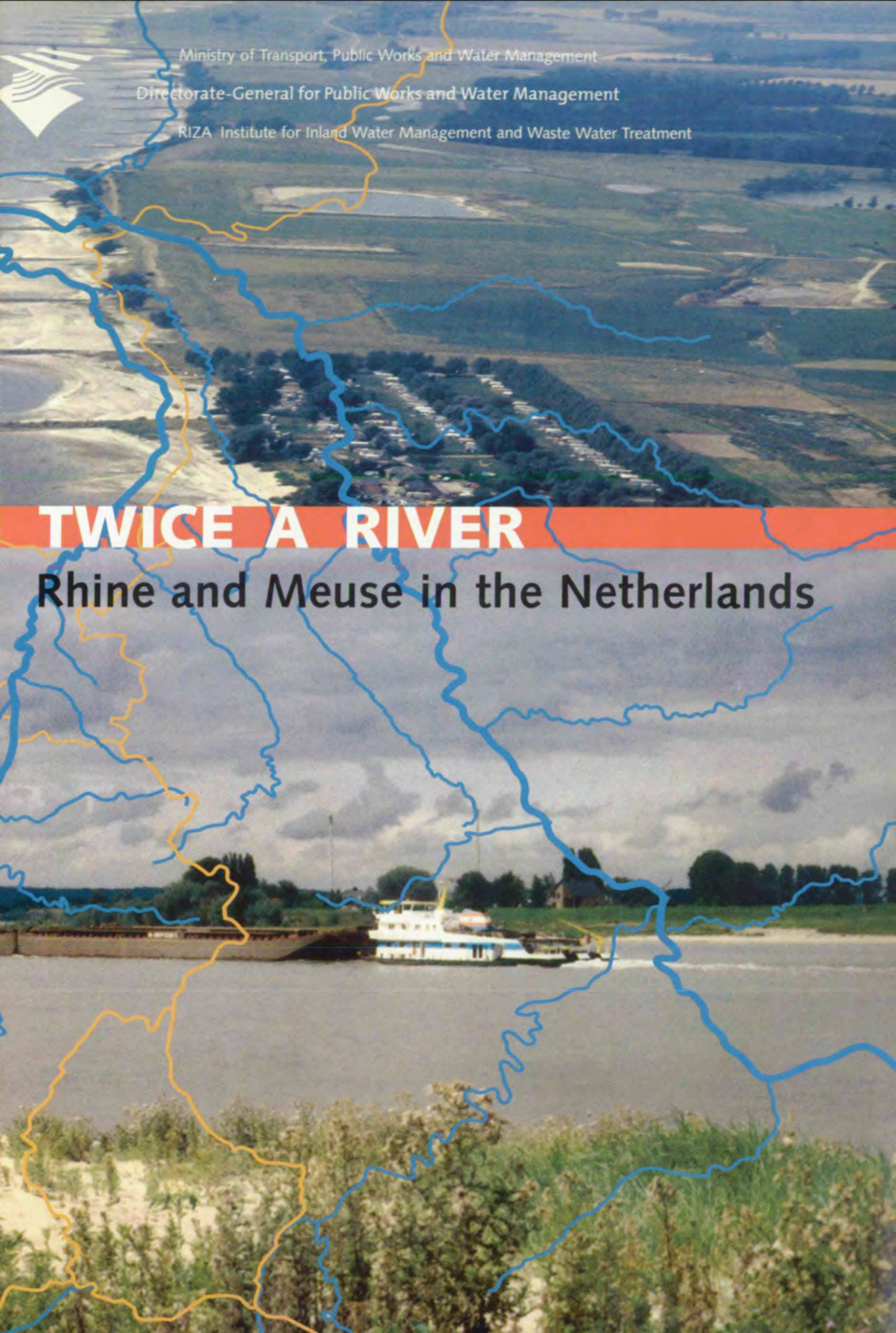
Ministry of Transport, Public Works and Water Management

Directorate-General for Public Works and Water Management

RIZA Institute for Inland Water Management and Waste Water Treatment

TWICE A RIVER

Rhine and Meuse in the Netherlands



TWICE A RIVER
RHINE AND MEUSE IN THE NETHERLANDS

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Preface

When crossing the Rhine or the Meuse, what traveller could resist the urge to allow his gaze to linger on the fascinating river landscape below? The barges and river boats plying the broad river, the flood plains dotted with water birds and lined with willows, the brick factories, the ferry boat houses and dikes; it is a compelling scene. Described so vividly by Marsman in his poem *Thinking of Holland*, the Netherlands' great rivers have the power to captivate many — if not all — of those who look upon them.

