

Box 25. The Wetland Evaluation Decision Support System (WEDSS)

One of the key outputs of the EVALUWET project is the development of a Wetland Evaluation Decision Support System (WEDSS) (Mode et al., 2002). This tool has been developed on a wide range of wetland systems including floodplains. In simple terms the WEDSS links a functional assessment knowledge base with methods of socio-economic valuation within a GIS environment. The knowledge base carries out assessments of hydrological, biogeochemical and ecological wetland functions using data which can be rapidly gathered in desk studies or field visits.

The WEDSS is supported by a simple user interface with input data and outputs being displayed as GIS layers. The use of a GIS environment permits decision support at various scales, from individual wetlands up to catchments. By integrating functional and valuation information within a single tool, decision makers can consider all of the relevant information within wetland management and can fully consider wetlands within integrated catchment management. In this way, the WEDSS will facilitate floodplain management in the context of the WFD and support the implementation of other national, European and international policies such as the Habitats Directive, Birds Directive, Convention on Wetlands (Ramsar), Convention on Biodiversity (CBD) and Convention on Sustainable Development (CSD).

The WEDSS can be used for a variety of purposes, such as targeting sites for restoration or establishment of buffer zones, comparison of wetland sites and testing of management scenarios.

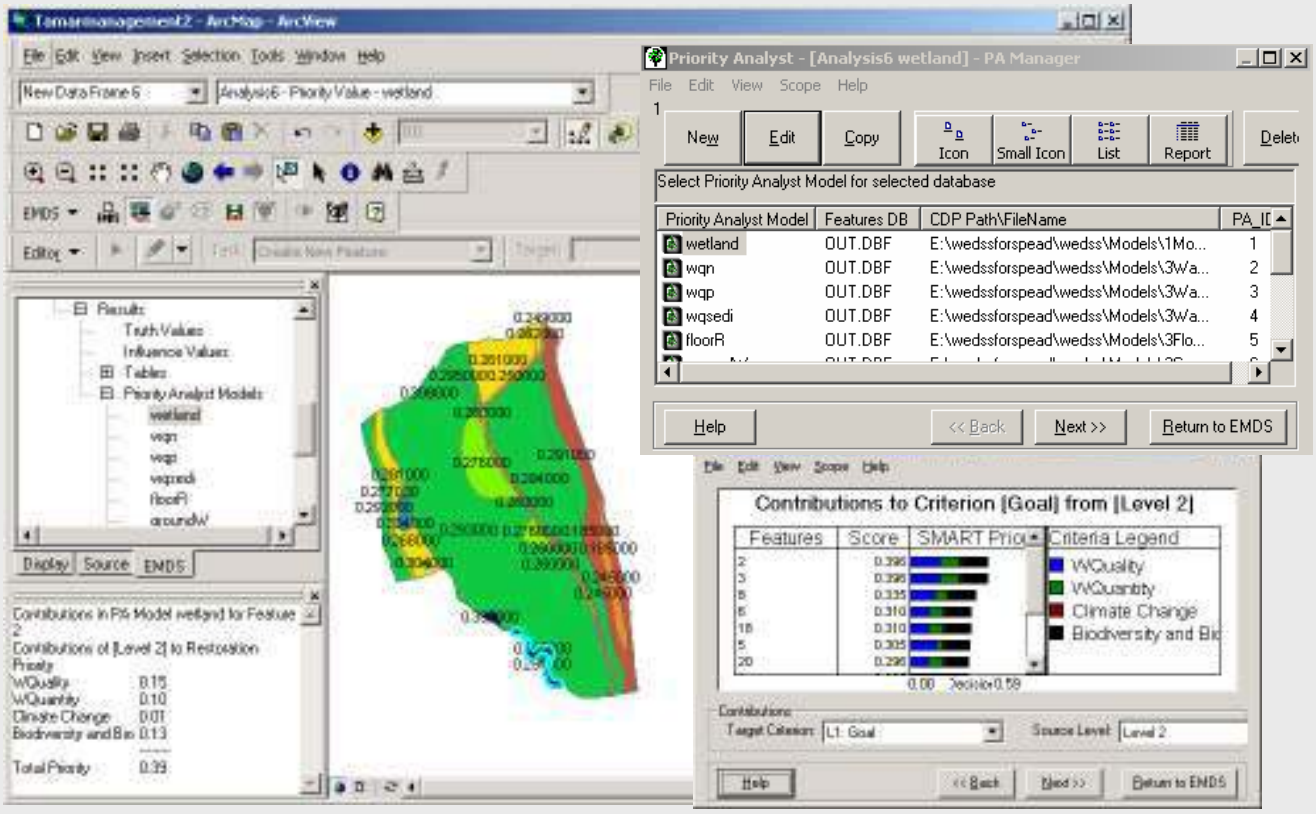


Figure 41. Social evaluation of a floodplain using WEDSS – each HGMU is assessed with regard to its value for different social functions

The importance of the role of individual environmental functions in this analysis can be adjusted to suit the needs of a range of stakeholder groups, producing values that can be used to assess priorities for management.

How do I get from starting points to target systems?

When carrying out a floodplain restoration project various opportunities and constraints will be encountered. The hydrological constraints closely connected to both the physical features of an area and its position within the greater context of its river basin and the hydrological aims of flood management will usually be the most important and least flexible constraints. The ecological objectives must be compatible with the amount and quality of (river) water that needs to be stored or transported for flood alleviation purposes. This compatibility might work both ways: it might be possible to aim only for ecological targets which permit the proposed hydrological conditions, or which need the proposed hydrological conditions.

Other limitations on the development of target landscapes and habitats may come from various abiotic factors, e.g. the degree of eutrophication of water or soil, the presence of drainage from former land use, the presence of contaminated water or soil, etc. Some considerations when setting objectives in the case of polluted soils are given in Box 27.

For all or most of these limitations, sets of additional measures can also be defined and if cost-effective, applied when financially viable. Table 9 summarises the desirability, the potential and the available means of stimulating the transition from initial landscape types towards target systems and also offers a first indication of the differences among potential measures with regard to compatibility with hydrological objectives of a restoration project.

Table 9. From starting points to target systems: desirability, feasibility and measures

Starting points	Target systems		
	a) Fens	b) Wet production grasslands	c) Semi-natural grasslands
1) Fens	conservation MHG, AE, ACR AFR	undesirable	undesirable
2) Degraded fens	difficult development RAU, RHG, ACR, AE, AFR	relatively easy, generally undesirable, development, IGR, MHG, FRF, NRH,	relatively easy, often good option, development, AVS, MHG, FRR, NTH,
3) Production grasslands	impossible	relatively easy, good option, slight development, IGR, PTR, MHG, FRF, NRH	possible, good option, development, AVS, PTR, MHG, FRR, NTH
4) Semi-natural grasslands	difficult, (very) long-lasting process, development, RAU, RHG, TR, ACR, AE, AFR	undesirable	conservation, most likely option, MBM, AVS, PTR, MHG, FRR, NTH
5) Arable land	impossible	relatively easy, often good option, development, IGR, PTR, MHG, FRF, NRH	relatively easy, often good option, development, AVS, PTR, MHG, FRR, NTH
6) Urbanised areas/ settlements	impossible	difficult due to high level of social commitment, development, RCI, IGR, PTR, RHG, FRF, NRH	almost impossible
7) Natural forest	undesirable	undesirable	undesirable
8) Forest plantation	impossible	almost impossible	possible, requiring much effort, development, RTS, AVS, PTR, MHG, FRR, NTH
9) Swamps	difficult, (very) long-lasting process, probably undesirable, development, RAU, RHG, TR, ACR, AE, AFR	undesirable	possible, not very desirable development, development, AVS, PTR, MHG, FRR, NTH
10) Isolated waters	difficult, (very) long-lasting process, generally undesirable, development, ACR, AE, AFR, MHG, NGM, AD, NCR, NM	undesirable	undesirable

Key to abbreviations for table 9

Measures that also imply flood reduction (blue)

AVS - extensive grazing/ mowing regime (avoid vegetation succession)
DE - digging/ excavating
FRF - flooding by river water frequent, but not too high
FRO - flooding by main river occasional
FRR - flooding by river regular, but not too high
IGR - intensive grazing regime (avoid vegetation succession)
PE - possibly excavation
PTR - possibly topsoil removal (no pesticides)
RAU - removal agricultural use
RCI - removal of constructions and infrastructure
ROS - removal or erosion of organic soil
RTS - removal of tree stands
TR - topsoil removal
TWR - two-way connectivity to river

Measures only for ecological restoration (green)

ACR - avoid connectivity to river
AE - avoid eutrophication
AFR - avoid flooding by river water
AVS - avoid vegetation succession
MBM - maintain actual biotic and management situation
MHG - maintain/install high groundwater table
NGM - no grazing/ mowing regime (enable vegetation succession)
RHG - restoration high groundwater table (removal drainage ditches, etc.)
RTS - removal of (exotic) tree stands
SFM - stop forestry management
VBS - variation in bank slopes
VWD - variation in water depths

Necessary conditions (red)

AD - avoid desiccation
NCR - no (regular) connectivity to river
NM - nutrient levels moderate
NRH - nutrient levels in soil and/or inundation water relatively high
NTH - nutrient levels in soil and/or inundation water not too high
STS - spatial variation in trophic states

cont. Table 9

Target systems			
d) Natural forests	**e) Swamps**	**f) Running water**	**g) Standing waters**
undesirable	undesirable	undesirable	undesirable
relatively easy, often good option, development, NGM, MHG, FRF, NTH	possible, not very likely, development, ROS, MHG, FRO, NM	undesirable	undesirable
relatively easy, often good option, development, NGM, PTR, MHG, FRF, NTH	relatively easy, good option, development, ROS, PTR, PE, MHG, FRO, NM	relatively easy, good option, development, DE, TWR, VBS, VWD	relatively easy, good option, development, DE, NCR, VBS, VWD, FRO, STS
relatively easy, not very desirable, development, NGM, MHG, FRF, NTH	generally undesirable, possible, development, ROS, PTR, PE, MHG, FRO, NM	relatively easy, less desirable option, development, DE, TWR, VBS, VWD	relatively easy , fair partial option development, DE, NCR, VBS, VWD, FRO, STS
relatively easy, often good option, development, NGM, PTR, MHG, FRF, NTH	relatively easy, good option, development, ROS, PTR, PE, MHG, FRO, NM	relatively easy, good option, development, DE, TWR, VBS, VWD	relatively easy, good option, development, DE, NCR, VBS, VWD, FRO, STS
impossible	impossible and unlikely	relatively easy, **but** difficult option due to high level of social commitment, development, DE, TWR, VBS, VWD	relatively easy, **but** difficult option due to high level of social commitment, development, DE, NCR, VBS, VWD, FRO, STS
conservation, maintenance	undesirable	undesirable	undesirable
possible, likely to be best option, development, RTS, SFM, PTR, MHG, FRF, NTH	difficult, relatively good option, development, RTS, SFM, PE, MHG, FRO, NM	relatively easy, good option, development, DE, TWR, VBS, VWD	relatively easy, fair partial option, development, DE, NCR, VBS, VWD, FRO, STS
possible, not very desirable development, development, NGM, PTR, MHG, FRF, NTH	easy, conservation, maintenance, AD, MHG, AVS, FRO	relatively easy, fair option development, development, DE, TWR, VBS, VWD	fairly undesirable
undesirable	possible, but long-lasting process, generally undesirable, development, FRO, MHG, AD, NRH	relatively easy, generally undesirable, development, DE, TWR, VBS, VWD	easy, conservation, maintenance, FRO, ACR, VBS, VWD, NM

Box 26. Potential negative effects of re-introducing regular flooding

The re-introduction of regular flooding in (parts of) a former floodplain may result in some negative effects that could compromise the benefits of restoring conditions favourable for riverine biodiversity. Runhaar et al. (2004) distinguish five types of potential negative effects:

1. *Direct drowning of organisms during floods.*
2. *Increase of trophic state due to influx of nutrient-rich river water (external eutrophication).*
3. *Increase of trophic state due to re-mobilisation of soil-stored nutrients (internal eutrophication).*
4. *Re-mobilisation or formation of toxic substances due to flooding, causing lethal or sub-lethal effects in the food chain.*
5. *Increase in pH due to influx of calcium-rich surface water (alkalinisation).*

Box 27. Suggestions to deal with risk of polluted floodplain soils

Ten rules of thumb to deal with this problem for floodplain restoration projects in the Netherlands are provided by Stuijfzand et al. (2005):

1. *Determine the extent of pollutants in the area at an early stage. Concentrations tend to be highest in parts that are or used to be regularly flooded.*
2. *Design target systems with care, e.g. stimulate grassland development on 'clean' soils, which will lead to 'cleaner' earth worms.*
3. *Make polluted parts less attractive to target species at risk, thus lessening direct contact between contaminated worms and their potential predators. Marshlands and rough vegetation tend to attract less worm-eating predators.*
4. *Cover contaminated soils with cleaner material or concentrate the polluted material in a small area. This will also decrease the probability of exposure.*
5. *Design the habitats you wish to establish on polluted soils also unpolluted soils nearby.*
6. *Offer alternative prey for worm-eating predators. Try to design several types of riverine habitat for this purpose.*
7. *Take into account that many larger animals (e.g. badgers) may forage over a larger area than the just the river floodplain. This may require incorporating larger areas into the restoration area.*
8. *Heavy metals tend to accumulate into the food chain more easily in terrestrial than in aquatic ecosystems, while PCBs and PACs show an opposite trend. Keep this in mind when designing a plan.*
9. *Evaluate the effects of design and management by means of monitoring. Try to learn from comparable projects and experiences.*
10. *The best defence against bio-accumulation of pollutants is the removal of the contaminated layers from the floodplain.*

THE ROLES OF FLOODPLAINS FROM A SOCIO-ECONOMIC PERSPECTIVE

Floodplains are often exploited by humans because they comprise large areas of flat, fertile soil close to rivers, making them appear suitable for the development of agriculture, housing and transport. One of the main drawbacks of using floodplains for these purposes is that floodplains inherently flood, and this process generally is not compatible with these societal uses. However, flooding is a vital process in the creation, maintenance and regeneration of natural floodplain habitats.

In today's European market economy, the fact that flooding is a vital part of a natural river system is often ignored. Many rivers have been canalised and their natural dynamics have been limited. Flooding often is not acceptable or at best regarded as a severe nuisance, limiting human activities in an area. It is important to distinguish between flood management in floodplains that are not used intensively and flood management in highly developed floodplains because the socio-economic aspects of these two extremes are quite different. In floodplains with minimal human uses ((semi-) natural systems), the likelihood that severe damage will occur is much lower than in highly populated areas, while flooding in intensively used floodplains is likely to result in much greater damage.

The social importance of floodplains can be expressed in terms of stakeholder-appreciation of their aesthetic (e.g. landscape) and recreational properties. In addition to these positive features, negative aspects can exist in the form of potential nuisances and hazards such as high numbers of flying insects. These social aspects are difficult to link to the potential economic benefits of floodplains because they are difficult to measure in economic terms. However, both tangible and intangible aspects of natural flood defence schemes must be considered equally.

How can I assess the socio--economic values of floodplains?

There are many functions performed by floodplains that have clear socio-economic values such as recreation, tourism, flood mitigation, agriculture and water supply. Several methods have been developed to determine the values of floodplain functions. Valuation is a process that gives insight into the trade-offs of different functions of a river floodplain, both tangible and intangible. For functions to which a direct economic value can be attached, a trade-off analysis can be performed once targets or objectives have been set. For example, through a hydrodynamic model, the impact of a range of river discharges on navigation can be expressed as the number of days per year for which a certain minimum depth criterion cannot be met. This can then be translated into an economic loss for the transport sector. For other functions, namely for those which materialise through specific components of an ecosystem, this trade-off is more difficult to perform. This includes the gene pool function, recreation and tourism, existence value (nature conservation), health and (traditional) exploitation functions such as agriculture, fisheries, forestry, livestock and hunting.

In order to be successful in implementing a natural flood defence scheme it is necessary to show the 'added value' of a proposal. Cost benefit analyses should include both tangible and intangible costs. A good example of added value is the fact that properties adjacent to newly created natural flood defences can increase in value, because of the increased attractiveness of the area. Houses located near (safe) water or natural areas can have an increased value (up to 25%), compared to similar houses in less attractive areas. Some insight into the different dimensions of the socio-economic value of floodplains is given in Table 10. The most important distinction made is between use value and non-use value.

How can I assess the socio--economic consequences of changing floodplain use?

As described above, it is complicated to assess all the changes in values that result from changes in floodplain use. There are some techniques, each with their own various strengths and weaknesses, which are helpful in obtaining an overview of the distribution of losses and benefits. Four of the most widely used are outlined in Table 12.

Table 13 provides details on the different ways a cost-benefit analysis, including values which have no direct monetary value such as biodiversity or aesthetic values, can be carried out.

In Box 28 an example is presented of a cost benefit analysis which has been conducted for a river system in Denmark (the Skjern Å). It describes the costs and benefits of this floodplain restoration project and discusses some of the limitations of this approach.

Table 10. Details of the components contributing to the economic value of wetlands (Stuip et al., 2002)

Total Economic Value of Floodplains			
Use Values			Non-Use Values
Direct Use Values	**Indirect Use Values**	**(Potential) Future Values**	**Existence Values**
Wetland products (fish, reeds)	Flood control	Potential future uses (as per direct and indirect uses)	Biodiversity
Recreation and tourism	Groundwater recharge	Future value of information	Cultural and heritage value
Transport	Shoreline stabilisation and storm protection	–	Bequest values (value for future generations)
Agriculture	Water quality improvement	–	–
Peat/energy	Climate change mitigation	–	–

Box 28. Skjern Å case study – cost-benefit analysis

The primary objective of the Skjern Å project was to re-establish a large nature conservation area. Before the 1960s the Skjern River floodplain was managed as extensively grazed meadows and hayfields. During the 1960s the lower 20 km of the river were straightened and embanked. Pumping stations were established and 4,000 ha of meadows were drained and converted to arable land. In 1987 the Danish Parliament decided to initiate restoration studies, culminating in the completion of floodplain restoration by mid-2003. Of the 4,000 ha reclaimed in the 1960s 2,200 ha were included in the project. Further details are available in the Case Study section (Case Study 6).

In Table 11 a summary of the cost-benefit analysis for the Skjern Å restoration project is presented. In this table the different relevant costs and benefits of the project are shown. Originally three scenarios were analysed, which differed in the assumed value of land rental forgone due to land use changes and in other expected costs and benefits. Results for a 5% discount rate are presented here. The table presents the types of costs and benefits that are relevant. In this case the net benefits are positive. Therefore it can be concluded that the restoration project is beneficial to Danish society. Interestingly the highest benefits originate from new income from outdoor recreation and improved fishing opportunities. The non-use value of biodiversity also contributes significantly to the positive result of the cost-benefit analysis.

Table 11. Cost-benefit results of the Skjern Å project (Dubgaard et al., 2003) (Figures in million Danish Krones, DKK)

Project costs	143.0
Operation and maintenance	14.9
Forgone land rent	52.5
Total costs	**210.4**
Saved pumping costs	7.4
Better land allocation	19.4
Reed production	5.0
Miscellaneous benefits	2.4
Reduction of nitrogen and phosphorus	34.0
Reduction of ochre	27.0
Improved hunting opportunities	9.0
Improved fishing opportunities	52.4
Outdoor recreation	70.7
Non-use value of biodiversity	50.6
Total benefits	**277.6**
Net benefits	**67**

The costs and benefits of the project have been analysed on the scale of Denmark as a whole (macro level). Consequently it is not clear if the project has been beneficial (from a welfare perspective) on a regional (meso) or local (micro) level. With the method used it is also not yet clear how the costs and benefits have been distributed between, for example, governmental bodies, farmers, nature organisations, etc. Even so the overview given of costs and benefits can be very useful for decision-makers.

For more information on the method used see 'Cost-benefit analysis of the Skjern river restoration in Denmark' (Dubgaard et al., 2003).

Table 12. Methods for analysing costs and benefits (based on NERA, 2001)

Financial analysis	An assessment of the impact of an option on the decision-making organisation's (e.g. a water board) own financial costs and revenues. Societal costs are not included. Each project should include a financial analysis.
Cost-effectiveness analysis	An assessment of the costs of alternative options which all achieve the same objective. The costs need not be restricted to purely financial ones. With a cost-effectiveness analysis the least-cost way of achieving the objective can be assessed.
Cost-benefit analysis	An assessment of all the costs and benefits of alternative options in monetary terms. A project is desirable if the benefits exceed the losses. Most cost-benefit analyses will incorporate some additional items; it is either not possible to value, or is not economic to do so. Non-monetary costs and benefits can be monetarised by assessment methods, which are explained in Table 13. These methods are not yet fully accepted by the scientific community, but commonly are used.
Multi-criteria analysis	Multi-criteria analysis (MCA) establishes preferences between options by reference to an explicit set of objectives that the decision-making body has identified, and for which it has established measurable criteria (not being money) to assess the extent to which the objectives have been achieved. MCA provides ways of aggregating data on individual criteria to provide indicators of the overall outcomes of different options. A key feature of a MCA is its emphasis on the judgment of the decision-making team, in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion. With this method economic issues can be directly compared to non-economic concerns. One limitation of MCA is that it cannot show that an action adds more to welfare than it detracts. The best option, according to an MCA, can be inconsistent with improving welfare.

Table 13. Methods for assessing the economic value of 'soft' values. (Source: Stuip et al., 2002: 'The Socio-economics of Wetlands')

Method	Applicable to:	Description & importance	Constraints
Market Price Method	Direct use values	The value of wetland products and services is estimated from prices in commercial markets.	Market imperfections and policy failures distort market prices.
Damage Cost, Avoided, Replacement Cost & Substitute Cost Method	Indirect use values	The value of flood control can be estimated from the cost of damage if flooding occurred (damage cost avoided); the value of groundwater recharge can be estimated from the costs of obtaining water from another source (substitute costs).	It is assumed that the costs of avoided damage or substitutes match the original benefit. However, this match may not be accurate, which can lead to underestimates or overestimates.
Travel Cost Method	Recreation	The recreational value of a site is estimated from the amount of time and money that people spend on reaching the site.	Overestimates are easily made, as the site may not be the only reason for travelling to that area. The technique is data intensive.
Hedonic Pricing Method	Aspects of indirect use, future use and non-use values	This method can be used when wetland values influence the price of marketed goods. For example: clean air, presence of water and aesthetic views will increase the price of surrounding real estate.	The method only captures people's willingness to pay for perceived benefits. If people aren't aware of the links between the environmental attribute and benefits to themselves the value will not be reflected in the price. Very data intensive.
Contingent Valuation Method	Recreation, non-use values	This method asks people directly how much they would be willing to pay for specific environmental services. It is often the only way to estimate non-use values.	There are various sources of bias in the interview techniques. In addition, there is controversy over whether people would actually pay the amounts that they state in the interviews.

What should I consider with regard to socio-economics when restoring floodplain functioning?

There are several important points relating to socio-economics and the value of floodplains that should be considered when restoring floodplain functioning. These are listed below and are based on work by Stuip et al. (2002) for wetlands, adapted here for floodplains.

- The total economic value of a floodplain is the sum of all mutually compatible values. The value of a floodplain is not the sum of all possible values – not everything can be realised at the same time (for example, housing development is not always possible in combination with protecting wildlife).
- The total economic value of a floodplain is a function of perspective; there is no right or wrong. For a local village, only some goods and services provided by floodplains might be important. For a whole region or a country other values of floodplains are important.
- Development of a floodplain resource by one stakeholder group may deprive another of an essential resource. Costs of mitigating the negative social impacts of resource use by one stakeholder may be more costly but sometimes less obvious than the economic benefits gained.
- It is often the poorest people that rely most on natural resources and functions.

In addition to these points, several other factors should be considered. Firstly, it is important to consider the wide range of possible financial sources. Funds may be available for specific aspects related to floodplain restoration, such as the promotion of conservation or the stimulation of cross-border cooperation. Consequently several sources of funding may be sought in order to achieve a broad range of project objectives. It is also wise to see if stakeholders who benefit from floodplain restoration (e.g. house-owners or recreational businesses) can share the costs that will be incurred by a project, as ultimately they will benefit. An example of this is the involvement of clay extraction companies in habitat restoration and flood storage schemes along the Rivers Waal, Rijn and IJssel in the Netherlands (Case Studies 1, 3 and 4) and gravel mining along the River Meuse (Case Study 2).

Secondly, it is important that 'added values' are incorporated into a scheme. These are values that are continually visible or present, not just during periods of flooding. Added values can include intangible costs. For example, local communities may appreciate an increase in the ecological value of an area, but it is difficult to determine the economic value of this benefit. In the Skjern Å case study (Case Study 6) even people that were opposed to the initial plans are now very proud of the restored Skjern Å, largely as a result of the 'valuable' and accessible nature reserve that has been established and which they can access. In practice a lot of added value comes from costs avoided (damage reduction), rather than added income, although often income from tourism increases. In a research project on the valuation by people of nature development around the Dutch River Waal the conclusion has been reached that inhabitants and visitors of floodplain areas greatly appreciate the development of nature (Buijs et al., 2004).

Thirdly, when a site has been selected for floodplain restoration the administrative options will become very important. If the land is likely to be flooded only once in a 100 years, then in most cases it would be economically unwise to purchase the land, unless other interests make this an attractive option. If an area is to be converted into a nature reserve, purchasing the land is usually the best option. In Table 14 some administrative options for organising land use are given. Managers should be aware that there are more options than simply purchasing land. For example, existing land users can remain in the area but change the way in which they use the land.

For more information on these organisational aspects see 'Integrating Flood Management and Agri-environment Through Washland Creation in the UK' (Morris et al., 2004). An additional option not mentioned above is payment for damage that occurs during occasional flooding, such as by insurance companies. When flooding occurs with a very low frequency (for example less than once in 100 years) it could be more efficient to pay compensation for any damage that occurs at the time.

What should I consider with regard to floodplain landscape when restoring floodplain functioning?

Landscape is an important element in the public perception of a floodplain restoration project. To a large extent it determines the aesthetic perception of a project and relates to direct use values such as recreation and tourism as well as the appeal of living in a specific area. Landscape also has an existence value (non use value) and therefore is an important feature from a socio-economic point of view.

How can the floodplain landscapes be characterised?

There are two distinctly different types of floodplain landscapes:

1) those that have been modified and developed,
2) those that are natural and unmodified.

Table 14. Administrative options for flood storage (based on Morris et al., 2004)

1. Land purchase.	Under this arrangement the land is voluntarily sold by owners at prevailing market prices to a responsible organisation. The organisation involved may operate the site directly or may manage it indirectly on short term or seasonal tenancy agreements with farmers, possibly giving preference to previous owners/tenants. An alternative is to purchase the land involuntarily. This may be counterproductive, because it can cause strong opposition, but is more likely to be accepted if there is general agreement on the need for the measures. In the Netherlands there is a tradition of buying land from farmers to create new nature areas, including land which can be flooded.
2. Paying before damage occurs.	This involves upfront payment, expressed as a percentage of prevailing market prices, to reflect loss of asset value (and related income loss) associated with specified increased flood risk. The arrangement is the subject of an agreement, specifying conditions. Owners retain rights which are not the subject of the agreement. This model has, in the United Kingdom, been used over the last 20 years in flood alleviation schemes by responsible authorities.
3. Management agreements supported by annual payments.	Under this arrangement, existing tenure continues. Farmers sign a management agreement for a specified minimum period with a responsible organisation which defines land management in accordance with the objectives of the sponsoring programme.
4. Lease-back partnership arrangements.	In a lease-back arrangement land entitlement passes in the form of a lease from original land owners to a newly created project organisation or 'trust' for a specified period (20 to 30 years). Farmers manage the land in accordance with programme objectives for which they receive annual payments. At the end of the lease, the arrangement can be extended or terminated. In the latter case, land returns to the original owners. A joint management committee with representation by the major partners is formed to manage the initiative.

Box 29. Summary of key questions that should be addressed for socio-economic consideration

To help project managers and policy makers make decisions on the economics of floodplain restoration a summary checklist has been compiled. This focuses on economic aspects, but in the wider context of policy-making processes.

1. *What kind of restoration is necessary in your floodplain? Is the goal to create water storage capacity or is the main goal creating a nature reserve? How much storage space is necessary? Will land be converted to areas of open water? These kinds of questions should be asked and answered in order to address socio-economic aspects.*
2. *Which geographical dimensions are of importance (local, regional, national)? By answering this question it will become clear on which geographical scale costs and benefits should be addressed.*
3. *Which locations can be chosen and what are their characteristics? In what way is the floodplain used today? What is the current value of the floodplain (on the relevant geographical scales)? Are there opportunities to combine different kinds of land use, or to cover the costs of implementation through other means (such as mining or clay extraction)?*
4. *What are the financial resources available for the project?*
5. *Can stakeholders be identified who will benefit from the project? Can they support a justified part of the costs?*
6. *Can extra funds be obtained (e.g. from local, regional, national, EU, UN, NGOs, businesses)?*
7. *What are the costs of the project? Are there stakeholders who should be compensated for losses? A financial analysis should be made.*
8. *Which location is the most cost-effective?*
9. *Is the project beneficial for society (on relevant geographical scales)? Cost-benefit analysis or multi-criteria analysis can be used to determine this. It is recommended not only to take into account the values which can be monetarised, but also non-economic values. The values which are given to the different costs and benefits by decision-makers are, in principle, political decisions. Economic values are an input in this decision-making process but there are others, such as nature conservation, agriculture and water policy.*

1) Landscape characteristics of modified floodplains
Generally agriculture is the main land use in modified floodplains, but often more economically valuable land uses such as housing development and industrial activities occur. Besides these characteristic forms of land use, modified floodplains and rivers possess characteristic elements such as embankments, dams, reservoirs and groynes: elements that reflect human efforts to confine rivers (Figure 42).



Figure 42. The landscape of a modified floodplain in The Netherlands
Photo: Grontmij

Modified floodplain landscapes are typically open landscapes with the main land use being grassland farming. Many of these man-made landscapes contain important cultural heritage features in the form of archaeological remains. Both the Rhine and Meuse floodplains contain remains of Roman and pre-Roman settlements. Other cultural and historical features commonly found are castles, fortifications, old towns and settlements and elements that reflect the processes of land reclamation and former land use such as ancient windmills, bridges, old embankments and industrial clay mining relics. The Loire Valley is an example of a cultural river landscape containing historic towns and villages, architectural monuments (châteaux), and cultivated lands formed by many centuries of interaction between their population and the physical environment, primarily the River Loire itself. Another example is the Wachau area along the Danube in Austria, in which landscape values are closely connected to human settlement (Box 30). There is a big difference between the landscape of large and small rivers, with cultural and historical elements generally being more prevalent in large river floodplains than in small ones.

2) Landscape characteristics of relatively undisturbed and natural floodplains
The landscape of relatively undisturbed floodplains is primarily determined by morphological features and its characteristic ecosystems. Important morphological features are meanders, side channels, river dunes, alluvial levees, oxbows and backswamps. The mosaics of morphological features are associated with various vegetation communities ranging from forests, shrubs, marshes, swamps and meadows to open water (stagnant or flowing). Parts of a floodplain may be used for hay production or pasture by farmers. An example of this is the Biebrza Natural Park (Poland) where wet meadows are mowed by farmers, keeping the valuable species rich ecosystems intact. Generally undisturbed floodplains are only sparsely inhabited and habitation typically is restricted to natural high points within the landscape. Another important element of the landscape of natural floodplains is the dynamic character caused by flooding. A key element of river and floodplain rehabilitation projects is the transformation of the landscape through restoration of the original morphological elements and flooding dynamics.

What should I consider with regard to landscape values when restoring floodplain functioning?

It is acknowledged that both man-made landscapes in modified floodplains and the natural landscape of unmodified floodplains have their own values. In man-



Figure 43. The Bug River, north-east Poland: an example of a relatively undisturbed floodplain landscape
Photo: F. Vliegenthart

made landscapes cultural and historical elements often are regarded as being of high value. It is the combination of these elements with the current land use and regional folklore that gives people an emotional connection to a landscape. In more natural floodplains the dynamics, biodiversity and the coinciding patterns of geomorphological elements and riverine vegetation communities are highly valued. The values of both man-made and natural landscapes are recognised by UNESCO and examples of these two types of landscapes are on the UNESCO World Heritage List.

Consequently the conservation of (valuable elements of) man-made landscapes must be considered when developing natural flood management plans involving the restoration of flooding on floodplains.

The question remains on how best to compare landscape values in modified floodplains with those in natural floodplains. Several cost-benefit analyses and functional analyses of river restoration and wetland conservation projects have identified benefits that can be derived from both restored and natural landscapes (Stuip et al., 2002; Dubgaard, 2003; Maltby and Blackwell, 2005). For example direct use values arising from tourism will in part be derived from landscape values, while a non-use value of restored landscapes is 'existence value'. It is important that both these types of value are considered carefully when planning floodplain restoration projects. A recent study in The Netherlands clearly illustrates the positive effects river and floodplain restoration projects can have on the way a landscape is perceived (Box 31).

Box 30. River landscapes on the UNESCO list

The Danube Delta in Romania is on the UNESCO list as an example of a natural system with high biodiversity and river delta characteristics. The Danube Delta is of essential interest for many kinds of birds. The Wachau cultural landscape along the Danube River in Austria is an example of a site chosen because of the landscape values connected to the history of human settlement (Figure 44). The architecture, human settlements, and the agricultural use of the land in the Wachau vividly illustrate a basically medieval landscape which has evolved organically and harmoniously over time. Another example of a cultural river landscape on the UNESCO world heritage list is the River Loire (France) between Sully-sur-Loire and Chalonnes.



Figure 44. The River Danube in the Wachau area of Austria
Photo: H. Leimar

Box 31. Public perception of a floodplain restoration project

Buijs et al. (2004) report the results of a survey investigating the public perception of river/floodplain restoration projects along the River Waal in the Netherlands. The survey was carried out on behalf of the Ministry of Public Transport and Water and was part of the evaluation of river/floodplain restoration projects concerning economy, ecology and public perception. Participants in the survey numbered 1,375, many of whom were inhabitants of the restoration area. The results can be summarised as follows:

- *Almost 90% of the inhabitants of areas bordering the restoration area thought the scheme had positively influenced the visual quality of the area. The majority of other participants in the survey (predominantly tourists) also thought visual quality had been improved.*
- *72% of people living in or adjacent to non-restored floodplains were in favour of a restoration project. The majority of opposition to restoration schemes came from farmers who had lived in the area for a long time.*
- *The restoration of a dynamic and broad river along with natural riverine ecosystems were highly valued by most participants.*
- *Most inhabitants of areas in or near the project area felt safer following the restoration.*
- *The provision of good public access to the restored floodplain and river for recreational purposes was deemed important.*
- *One negative aspect of the project was considered to be the fact that many local people felt emotionally less connected to the restored areas than they had previously.*

The overall perception of the changes to the landscape was dominated mainly by visual quality rather than other aspects such as safety, access and emotional connection. Consequently an important lesson in floodplain design can be taken from this study:

To obtain public support for a restoration scheme it is of primary importance that a visually attractive landscape is developed, and other factors such as dynamics and access are of secondary importance.

Box 32. Summary points: What do we need to consider with regard to landscape?

The main aspects that must be considered with regard to landscape when planning a floodplain restoration project are:

- *Landscape is an important element from a socio-economic point of view as it partly determines direct-use values such as recreation and tourism as well as having an existence value (non-use value).*
- *Landscapes of both modified floodplains and relatively undisturbed, more natural floodplains have their own specific values.*
- *With regard to flood mitigation plans, finding a balance between the conservation of current and future landscape values is of vital importance.*
- *Surveys have shown that river and floodplain restoration projects have a positive effect on the public perception of the visual attractiveness of an area.*
- *To obtain public support for a restoration scheme it is of primary importance that a visually attractive landscape is developed.*

What should I consider with regard to human health when restoring floodplain functioning?

Water is the source of life for humans, animals and plants. A human being can survive without drinking water for only a few days. Despite this need for water, many water sources such as wetlands historically have been associated with fever and poor health. This perception lasted well into the 19th century when the precise relation between infected water sources and diseases such as cholera became known. Currently a large group of major water and sanitation related diseases are ascribed to microorganisms. In tropical countries these microorganisms form by far the largest threat to health, although various waterborne chemical pollutants (e.g. arsenic, lead etc.) can also cause considerable health problems. While many health benefits can arise from floodplain restoration schemes (e.g. the use of recreational areas, improved water quality etc.) it is important to consider that some aspects of floodplain restoration can potentially be deleterious to human health. Generally health threats arise because of the association of water with waterborne diseases. The nature of the threats varies depending on the potential type of restoration scheme proposed and the associated likely causes of poor health. In addition, problems can arise from the encouragement of 'nuisance' species to an area, such as mosquitoes, which not only can be annoying to the public but in some situations can be associated with specific health risks (Boxes 33 and 34).

Box 33. Problems associated with mosquitoes

Mosquitoes are often regarded as a nuisance to people. They are, however, only a nuisance when they bite and form large swarms. There are several species from which only a few are of a biting kind. In general the Chironomidae (dancing mosquitoes), the Calucidae (stinging mosquitoes) and the Ceratopogonidae (midges) are considered as annoying.



Figure 45. Mosquitoes can transfer diseases to humans
Photo: RIZA

Nuisance from Chironomidae?
Populations of these species vary from year to year. The mechanism behind this is unclear, but it is known that in constructed lakes and ponds in which a transition from salt to fresh water exists, large populations occur more frequently due to a lack of grazing by their natural predators. Preventing these swarms is not easy. Currently no regulating measures have been developed. High quality, clear water promotes greater species diversity and therefore more predators are likely to exist, and the occurrence of swarms is likely to be reduced.

Nuisance from Calucidae?
These mosquitoes occur mostly in still, shallow water and are resistant to temporary drainage. In general if the ecosystem is in balance the quantity of mosquitoes is low and hardly any nuisance occurs. By constructing new wetlands this equilibrium often is temporarily disturbed and large swarms can occur. Simple measures such as creating flow will decrease the occurrence of this species. Also creating woodlands as a barrier between breeding places and urban areas is an easy and effective measure.

Nuisance from Ceratopognidae (midges)?
Midges occur in fresh and saltwater swamps and peatlands. Midge bites can be painful and cause considerable itching. Effective measures to reduce the occurrence of midges associated with wetlands have not yet been developed.

Box 34. Transmission pathways for water-related diseases

Waterborne diseases *are caused by ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria, viruses or parasites. These diseases include cholera, hepatitis, typhoid fever, amoebic and bacillary dysentery and other gastro-intestinal diseases.*

Water-washed diseases *are caused by poor personal hygiene and skin or eye contact with contaminated water. These include trachoma, scabies, and flea-, lice- and tick-borne diseases. Diarrhoeas are the most important water-washed diseases in tropical areas.*

Water-based diseases *are caused by parasite (worm) infections. The parasites are found in intermediate organisms living in water and include legionellosis, dracunculiasis (guinea worm), disease of Weil, schistosomiasis and other helminth infections.*

Water-related diseases *are caused by insect vectors breeding in water (Box 33). Diseases include denque, filariasis, malaria, onchocerciasis, tryponasomiasis and yellow fever.*

What kinds of disease should be considered?

Diseases caused by microorganisms are classified in four categories based on their transmission pathways, namely waterborne diseases, water-washed diseases, water-based diseases and water-related diseases (Box 34).

How can I assess the potential health risks of a floodplain restoration project?

The potential health risk posed by a floodplain restoration project can be assessed by the performance of a quantitative risk assessment as part of the quantitative risk analysis framework (Codex Alimentarius Commission, 1996) (Box 35). This requires a detailed survey including hazard identification and characterisation, exposure assessment and risk characterisation. The process involves the quantification of certainties and expected consequences of identified risks. Quantitative risk analysis contains three related activities; risk assessment, risk management and risk communication (Box 35).

Risk assessment can be divided into four steps: i) hazard identification, ii) exposure assessment, iii) hazard characterisation and iv) risk characterisation (Box 36). A general scheme for such an assessment with the necessary steps or points of attention is given below. The public health risk analysis described here focuses mainly on microbial risks. The same assessment can be done for chemical agents or other potential hazards.

i) Hazard identification

In this first step (Table 15) all possible hazards should be considered and therefore a long list can be the result. Different situations or environments will give different lists for the possible public health hazards. This list will be shortened in the following steps of the risk assessment.

Table 15. Overview of possible hazards (Riza, 2002)

Faecal contaminated water	Water/aerosols	Small animals and pollinosis	Animal contact
1=Amoebiasis	15=Cholera	29=Anafylaxia	40=Chlamydia infections
2=Giardiasis	16=Swimmers itch	30=Pollinosis	41=Rat bit disease
3=Cryptosporidiosis	17=Amoebiasis	31=Contact eczema	42=Q-fever
4=Cyclospora infection	18=Legionellosis	32=Inhouse allergy	43=Hantane
5=Shigellosis	19=Granulome	33=Vector infections	44=Tuberculosis
6=Salmonellosis	20=Cyanotoxins	34= Lyme disease	45=Echinoccosis
7=Campylobacteriosis	21=Botulism	35=Acariasis	46=Cryptococcosis
8=Yersiniosis	22=Otitis	36=Malaria	47=Rabies
9=Listeriosis	**Wetted soil**	**Intoxication**	**Physical hazards**
10=Hepatitis	23=Larva migrans	37=Poisoning	48=Drowning
11=Polio	24=Tetanus	38=Natural toxins	49=Harm
12=Viralegastro-enteritis	25=Mycosen	39=Chemical contamination	
13=Disease of Weil	26=Helminths		
14=Travellers diarrhoea	27=Trombidiosis		
	28=Toxoplasmosis		

Box 35. The quantitative risk analysis framework

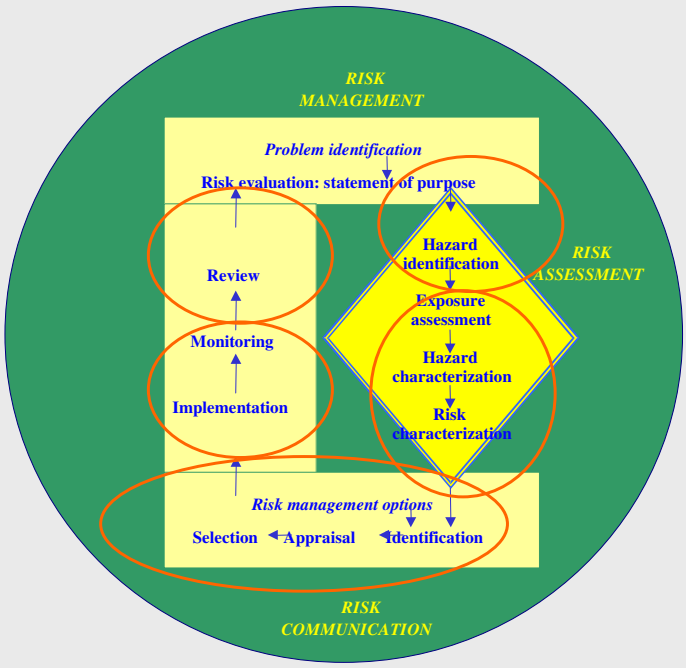


Figure 46. Diagram of the quantitative risk analysis framework
Source: Jouve, 1999.