In the last decade or so, various events and initiatives have focused increasing public attention on the Rhine and the Meuse. The Sandoz fire, for instance, led to the Rhine Action Plan, designed to improve water quality and encourage salmon to return. The Stork Plan, Living Rivers, Green for Gravel and numerous other such initiatives had a major impact upon thinking about the rivers and their ecology. Then, in the winters that followed, unusually high water levels reminded everyone that the Rhine and Meuse can still be capricious and dangerous. The national policy statement *Make way for rivers* was published, followed by international flood action plans for both rivers.

The Dutch people rely on the Rhine and Meuse in all sorts of ways. Consequently, the rivers must be managed with due regard for safety, the environment, transport, agriculture and water consumption. And, partly because no-one can be certain what the future may bring, increasing emphasis has to be placed on flexibility and on allowing "room" for the various river functions. So, for instance, flood defences need to take account of the potential impact of climate change. And what of the future? Waterways may very well come to play a more significant role in the transport of people and goods; fresh water will be in greater demand; more people will want to live in pleasant green surroundings and water management will become an increasingly international activity.

For those whose working lives are tied up with the Rhine or the Meuse, events tend to resemble the river itself. Periods of low water alternate with periods of flood, between straight stretches of river come long meanders, and deep waters are followed by shallow foaming riffles. It is a rhythmic pattern of change that reflects the caprice of nature.

This booklet deals with all the factors which make our two great rivers so fascinating. It describes the characteristics of the Rhine and the Meuse, their similarities and their differences. It invites the reader to take another look at the rivers, to ask questions. And it seeks to answer those questions.

But beware! Those who fall under the spell of the river are in its power for ever. And the world is full of rivers!

I hope you enjoy reading *Twice a river*.

Eric C.L. Marteijn, Head of River Section, RIZA

A MARSHY DELTA

1

A marshy delta

Living in a river delta means constantly fighting to prevent flooding. However, the river is much more than just a hazard. It is also an invaluable resource, used for transport, recreation, industry, fishing, agriculture and drinking water. In addition, the river environment forms a valuable habitat for animals and plants. A carefully balanced river management strategy is therefore required, with safety as the highest priority.

Areas subject to flooding by the sea in the absence of dikes or dunes

Areas subject to flooding by rivers in the absence of river dikes

Dunes

Without dikes and dunes almost two-third of the Netherlands will be flooded.

THE NETHERLANDS — A LAND OF RIVERS

Napoleon described the Netherlands as "nothing more than a silty delta formed by the great rivers of my empire" — a statement that is hard to contradict. The land consists to a large extent of sediments deposited by the Rhine and the Meuse over the millennia. Down through the Pleistocene and Holocene periods the rivers, sometimes several kilometres wide, have constantly changed their course, running at one time or another through every part of what today we call the Netherlands.

The Netherlands covers an area of 34,000 square kilometres. If enclosed water bodies such as the IJsselmeer are included, Dutch territory extends over 41,160 square kilometres. Behind the dune line, about 25 per cent of the Netherlands is below Dutch Ordnance Datum. The lowest spot is in a polder near Nieuwerkerk aan de IJssel, where the land lies 6.7metres below Dutch Ordnance Datum.

Flood defences are therefore absolutely vital. Without the coastal dunes and river dikes, two-third of the country — an area in which 1,200 billion euro (rate 1999) is invested — would be flooded at times of high water.

When the first settlers came to the Netherlands around five thousand years ago, they found a marshy river delta. They raised terps or mounds to keep all their goods dry and they constructed primitive river dikes. Over the centuries since, water management has been perfected, with the development of dikes, overflows, drainage pools, pumping stations and storm flood barriers. Yet the land

Rivers play a very important role for society: transport of water and sediment, navigation, nature, water supply for drinking-water, agriculture and industry.

beside the Rhine and Meuse has been inundated repeatedly in recent centuries; even today, the dikes still bear the telltale marks of occasions when the water has broken through.

In geological terms, the rivers' present courses are merely temporary — part of a constantly changing picture. Human intervention has, however, given an artificial permanence to the situation. Modern rivers are no longer free to meander, to push back their banks or alter their courses. They are hemmed in by dikes, groynes and ripraps. Nevertheless, each time the Rhine or the Meuse overflows its banks, one readily appreciates the power of nature.

Ferry (boats) and warden houses are characteristic.