***Risk management**:*

- *Defines the problem and the limiting conditions for the risk assessment (problem identification).*
- *Receives the results from the risk assessment (identification).*
- *Chooses from independently formulated options and evaluates the expected efficacy and costs (selection).*
- *Defines a policy and starts implementation of this policy.*
- *Monitoring and reviewing of options when necessary.*

***Risk communication**:*

- *An interactive process which exchanges information and opinion in relation to risk between risk experts, managers and other parties.*

***Risk assessment**: this explained in further detail in the main text.*

Box 36. The four stages of risk assessment

Hazard identification. A hazard is an agent or physical situation with potential undesirable consequences, such as negative consequences for human health and/ or the environment

↓

Exposure assessment. The measurement or estimation of the intensity, the frequency and the time of human exposure to an agent which is theoretically present in the environment or the calculation of the theoretical exposure that can occur by the release of new agents in the environment

↓

Hazard characterisation. The qualitative and quantitative analysis and evaluation of the physical, chemical and biological aspects of a hazard

↓

Risk characterisation. The classification of the severity and frequency, perception and economical and social consequences in such a way that a decision can be made about the character of a certain risk. Risk characterisation should also contain the analysis of the most important factors which causes the risk

ii) Exposure assessment
For an exposure assessment the possible transmission routes in the environment are important as well as the exposure route for humans. The transmission routes for infectious diseases can be summarised as:

a. human-to-human via the environment,
b. human-to-human multiplying in the environment,
c. human-to-animal-to-human via the environment,
d. animal-to-human via the environment.

For water near cities the exposure to some infectious hazards will be much lower than in the case of a bathing site. The amount of infected water swallowed, inhaled or contacted will be different. Another important aspect, which should be considered is the exposure route. Infected water can cause skin problems by having contact with the infected water or breeding insects, gastrointestinal complaints after swallowing/consuming the infected water or pneumonia or related complaints after inhaling infected aerosols/water droplets. All these aspects should be listed and preferably characterised.

iii) Hazard characterisation
After the list with possible hazards is made they all have to be characterised. An example of such characterisation is given in Table 16. In this characterisation more information on the agent/hazard are given which will help to identify if it is important in the risk assessment or not.

iv) Risk characterisation
In this step of the assessment all other steps are combined in such a way that risks can be characterised. For example, it is possible that by promoting floodplain wetlands, wildlife might be encouraged that can be vectors for human diseases and if so, is it possible to manage this risk? For instance if large colonies of birds breed or roost in a floodplain and at the same time it has a recreational use such as bathing, these birds could pose a serious threat to humans in the form of gastrointestinal diseases. By managing the site in such a way that the spot were birds are breeding is physically divided from the bathing site and the contaminated water cannot reach the bathing areas these risks can be minimised. After characterising the risks the risk manager must make decisions and communicate the risks to the public.

Table 16. Example of a characterisation of a hazard: Disease of Weil

Agent	**Leptospira species**
Transmission	Stagnant water, vegetation on the shore. Rats secretion via urine.
Presence	Whole world.
Incidention	10-100
Transmission	Direct contact with urine of infected animals. Indirect via surface water.
Disease	Fever, muscular pain, hepatitis caused by liver failure, vomiting possibly at later stages, kidney problems, heart problems, encephalitis.
Habitat	Urine tract of infected animals. Survives in water.
Details	Also other types of leptospirose infections can be found transmitted via cows.
Impact factor	6

Box 37. Summary points: What should I consider with regard to human health?

The main aspects that must be considered with regard to human health when planning a floodplain restoration project are:

- *The re-introduction of water onto floodplains and restoration of wetlands can bring associated water-related diseases.*
- *Sometimes pests such as mosquitoes or other wildlife may appear in quantities that cause nuisance.*
- *Health factors can be decisive in whether or not a project goes ahead, particularly with regard to spatial planning (i.e. should restoration projects take place near large human populations?).*
- *Risk assessments with regard to human health/nuisance aspects should be carried out, enabling the prevention and management of any potential risks.*
- *These risk assessments should call on the expertise of flood defence, health, microbiological and engineering experts.*

ORGANISING A FLOODPLAIN RESTORATION PROJECT

Organising a floodplain restoration project can be a difficult and complex task. Although several guidelines on how to initiate and implement such projects have been published (Naiman et al., 1995; Sparks, 1995; Gore and Shield, 1995; Stanford et al., 1996; Brookes and Shield, 1996; Bergen et al., 2001; Wolters et al., 2001; Buijse et al., 2002), most are applicable only to small streams or focus on impacts arising specifically from dam construction. The guidelines presented here aim to be generally applicable, providing practical guiding principles derived from existing knowledge on how to successfully carry out natural flood defence schemes.

Integration and communication are vital when organising floodplain restoration schemes. Plans should be incorporated into spatial planning processes in order to ensure the involvement of all stakeholders, who can be local and national level decision-makers, local inhabitants, farmers, fishermen and nature conservationists. Additionally the inclusion and integration of all relevant disciplines (e.g. hydrology, geomorphology, biogeochemistry, ecology and socio-economics) will ensure optimal solutions are found to any problems encountered.

The participation of stakeholders in water management issues is one of the means prescribed in the EU Water Framework Directive for achieving the required quality standards for water bodies. Early participation of stakeholders is essential to enable people to understand the problems, to search for solutions and to participate in drawing conclusions (Arvai, 2003). The Danish Skjern Å project was highly successful and delivered many positive results (see Case Study 6), mainly as a result of a well organised stakeholder involvement process.

The Wise Use of Floodplains (WUF) project (Cuff, 2001) addressed the issue of public participation in detail and produced guidelines for stakeholder involvement. The benefits identified from public participation included:

- Help with the identification of long-term sustainable solutions for people, their livelihoods and the environment.
- Development of ownership and trust.
- Reduction of costs in the long term through early identification of issues and consensus-building.
- Raising awareness of catchment management issues.
- Provision of a means of accessing local knowledge and expertise.

There are several steps involved in implementing a floodplain restoration project (Figure 47). These are described in detail below and some suggestions and tips are given on the organisation and involvement of stakeholders, contractors and financial support. At all stages of a project the socio-economic and ecological perspectives should always be considered together, whilst also complying with the initial goal of flood alleviation.

Where do I start?

Step 1 – Problem recognition

All schemes are initiated when problems associated with a floodplain have been identified by one or more stakeholders. These problems typically relate to flood control issues and associated ecological degradation

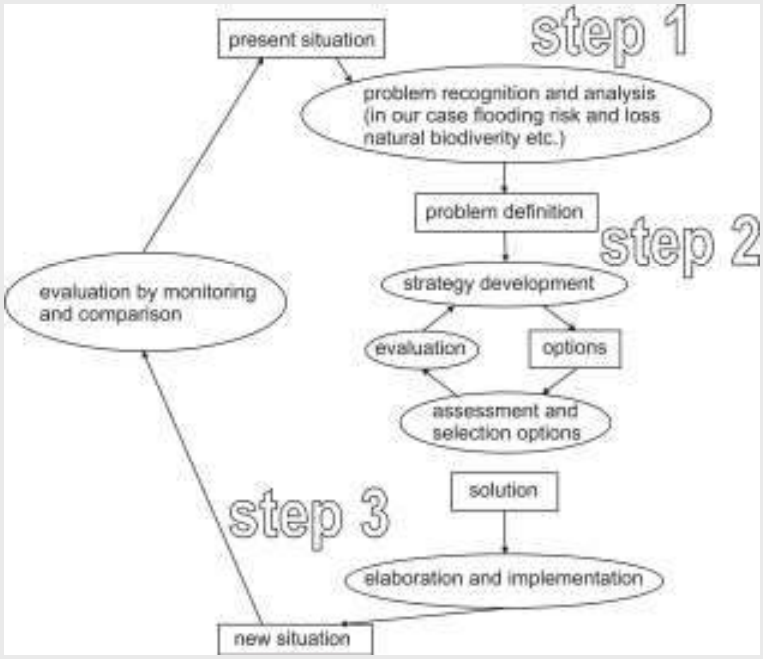


Figure 47. Steps involved in a restoration project
Source: After Lenselink et al., 2003

(e.g. biodiversity, fish production, etc.), or economic losses. The problem, as perceived by some stakeholders, is brought to the attention of local and national decision-makers as a point of concern. This is the first step in the planning process, and falls under the responsibility of the official local and/or national authorities. At this stage, it is important to obtain general acceptance of all the problems that exist among the public (Hansen, 1996) and to analyse the problems with regard to cause-effect relationships. In this way definition of the problems arises as a common product.

Stakeholder identification and analysis

Once a problem as perceived by any one stakeholder or group of stakeholders is acknowledged, the first thing to do is to make a complete stakeholder analysis. It is essential that this analysis is carried out at a very early stage, because the involvement of stakeholders is crucial in reaching a consensus about the nature of the perceived problem and consequently, a shared definition of it. Moreover, a stakeholder analysis is useful for identifying which stakeholders are involved and in what way. The types of stakeholder commonly encountered and some simple questions that can be asked in order to identify them are given in Box 38. The first of the three main groups of stakeholders is often the most important one; inadequate involvement of national and regional policy level administrations, NGOs and farmer's organisations often results in project failure. This group of stakeholders should be contacted as early as possible during the planning phase. Once all stakeholders have been identified, it is necessary to identify each stakeholder's relationship with a project. This is best done by asking the following questions:

1. What interest(s) is/are at stake? Or: what is the relationship between the project and the stakeholder?
2. What are the effects of the project on the interests of the stakeholder: is it positive, negative or neutral?
3. How important are these effects for the stakeholder?
4. How important for the project is the influence a stakeholder can have on it?

Box 38. Types of stakeholders and stakeholder identification

There are three main types of stakeholders that can be identified:

1. *National and regional groups.*
2. *Local communities who live in the project area and use the facilities.*
3. *People directly affected that might require re-housing or compensation for loss of income or devaluation of their properties.*

Stakeholders come in many different forms, have different backgrounds and different values. For example, it is possible to distinguish the following groups of stakeholders:

- *decision-makers (local, regional or national politicians);*
- *users (e.g. inhabitants, farmers, fishermen, tourists);*
- *executors (e.g. engineering companies);*
- *contributors (e.g. conservation NGOs, waterboards).*

Two questions that may be asked in order to identify stakeholders in a project are:

1. *Who will be affected by the project (individuals, groups, organisations)?*
2. *Who can influence the project?*

Answers to these questions can be tabulated and scored using Table 17. By combining the last two columns of Table 17, a matrix of stakeholder influence and importance in a project can be derived as shown in Table 18.

The stakeholder analysis should be carried out with people from different backgrounds and the draft tables should be discussed with some of the stakeholders. This prevents important stakeholders or interests being omitted, or incorrect estimation of a stakeholder's influence and importance. Some key tips that should be considered at this stage of a project are given below.

Table 17. Listing of stakeholders and their relationship to a project

(In the last two columns the following scale can be used: u = unknown, 1 = little, 2 = some, 3 = moderate, 4 = very, 5 = extremely, 6 = critical)

Stakeholder	Interest(s) at stake in relation to the project	Effect of the interest(s) (+, 0, –)	Importance of project for stakeholder (1–6)	Influence of stakeholder on Project (1–6)

Table 18. Matrix of stakeholder influence in projects and project importance for stakeholders

Importance: Influence:	unknown (U)	no (1)	some (2)	moderate (3)	significant (4)	essential (5)	critical (6)
unknown (U)							
no (1)							
some (2)							
moderate (3)							
significant (4)							
essential (5)							
critical (6)							

TOP TIPS: Key advice on stakeholder analysis and identification

TIP: *Assess the 'bottleneck'. 'Bottlenecks' can arise due to a few individual stakeholders and they are best dealt with individually. By giving more attention to individual problems you can convert them into opportunities.*

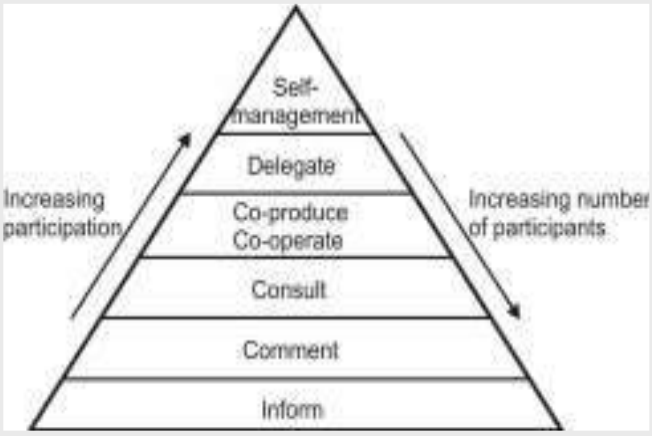
TIP: *Consider the cultural background of an area thoroughly. Depending on the country, there might be different ways to approach people. For example, there is no national farmers' organisation in Poland, so in such a situation it is necessary to talk with individual farmers, whereas in the Netherlands the national farmers' organisation is well organised and very powerful and therefore a good partner in a project.*

Stakeholder engagement in a project

Stakeholder analysis enables identification of which stakeholders need to be engaged and at which stage their engagement is needed. The desired level of participation by each stakeholder in the project and the number of steps and stages in which to involve them are determined by a combination of the importance of a project for the stakeholder and their level of influence. The more influential the stakeholder, the more important will be their participation in, and the need for their commitment to, the project.

A highly participative (or interactive) planning process will often only be possible with a small group of stakeholders. With lower degrees of participation it is possible to involve larger groups of stakeholders. Here we have one of the principal dilemmas in interactive planning, namely how to keep the process manageable. This is summarised by Arnstein's ladder of participa-

Box 39. Arnsteins ladder of participation



Arnstein's ladder of participation (1971) provides an overview of the different possible levels of participation that various groups of stakeholders can have in a floodplain restoration project. The number of participants generally decreases as the significance of the level of participation increases.

Figure 48. Arnstein's ladder of participation
Source: After Arnstein, 1971

tion (Arnstein, 1971) (Box 39). The level of participation that is selected for each stakeholder depends on:

- the total number of stakeholders involved;
- the characteristics of the stakeholders as described in Tables 17 and 18;
- the abilities and willingness of stakeholders to participate.

It is difficult to present general rules on this subject, and each project management team has to make choices, based on personal experience and knowledge of individual situations. It is also possible to discuss these issues with the stakeholders themselves. When using interactive planning it is important that stakeholders are aware of their own position and the position of others within the process and that they agree with these positions. The 'rules of the game' must be outlined at the beginning of the process and all stakeholders should be aware of the following:

1. What they might expect of the interactive planning process – which stakeholders are involved and in which phase of the interactive planning process will they be involved?
2. The decision making process in question – who is responsible for taking the decisions and what is the contribution of other stakeholders to the process?

At the lowest level of participation stakeholders are provided only with information about a project. On the next level they have the opportunity to comment on the plans. On the third level stakeholders are consulted during the development of plans, while on the fourth level stakeholders are directly involved in a project and the associated decision-making. The highest level of engagement involves delegating and self-management in which total responsibility is given to stakeholders.

Some useful tips at this stage involve the assignment of an independent local person to act as an intermediary between project officials and local stakeholders. A contact person familiar with the culture and social system of an area is often more successful in communicating a project to stakeholders than an 'outsider'.

TOP TIPS: Liaising with stakeholders

TIP: *Assign a local independent person to act as an interface between the technical project and the local situation.*

TIP: *Make sure the person assigned to act as a project contact is independent, in order to avoid a subjective and biased approach.*

TIP: *Make use of landowners that have been involved in previous projects to help initiate a new project.*

Box 40. Example of a successful project with a local person as project contact: Skjern Å (Denmark)

Ole Ottosen, an attendee of the ECOFLOOD Thinktank Meeting, remarked "On the River Skjern Å project we employed a community liaison officer, a local person with a friendly face and able to speak with the local accent, so that the stakeholders could speak to a local that they were able to trust. It costs you a bit of money to employ someone, but it pays off".

Knowing with whom to talk and who to involve, they can communicate between the local stakeholders and the project officers. In rural projects this person could be a land agent, or someone from the rural society with farming knowledge. In an urban project it should be a local person with insight to the social structures of the community. An example of the role of such a contact person and the effectiveness of his activities is presented in Box 40 for the Skjern Å in Denmark.

Together with the local project manager identify which groups should be involved in a project, and what their possible view of the project will be. An inventory should be made of possible opportunities and constraints from a stakeholder's point of view. The next step is to make an action plan on how and when to involve them. It is important that the different stakeholder groups are engaged at the correct time. For example, national and regional groups should be contacted at a very early stage, while a single landowner probably should be engaged later in the process.

What are the main things I should do?

Step 2 – Strategy development

During the strategy development stage of a project, technical experts (e.g. hydrologists, ecologists, spatial designers and social scientists) define possible solutions for any problems identified. These should be presented to stakeholders in the form of options. By including targets to be achieved in each of the options, their consequences for the different stakeholders are made clear, thus allowing clear criteria for jointly selecting the most promising option. Here it has to be kept in mind that interests and opinions of different stakeholders may vary widely (Box 41). The options are therefore evaluated and refined by experts and stakeholders until the most promising one is selected as the solution to be implemented.

Box 41. Different concerns of stakeholders and planners

A remark from Martin Janes (River Restoration Centre, UK): "Sometimes we have to remember that our main objective is not the main concern of the local stakeholder. The local stakeholders might be interested in how the area can be used afterwards and they are not necessarily so much interested in the flood level or the reduced flood risk after the measure. We experienced that tenant farmers were quite happy to be compensated after a flood as the stock could move to higher ground. In another project the football pitch located in the middle of the proposed flooded area was of key importance to the local community".

The step of strategy development is generally the most creative stage of a restoration process. The task of designing the solutions to the problems identified in the previous step is undertaken, and should address the targets for almost all stakeholders as well as those of (inter)national policies on water management and conservation (e.g. EU Directives). Following the initial investigation of potential problems and stakeholder's opinions (both positive and negative), more technical assessment can commence. Firstly a delineation of the project area and the total area that will be impacted should be carried out. Given this delineation it might be possible to estimate what consequences the initial plans will have for the types of land use following implementation of a plan. The different options for financial compensation and legal requirements should be quantified as far as possible, preferably giving different options so that stakeholders can choose or suggest what is most convenient for them. Important boundary conditions such as financial compensation, legal requirements (including possibilities for compulsory land purchase) and support from the government should be determined early, because they will be important in all communications with stakeholders. A topographic, hydrological and ecological survey of the current state and predicted state of the area should be done and a list of the different types of potential measures likely to be carried out should be compiled.

A good way to help raise both the socio-economic and ecological perspectives of a project is to set-up an 'integrated decision support system' (IDSS). Box 42 provides an example applied to a small catchment area in the Dutch-Belgian border region (Pieterse et al., 2002). An IDSS is only one of the instruments suitable for use in the planning stages of 'strategy development' and 'assessment and selection of options' as shown in Figure 47. Obtaining an overview of the financial possibilities for the available options is essential for dialogue with stakeholders and it is important to know that the project is financially viable. Landowners affected by proposals appreciate having different options from which to choose and it can make the discussions easier. Keep in mind, however, that in the phase of assessment and selection a simple trade-off between ecological benefits and economic costs can be restrictive. In addition, a more comprehensive approach might be needed, which also includes other possible socio-economic benefits as referred to in the previous sections.

Since it is not always possible to separate technical facts from political visions, stakeholder involvement at this stage of the planning process is crucial for strategy development. In some regions or countries political power or wider societal objectives may be the driver of a project. Therefore, social priorities and technical issues preferably should be merged to achieve optimal management of floodplains. In most cases it will be possible to develop a scheme that takes these factors into consideration and delivers multiple benefits.

Since floodplain restoration aims at both reducing flood risk and enhancing the functions and benefits of natural river systems, the objectives and values of individuals are crucial to what options will emerge from the strategy development. Whether nature has an intrinsic value itself is a contentious issue (Lockwood, 1999), but the protection of nature is a common value held by many people, and targets for ecological rehabilitation are often related to it. Authorised targets

TOP TIPS: Points to consider during strategy development and first contacts with stakeholders

TIP: *Be aware that your concerns are not necessarily the concerns of the local stakeholders (Box 40).*

TIP: *It only costs a little extra to make a project successful. It is common for less than 10% of the total budget of a natural flood defence scheme to be spent on public access and information. However, the inclusion of public access and recreation components in a scheme can greatly influence the degree of support it will receive, and spending a little more on these aspects can greatly enhance the likelihood of a scheme being successful.*

TIP: *Treat local stakeholders that might be directly affected by the plans with care. During the first phase of contacts don't mention plans and decisions, but refer to ideas and suggestions for plans. Make note of peoples ideas and interests, and avoid widespread publicity for a scheme (e.g. publication in a local newspaper). Ensure that the first time a landowner affected by a proposed scheme hears about it is through a personal discussion.*

are related to policies (conventions, directives or laws), while non-authorised targets can be assigned by specialists or the general public. Although people often share the same value, they often do not agree about specific targets.

Targets for river rehabilitation are not only related to values, but also to our knowledge of river systems. It is important to have a thorough knowledge of river ecology for management and rehabilitation (Stanford et al., 1996; Ward et al., 2001; Bergen et al., 2001). Restoration of the processes and interactions that are natural to rivers and floodplains help the overall ecological rehabilitation of floodplains. However, opportunities for this approach to restoration are often limited because human use of the river system makes restoration of a pristine state impossible (Van Dijk et al., 1995; Stanford et al., 1996; Middleton, 1999; Ward et al., 2001). The challenge for floodplain rehabilitation is the development of targets that fit the properties of the ecosystem and that can be realised within the constraints of human use.

Some guiding principles for the development of a floodplain restoration scheme should be borne in mind, based on the approach by Pastorok et al. (1997). A seven-step approach is suggested towards prioritising restoration or rehabilitation measures for floodplains within any given set of boundary conditions (Box 43). This sequence of restoration priorities focuses on restoration of processes because these constitute an important control on the ecological diversity of a system (Richards et al., 2002; Ward et al., 2002). Furthermore, restoration projects that do not take catchment scale processes into account may not achieve objectives of increased biodiversity if the restoration only involves partial restoration on the level of local spatial patterns or even on the species level (Richards et al., 2002).

Stakeholder involvement and stimulation of stakeholder commitment to (floodplain) restoration programmes can be assisted in several ways. Organise stakeholder meetings for all stakeholders directly affected by the proposed plans as soon as they have been developed, following the initial stakeholder contributions to the development of options. It is important to start meetings in the right way in order to set the right tone and atmosphere. Therefore a meeting must be well planned. Experts advise that influential people such as politicians should chair meetings. Subsequently technical experts should present facts and figures about the proposal and then stakeholders should be able to comment on the proposals. When any potential opportunities or problems are being addressed by people directly affected by the plans, a discussion with the general public on the final proposal should be held. This way everyone is able to constructively comment upon the plans in hearings involving all three groups of stakeholders.

Box 42. An integrated decision support system (IDSS) to help with the strategy development phase of a restoration project

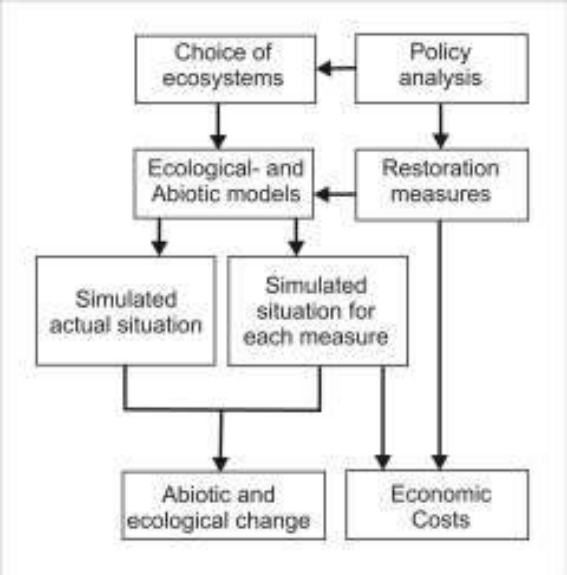


Figure 49. Structure of the integrated decision support system developed by Pieterse et al. (2002)
Source: Pieterse et al., 2002

The integration within an IDSS of abiotic and ecological models as well as economic cost-benefit analyses of the measures likely to be taken in a project for the Dommel area (The Netherlands/Belgium) showed that when finance is limited and uncertainties exist about the impacts of a project, the use of an IDSS can help develop the most attractive options for restoration.

Not only does such an approach consider that any particular set of measures may have both positive and negative effects (e.g. favouring one ecosystem and its habitats while hampering the maintenance or development of another), but it also allows decision makers, after consulting with stakeholders, to opt for the most cost-effective solution that promises the best solution for the local circumstances.

Box 43. Guiding principles for ecological floodplain restoration

To help bridge the gap between the objectives of policies and the specific objectives of an individual floodplain restoration project, considering how natural processes and landscape patterns interact in a pristine environment, seven guiding principles have been developed for ecological rehabilitation of aquatic systems, adapted here to floodplains:

(1) ***Natural processes have priority over the development of spatial patterns.*** *Natural processes form the landscape. When possible, natural landscape forming processes are preferred to direct measures to recreate specific landscape units.*

(2) ***Spatial patterns have priority over measures for specific species.*** *If possibilities for natural processes are limited, restoration projects may focus on the (re)creation of specific landscape units. Only in special situations are measures for specific species advisable.*

(3) ***Large-scale projects and/or contributions to spatially coherent systems have priority over small scale and scattered projects****. Scale and connectivity are important criteria in floodplain restoration. Large areas are needed to sustain viable populations of species, but small areas may still be valuable if they are connected.*

(4) ***Low maintenance effort is preferable to high maintenance need.*** *Projects requiring low maintenance are preferred for two reasons: maintenance is costly and a high need for management is an indication that a system is not functioning naturally. When maintenance measures are necessary, then look for the most natural methods (e.g. grazing instead of mowing).*

(5) ***Existing natural values have a priority over potential values.*** *Existing natural values are protected by the EU Habitats and Birds Directives. Existing values (including aesthetic, cultural and archaeological values) are often appreciated by local inhabitants and degradation of these values for the creation of 'new nature' is only acceptable if the existing values are not characteristic for the system, when the new situation will have an obvious surplus value when the existing values can be compensated for, or when existing values will disappear as a consequence of autonomous developments.*

(6) ***Multifunctional use is preferable to mono-functional use.*** *Within the constraint that the ecological objectives are met, multifunctional use of floodplain areas is preferred. Multifunctional use is especially important in densely populated countries such as The Netherlands.*

(7) ***No regret options are preferred above measures related to specific conditions.*** *Finally, it is important to take into account the possible changes in environmental pressures and boundary conditions in the future.*

(Pastorok et al., 1997)

TOP TIPS: How to organise and structure public meetings about restoration projects

TIP: *Don't make meetings too large and get an experienced chairperson. It might be best to organise several small meetings, rather than to organise one big one, as everyone should have the opportunity to be heard. In big crowds not everybody gets an equal opportunity to do so.*

TIP: *Sometimes an external technical expert will need to explain some issues: make sure that the external expert is aware of the type of audience to which they will speak and if possible, make sure that they have already been introduced to a few key players before the meeting is held.*

TIP: *Address the 'what's in it for me' question of the stakeholders who are present.*

TIP: *Clearly mention the purpose of the hearing and the expected input from the invited stakeholders. For example, there is a large difference between a meeting that intends to inform and a meeting in which input is needed for alternative solutions. The format of a hearing will largely depend on the purpose of the meeting.*

What are the main obstacles I am likely to encounter?

Step 3 – Implementation and monitoring

Following strategy development and option selection, obstacles and uncertainties will almost certainly be encountered during implementation of the selected plan. Therefore it is useful to anticipate and be prepared to deal with these problems. Ways in which to do this are summarised in Box 44.

The selected option is usually implemented by a contractor and may involve various engineering and management changes. The subsequent conditions that result from this implementation should be monitored and evaluated by comparing both the changes in hydrology and natural values with the original conditions. Any deviations from the expected changes should be carefully identified and analysed in order to allow adaptive management for the site, i.e. a management strategy that allows for adaptations when the outcome does not meet the expectation, according to the findings of the monitoring programme (Pastorok et al., 1997).

An example of how larger-scale restoration programmes may profit from lessons learnt by smaller-scale experimental projects is presented by the Room for the River programme for flood alleviation and enhancement of spatial quality in the lower reaches of the rivers Rhine and Meuse, The Netherlands (Box 45). Experimental sites have investigated aspects of flood reduction, navigation, ecological responses and conservation values of various measures. Consequently the ability to assess the impact of larger-scale plans for the entire lower reaches of this river catchment basin has been improved by learning from the smaller-scale projects.

How can I fund a floodplain restoration project?

Individual European countries have many different national sources of funding that can be used to support floodplain restoration projects. Both governmental and local authorities have in many cases contributed to financing floodplain restoration projects, and private funding is an opportunity that should not be overlooked. The vast range of potential national sources of funding precludes their inclusion here, and consequently this section focuses on EU level sources of funding.

Within the EU there are several potential sources of funding for natural flood defence projects. Most EU funding is not paid directly by the European Commission, but via national and regional authorities of the Member States. This is how payments are made under the Common Agricultural Policy and most payments under the structural policy financial instruments (European Regional Development Fund, European Social Fund, European Agricultural Guidance and Guarantee Fund and Financial Instrument for Fisheries Guidance), which make up, in money terms, the majority of EU funding. The Commission pays direct grants to beneficiaries (public or private legally constituted bodies – universities, businesses, interest groups, and NGOs).

A survey, which should be consulted is titled: 'Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions – Flood risk management – Flood prevention, protection and mitigation' (Brussels, 12.07.2004 COM (2004) 472 final). The document can be downloaded from http://europa.eu.int/comm/environment/water/pdf/com_2004_472_en.pdf. This paper provides important information about funding issues related to floods.

Box 44. Dealing with uncertainties

Uncertainties that might exist in a restoration project can include the type of habitat or vegetation that will develop, or the period of flooding that occurs. Pastorok et al. (1997) suggest ways of dealing with such uncertainties.

1. ***Use of experimental sites**: by using small scale experimental sites where the proposed measures to be carried out in a project are replicated can enable identification of the outcomes of specific measures. Results can be used to determine the extent to which a restoration project is likely to be successful. This enables adaptation of the spatial design and/or management in such a way that any shortcomings are remedied before the restoration plan is applied to the entire floodplain. Another function of experimental sites is that they may be used to demonstrate to sceptics the opportunities and benefits arising from restoration of a floodplain.*
2. ***Adaptive management:** inclusion of a plan for monitoring and adaptive management of the site after the implementation will mean that any deviations from the intended outcome are not only immediately detected, but may also be evaluated and incorporated in the management of a site.*

Box 45. The Room for the River Project, The Netherlands

The 'Room for the River' project provides an integrated plan for the lower reaches of the Rivers Rhine and Meuse within The Netherlands, and aims to provide a combination of protection against flooding and enhancement of 'spatial quality' by providing more room for peak discharges. The plan recommends a large series of measures. The project was initiated in 2002, and follows-on from earlier preliminary studies on the feasibility of spatial rather than purely technical solutions for improving flood protection. It is intended to provide a standardised level of safety by 2015. In 2005 a set of measures will be selected and elaborated in more detail and subsequently the agreed measures will be implemented. Some earlier projects involving preliminary studies were:

- ***Gamerensche Waard, Lower Rhine – Waal***

This is a completed project involving active floodplain widening. A plan was initiated in 1993 to widen the originally narrow floodplain known as the Gamerensche Waard, along the Lower Rhine, and combine this with the construction of three artificial secondary channels. A detailed plan was produced in 1995 and between then and 1999 the floodplain was reconstructed correspondingly. Close monitoring of both abiotic and biotic effects of the measures undertaken enables comprehensive evaluation of this project.

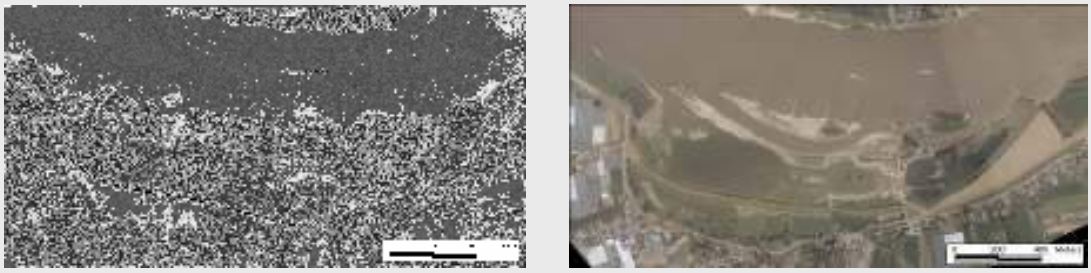


Figure 50. Situation before (1995, left) and after (1997, right) project implementation
Photos: Courtesy of Rijkswaterstaat, The Netherlands, Jan, 2004

- ***Afferdensche en Deestsche Waarden, Lower Rhine, Waal***

This is a floodplain restoration project still in the process of implementation. The intended completion date of of the whole project is unknown. The project is located on the south bank of the River Waal, a branch of the River Rhine, in a 336.5 ha area of floodplain of high landscape diversity. A relatively open landscape occupies an area of over 110 ha, with woodland and scrub occupying approximately 30 ha and both pioneer and tall herb vegetation is also present. The rest of the area was used by a brick factory and for farming (corn fields) before the project commenced. A vegetation survey in 1998 showed that on the lowered areas a variety of different landscape types has developed. The amount of shallow and non-connected water bodies and highly dynamic pioneer vegetation communities has increased.

Many species characteristic of dynamic floodplain conditions have returned and the overall biodiversity has increased. Further biodiversity increases could occur as a consequence of the construction of a secondary river channel and lowering of the remaining floodplain. Introduction of a year-round grazing regime by cattle and horses favours natural habitat diversity, especially the vegetation in the lowest zone, with Limosella aquatica being an important species. Floodplain lowering also resulted in an increase in breeding bird species, especially in the lowered areas.

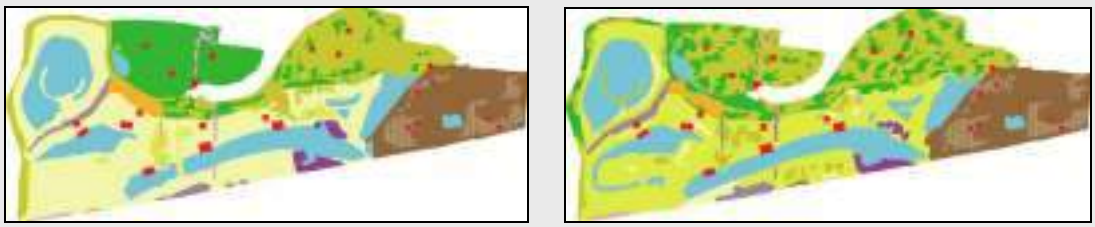


Figure 51. Condition of the lowered part of the floodplain in 1997 (left) and in 2001 (right). Note the vegetation succession
Source: Pelsma et al., 2003

To get an overview of the funding opportunities available, consult the 'Introduction to EU funding' web page, which can be found at the following address: http://europa.eu.int/grants/info/introduction_en.htm. On this web-page there are several links to other web-pages dealing with funding opportunities. In this context there are two interesting DG's that administrate funds which give financial support to flood prevention activities and flood disasters. The first is DG Environment: http://europa.eu.int/comm/environment/funding/intro_en.htm, which provides an introduction to funding opportunities within DG Environment, and it is possible to download the 'Handbook for Environmental Project Funding' http://europa.eu.int/comm/environment/funding/pdf/handbook_funding.pdf, which provides information about funding related to floods.

DG Environment administrates LIFE–III, which is the financial instrument for the environment. LIFE co-finances environmental initiatives in the European Union, some countries bordering the Mediterranean and the Baltic Sea and Central and Eastern European accession candidate countries that have chosen to participate in LIFE. Access to information about the LIFE program can be obtained through the LIFE homepage: http://europa.eu.int/comm/environment/life and the LIFE news page: http://europa.eu.int/comm/environment/life/news.

The LIFE-Environment funding source aims to implement policy and legislation on the environment in the European Union and candidate countries. In LIFE--Environment a summary and guidelines for LIFE--Environment demonstration projects can be found. The guidelines were adopted by the Commission on 27th July 2004 (Decision 2004/C 191/02), and can be found at http://europa.eu.int/comm/environment/life/funding/life-env_call2006/part1_en.pdf. In the 'Sustainable management of groundwater and surface water' section of the guidelines for LIFE-Environment demonstration projects the following objectives are stated:

- Impact of agricultural and forest practices on water quality with regard to consequences on river basin management (surface and groundwater) and marine environment (eutrophication). This includes issues of pesticides, nutrient pollution and eutrophication, nitrogen balances in grassland and arable land taking into account quantitative aspects relevant to integrated water management.
- Flood prevention and control in the context of river basin management.

DG Regional Policy administrate several funds that can be used to finance flood prevention, protection and mitigation. The web address is http://europa.eu.int/grants/dgs/regional_policy/regional_policy_en.htm.

The Structural Funds, in particular the European Regional Development Fund and the Cohesion Fund can fund preventative (infrastructure) investments including those related to flood protection. The European Regional Development Fund can also contribute to financing infrastructure-related research and technological development.

The INTERREG III initiative (Time Frame: 2000–2006) under the European Regional Development Fund has the following general objectives:

- The overall aim is that national borders should not be a barrier to the balanced development and integration of the European territory.
- Strengthening of economic and social cohesion in the new phase by promoting cross-border transnational and inter-regional co-operation and balanced development of the Community territory.

The IRMA programme – INTERREG Rhine Meuse Activities (see Case Study 2) – provides a good example of an INTERREG funded project.

Following the 2002 flood events in central Europe, the EU created the European Union Solidarity Fund (EUSF) as a specific financial instrument to grant rapid financial assistance in the event of a major disaster (defined as direct damage in excess of €3 billion or 0.6% of Gross National Income). Details can be found at http://europa.eu.int/scadplus/leg/en/lvb/g24217.htm. The EUSF may only intervene for emergency operations. It was not set up with the aim of meeting all the costs associated with natural disasters and the EUSF does not compensate for private losses or damage covered by insurance. Long-term action (reconstruction, economic redevelopment and prevention) can qualify for aid under other instruments, most notably Structural Funds.

The European Investment Bank has participated in environmental financing, including the following flood protection projects: Flood prevention and reconstruction in Poland, the Czech Republic, Slovakia, Tuscany, Valle d'Aosta and Piedmont regions, conservation of the Venice Lagoon and the St. Petersburg flood protection barrier.

What are the characteristics of a successful floodplain restoration scheme?

The successful implementation of any project is based partly on the concept of incentives and disincentives. Incentives motivate desired behaviour, and disincentives discourage behaviour that is not desired. The incentives can be in cash or in kind, e.g. using subsidies provided by the government (McNeely, 1988). When compensation, either financial or through the provision of contentment (e.g. a sense of improved safety from flooding), can be provided for the losses of landowners and other stakeholders, flooding is more likely to be accepted. As an example an overview is presented in Box 46 of the conditions that proved to be essential for the successful implementation of floodplain restoration schemes in Denmark.

Box 46. Conditions that normally will be essential for the successful implementation of floodplain restoration schemes (by Ole Ottosen, NERI, Denmark)

1. *Political desire to solve problems by implementing restoration of floodplains. It is important that there is economic support from government for implementing the projects.*
2. *Selection of areas that are suitable for floodplain projects.*
3. *Preparation of an action programme with objectives for the extent of projects within the economic constraints.*
4. *Existence of a clear overall objective e.g. solve the conflicts between farming and flooding on floodplains.*
5. *Clarification of the attitude (and preferably support) of national (and regional) interest groups and organisations.*
6. *Implementation of preliminary studies to demonstrate the consequences (flooding, nature, environment, farming) of a project.*
7. *Establishment of an efficient project organisation - it is essential that a project organisation committee has knowledge about the many different subjects associated with floodplain projects and that there is an ability to understand landowners and interest groups' wishes and needs.*
8. *Opportunities for buying areas inside and outside of potential project areas.*
9. *The ability to offer reasonable compensation to landowners - it will be an advantage if landowners can choose between different types of compensation.*
10. *The ability to make compulsory purchase of property if landowners reject reasonable compensation.*
11. *Early involvement of landowners and supply of information to them about which parts of the projects they can influence.*
12. *Reasonable involvement of various interest groups. When planning a project it is reasonable to make assumptions about the expected levels of interest from potential interest groups and plan how they shall be informed and involved. The most important aspects of a project for interest groups are often subjects connected to the future use and protection of the project areas.*

EXISTING INTERNATIONAL POLICY AND FLOODPLAIN MANAGEMENT

Although the greatest impacts on rivers and floodplains have been experienced within the last 200 years, this has been accelerated within the last 50 years by inappropriate national and EU policies which are the most important driving forces affecting floodplain use. These policies have promoted largely sectoral exploitation of rivers and floodplains, resulting not only in the degradation of these systems but also their sub-optimal use. There is a wide range of political, institutional and administrative processes which affect the delivery of sectoral policies and it is only through the radical reform of policies that ecologically and economically sustainable use of floodplains will be possible, based on restoration and management of natural processes (WWF, 2000).

What are the consequences of conventional sectoral policies?

One of the key policy factors affecting the sectoral exploitation and degradation of floodplains has been the Common Agricultural Policy (CAP), affecting two-thirds of the European Union's land area. This determines the principles according to which agri-environment and rural development support schemes should operate, and the details of mainstream agriculture support payments. Many accuse the CAP of being one of the main offenders in the promotion of river and floodplain degradation in recent times. Historically CAP has promoted intensification through the increased use of fertilisers, pesticides, high stocking densities and land drainage. Even today, despite supposedly environmentally beneficial changes to the CAP, payments are still stacked heavily in favour of encouraging maximum production and intensification of farming practices. The Agenda 2000 reform introduced a new regulation aimed specifically at promoting rural development, under which Member States are obliged to take whatever measures they consider appropriate to comply with EU or national environmental law. While this option of using cross-compliance within CAP does provide the opportunity for governments to develop environmental standards in agriculture, which would encourage the sustainable farming of floodplains, it is optional and so there is no guarantee that it will be widely used by Member States. Additionally, while it addresses some of the direct impacts on the environment, it does not assist with redressing past damage. Consequently, despite these CAP reforms, there are still imbalances between policies that encourage production and those that support nature conservation. This has led to continued change to the way land is managed and to a decline in the area of semi-natural habitats, biodiversity, and the diversity of landscape features, conflicting with the Habitats Directive and the objectives of the Convention on Biological Diversity. The amount of land available to agriculture has been increased and floodplains have been one of the key areas targeted in this way (JNCC, 2002).

Recognition of the problems caused by sectoral policies has resulted in an increasing number of international agreements promoting the restoration and conservation of riverine habitats (Dobson et al., 1997; Hector et al., 2001; Nienhuis and Gulati, 2002; Pastorok et al., 1997; Verhoeven, 2000). The first major agreement of this type was the Ramsar Convention on Wetlands, signed in 1971. Subsequently many international agreements have been signed including the Convention on Biological Diversity (CBD), signed at the 1992 Earth Summit in Rio de Janeiro. It has developed in parallel with another initiative, the Ecosystem Approach (EA), adopted formally by the CBD and the Water Framework Directive (WFD), originating out of Brussels (see below). Together it is anticipated that these will support the 'wise use' provisions of the Ramsar Convention, and promote conditions which can stimulate a return to more natural, dynamic, sustainable and valuable riverine ecosystems. The Ecosystem Approach (EA) is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable (or fair and impartial) way. It has been embraced by the CBD as the means to help reach a balance of the objectives of the Convention by taking into account ecological, economic and social considerations within a single framework. It has an emphasis on broad-based integrated methodologies involving a wide range of stakeholders and different scales of application. It is not a rigid framework but a highly flexible methodology which can be adapted to a wide range of situations and particular problems of sustainable natural resource management, and therefore is directly applicable to the management of floodplains. The approach is underpinned by twelve principles and additional notes of guidance. In further endorsing the approach the Conference of Parties of the CBD have recommended its implementation with appropriate adaptation to local, national and regional conditions. Above all, whilst there is increasing knowledge of what the EA is trying to achieve there is still a major gap in the understanding of exactly how to do it. One way in which the Ecosystem Approach can be implemented is through the WFD.