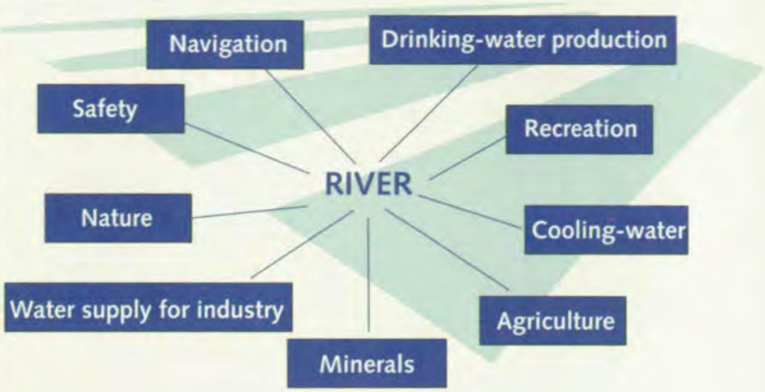
The Waal during the flood of 1995. Loevestein Castle (near Gorinchem) as a historical element.

The rivers Rhine and Meuse have a significance which goes beyond the potential for flooding. Some 65 per cent of the Netherlands' fresh surface waters originate from the Rhine and 8 per cent from the Meuse; the remaining water comes from precipitation and from a few smaller cross-border rivers. One of the main priorities of river management is to ensure the safety and reliability of shipping. The inland waterways are very important to the Dutch economy and international freight transport is expected to grow substantially in the years ahead.

During the seventies in particular, the Rhine and the Meuse were seriously polluted. The

The rivers' functions

The great rivers and their flood plains have numerous functions. First, they naturally drain the land and carry away ice and sediment. To do this job properly, they need adequate capacity, so that the safety of the areas behind the dikes is not threatened. The rivers also serve as a medium for the disposal of waste water and other substances, although untreated discharges are generally no longer permitted in the Netherlands. For the inland navigation, the rivers act as arteries, connecting coastal ports with the hinterland. In addition, river water is used as a source for drinking water, for industrial applications, for cooling and for sprinkling crops. In the summer, river water is let into secondary channels to maintain surface water levels, while in the western Netherlands river water is used to 'rinse' the polders and thereby prevent salinization. Hydro-electric power stations near to the river produce electricity. The river flood plains are used for agriculture and, increasingly, as nature reserves and recreational facilities. Sand and gravel are extracted from the rivers' channel beds. The flood plains are important sources of clay, which is used for brick manufacture, sometimes in combination with nature development or dike reinforcement projects.



Valuable nature areas are developing along rivers.

pollution has affected the river beds and flood plains where contaminated sediments have been deposited in recent decades. Rectifying this situation is expensive, and there are few alternatives for disposing of polluted silt extracted by dredgers. The quality of the water in the Rhine has improved considerably since the eighties. Under the Rhine Action Programme, the countries along the Rhine undertook to halve pollution between 1985 and 1995. In fact, the concentrations of various substances have been cut by well over half, but the targets for diffuse discharges of fertilizers, crop protectors and other agricultural chemicals have not yet been met. A similar international action programme is now being considered for the Meuse.

Now that water quality is improving, the river ecology is recovering as the plants and animals naturally associated with the rivers are returning. Greater emphasis is now placed upon developing the Rhine and Meuse as natural habitats. As long and unbroken strips of the landscape, the rivers offer unique opportunities, provided that certain basic conditions are met. Nature development projects also awake the recreational potential of the rivers.

TOWARDS BALANCED RIVER MANAGEMENT

River water is used in industry, in drinking water production, in agriculture and for water management in the polders. Furthermore, the rivers are integral to the nation's transport infrastructure, so navigational safety has to be ensured. At the same time, flood defence, nature, agriculture, recreation and mining all have to be accommodated on the relatively narrow strips of flood plain. Since so many activities and users have legitimate claims upon the Rhine and the Meuse, a carefully considered and creative approach must be worked out by those responsible for river management. In this approach, safety, access and quality of life remain the constant objectives.

In response to the floods seen in 1993 and 1995, the Great Rivers Delta Plan was set up to urgently improve the safety of areas adjacent to the rivers. Action plans setting out flood defence measures were also developed for the branches of the Rhine, the Meuse and their basins. In the decades ahead, the rivers, which have been confined within their narrow beds by man, must be given more space. At the Ministry of Transport, Public Works and Water Management, the policy to 'Make way

River water is used as cooling-water.

for rivers' is a high priority. Under this policy, emphasis is placed on activities such as removing obstacles from the flood plains, reducing flood plain levels and creating retention basins. The dikes are only to be made higher where other measures are insufficient to counter the threat of flooding.