How does floodplain restoration relate to EU Directives?

The most important piece of recent legislation that affects the restoration and conservation of floodplains is the Water Framework Directive (EC/60/2000), although it does not explicitly address natural flood defence. Indirectly, however, the issue of flood management is included, since the Directive requires that no further deterioration of river systems is to be allowed. Reduction of flood impact is a stated goal of the Water Framework Directive, though precautionary measures are not specified. The basic idea of this Directive is that all water bodies within the European Union should be in 'good ecological status' by 2015. For water bodies classified as 'natural' this implies the realisation of good quality for both chemical and biological quality parameters, at levels close to so-called 'natural reference' circumstances, i.e. circumstances without any human influence. For so-called 'heavily modified' water bodies (i.e. regulated river systems), member states are required to identify and quantify the irreversible hydromorphological measures and their past effects on the biological quality parameters. These effects should be mitigated or compensated for by measures designed for restoring these parameters to reach 'good ecological potential'. In river systems, the biological quality parameters required to attain a good 'status' or 'potential' include: aquatic macrophytes and phytobenthos, aquatic macrofauna and fish. Since naturally functioning floodplains are essential to the occurrence of all of these parameters, floodplain restoration may very well be one of the means by which this Directive's objectives are met along heavily modified stretches of river.

In order to preserve the naturally occurring biodiversity within the European Union, important species and habitats have become specifically protected by the EU Habitat Directive (EEC/92/43 1992), which was merged with the EU Bird Directive (79/409/EEC) into Natura 2000. This has also resulted in the establishment of a network of so-called Special Protected Areas (SPAs). Wetland areas in general and floodplains in particular may play crucial roles in this pan-European network of protected nature reserves. This Natura 2000 approach not only offers protection of species and habitats, but may also imply specific obligations for restoring certain endangered habitats. Some floodplain habitats have also been offered protection by the Pan-European Biological and Landscape Diversity Strategy (UNEP 1996), and many habitats have also recently been included on the lists of protected habitats and priorities of European member states to comply with agro-environmental schemes (EC/1257 1999, EC/1750 1999).

The problems of flooding and safety are being tackled by agreements and treaties between individual Member States and are not yet directly covered by EU policy. However, in 2002 the European Commission proposed the development of the 'Initiative on flood protection, prevention and mitigation' to Member States and Accession Countries. The aim of this initiative is to share experience and compile 'best practice' examples for sustainable flood management. A key concept of this development is policy integration at EU and national levels. As a result of this decision and under the general framework of the Common Implementation Strategy of the Water Framework Directive, Water Directors approved in November 2003 a document titled 'Best practice on flood protection, prevention and mitigation'. This is basically an update of the United Nations and Economic Commission for Europe Guidelines (UN/ECE) on Sustainable Flood Prevention (2000). In this document measures and best practices are described for preventing and mitigating the adverse impact of river flood events on human health and safety, valuable goods and property and aquatic and terrestrial environment. At the same time the EU Commission (DG Environment) envisaged preparation of the legislative proposal focusing on flood prevention and protection plans at the river basin level.

The WFD and the 11 water related Directives associated with it provide a mechanism for the support of floodplain restoration for the purposes of natural flood defence, and support not just hydrological criteria (e.g. flood reduction), but many of the additional benefits a naturally functioning floodplain can deliver through promotion of good ecological status of wetlands (and floodplains).

What role can floodplain restoration play in IRBMPs?

Experience has shown that for effective flood prevention and protection, measures have to be implemented at the river basin scale. The Water Framework Directive (WFD) explicitly requires Member States to produce a management plan for each of their River Basin Districts (RBDs). This requirement is described in Articles 13 and 15. A River Basin Management Plan (RBMP) is intended to record the current status of water bodies within the RBD, set out what measures are planned to meet the objectives of the Directive, and act as the main reporting mechanism to the European Commission and the public. The full contents of the plan are specified in Annex VII of the WFD. The plans, to be published by 22 December 2009, must finalise the quality and quantity objectives to be achieved by 2015.

Planning is a systematic, integrative and iterative process that is comprised of a number of steps executed over a specified time schedule. The primary purpose of planning is to provide a plan as an instru-

ment for making decisions in order to influence the future. The typical approach to planning in this context usually includes three main stages:

i) current and foreseen scenario assessment;

ii) target setting;

iii) development of alternative programmes of measures.

These stages are part of a cyclical and iterative process. The river basin planning process is followed by implementation of a programme of measures. Together these comprise river basin management. The actual planning process may vary significantly because of different traditions in policy making and its implementation.

River Basin Districts are based mainly on surface water catchments, together with the boundaries of associated groundwater and coastal water bodies. In the case of small river basins adjacent to large ones, or of several neighbouring small basins, the Directive allows the competent authority to combine them in order to make water management in the River Basin District more efficient. By creating a spatial unit for water management based on river basins, it is inevitable that spatial conflicts will occur with other policy sectors that have a significant impact on water, but are structured along administrative and political boundaries.

Box 47. Action Plan Flood Control Elbe

The Action Plan Flood Control Elbe was approved by the ICPE (International Commission for the Protection of the River Elbe) in October 2003 (ICPE, 2003) as a large scale flood risk policy of the riverine federal states in the Elbe Valley, supported by the German federal government. The plan incorporates 15 local floodplain restoration projects distributed along the Elbe, encompassing approximately 2,600 ha. Embankment replacement is the main action to be undertaken in each project. Figure 52 shows the areas at which embankment relocation is proposed in the Elbe valley.
(For further details see http://www.bmu.de/gewaesserschutz/doc/5099.php)

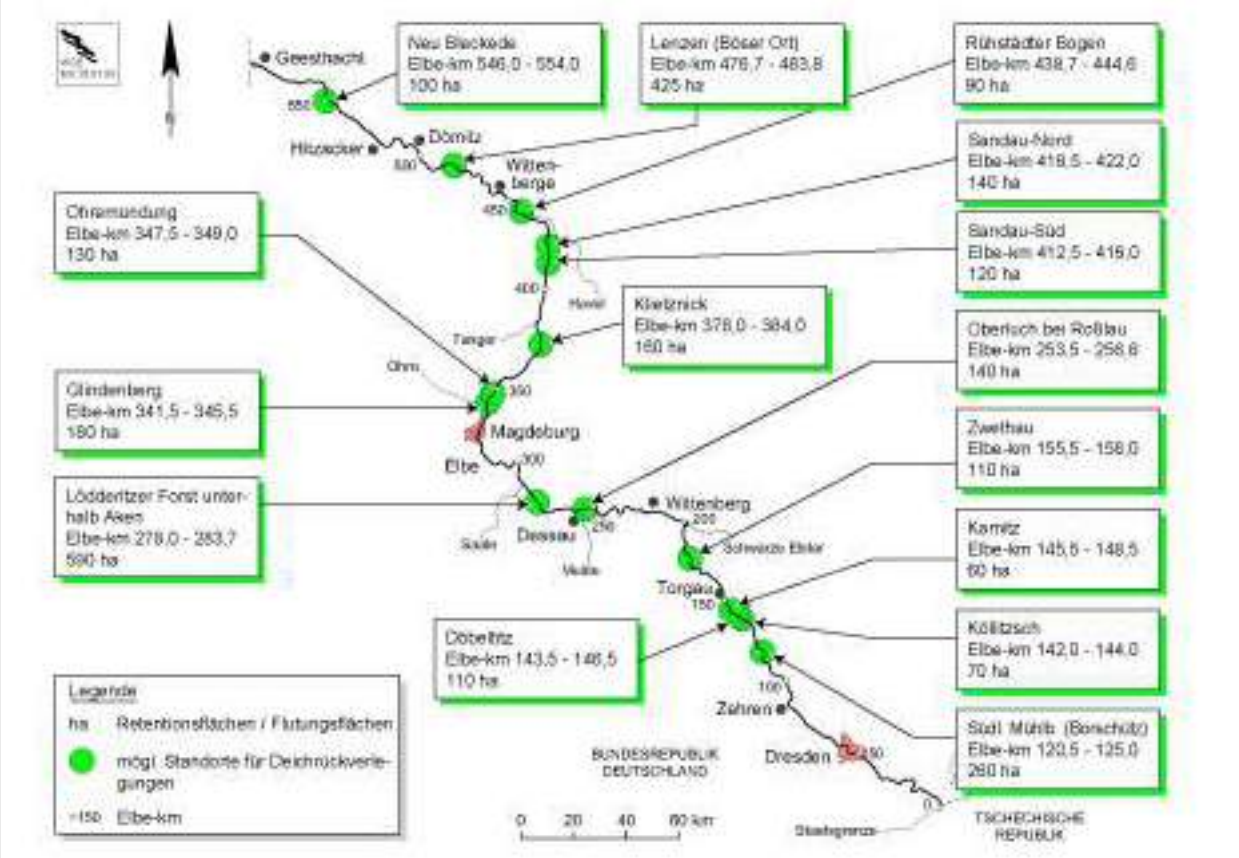


Figure 52. Locations of proposed embankment realignment along the River Elbe
Source: http://www.bmu.de/files/pdfs/allgemein/application/pdf/hochwasser_aktionsplan_grafik03.pdf

Box 48. Seven Guiding Principles for IRBM initiatives

WWF has established a set of seven key elements or 'guiding principles' that should be in place for an IRBM initiative to succeed. These are:

- *A long-term **vision** for the river basin, agreed to by all the major stakeholders.*
- *A solid foundation of knowledge of the river basin and the natural and socio-economic forces that influence it.*
- ***Integration** of policies, decisions and costs across sectoral interests such as industry, agriculture, urban development, navigation, fisheries management and conservation.*
- *Strategic decision-making made at the river basin **scale**, which guides actions at sub-basin or local levels.*
- *Effective **timing**, taking advantage of opportunities as they arise while working within a strategic framework.*
- *Active **participation** by all relevant stakeholders in well-informed and transparent planning and decision-making.*
- *Adequate investment by governments, the private sector, and civil society in **capacity** for river basin planning and participation processes.*

WWF Policy Briefing, June 2004, Living with floods: Achieving ecologically sustainable flood management in Europe

Box 49. Room for the River – natural flood risk reduction measures incorporated in integrated river management planning

***The 'Room for the River'** project provides an integrated flood protection plan and 'spatial quality' enhancement plan for the lower reaches of the Rivers Rhine and Meuse within The Netherlands. The project was initiated in 2002, and follows-on from earlier preliminary studies on the feasibility of spatial rather than purely technical solutions providing more room for peak river discharges. It is intended to provide a standardised level of safety, adapted since the peak discharges of 1993 and 1995 in both rivers, by 2015. At the same time it delivers minimum losses and maximum gains of ecological values, with a small net increase in biodiversity. The project is financed mainly by the Dutch government, but whenever possible finances are generated within the project, such as through the extraction of gravel, sand or clay, or other alternative sources of finance are sought e.g. EU-funding, local authorities and public contributions.*

The area of naturally functioning floodplain along these rivers has declined to approximately 10% of its original extent due to the construction of embankments. The remaining floodplains have been subject to enhanced deposition of clay, resulting in higher floodplain elevation than in the former floodplain areas, now protected by embankments.

***The main goal** of the project is to provide the required level of safety in the Netherlands, adapting the Lower Rhine and Meuse branches so that they can cope with peak discharges of up to 16,000 $m^3 sec^{-1}$ on the Rhine (at the Dutch-German border) and of up to 3,800 $m^3 sec^{-1}$ on the Meuse (at the Dutch-Belgian border) by the year 2015.*

***Measures** recommended in the plan include: re-enforcement of embankments; deepening the summer bed; lowering of floodplain area; widening the floodplain by re-location of embankments; downstream storage; construction of an emergency 'high-water' channel; lowering minor embankments; lowering or removal of groynes; removal of obstacles.*

***Hydrological modelling** suggests that the present set of measures provides sufficient floodwater storage for coping with peak discharges in the Rhine of 16,000 $m^3 sec^{-1}$ and in the Meuse of 3,800 $m^3 sec^{-1}$. This would provide protection for the surrounding areas against floods with a return period of 1250 years.*

For further information see www.ruimtevoorderivier.nl

Member States will need to establish planning frameworks with explicit purposes and clear national policies, including a set of objectives for protecting and improving the environment in relation to other sectors. Integration of different policy sectors including the WFD objectives is one of the biggest challenges for the implementation process. The other challenge with regard to the water management sector is coordination at the operational level, especially:

- Among bodies involved directly with water management (e.g. those responsible for water storage and supply, flood management and treatment of waste water);
- Between surface water and groundwater managers (if relevant);
- Between water managers and other sectors, such as land use planning, agriculture, forestry, flood management, industry and tourism/ recreation.

Working on a long-term vision for an RBD is an essential approach in order that agreement can be reached among authorities and stakeholders on objectives, as well as to plan the actions required to achieve these objectives. A stable, long-term plan is also important to have as a reference during the whole implementation process. At the end of each reporting period, progress made can be compared with the initial vision and measures can be adjusted if necessary.

PART IV

WHAT NEXT?

GAPS IN KNOWLEDGE

These guidelines provide information based on our current state of knowledge with regard to the topics covered, but there are still things we don't know and our knowledge will develop in the future. Also, there are likely to be various changes of environmental, economic and social significance that will affect the way in which natural flood defences are used and managed. Some of these issues are covered below.

Despite increasing knowledge of the role floodplains play in catchment hydrology (particularly flood defence), and the many other values and benefits they can provide, there are a number of areas in which knowledge is still lacking. These include the role of forests on floodplains, the hydrological role of wetlands, best management practices upstream of floodplain limits, and floodplain management in estuarine /intertidal zones. These topics are discussed below.

What are the roles of forests on floodplains?

Forests on floodplains perform a range of functions. In ecological terms, generally they are beneficial because they increase biodiversity and are a natural feature of floodplain ecosystems. These aspects in relation to the restoration of floodplain forests are covered in detail in the output of the FLOBAR 2 Project (EVK1-CT-1999-00031) (Hughes et al., 2003). Economically they can provide a source of income through the production of timber. They can offer recreational and aesthetic value, but hydrologically their role is complicated. There are many questions regarding the impact of forests on flood hydrographs. Their high roughness coefficient promotes the retention of water, generally



Figure 53. The hydrological role of forests on floodplains is still uncertain
Photo: M. Haasnoot/WL Delft Hydraulics

Box 50. Estuarine Managed Realignment



Figure 54. Before – an estuarine floodplain protected from tidal flooding by embankments



Figure 55. Breaching – the construction of breaches in the embankment allows water to flood the site at high tide



Figure 56. After – two years after the re-instatement of tidal flooding saltmarsh species colonise the MR site

Photos: M. Blackwell /SWIMMER

lowering flood peaks downstream, but may cause increased flood peaks in the vicinity of the forest itself. Additionally the delivery of woody debris from forests to the river may cause blocking of bridges and culverts during floods, and create flooding in places it is not wanted. This is why in many cases local felling of floodplain forests takes place. In the past there has been a strategy to remove woody debris from rivers; ecological and water quality issues now have lead to a reversal of this view and woody material in streams generally is seen as beneficial.

There is a strong case for the positive role of floodplain forests in flood defence. However, they need to be strategically located where they can provide most benefit and not cause any unwanted flooding. In the Netherlands, the development of floodplain forests is discouraged largely because of their potential to promote local flooding. This attitude has resulted in the development of the concept of 'Cyclic Floodplain Rejuvenation', whereby the succession of forests is controlled by felling or grazing (Duel et al., 2001).

The precise effects forests have depend on the scale and size of floodplain, the type of vegetation, the geometry of the valley, position within the catchment and the morphodynamics of the river itself. It is generally considered that floodplain forests have to be relatively large if they are to have a significant effect on flood hydrology, but calculating the exact size and related impacts are modelling issues, and currently at the limits of modelling capability.

There has been some research into the effects of different vegetation on flood hydrographs. The nature of the vegetation is important because of the type of friction effects it has. Trees create more of a barrier than bushes because the latter flatten during high flows. Also, the smoothness of trunks, presence of branches lower down the trunk, branch density and tree size and age all effect the amount of friction and water retention, but are very hard to measure and further research is required in order to quantify the impacts all these factors.

In general, floodplain forests should be seen as being potentially useful in flood impedance. They are not barriers so their role is in the detention of water, not retention (detention refers to short-term storage of water, while retention refers to longer-term storage), and their impact on flood hydrographs is that peaks are lower but of longer duration. However, it is necessary to quantify their flood impedance effects, and there is a strong case for establishment of a demonstration floodplain forest site where this habitat has largely disappeared from the

landscape. Also, research is required into the different effects of varying spatial designs of floodplain forests. For example, narrow linear forests might be more acceptable to establish than large blocks of forest, but it is not known what their relative impacts will be.

What are the roles of wetlands in catchment hydrology?

Wetlands often comprise major parts of floodplains, and by some definitions, floodplains themselves are wetlands. The hydrological role of wetlands is widely accepted as being significant, either influencing floods, recharging groundwater or augmenting low flows. Consequently they comprise an important element of water management. However, different wetlands perform different functions to varying degrees. Indeed some wetlands can increase floods, prevent groundwater recharge and even reduce low flows. A review of the role of wetlands in the hydrological cycle by Bullock and Acreman (2003) clearly demonstrated that the role of wetlands is highly variable, and not always easy to discern. However, the vast majority of studies into floodplain wetlands reviewed in their paper concluded that these wetlands did reduce or delay floods. However, the roles of other wetlands on slopes and in the headwaters were not as conclusive, and more research is required into the hydrological functioning of wetlands, and perhaps more importantly, how their functioning can be best assessed.

What is the role of land management upstream of floodplain limits?

As mentioned above wetlands, and indeed all land outside a floodplain, can influence the hydrology of a catchment. The way in which these wetlands and other land is managed will significantly effect flood hydrographs. The development of best management practices for hydrological management concerning all land use types is an important requirement for flood control.

What is the role of floodplain management in estuarine/intertidal regions?

The practise of managed realignment (MR) is increasing as it is realised that natural saltmarshes and intertidal zones not only are ecologically important habitats, but also they act as natural flood defences, preventing wave damage and providing areas where water can be stored during high tides (Box 50). The hydrological consequences of realigning artificial flood defences varies depending on the characteristics of the estuaries in which they are found, and further research is required into how these areas can be optimised for their flood defence functions and how this can be best combined with conservation and restoration of estuarine intertidal zones. Fluvial (riverine) MR, involving the breaching of flood protection embankments along rivers, is not as widely practised or accepted as coastal and estuarine MR, and another challenge is promoting this management technique in riverine areas.

What about pollution swapping?

Many of the techniques described in this document provide numerous benefits in addition to that of natural flood defence. However, it must be acknowledged that in some circumstances, while practises may alleviate certain problems, they can actually generate different problems. For example, the removal of nitrate from surface waters by the process of denitrification is generally seen as a beneficial process with regard to water quality. However, under certain conditions the product of denitrification can be nitrous oxide which is a greenhouse gas, and therefore while solving one pollution problem another may be generated. Also, wetlands are one of the largest natural sources of methane, another greenhouse gas, and therefore consideration must be given to pollution swapping effects when implementing natural flood defence schemes.

While floodplain restoration may cause reductions in flood damage in some places, the costs of associated pollution problems generated potentially may exceed those of the damage that has been mitigated. However, more work is required into the various relationships involved in pollution and problem swapping in order that these factors are fully considered when evaluating natural flood defence schemes.

What is likely to happen in the future with regard to natural flood risk reduction measures?

The factor that is most likely to impact natural flood defence schemes in the future is global change. Predictions for changes in climate vary widely, but inevitably changing patterns of rainfall and sea level rise will impact the need for flood defences, and the ways in which flooding is managed.

In coastal and estuarine areas sea level rise will almost inevitably mean an increase in the amount of managed realignment of flood defences, and consequently anthropogenic activities in such areas are likely to decrease. In low-lying countries such as the Netherlands, where retreat is not often an option,

problems associated with sea level rise manifest themselves in a different way. Much of the Netherlands is effectively a large delta of the River Rhine, with vast quantities of water discharging to the North Sea everyday. While it is possible through engineering solutions to keep the sea out of the country, high sea levels make it difficult to discharge water flowing down the Rhine to the sea, and therefore there may be an increased need to temporarily store water from the Rhine in the Netherlands. This problem is exacerbated during periods of high discharge, and therefore the need for natural flood reduction measures and storage of water on floodplains is likely to increase.

Another problem that may develop with climate change is that upland peatlands are subject to degradation under both drier climatic conditions and increased concentrations of carbon dioxide in the atmosphere. Degradation of these ecosystems could pose many threats including the loss of major water storage systems, resulting in more rapid runoff and higher flood peaks in rivers draining these areas.

The future management of European floodplains will be determined by the particular balance reached among different sectors of civil society. The real challenge is not so much where the balance of different policies and interest groups actually is but more importantly what the mechanism is whereby society can reach agreement on its position. It is here that the Ecosystem Approach provides a methodological framework to assist in developing the processes which can lead to the most appropriate balance of natural floodplain dynamics against other social and economic priorities. The Ecosystem Approach is underpinned by twelve principles which, taken together, aim to ensure a sustainable and equitable balance of conservation, production and diverse sectoral interests in water, land and living resources (Maltby, 1999). The priority now is to develop the techniques to apply the approach in practice. The CBD is developing a 'source book' to help and which will go beyond the range of case study examples already reported by Smith and Maltby (2003).

Laffoley et al. (2004) recognised seven areas of 'coherence' under which priority actions could be defined to help in the practical implementation of the Ecosystem Approach: environmental, economic, social, spatial, temporal, scientific and institutional. Their report to the UK government is focussed on the marine and coastal environment. It is now necessary to examine these areas of coherence in the context of floodplain management. This should be geared to identify the necessary priority steps to better inform the decision-making processes leading to floodplain restoration where this provides the most appropriate solution to sustainable floodwater and natural resource management. The principles of the EA are fully congruent with the structure of the WFD and thus the further elaboration of the EA also will be of significant assistance in the practical implementation of the Directive itself.

In the future it is likely that the need and demand for natural flood defences will increase. Already the construction of housing and other developments is commonly forbidden or restricted on floodplains in recognition of the problems it can cause. If our rivers are to be managed in a sustainable way, it will be necessary to manage them in as natural a way as possible, and natural flood defence schemes, when managed and undertaken in the correct fashion, can form part of a holistic solution to the sustainable management of flood risk, nature conservation, water quality and economics.

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Case Studies

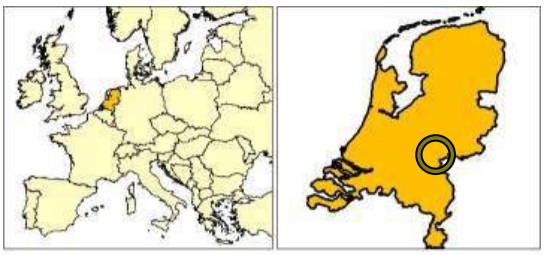
CASE STUDIES SUMMARY

Fourteen natural flood defence case studies from across Europe are presented, providing information on a broad range of circumstances and measures. Table 19 provides a summary of the types of measures implemented or proposed at each case study site.

Table 19. Summary of measures undertaken or proposed for each case study

	Stage of project: Proposed (P), Initiated (I), Completed (C)	Side channel excavation	Riverbed or bank reconstruction, main channel widening or dredging	Removal of weirs	Floodplain lowering, excavations	Lowering embankments, groynes	Wetland rehabilitation	Relocation of embankments	Landscaping works	Detention areas and small retention reservoirs
1) Meinerswijk, Rhine (The Netherlands)	C		x		x		x		x	
2) Zandmaas and Grensmaas, Meuse (The Netherlands)	I	x	x				x			x
3) Gamerensche Waard, Lower Rhine (The Netherlands)	C	x					x	x		
4) Afferdens-che en Deestsche Waarden, Lower Rhine (The Netherlands)	I	x			x		x			
5) Harbourne River (UK)	C		x					x	x	x
6) Skjern Á (Denmark)	C	x	x	x			x			
7) Brede (Denmark)	C	x	x	x	x					
8) Elbe River (Germany)	I	x	x					x		
9) Odra River (Poland)	P							x		
10) Łacha River (Poland)	C				x		x			x
11) Regelsbrunner Au, Danube (Austria)	C	x	x			x	x			
12) Upper Drava River (Austria)	C	x	x				x			
13) Tisza River (Hungary)	C						x			x
14) Sava River (Croatia)	C		x					x		x

1. Meinerswijk, Rhine
– The Netherlands



Type of case study and stage of implementation

This is a completed river restoration and flood alleviation project carried out in an urban location. It was initiated in 1990.

Project area

Meinerswijk is located opposite of the centre of the city of Arnhem on the southern bank of the River Rhine. In Arnhem the river is bounded by embankments creating a high flood risk. Meinerswijk is managed by the city of Arnhem and is known as a 'river foreland park' which was established in 1990 as a nature conservation area in de Gelderse Poort. Approximately 110 ha are used by the citizens of Arnhem for recreation, and a further 100 ha is grazed by herds of Konik horses and Galloway cattle.

In the Meinerswijk area, historical sand and clay mining has resulted in the creation of several small lakes, providing diverse morphology to the floodplain which supports high biodiversity. In particular the area is popular with wintering birds.



Figure 57. A nature conservation area providing room for flood retention in Meinerswijk
Photo: E. Penning/WL Delft Hydraulics

Major goals of the project

The main goal of this project was to make the river foreland park freely accessible to the public. Simultaneously, the area has to act as a flood polder, providing protection for the city of Arnhem. Also, the industrial heritage (historical sand and gravel mines) as well as a number of archaeological sites had to be protected. Another aim was to improve biodiversity.

Organisational background

The project was initiated by the city of Arnhem, based on the ideas in the 'Stork' plan (Plan Ooievaar) which called for restoration of the Dutch floodplains to improve their natural functioning and provide habitat for valuable species such as the Black Stork. A plan that could be carried out relatively easily was elaborated and approved by the city of Arnhem in February 1991. Originally, a foundation called 'Stichting Ark' was responsible for the management of the area, including grazing by Galloway cattle and Konik horses. The city took over the ownership and management after 1998. WWF adopted the river foreland park and have supported its maintenance and educational facilities. The restoration activities have been undertaken in cooperation with sand and clay miners, making the restoration economically viable.

Funding sources

The project was funded by the following organisations: the City of Arnhem, WWF, the Province of Gelderland, the Ministry of Agriculture, Nature Conservation and Fisheries, the Ministry of Housing, Spatial planning and Hygiene, National Water Management Authorities and the Provincial Electricity Company.

Measures

- Purchase of land.
- Restoration of degraded, post-industrial sites (removal of a dumping site, asphalt roads and old factory buildings).
- Restoration of natural river banks.
- Additional clay and sand excavation in some areas to create refuge islands for birds and improve water quality in lakes in the area (through increased upward seepage of groundwater).
- Vegetation management by Konik horses and Galloway cattle.

Effects

- **Flood risk alleviation**

  Extra room was created for the river in a flood alleviation site near the bottleneck of Arnhem, though the effects have not been documented.

- **Ecology and biodiversity**

  No documentation of the ecological effects is available. According to the project managers, the ecological functioning and biodiversity of all groups of flora and fauna have improved and the landscape diversity has been enhanced through grazing by horses and cattle.

- **Socio-economic aspects**

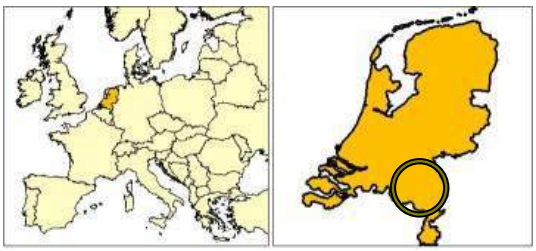
  The excavated clay and sand was sold making the activity economically viable. The area serves as a recreational area and is used for environmental education. People and animals roam the area freely and the historic sand and gravel mining areas are protected. In the park numerous communication and field education projects are carried out involving the public and primary schools in the city; facilities include excursion programmes, video clips and a field education tool kit.

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2. Zandmaas and Grensmaas, Meuse

– The Netherlands



Type of case study and stage of implementation

This is a long-term flood protection project for urban areas in the south of The Netherlands. It comprises two sub-projects: Zandmaas and Grensmaas, both initiatated in 1995 and expected to be completed in 2022.

Project area

The projects are being carried out along the southern stretch of the River Meuse between the town of Borgharen and the city of Den Bosch in The Netherlands. No flood protection embankments are present along this part of the river. In 1993 and 1995 the urban areas along this stretch were flooded causing damage to goods and houses and leaving the inhabitants of the area feeling insecure. These flood events triggered the Zandmaas and Grensmaas projects.

Major goals of the project

The main objective of the project is protection against flooding of the urban areas along the Southern Meuse, in combination with gravel mining and restoration of the river channel and floodplain. It aims to reduce flood events in urban areas to a frequency of once every 250 years.

Organisational background

The project was initiated by the Dutch Ministry of Transport and Waterworks and it is being carried out in close collaboration with the Ministry of Transport and Waterworks, the Ministry of Agriculture, Nature and Food Safety and the Provincial Government of Limburg.

In the Zandmaas project an extensive study phase has been completed, during which various flood reduction strategies have been modelled. This was followed by an environmental assessment and a planning phase in which detailed plans have been developed. Throughout the planning phase close involvement of gravel miners was important, as they will carry out the work in the implementation phase. During the project, a lot of attention has been paid to involvement of local governments (town councils and provincial government), regional waterboards and nature protection organisations.

Communication with the inhabitants and local stakeholders (*e.g.* farmers) was also a major feature. The main objections to the Zandmaas and Grensmaas plans came from local communities in areas where agricultural land was to be converted into floodwater retention areas. The mining of gravel was also a contentious subject. Finally, following discussions and adjustment of the plans, the stakeholders generally agreed to the proposals.

Funding sources

The main financial resources have been provided by the Ministry of Transport and Waterworks. Additionally parts of the project will be financed by the income generated from clay and gravel mining. The mining activities are to be carried out by commercial mining companies that have acquired concessions for these activities.

Measures

- Land purchase (Dutch legislation provides the government with the option of compulsory land purchase from private owners in large planning projects; land purchase for wildlife conservation purposes is voluntary).
- Construction of embankments near urban areas.
- Widening and dredging of the river channel to enlarge discharge capacity.
- Construction of a high-water retention area to store water during peak discharge.
- Reconnection and (re)construction of side channels to help reduce peak discharges.

- Lowering of the river floodplain bordering the side channels to enlarge the floodplain storage capacity.
- Transformation of agricultural grassland to floodplain meadows. Land will be bought from farmers and an extensive grazing regime will be introduced.

Effects

- **Flood risk alleviation**

  Increased protection for urban areas against flooding will be provided. The intention is to reduce flooding to once every 250 years.

- **Ecology and biodiversity**

  The project should result in an increase in biodiversity of the floodplain and the river channel, as well as improved migration opportunities for fish. It will also contribute to the creation of an ecological stepping-stones network. However, the mining works carried out in the Zandmaas project have resulted in some pollution of the river and floodplain sediment.

- **Socio-economic aspects**

  Considerable income has been generated from the gravel mining, which is estimated will satisfy the national gravel requirements for several years. The restored floodplain areas are being used as recreational areas, nature conservation areas and for environmental education. The restored river channel provides improved opportunities for fishing and boating.

Other

In accordance with the Zandmaas project, plans were developed and are being implemented to improve the navigability of this stretch of the River Meuse.

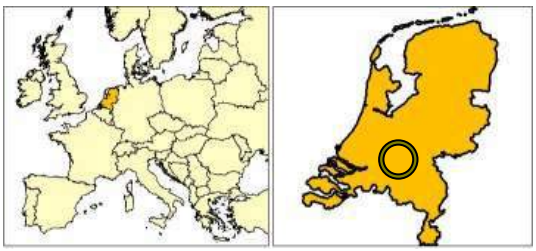
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Ruimte voor de Rivier. http://www.ruimtevoorderivier.nl

3. Gamerensche Waard, Lower Rhine - Waal - The Netherlands



Type of case study and stage of implementation

This is a completed project involving enlargement of the area of active floodplain. A plan was initiated in 1993 to widen the originally narrow floodplain known as the Gamerensche Waard along the Lower Rhine, and to combine this with the construction of three artificial secondary channels. A detailed plan was produced in 1995 and between then and 1999 the floodplain was reconstructed. Close monitoring of both abiotic and biotic effects of the measures undertaken has enabled comprehensive evaluation of this project.

Project area

The Gamerensche Waard floodplain is located on the southern bank of the River Waal, a branch of the Lower Rhine. The floodplain has a surface area of approximately 200 ha, and now includes three newly constructed secondary channels. At this site, the river is characterised by a very low slope at periods of low river discharge (4 cm km^{-1} at a discharge of 1000 m^3 s^{-1}) and an absence of very low water levels. These features are a consequence of its proximity to the sea. Extensive deposition of sand occurs in the floodplain during high floods.

Major goals of the project

The main objectives of the project were to enhance flood safety by widening the floodplain and increasing the maximum flow capacity through secondary channels, while at the same time restoring slow-flowing and shallow water habitats crucial for a wide range of typical lowland river organisms.

Organisational background

The project was initiated by the Ministry of Water Management, Transport and Public Works of The Netherlands. The local waterboard was involved in the planning process and development of the vision document, while a consulting engineering company was contracted to design the morphology of the floodplain. The area is managed by the State Forest Service.

Funding sources

The project was funded by the Dutch government, as part of the so-called 'Delta-plan Large Rivers' scheme, introduced to reduce flood risk in response to high peak discharges in 1993 and 1995.

Measures

- Small-scale widening of the floodplain by relocation of part of the winter embankment, allowing higher flow capacity and increasing the total area of floodplain.
- The construction of three secondary channels, further enhancing the flow capacity of the river as well as providing shallow, undisturbed but slowly flowing river water as a habitat for specific reophilic (i.e. requiring flawing water) organisms.
- The introduction of seasonal, low intensity grazing by young cattle and Shetland ponies in order to prevent the development of dense riverine woodland, which because of its high hydraulic roughness might limit local flood protection benefits.

Effects

- **Flood risk alleviation**

  The monitoring period (1996-2002) was characterised by relatively high river discharges, as a result of which the secondary channels flowed more frequently than expected. At median flow the combined discharge through the three secondary channels is approximately 2% of the total discharge. The re-designed floodplain has caused a lowering of peak flood water levels by approximately 3 cm. Sedimentation has occurred in the main channel parallel to the Gamerensche Waard. No large morphological changes have taken place in the secon-

dary channels and the erosion and sedimentation rates in the three years following construction were greater than in subsequent years. A former sand extraction pit is expected to fill up with sediment by 2050 (net sedimentation rate is 0.05 m to 0.11 m yr^{-1}). Neither the sedimentation of the channels, nor the vegetation succession have led to a significant lowering of the flow capacity during peak flood periods, so the flood defence gain has been proven to be sustainable.

- **Ecology and biodiversity**

  The establishment of trees and bushes has been restricted by dense grass cover and large water level fluctuations. Hardly any target plant species have been found in or near the secondary channels. In the largest of the secondary channels some small areas containing aquatic vegetation were found in 2002 (*Myriophyllum spicatum* and *Potamogeton pectinatus*). Out of 46 aquatic invertebrate target species only three were found in the secondary channels. This low number can perhaps be attributed to the absence of specific substrate types (e.g. gravel, dead wood, etc.). However, fish species richness is higher in the secondary channels than in the main channel, with various fish species with a preference for flowing water being found, including five target species (*Barbus barbus*, *Leuciscus cephalus*, *Chondrostoma nasus*, *Leuciscus idus* and *Lampetra fluviatilis*), for which the secondary channels function as nursery grounds during their early stages of life.

- **Socio-economic aspects**

  Despite the fact that neither local inhabitants nor other stakeholders have been actively involved in the planning or designing process of this project, a questionnaire on nature and landscape appreciation among people living and working in the river district revealed that the development at Gamerensche Waard generally was highly valued.

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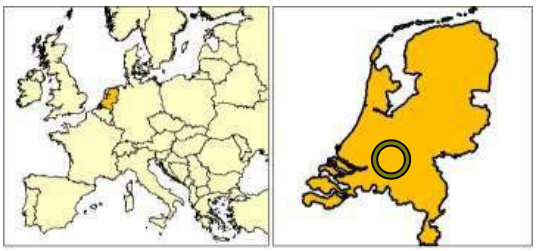
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4. Afferdens-che en Deestsche Waarden, Lower Rhine, Waal – The Netherlands



Type of case study and stage of implementation

This is a floodplain restoration project that is in the process of implementation. The project was initiated in 1993 and its first stage was completed in 1996. The intended completion date is unknown.

Project area

The project is located on the southern bank of the River Waal, a branch of the River Rhine, in 336.5 ha of floodplain called Afferdensche en Deestsche Waarden, a highly diverse landscape, between the towns of Nijmegen and Tiel. A relatively open landscape occupies an area of over 110 ha, with woodland and scrub occupying approximately 30 ha and both pioneer and tall herb vegetation are present. The rest of the area was used by a brick factory and for farming (corn fields) before the project commenced.

Major goals of the project

The objectives of the project are to lower flood risk by enhancement of peak flow capacity of the river, and to increase wildlife value, so creating an attractive and diverse landscape on the Afferdensche en Deestsche Waarden floodplain. Its goal is also to provide a practical example of how floodplain lowering can make these projects economically viable through the extraction of clay for commercial use.

Organisational background

The project was initiated by the municipality of Druten and is being implemented by the regional directorate 'East' of the Dutch Ministry for Water Management, Transport and Public Works in cooperation with the Institute for Inland Water Management and Waste Water Treatment, RIZA, representatives of the Ministry for Agriculture, Nature Management and Food Quality, the State Forestry Service, the Province of Gelderland, the Polder District 'Groot Maas en Waal' and the consulting engineers of Grontmij, who are responsible for coordinating the project.

Funding sources

The project has been funded by a combination of revenue generated by clay extraction and support by the Dutch Ministry for Water Management, Transport and Public Works with some additional funding from the company extracting clay.





Figure 58. Project area during restoration (above) and after restoration (below)
Photos: T. Vulink/RIZA and A. Remmelzwaal/RIZA

Measures

- Extraction of surface layers of clay resulting in the lowering of the floodplain surface (the first project stage, completed in 1996), enhancing peak flow capacity of the river, stimulating the development of shallow, un-

connected water bodies and development of riverine vegetation and associated fauna.

- Introduction of a year-round grazing regime by cattle and horses in order to prevent vegetation succession to riverine woodland (implemented).
- Lowering of the remaining floodplain (intended works).
- Secondary channel construction (intended works).

Effects

- **Flood risk alleviation**

  The combination of lowering the floodplain and the construction of a secondary channel should result in the reduction of flood peak levels by several centimetres.

- **Ecology and biodiversity**

  A vegetation survey in 1998 showed that on the lowered areas a variety of different landscape types have developed. The amount of shallow and non-connected water bodies and highly dynamic pioneer vegetation communities has increased. Many species characteristic of dynamic floodplain conditions have returned and overall biodiversity has increased. A further increase in biodiversity could occur as a consequence of the construction of a secondary river channel and lowering of the remaining floodplain. Introduction of a year-round grazing regime by cattle and horses favours natural habitat diversity.

  Floodplain lowering has also resulted in an increasing number of breeding bird species especially in the lowered areas. This is partly the result of the establishment of a colony of Sand Martins (*Riparia riparia*), which found a suitable habitat on some steep slopes. Also water birds such as Coot (*Fulica atra*), Greylag Goose (*Anser anser*), Avocet (*Recurvirostra avosetta*) and Little Ringed Plover (*Charadrius dubius*) have become abundant in the lowered areas.

- **Socio-economic aspects**

  The restoration works were funded largely by income generated from the commercial extraction of clay within the project area.

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5. Harbourne River
– United Kingdom



Type of case study and stage of implementation

This is a completed flood prevention scheme on a small river incorporating a combination of conventional (damming) and ecological (wetland creation) measures. The project was implemented between 1999 and 2002.

Project area

The River Harbourne is located in the southwest of England and has a catchment area of 38 km^2. The river is a dynamic, meandering watercourse with a gravel bed. The project is located around Harbertonford, a village that historically has been flooded on average once every three years, and on six occasions between 1998 and 2000. The development of the village around the river has resulted in there being no significant floodplain that can be reconnected, and also restricts any potential channel enlargement.





Figure 59. Small dam (above) supporting a shallow created wetland (below) that serves a water retention area
Photos: Warren Bradley/Halcrow

Major goals of the project

The major goal of the project was to construct a flood defence scheme for the village of Harbertonford. It was intended to provide a combination of flood defence measures that are inherently capable of providing environmental enhancement. The scheme had to be sustainable both in terms of use of natural resources, but also to have minimal maintenance with regard to actions such as dredging.

Organisational background

Creation of this flood defence scheme was initiated and approved by the Environment Agency for England and Wales and the Department for Environment, Food and Rural Affairs (Defra). Considerable help in kind was provided by Devon County Council. Design of the scheme was by Halcrow Group Ltd of Exeter and construction by E. Thomas Civil Engineering of Truro, part of Mowlem Civil Engineering. Mowlem also participated in raising safety awareness at the school, and posters prepared by the pupils were used to reinforce the safety message whilst works were in progress in the village.

Funding sources

The £2.6 million scheme was funded by the Environment Agency for England and Wales, the Department for Environment, Food and Rural Affairs (Defra), South Hams District Council and Harbertonford Parish Council.

Measures

- Improving drainage in the urban section of the riverbed, replacing earthbanks with stone walls and doubling the width of the river channel.
- A gravel shoal (lower part of the bank), colonised with wetland plants, was created

as part of a two-stage channel; the central part of the channel maintains flowing water during low flows, whilst the shoal is submerged during floods.

- Removal of an existing boulder stone weir and lowering the bed of the channel by 600 mm to increase flow capacity. The river channel was un-natural, having been widened for milling in the past. This caused the river to silt-up and required frequent drainage.
- Creation of 'riffle/pool' sequences through the village was constructed on advice from the River Restoration Centre, Silsoe, Bedford.
- Establishment of a flood storage area, measuring 4.1 ha, one kilometre upstream of the village, using a clay core earth dam to retain the water in times of flood. Material for the construction of the dam was excavated within the project area. This helped to reduce costs and keep transport of materials to a minimum. This area has become a wildlife refuge, replacing a grass field.
- Landscaping works and planting on the village green has increased accessibility to the river.

Effects

- **Flood risk alleviation**

  The dam has been designed to allow a once in 10-year flood event to flow through the opening in the dam, whilst retaining larger floods up to a once in 40-year event. The dam can hold 150,000 m^3 of water in a 4 ha storage area and is designed to overtop in a safe and controlled manner above the once in 40-year flood event. The downstream slope is grassed in order that overtopping floodwater is not impeded.

- **Ecology and biodiversity**

  The fields purchased to create the flood storage area were used for the temporary construction site compound and subsequently restored to comprise part of the nature reserve. The hollows from which clay was removed have been colonised by a variety of wetland plant and animal species. The opening through the dam has been engineered to allow the movement of migrating salmon and trout. The downstream face of the dam slopes gently and the whole structure has been carefully orientated and contoured to fit in with the surrounding landscape. The dam is located near the narrowest point in the steep river valley and designed to link existing woodlands on either side of the valley. Children from Harbertonford Primary School are monitoring the colonisation of wildlife in this area as part of their nature studies.