Nature development along the rivers is not allowed to compromise flood defence. Flood plain forests and other rough vegetation on the flood plains impede a river's flow when water levels are high and, without compensatory measures, would increase the danger of flooding. River managers attach great importance to finding ways of serving several objectives at once. Local excavation of the flood plains, for instance, can be valuable not only in terms of flood defence, but also for nature development and the extraction of clay and sand. In some cases, clay extraction can act as a "green engine": a financial incentive for projects which promote nature development. Nature development schemes can also often be tacked onto flood defence initiatives. At the same time, however, steps must be taken to ensure that such activities do not adversely affect shipping.

To guide future river management work, studies are underway to determine the best design for the river area. Computer simulations are being used to test combinations of measures such as cutting summer embankments, creating secondary channels and removing clay from the flood plains ("landscape planning alternatives "). Further computer models are under development, simulate the effects of climate and land-use changes on the discharge in the river basin. With these models, it should also be possible to investigate the impact of hydraulic engineering measures on, for example, very high water levels. The various models are to be incorporated in a decision support system (DSS), making it possible to modify and harmonize plans and thus to optimize the landscape planning of the river area.

Twice a river — The Rhine and the Meuse in the Netherlands

This booklet describes what the Rhine and the Meuse are like today. It outlines the main issues relating to the rivers and sketches the developments which are likely to take place. Chapter 2 describes the Rhine and the Meuse in their historic context. The following five chapters are devoted to the issues of flood defence (3), water distribution (4), shipping (5), water quality (6) and nature development (7), respectively. Chapter 8 deals with integrated water management and explains why the diverse and sometimes conflicting interests associated with the rivers need to be addressed by a comprehensive and coherent policy. In the final chapter, chapter 9, consideration is given to the future of the rivers.

RHINE AND MEUSE 2

Rhine and Meuse

In European terms, the Rhine and the Meuse are medium-sized rivers. For centuries, mankind has been seeking to control the rivers in one way or another. The river landscape has become a cultural landscape, with considerable differences between the river branches. Although the rivers today are far from natural, they retain the ability to surprise, as evidenced by the floods of 1993 and 1995. The processes of erosion and sedimentation also continue relentlessly, despite human interference.

The Rhine and Meuse basins.

THE RHINE AND MEUSE BASINS

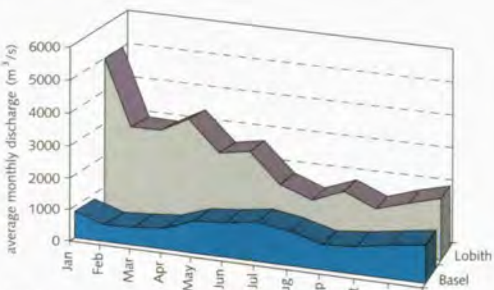
The Rhine

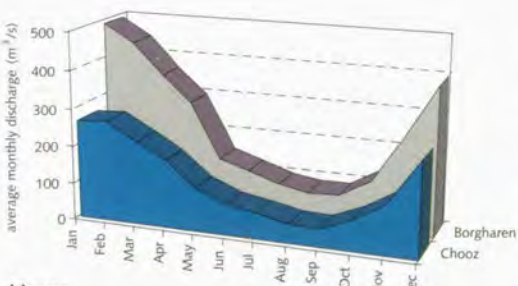
The Rhine is 1320 kilometres long. It rises in Switzerland, where it takes the form of a rapid mountain river, fed by Alpine glaciers in the Gotthard massif. Swollen by rainwater and meltwater from nine different countries, the river makes its way towards the North Sea. The Rhine's basin covers an area of 185,000 square kilometres, some 25,000 square kilometres of it in the Netherlands. Average river currents in the Netherlands vary from 0.5 to 1.5 metres a second, although they can reach more than 2 metres a second in places. At Lobith, an average of 2,300 cubic metres of water flows down the river every second.