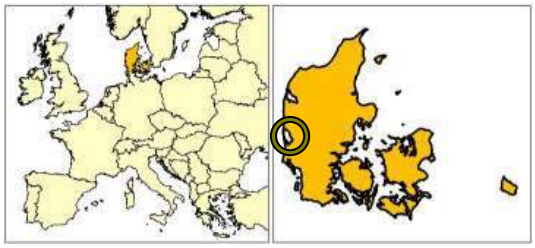
- **Socio-economic aspects**

  An awareness campaign about flood safety issues was carried out in the local school, and posters prepared by the pupils were used to reinforce the safety message whilst works were in progress in the village. The primary school children planted wildflowers within the project area, which will help to give them a sense of ownership of the project.

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6. Skjern Å
– Denmark



Type of case study and stage of implementation

This is a completed, large-scale restoration project. In 1987, the Danish Parliament decided to initiate studies into restoration possibilities. Subsequently river restoration has proceeded as follows: 1987 to 1999 – investigation and planning period; 1991 to 2000 – land purchasing and distribution period; 1999 to 2002 – construction period (implementation of the project). Flood risk was not a focal issue of the project but it has many implications for designing natural flood defences.





Figure 60. Skjern Å during (above) and after (below) restoration in 2000
Photo: J.W. Luftfoto

Project area

The River Skjern Å has the greatest discharge of all Danish rivers, having a catchment area of 2,500 km^2 and a length of 95 km. It discharges into the Rinkøbing Fjord, a shallow 300 km^2 coastal lagoon, which is connected to the North Sea by a floodgate. A large part of the river valley was straightened and drained around 1900. In the 1960s, approximately 4,000 ha of meadow and swamp were transformed into arable land, drained by pumping stations and the meandering and free-flowing streams were replaced by embanked rivers and canals. The nature restoration project affects the lowest 20 km of the Skjern Å as well as some of its tributaries, the Omme Å and Gundesbøl Å. The area covered by the project totals 2,200 ha.

Major goals of the project

The purpose of the nature restoration project was to restore a large, continuous natural floodplain area and improve conditions for wild plants and animals. Another objective was to restore the self-purifying effect of the river valley and with that improve the quality of water in Ringkøbing Fjord. Flood risk was of less significance.

Organisational background

The project was implemented on behalf of The Danish Government by The Danish Nature and Forest Agency. The Agency published a detailed proposal for nature re-establishment in 1997. The Danish Parliament passed it in 1998 (Construction Act for the project). Construction works were carried out by civil engineering companies.

Measures

- Excavation of a new river course including re-establishment of old meanders. The length of the Skjern Å in the project area in-

creased from 19.0 km to 25.9 km, while the Omme Å increased from 2.8 km to 4.8 km.

- Removal of old embankments and pumping stations (re-establishment of the contact between the river and riparian areas).
- Re-establishment of a delta at Ringkøbing Fjord (realigning the river through several channels to the Fjord).
- Filling-in of old drainage canals and re-creation of natural wetlands in the Skjern Å valley.
- Creation of a 160 ha lake.
- Transfer of 1,550 ha of arable land to extensive grazing.

Effects

- **Flood risk alleviation**

  Flooding was not regarded as a major problem for settlements in the area. However, it is estimated that the safety of approximately thirty houses located within the project area has improved due to flood mitigation. Agricultural land was bought from farmers to eliminate concerns over flooding.

- **Ecology and biodiversity**

  The restoration project has created a mosaic of ponds, meadows, reedbeds, meandering watercourses and an open river valley landscape with associated marshlands. This large area of undisturbed wetlands provides suitable habitat for numerous species of birds and animals. The area has become one of Denmark's best bird habitats. The Bittern (*Botaurus stellaris*), Black Tern (*Chlidonias niger*) and Corncrake (*Crex crex*) are expected to increase in numbers along with Otters (*Lutra lutra*). The project has created a wetland area with good spawning grounds and nurseries for fish such as the Atlantic Salmon (*Salmo salar*), which was close to extinction in this area before the restoration was initiated. Small increases in its rates of spawning have already been observed, as have increases in the number of Lavaret (*Coregonus laveretus*).

- **Socio-economic aspects**

  Almost 2000 ha of the 2200 ha that make up the restoration area are owned by the Danish State. The land has been bought over a period of 11 years through voluntary negotiations with approximately 350 farmers. The land has been acquired through purchase or land exchange. In the remaining areas of the project voluntary agreements have been made regarding management and public access in return for compensation.

  Early in the project many local inhabitants opposed the plans largely over fears of inadequate compensation. Today the general opinion is that the farmers involved have benefited from the project. Primarily this is due to the Danish State providing farmers with exchange land in compensation for the land they had in the Skjern Å floodplain, in addition to the State purchasing land in the floodplain area. The land received in compensation was almost always located closer to a farmer's property than the land they owned in the project area.

- **Other**

  Improved water quality and the re-establishment of spawning grounds will have a positive effect on salmon and trout populations in the river system. The Skjern River discharges into the Rinkøbing Fjord, which is highly eutrophic. Raising the groundwater level in the Skjern Å valley has reduced the leaching of ochre. The project will significantly reduce nutrient emissions to the Fjord due to the retention of nitrogen and phosphorus in the wetlands in the river valley. The project will increase the opportunities for outdoor recreation such as hiking, cycling, boating, camping, the study of flora and fauna, angling and hunting.

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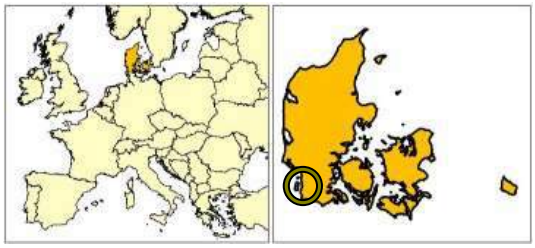
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7. Brede

– Denmark



Type of case study and stage of implementation

This is a completed large-scale project involving re-meandering and wetland restoration, implemented partly as a demonstration project. The River Brede was re-meandered during six phases of construction works between 1991 and 1998.

Project area

The River Brede has a catchment of 473 km^2, comprising more than 1,000 km of open watercourses, channels and ditches. It originates southeast of Toftlund, flows south to Løgumkloster from where it flows west to Bredebro and into the Wadden Sea. At its mouth the mean flow is 6 $m^3 s^{-1}$. In its upper reaches the land use is mainly agriculture. In the 1950s the main reaches of the River Brede were straightened and riverside meadows drained to promote agricultural production. The streambeds were lowered to increase the storage capacity of the channel and to lower the watertable in riparian fields. To prevent the river meandering weirs were installed. Many valuable wetland ecosystems and flood retention areas were lost. Initially, following drainage, intensive arable agriculture was developed on the floodplains. However, rapid degradation of soils occurred (mainly peat decomposition) and resulted in reduced agricultural productivity. Land drainage caused pyrite oxidation and mobilisation, resulting in pollution of the river and shallow areas of the Wadden Sea. Subsequently restoration work has been carried out along the whole of the Brede Valley.



Figure 61. River Brede before (above) and after (below) restoration
Photos: J.W. Luftfoto

Major goals of the project

The objectives of the project were to increase landscape and wildlife values, improve environmental conditions, restore connectivity between the floodplain and the river and improve the quality of spawning grounds.

Organisational background

The project was prepared and implemented by the County Council of Southern Jutland, with the voluntary support of landowners who had direct input during the planning phase. A 5 km reach of the river was re-meandered as part of an EU-LIFE project, and over 15 km of the Brede was restored as part of a nationwide strategy to improve the environmental management of rivers in Denmark. The EU-LIFE project involved two river restoration projects in the United Kingdom, on the rivers Skerne and Cole. All three sites were promoted under the EU-LIFE umbrella as a demonstration project entitled River Restoration: Benefits for Integral Catchment Management. Here, only the Danish part is described.

Funding sources

The project was jointly funded by several organisations, namely the EU-LIFE project (LIFE 93:DK:A25: INT:2504), the Danish National Environmental Research Institute, the County

Council of Southern Jutland, the Danish Environmental Protection Agency, the municipalities of Løgumcloster and Nørre Rangstrup and the Bioconsult company.

Measures

- Re-meandering of the whole river system (in six phases between 1991 and 1998). A total of 19 km of straightened river channel has been converted into 25 km of meandering river.
- Removal of weirs from the streambed.
- Restoration of the natural sequence of pools and riffles.
- Construction of spawning sites.
- Some fragments of the original channel have been left as bays and ox-bow lakes.
- Sections of the old and new river channel have been allowed to cross each other in many places to facilitate colonisation by flora and fauna.
- Elevation of the streambed by 0.5 m to 1.0 m.
- Construction of lakes in tributaries of the river.
- Widening (by 2 m) and deepening (by 1 m) of the river downstream of each re-meandered reach to promote sediment deposition.

Effects

- **Flood risk alleviation**

  Re-meandering the river contributed towards the re-establishment of natural flooding events in the valley. The project is a good example of how promotion of flooding in one place can help prevent flooding downstream. However, as there are no settlements in the area, locally flooding has never been a problem.

- **Ecology and biodiversity**

  Recolonisation by flora and fauna was rapid. In particular, increases in the number and species diversity of fish, invertebrates and nesting birds have occurred.

- **Socio-economic aspects**

  Landowners participated voluntarily in the scheme and received compensation for any loss of production capacity. The unique aspect of this project is the exchange of land between farmers, which has enabled this large scale restoration. Landowners have retained ownership of land even where lakes are now present on their property, and riparian areas have been redistributed among landowners. The County of Southern Jutland has played an important role as a 'land bank' in this respect. The area has been designated as an Environmentally Sensitive Area (ESA), meaning additional EU subsidies can be granted to farmers for some agri-environmental services, such as maintenance of grazing meadows without the use of fertilisers and pesticides.

- **Other**

  During flood events, the floodplain and lakes are effective traps for sediment. The regular inundation of meadows has prevented the oxidation of iron compounds while nitrate removal in riparian areas has increased. Other projects in and around the River Brede are being developed.

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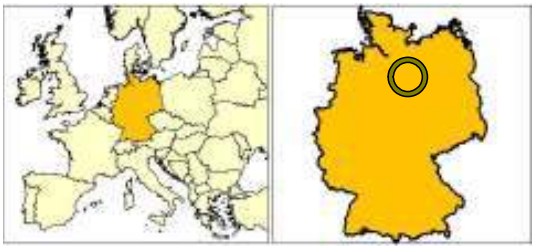
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8. Lödderitzer Forst - Middle Elbe

– Germany



Type of case study and stage of implementation

The restoration of floodwater retention areas along the floodplain of the River Elbe is part of a large-scale flood risk policy by the riverine Federal States in the Elbe Valley, supported by the German Federal Government. There are several projects at various stages of implementation, ranging from the early stages of planning to the near completion of engineering works. Here the largest floodplain forest restoration project involving the realignment of flood embankments in the Middle Elbe floodplain near Löderitzer Forst is presented. The project is being implemented between 2001 and 2010.



Figure 62. An oxbow lake surrounded by hardwood forest
Photo: Mathias Scholz/UFZ



Figure 63. The River Elbe near Dessau
Photo: Mathias Scholz/UFZ

Project area

The Elbe is one of the largest rivers in Central Europe with a length of 1,165 km. Its source is in the Czech Republic from where it flows north into the North Sea near Cuxhaven. The catchment is approximately 150,000 km^2, two-thirds of which is located in Germany, the remainder being in the Czech Republic.

The Middle Elbe floodplain is characterised by typical floodplain habitats, e.g. riverine meadows, hardwood forests and oxbow lakes. The whole area is part of the 'Riverine Landscape Middle Elbe' UNESCO Biosphere Reserve.

Since the 12th century increasing amounts of the floodplain have been isolated from the river by the construction of flood embankments, such that today more than 76% of the original floodplain area (~ 617,000 ha) is protected from flooding. Additionally, much of the original forest in the unprotected floodplain has been felled.

Major goals of the project

A national conservation and rehabilitation project has been established with the aim of protecting existing important habitats and improving degraded habitats in the Elbe floodplain between the confluences of the River Mulde and Saale. The main objective of the project is to protect and to restore the alluvial forests and the typical species and habitats associated with them.

Organisational background

In the early 1990's various floodplain restoration initiatives were implemented including the 'Action Plan Flood Control Elbe' which was updated and approved by the ICPE (International Commission for the Protection of the River Elbe) in October 2003. The UNESCO-Biosphere Reserves Flusslandschaft Elbe, which comprises most of the Lower Elbe and its floodplain, provides the framework within which restoration projects are organised, and the project is managed by WWF Germany.

Funding sources

The project is funded by the German Federal Agency for Nature Conservation.

Measures

- Acquisition of land (ca. 1000 ha) to avoid conflicts in management of valuable habitats.
- Re-establishment of natural hardwood floodplain forest.
- Reconnection of flood channels.
- Rehabilitation of former floodplain forest by realignment of flood embankments.

Effects

- **Flood risk alleviation**

  Natural hydrology will be re-established on approximately 600 ha of former natural floodplain, enabling it to act as a floodwater storage area.

- **Ecology and biodiversity**

  The restoration project will re-establish a range of floodplain habitats including alluvial hardwood forest and reconnect former river channels and oxbow lakes with the hydrology of the main river. The project will increase the amount of habitat for numerous species of plants and animals including endangered species such as the beaver.

- **Socio-economic aspects**

  Almost all of the project area is in public ownership. Some problems may arise as a result of increased water table heights in arable land adjacent to the project areas. However, the newly aligned flood defences should offer an increased level of protection from flooding to houses adjacent to the restoration site.

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9. Odra River

– Poland



Type of case study and stage of implementation

This project is still in the proposal stage. It has been proposed by an NGO (WWF Poland) and currently is being negotiated with administrative officials. Its implementation will depend upon stakeholder commitment and decisions at the national level.



Figure 64. The Odra Valley near Tarhalice
Photo: J. Moczulski/WWF Poland



Figure 65. Floodplain forest on the Odra during a flood
Photo: G. Bobrowicz/WWF Poland

Project area

The Odra River Valley is one of the most important ecological corridors in Europe. Most of the river has been regulated but it still has many important floodplain forest and meadow ecosystems along its course. The most important areas are the floodplain forests; their size and quality makes them some of the best examples of floodplain forest ecosystems in Europe. The River Odra is 854 km long and its catchment is over 118,000 km^2 with almost all of it (90%) located in Poland. The Odra became infamous following a disastrous flood in 1997 when the existing flood control system failed, many kilometres of embankments were destroyed and many villages and towns were flooded, some of them for several weeks.

Major goals of the project

The main aim of the project is to decrease flood risk by preserving and restoring floodplain habitats and their biodiversity.

Organisational background

The project has been initiated by WWF-Poland and implemented in co-operation with the 'Green Action Fund' (a local NGO), state bodies and NGOs. The proposed solution (embankment replacement) represents an alternative approach to the conventional flood control plans (i.e. water reservoir construction) currently being considered by the national authorities.

Proposed measures

It is proposed to move the existing embankments away from the river, allowing floodwaters to inundate floodplain areas. On the 670 ha floodplain located between the villages of Tarchalice and Domaszków the current forest

management system will be adjusted to the requirements of the flooding regime. These activities will serve as a model solution for other similar river valleys.

- **Anticipated effects of embankment replacement**

  The project in Tarchalice will create a natural floodwater retention area of 670 ha. The topography of the area allows it to be naturally flooded and drained without technical modifications. The new embankment will be lower than the existing one because it will be built on the river terrace, which will reduce further the risk of flooding. More detailed hydrological predictions are in preparation.

- **Ecology and biodiversity**

  Despite the fact that large areas of floodplain in the Odra River Valley are not hydrologically connected to the river, they still support riparian forests, semi-natural meadows and oxbows. Re-connecting floodplains to the river will prevent further degradation of wetland habitats and the loss of biodiversity. The section of the Odra River Valley described here is a proposed Natura 2000 site and is well known for its large and species-rich riparian forests.

- **Socio-economic aspects**

  Most of the land proposed for floodplain restoration is state-owned and managed by the Regional Directorate of State Forest. Potential conflicts with water and forest management bodies as well as maintenance of existing infrastructure (eg. forest nurseries) are among the main obstacles to implementation of the scheme. The social benefits of the project are related to local community involvement in the decision-making process, a change of peak flows and an increase in awareness of the natural values of the Odra River floodplains. Anticipated economic benefits include providing a good basis for tourism and educational activities, whilst maintaining forestry production under the new conditions and reducing costs associated with flooding downstream. Most of the excavation work will be carried out by local entrepreneurs and farmers, providing a source of income to local communities.

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10. Łacha River
– Poland



Type of case study and stage of implementation

This is a completed project involving the restoration of a small river and associated wetlands. The project was initiated in 1999 and completed in 2002.

Project area

The Łacha River is a small tributary of the River Barycz (itself a tributary of the Odra River, Dolnośląskie Voivodship), and has been approved as a Natura 2000 site (PLH 020003 'Dolina Łachy'). River regulation works carried out since the early 20th century resulted in straightening and deepening of the river and the conversion of wet meadows into drained agricultural fields. In many places flood protection embankments were built using soil excavated from the riverbed. The river canalisation resulted in an increased flood hazard in the lower reaches. Usually the water level in the river is very low with a shortage of water during dry periods. However, after heavy rainfall water levels increase rapidly and adjacent fields supporting cereals, sugar beets and potatoes are regularly flooded. Also the small village of Czaplewo, situated in the lower reaches of the river, has been increasingly threatened by floods.





Figure 66. Polder site during (above) and after (below) restoration
Photos: R. Guziak/proNatura and K. Konieczny/proNatura

The restoration project was implemented as a pilot project of a larger initiative known as 'Sustainable Development of the Barycz River Valley'. The works focussed on two areas: Polder (68 ha) and Ruskie Łąki (30 ha).

Major goals of the project

The main objectives of the project were to increase the floodwater retention capacity in the Łacha Valley (reduction of flood hazard) and the ecological restoration of wetland habitats and plant communities of wet meadows. The objective of demonstrating opportunities to combine nature conservation and flood protection was also important. In addition, the project had to provide economic stimulation in the region.

Organisational background

The project was carried out by the Polish Society of Wildlife Friends 'proNatura'. In 2001 the organisation owned approximately 190 ha of meadows in the Łacha Valley, and managed approximately 10 ha of privately owned meadows. The establishment of a biomass-based heating installation was carried out in close cooperation with the Lower Silesian Foundation for Sustainable Development (Dolnośląska Fundacja Ekorozwoju) and the Borough of Wińsko.

Funding sources

Land purchase was subsidised by the DOEN Foundation (The Netherlands), the Colin Reid Countryside Trust (UK), BUND Bodenseekreis (Germany), the Rufford Grant of Whitley Awards Foundation (UK), the Ciconia Foundation (Liechtenstein), the Global Nature Fund (international), and numerous others from Poland and abroad. The nature and technical consultancy studies and groundworks were sponsored by the EcoFund Foundation (Poland). Project supervision and co-ordination was financed by the EcoFund Foundation (Poland) and the Whitley Awards Foundation (UK), while the biomass heating installation was funded by the National Fund for Environmental Protection and Water Management (NFOŚiGW), the Regional Fund for Environmental Protection and Water Management in Wrocław (WFOŚiGW) and the Borough of Wińsko.

Measures

- Land purchase from the Agricultural Property Agency and private owners.
- Creation of a series of small retention reservoirs.
- Some nutrient rich soil layers were removed. In these locations, deposits of sand, gravel and even meadow ore were uncovered.
- The excavated soil was used to construct mounds on the floodplain for refuge areas during floods.
- The meadows are cut for hay and limited grazing is permitted.
- A biomass energy heating facility was established in a nearby school (for utilisation of biomass removed from the meadows).

Effects

- **Flood risk alleviation**

  The risk of flooding to crops and a few farm buildings located close to the river was decreased. Following pond construction and meadow restoration the floodwater retention capacity of Polder and Ruskie Łąki increased. The increase in floodwater retention capacities of Polder and Ruskie Łąki were estimated as 102,000 m^3 and 43 000 m^3 respectively. During a spring flood in 2001 the polder stored even more water and significantly reduced the flood peak.

- **Ecology and biodiversity**

  Following the restoration, new species of vegetation were recorded in the areas where topsoil had been removed. These included Bristle Club-rush (*Isolepsis setacea*), Lesser Centaury (*Centaurium pulchellum*) and Strawberry Clover (*Trifolium fragiferum*). Monitoring at the Polder and Ruskie Łąki areas revealed substantial increases in amphibian populations and some species new to the areas were observed, such as Common Toads (*Bufo bufo*), Tree Frogs (*Hyla arborea*), Fire-bellied Toads (*Bombina bombina)* and Green Toads (*Bufo viridis*). Several species of birds not formerly recorded at the sites have also been seen, such as Lapwings (*Vanellus vanellus*), Common Sandpipers (*Charadrius dubius)*, White-tailed Eagles (*Heliaeatus albicilla*), Black Storks (*Ciconia nigra)*, Kingfishers (*Alcedo atthis*) and Cranes (*Grus grus*).

- **Socio-economic aspects**

  Construction of the biomass heating installation at Wińsko School, the biggest school in the district, created a local market for hay as a fuel, and consequently provides an economic incentive to cut the haymeadows. Meadow cutting is necessary for conservation of their ecological values.

- **Other**

  This demonstration project shows how to integrate economics, flood protection and nature restoration interests.



Figure 67. Pastures of Ruskie Łąki flooded by Łacha River
Photo: R. Guziak/proNatura

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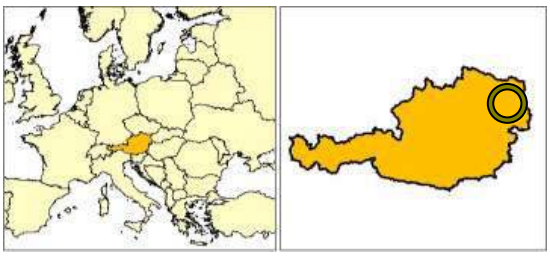
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11. Regelsbrunner Au, Danube

– Austria



Type of case study and stage of implementation

This is a large floodplain restoration project implemented between 1996 and 1998. Flood risk was not the focal issue of the project, but its results have strong implications for natural flood defence measures.