Upstream of Basel, the amount of water flowing down the river is determined not only by the large volumes of rainwater which drain into it, but also by meltwater from snow and some 150 glaciers. As a result, flow in the Rhine's upper courses peaks in the early summer. During the summer months, more than 70 per cent of the flow at Lobith originates from the Alps. Clearly, therefore, the amount of water originating from other parts of the basin is relatively small. Away from the Alps, a great deal of summer precipitation evaporates before reaching the river. Average flow at Lobith is highest in winter, when evaporation levels are very low and rainwater accounts for the bulk of the river's volume. During the winter, only around 30 per cent of the water in the Rhine comes from the Alps. This is because much of the winter precipitation falls

The various sections of the Rhine

The Alpenrhein in Switzerland is an energetic mountain river. Beyond Basel, however, the river becomes calmer. From this point it is referred to as the Oberrhein. The river originally followed a winding course through this part of Switzerland. And, having left behind the hard rocks which contained its Alpine reaches, it used to branch repeatedly. Along the river's banks, a rich natural habitat has developed, with marsh forests and little meadows. Downstream of Bingen, the character of the river changes once more. The Mittelrhein, as this stretch is known, flows through a deep narrow valley past the Taunus Mountains and the Eifel Plateau. At Bonn, where the landscape flattens out, the Niederrhein begins. In the Netherlands, the Rhine again starts to divide, before its various branches flow into the North Sea and the IJsselmeer. There is no significant drop on this section of the Rhine, and it is no longer directed along a particular course by rocky banks. Before man's intervention, the river used to branch continually here, spreading out across a wide marshy expanse of land on the last stage of its journey to the sea.





Amount of water discharge through the Rhine during the course of the year. The Rhine is a combined meltwater/rainwater river. Large volumes of water enter the river from Switzerland during the summer months, while the German tributaries make their greatest contribution in the winter. As a result, flow at Basel peaks in the summer, but flow at Lobith is greater in winter, when the discharges in the rivers feeding it are highest. The Meuse, on the other hand, is fed mainly by rainwater, so flow at all points is highest in the winter. Relatively little water flows down the Meuse in the summer.

as snow, which lies unmelted until late spring. Only then, when the thaw sets in, does this precipitation find its way into the Rhine. Because the Rhine is fed from different sources at different times of year, the amount of water flowing down the river is relatively stable, making it navigable all year round.

The Meuse

The Meuse is 935 kilometres long. It rises about two hundred kilometres north-east of Dijon, some 409 metres above Dutch Ordnance Datum. After passing through France, Luxembourg and Belgium, the river enters the Netherlands at Eijsden, to the south of Maastricht. The Meuse's course through the Netherlands, measured up to the mouth of the Haringvliet, is approximately 250 kilometres.

In area, the Meuse basin is roughly the size of the Netherlands: about 36,000 square kilometres. This is only a sixth of the area covered by the Rhine basin. Within the basin, there are no glaciers or snow accumulations to feed the river. Flow in the Meuse averages 230 cubic metres per second near the Dutch-Belgian border. Because the river is fed by rainfall all year round, flow is much higher in the winter

Rivers top-ten of Europe

River	Source-mouth	Length (km)	Basin area (km²)	Average discharge river mouth (m³/s)
Volga	Russia	3.550	1.4400.000	8.400
Danube	Germany-Romania	2.860	817.000	6.400
Wisla	Poland	1.068	194.000	1.000
Rhine	Switzerland-The Netherlands	1.320	185.000	2.300
Oder	Czech Republic-Poland/Germany	866	119.000	530
Loire	France	1.012	115.000	400
Rhone	Switzerland-France	812	98.000	1.700
Po	Italy	676	75.000	1.500
Meuse	France-The Netherlands	935	36.000	230
Tiber	Italy	393	16.000	230