Project area

The restoration project is located on the southern bank of the River Danube, between the villages of Haslau and Regelsbrunn, east of Vienna. The project area, occupied by a floodplain forest called Regelsbrunner Au, is 10 km in length and covers approximately 500 ha within the Danube Floodplain National Park. This section of the River Danube was regulated in the 19th century. Until the 1980s it had been intended that a hydro-electric power station would be constructed here, but these plans were abandoned in 1984 due to public protest. The Danube Floodplain National Park was established in 1996 and designated as an area meriting special protection (a category II reserve) by the IUCN in 1997.

During the river regulation process, embankments were constructed and the main river was isolated from its side arms, completely changing the flooding dynamics of the floodplains. Consequently, sediment layers that accumulated on floodplains during floods have not been flushed-out by the river during normal discharge. As a result, the level of the floodplains increased and its water table has lowered. This was enhanced by riverbed erosion in the main channel as well as further river regulation facilitating navigation and the building of hydroelectric power stations upstream.



Figure 68. The Regelsbrunner Au area, the Danube and its side arms near Haslau village
Photo: D. Miletich/www.4nature.at

Major goals of the project

The main objective of the project was to reconnect the River Danube to its floodplains and, as a consequence, to improve the quality of the natural environment. Restoration efforts targeted improvement of the natural dynamics of wetlands, the creation of diverse habitats, clearing of old sediments (enhancement of erosion), establishment of spawning grounds for fish and improvement of conditions for rare and endangered freshwater invertebrates. Flood defence issues were of minor importance here.

Organisational background

The project was carried out by the Waterway Administration (WSD) with the support of WWF-Austria and the Danube Floodplain National Park. The University of Vienna and the Bodenkultur University monitored its impact on flora and fauna.

Funding sources

The project was financed by the Waterways Administration (WSD) using approximately €2 million from the Austrian Ministry of Economics. The WWF owns 411 ha of the Regelsbrunner Au, with the other 80 ha being owned by the State Forest.

Measures

Approximately 10 km of the River Danube was reconnected to its side arms, affecting an area of 500 ha. This was carried out by:

- Lowering the existing embankments to a height of 1.5 m in four 30 m long sections together with construction of three 10 m wide inlets.
- Building five inlets along three embankments on the Regelsbrunner Au.
- Lowering the main embankment (Mitterhaufen Travers) by 1.5 m on a 110 m long section.

Effects

- **Flood risk alleviation**

  The project increased the capacity for floodwater retention over an area of 500 ha. The period for which the Regelsbrunner Au is inundated increased from 20 to 220 days per year.

- **Ecology and biodiversity**

  The project strongly influenced the Regelsbrunner Au landscape. As a result of the new river dynamics, the restored branches are becoming wider and deeper. The project has restored a natural rhythm to the functioning of the riparian wetland. The fluctuation of water levels (which can vary by as much as 7 m) subjects the riparian wetlands to an extreme range of conditions. The river dynamics have resulted in the creation of diverse habitats (e.g. gravel and sand banks, shallow and deeper waters and stable and temporary islands). As a consequence a high diversity of species is now present. The Regelsbrunner Au habitats have become breeding, nesting and refuge areas for many species, including rare birds, fish and insects.

- **Socio-economic aspects**

  Creation of migration paths, refuges and spawning grounds for fish will increase fish populations in the river. Previously fish had to be introduced to support angling activities. Serious conflicts arise from the necessity of maintaining the River Danube as a shipping river. It is included in the EU Trans-European Network for Transport (TENT) programme, which aims to improve connectivity between the markets of Western and Eastern-central Europe. It promotes complex river regulations on the River Danube and could affect the Danube Floodplain National Park.

- **Other**

  Additional benefits of the project include the enhancement of recreation, protection of high quality drinking water and an improvement in the quality of life in the region. The project is a good example of the benefits of wetland restoration and has facilitated the development of numerous Danube restoration projects. The project has been directly extended to the west to cover the Maria Ellend floodplain.

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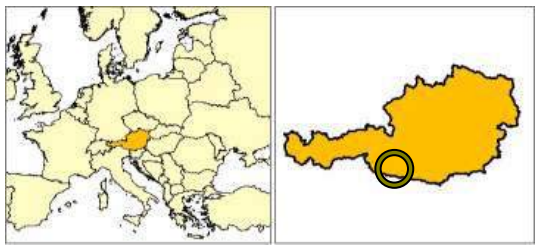
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12. Upper Drava River

– Austria



Type of case study and stage of implementation

This is a completed floodplain restoration project. The project started in 1999 with the intention of restoring the river to a semi-natural state. It was completed in 2003 and is one of the largest river restoration projects in Europe.

Project area

The Drava is an alpine river rising in the Southern Tyrol on the border between Austria and Italy. It is an important tributary of the Danube. Originally it was a typical, natural, alpine river with side arms, gravel banks, islands and oxbows. The river was regulated in the first half of the 20th century due to increasing pressure from agriculture and housing. The regulation resulted in large-scale degradation of natural habitats including alluvial forests and oxbows. Canalisation caused an increase in flow velocity which in turn caused an increase in erosion (deepening of the riverbed by 2 cm per year), resulting in lowered groundwater levels in the floodplain. Nevertheless, the Drava River is one of Austria's largest rivers and has been preserved as a free-flowing river with a continuous stretch of over 60 km free of dams. Though the natural flood retention capacity of floodplains was reduced by embankments, over 1,900 ha are still flooded once every 10 years. The project was carried out on a 57 km long river section in the Carinthia Federal State of Austria.



Figure 69. An island on the Upper Drava River before (above) and after (below) restoration
Photos: Tichy

Major goals of the project

The main goals of the project were to maintain and improve both the flood protection function and the natural river dynamic processes supporting habitats for riparian species.

Organisational background

The project was carried out by the Water Management Authority of Carinthia in partnership with the Nature Conservation Authority of Carinthia, WWF Austria (preparation) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management.

Funding sources

The project was financed mainly by the Federal Ministry for Agriculture and Forestry (51%) and EU LIFE funds (26%). The project budget amounted to €6.3million.

Measures

Three ecological 'core zones' along 7 km of the river were restored. Measures included:

- Land purchase for establishment of new habitats.
- River channel restoration: widening the riverbed, removal of river regulation structures and fish migration barriers in streams.
- Reconnecting former side-arms to the main channel.
- Restoration of natural floodplain forests, protection of endangered species and creation of diverse habitats along the whole river valley.
- Re-introduction of plant and animal species.

Effects

- **Flood risk alleviation**

  It is estimated that water retention capacity of the floodplain was increased by 10 million m^3 over an area of 200 ha. This should slow down the flood wave by more than one hour.

- **Ecology and biodiversity**

  Alpine and floodplain habitats were recreated, including over 50 ha of islands, gravel banks and steep banks. These habitats support rare fish species such as the Danube Salmon (*Hucho hucho*) and Grayling (*Thymallus thymallus* - populations of this fish have doubled), Bitterling (*Rhodeus sericeus*). Bird species such as the Common Sandpiper (*Actitis hypoleleuco*) and Kingfisher (*Alcedo attihis*) have also benefited along with many other species of flora and fauna.

- **Other**

  The riverbed stopped eroding, and in some locations deposition has occurred. The Water Management Authority of Carinthia is currently working on a follow-up project to restore other parts of the river. In total there are three completed or ongoing large river restoration projects in the Austrian Drava Basin.

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13. Tisza River

– Hungary



Type of case study and stage of implementation

The Tisza LIFE Project is a large-scale project in the final stage of implementation, of which floodplain wetland restoration is an important part. The first Tisza Programme was initiated by WWF Hungary in 1999, and the first pilot areas were restored in 2000. The Tisza LIFE Nature project started in January 2001 and is due for completion in December 2005.

Project area

The Tisza River, one of the major tributaries of the Danube, is a typical slow-flowing, meandering river of the plain regions of Hungary. Due to canalisation and construction of embankments along the Tisza River and its tributaries, the area of active floodplain in the Tisza basin within Hungary has decreased from 25,000 km^2 to only 1,200 km^2.

Until the mid-19th century a specific type of water management had been practised in the Tisza Valley: large areas of floodplains separated from the river by banks were inundated in spring by the use of sluice systems called 'foks'. When floods receded the foks were closed in order to retain shallow water which acted as fish nurseries. Additionally these areas were planted with fruit trees resistant to long periods of inundation, making 'jungle orchards'. This management ceased after 1846, when the majority of floodplains were converted to intensive agriculture and the river was engineered to facilitate transport. This involved draining floodplains, straightening meanders, construction of new embankments and enlargement of existing ones, decommissioning of foks and felling of riparian forests along the river to facilitate towing and planting of arable crops. Following these changes disastrous floods occurred in 1867-68, 1879, 1888, 1919, 1932, 1940-41, and four times during the 28 month period between 1998 and 2001. The Tisza Life Project affects an area of the Middle-Tisza Landscape Protection Area (MTLPA), which extends along 134 km of the river with demonstration restoration sites being established on approximately 950 ha.

Major goals of the project

The main objective of the project is the harmonisation of nature conservation, flood mitigation and land use. It aims to preserve and improve the biological diversity of the region,



Figure 70. Fishing in clay-pits is carried out with low-tech, hand-made instruments
Photo: F. Kis/WWF Hungary



Figure 71. Fighting the flood in Nagykörű, April 2000
Photo: V. Siposs/WWF Hungary

with particular regard to wetlands and riparian forests as well as extensively used agricultural areas. The project emphasises opportunities for integrated rural development and development of new flood prevention policy.

Organisational background

The project was organised by WWF Hungary and WWF Austria, as part of a joint project for the restoration of the Austrian section of the Upper Mura River and the middle section of the Tisza. The Tisza part of the project is being implemented in close co-operation with the Directorate of Horbobágy National Park, municipalities, local farmers and other relevant authori-

ties. Technical design and construction works were contracted to local companies.

Funding sources

The project is one of the first Hungarian nature conservation projects supported by EU LIFE funds and is also supported by the Hungarian Ministry of the Environment.

Measures

- Clay-pit rehabilitation: many pits were re-connected to the river by ditches equipped with sluice systems enabling them to function as fish spawning grounds.
- Restoration of the fok system: re-establishment of channels with sluices connecting the floodplains to the river.
- Poplar plantation removal: in some plantations semi-natural willow forests are being restored in place of poplar plantations.
- Pasture restoration: degraded crop fields are being converted into pastures grazed by Hungarian grey cattle.
- Water table management: the hydrological regime of 200 ha of wetland including ponds, grasslands and floodplain orchards is managed using a sluice-system.
- Extension of protected areas: the Middle-Tisza Landscape Protection Area is being extended.
- Re-introduction of fauna: beavers have been reintroduced to the Middle-Tisza.

Effects

- **Flood risk alleviation**

  It is likely that the re-establishment of fok systems will assist in the reduction of flood peaks if managed correctly. However, it should be recognised that if already storing water for the purpose of fishery support, the storage capacity of a floodplain could be compromised during a flood event.

- **Ecology and biodiversity**

  The main ecological effects are associated with restoration of the natural hydrological regime and, in some cases, re-establishment of traditional land use. Grassland management with extensive grazing should halt and reverse the damage caused by the alien, invasive shrub 'False Indigo' (*Amorphia fruticosa*). Mosaics of highly diverse habitats should develop, e.g. grasslands, traditional orchards and semi-natural forests, assisted by the re-introduction of beavers. Connecting spawning sites (clay-pits) to the river will increase fish populations.

- **Socio-economic aspects**

  It is expected that the proposed floodplain management scheme will in the future be supported by a subsidy system. Goods produced in a traditional manner may provide a reasonable source of income. Some of the activities in the Tisza basin will provide economic benefits throughout the wider catchment, e.g. fishery development. During project implementation, strong emphasis was placed on raising the awareness of local people and stakeholders with regard to conservation, management and the sustainable use of wetlands. There are some conflicts between agriculture and wildlife protection in the area, mostly related to land purchase from individual owners by Hortobágy National Park.

- **Other**

  In relation to the present project, a proposal to create a system of emergency reservoirs (polders), located behind embankments became the basis for a government flood protection plan. It is intended that these retention areas will be flooded to a shallow depth each year for conservation purposes, but will be available to act as temporary deep water storage facilities during floods. WWF is currently expanding its activities in the Tisza region. The project activities are strongly linked with the One Europe - More Nature (OEMN) initiative, a co-operative programme between WWF Hungary and the Danube-Carpathian Programme (DCP: Romania office). It aims to stimulate and promote integrated river basin management (IRBM) from the mountains to the lowlands.

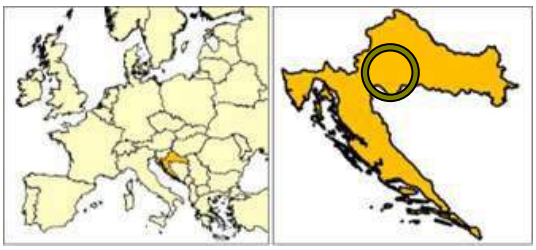
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14. Central Sava basin: Lonjsko Polje – Croatia



Type of case study and stage of implementation

This is a flood protection scheme on the River Sava based on controlled flooding of (semi-) natural floodplain areas. The flood storage capacity of the floodplains in the Lonjsko Polje Nature Park represents the key flood control mechanism in the Central Sava basin. The project was initiated after Zagreb was flooded in 1964, with the loss of 17 lives and material damage equal to 9% of the national GDP. At the beginning of the 1980s around 40% of the flood defence work was completed and subsequently two new projects were developed.



Figure 73. Lonjsko Polje during a flood
Photo: M.Haasnoot

Project area

In addition to its role in flood control, Lonjsko Polje is ecologically important on a regional, national and even global scale. The Lonjsko Polje Nature Park covers approximately 380 km^2, comprising lowland riparian forest and approximately 120 km^2 of common pasture land. It belongs to one of the biggest natural complexes of lowland riparian forests in Europe and contains the Krapje Dol and Rakita ornithological reserves. In 1963 the Krapje Dol reserve was designated as the first bird sanctuary in Croatia. Its spoonbill colony is important for the entire European spoonbill population. Lonjsko Polje Nature Park became a Wetland of International Importance (Ramsar-site) in 1993. The traditional grazing land, with its indigenous breeds of cows, horses and pigs, and the čardaks (the wooden houses typical of Posavina), are also of great cultural and historical value.



Figure 74. Lonjske Polje includes large areas of pasture
Photo: M. Baptist

Major goals of the project

The main objective of the Central Sava basin flood control scheme is to protect in a sustainable way the cities of Zagreb and Sisak from flooding. In addition, a recently proposed management plan for the Plonje Nature Park (2003) includes a demand for integrated and collaborative management, ensuring effective and appropriate use of the area within the Sava basin flood control system, by reducing nutrient impact from the upstream areas and by maintaining the cultural landscape, the natural geomorphology and the mosaic of wetland habitats.

Organisational background

The concept of the flood protection system originated following the major flood of 1964. The proposed solution was based on the imitation of centuries-old natural flood processes in the Central Sava basin i.e. using natural flood defence schemes. The project is the result of collaboration between the Water Management Authority and the Park Service of Croatia. The management plan for Lonjsko Polje Nature Park has been developed using stakeholder

involvement. A detailed model study of the Lonjsko Polje Nature Park is now under development within a Dutch Partners for Water Programme called 'Integrated Trans-boundary River Basin Management of the Sava' This is being carried out by a consortium of Dutch institutes (IAC, Ecorys, Alterra, RIZA and WL | Delft Hydraulics) in co-operation with the Lonjsko Polje Nature Park and Croatian Waters.

Measures

- The controlled flooding of (semi-) natural detention areas has reduced the flood peak of the River Sava. Four detention areas were constructed in the 1980s; The Lonjsko polje, Mokro polje, Zelenik and Kupčina.
- Realignment of embankments along main watercourses.
- Canals have been constructed to carry floodwater to and from the detention areas.
- Embankments have been constructed around the detention areas, to enhance the floodwater storage capacity and retention time.
- Inlet and outlet structures comprising sluice systems have been constructed, to control the intake of floodwater and duration of flooding.
- Grazing by livestock and wildlife suppresses vegetation succession, reducing the hydraulic resistance of the floodplains.

Effects

- **Flood risk alleviation**

  As a result of the controlled flooding of the detention areas, the risk of flooding in many inhabited areas has been reduced. Modelling results indicate a large capacity for floodwater detention.

- **Ecology and biodiversity**

  The combination of flooding and land use management in the area promotes a high diversity of habitats, ranging from old riparian forest to open grassland and ponds. To date, 744 plant species have been described, including aquatic plant communities of international importance and 250 bird species have been observed, many of which are protected by international conventions. As the Lonjsko Polje area is flooded each year and the water is deliberately detained, the flora and fauna have adapted to these conditions, although it differs from the former natural situation. Changes towards a more non-natural situation (flooding on an irregular basis, long-term flooding and deeper flooding) might reduce the ecological value of the area.

- **Socio-economic aspects**

  Local inhabitants are accustomed to flooding of the floodplain as this is part of the natural system in the Sava basin. Most houses are located on relatively high land such as natural levees. Old houses are adapted to survive shallow inundations during the wet season, but nowadays houses are protected from flooding by embankments. When the park is flooded cattle and fauna seek refuge on elevated areas within the floodplain. Plans for more water storage should be considered carefully as this might result in the loss of these refuges. Some conflicts of interests have arisen from the presence of a number of major land users in the area, such as Croatian Water, Croatian Forests, the local government, livestock breeders, arable farmers, hunters, anglers and tourists. In response the Lonjsko Polje Nature Park Public Service organised several meetings with all major land users soon after they started managing the park in 1998. These activities marked the start of a new policy in conservation planning in Croatia.

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GLOSSARY
OF KEY WORDS AND ABBREVIATIONS

Alluvial – Formed by river flow processes, e.g. alluvial plain.

Biodiversity – The variability among living organisms of different origin. This includes terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part of. It also includes the diversity within species, between species and of ecosystems (according to the Convention on Biological Diversity).

CAP– Common (European Union) Agricultural Policy.

Catchment area – (=watershed) An entire tract of land drained by the same brook, stream or river.

Channelisation – Channel alterations for the purpose of increasing flow and decreasing retention time, including re-sectioning, realignment, diversion, embankment, bank protection, channel lining, and culverting by dredging, cutting, and obstruction removal.

Direct use value – The value derived from direct use or interaction with a wetland's resources and services, such as the value of fish catches.

Diversion – Type of channelization in which flow is diverted around an area to be protected; the taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Drainage – Artificial run-off of waters by means of separated underground pipes and/or open trenches.

Economic value – The utility that individuals derive from the use or non-use of a good or service, consisting of current production value, service value, option value (future use value) and intrinsic or existence value (value from knowledge of continued existence).

Embankment – Type of channelization in which a levee, bund, or dike is used to prevent the flow from overflowing onto the floodplain; fill material, usually earth or rock, placed with sloping sides and usually with length greater than height. All dams are types of embankments.

Erosion – The process of wearing away of the lands by running water, winds, glacial ice, and waves. In areas with little vegetation or poorly developed soil, the rate of erosion can be greatly increased.

Estuarine – Estuarine wetlands contain a mixture of freshwater and ocean water. They are typically located in areas where freshwater rivers flow into the ocean. Major estuarine systems include the salt marshes, brackish tidal marshes and mangrove swamps.

Eutrophication – A process of over enrichment of a water body with nutrients (usually nitrates and phosphorus). The rapid increase in nutrient levels stimulates algae blooms. Bacterial decomposition of the excess algae depletes oxygen levels seriously. The extremely low oxygen concentrations that result may lead to the death of fish, creating the further oxygen demand and so leading to further deaths.

Floodplain – The land area along the river, brook or stream channel that is currently flooded at high water. The area that was formerly flooded at high water level is being referred to as the former floodplain. A third category can be distinguished, being the potential floodplain: the area that potentially can be flooded in case of for example major dike collapses.

Flood risk – Function of probability of flooding and the damage resulting from flooding.

Natural flood risk reduction measure – Flood risk reduction measures which support the protection, restoration and development of ecosystems. In these guidelines it concerns ecosystems (aquatic and terrestrial) of floodplains.

Floodplain functions – Activities or actions, which occur naturally in floodplains as a product of interactions between the ecosystem structure and processes.

Fluviatile – Influenced or characterized by rivers; or found in or near rivers.

Habitat – The local environment occupied by an organism (species/ sub-species). The locality in which a species or community of plant or animal naturally lives and grows.

Indirect use value – Indirect support and protection provide to economic activity and property by the wetlands natural functions, or regulatory environmental services, such as flood prevention.

Inter-tidal – The area between the high and low water marks which is exposed as low tide.

Levee – A long, narrow, earthen embankment usually built to protect land from flooding. Levees confine streamflow within a specified area to prevent flooding.

Meander – A more or less regular curve of a river or valley.

Oxbow lakes – Oxbow lakes are lakes or ponds found in association with river channels. When a river channel becomes obstructed by silt and debris, the river will often cut a new channel around the obstruction. With time the obstructed area may become completely cut off from the river and begin developing as a lake. Over time an oxbow lake may become filled with organic material and be transformed into a marsh.

Realignment – Type of channelization in which the stream channel is shortened via an artificial cut-off.

Riparian – Pertaining to a river (e.g., the riparian zone).

Run-off – Overland or near-surface flow of water following rain or irrigation events.

Information based on Lenselink et al. (2003).

Sediment – Particles of material that are transported and deposited by water, wind or ice.

Socio-economic valuation – The valuation of environmental services to human society.

Stakeholders – Anyone who lives in the watershed or has land management responsibilities in it. Individuals who represent the major land uses in the watershed. Stakeholders include government agencies, businesses, waterboards, private individuals, and special interest groups (for example on agriculture, fishery, nature etc.).

Sustainability – A characteristic of a process or state that can be maintained indefinitely.

WFD – Water Framework Directive.

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