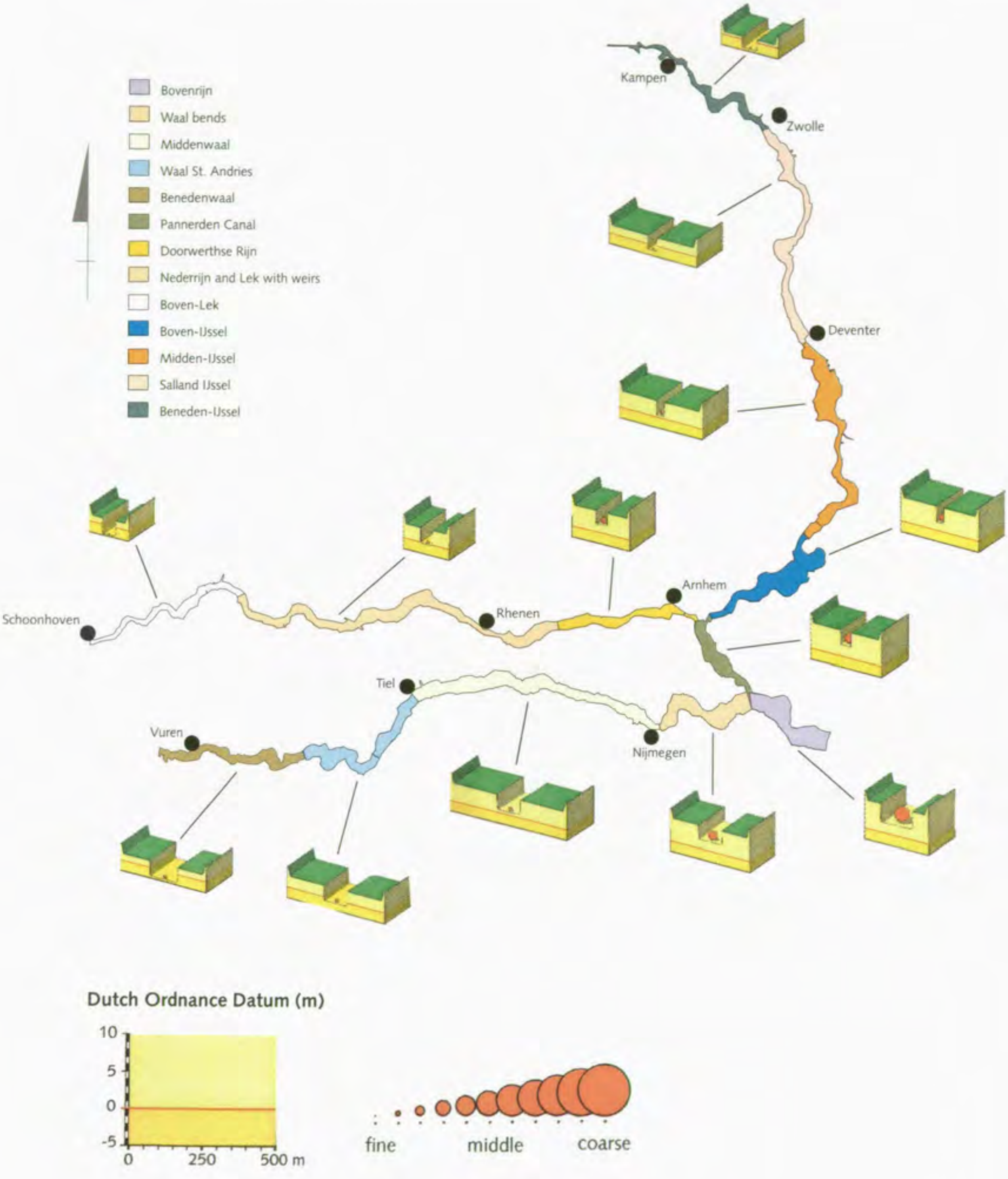
than in the summer, when evaporation levels are highest. In the Ardennes section of the Meuse basin, the terrain is hilly and the substrata are largely impervious. As a result, rainwater drains quickly from the surrounding countryside into the river. This in turn means that, if it rains heavily in the Ardennes, the Meuse in Limburg will be running high within twenty-four hours. Furthermore, because the Meuse basin is relatively small, it is not uncommon to have heavy precipitation across the entire area.

Canalization has rendered part of the French Meuse and the entire length of the Belgian Meuse navigable. To ensure all-year-round navigability despite the low summer flow, water levels in large stretches of the Dutch Meuse are also permanently controlled by weirs.

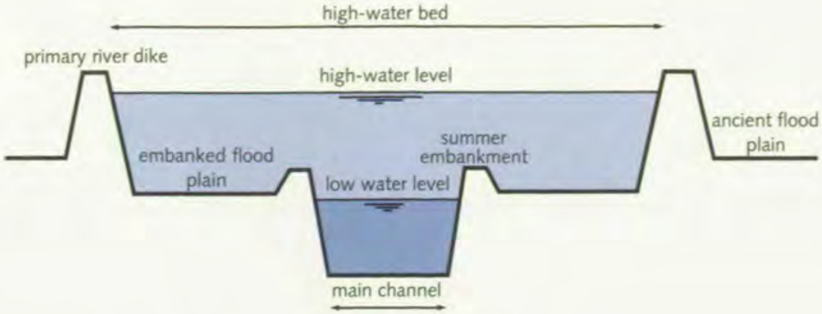
BRANCHES OF THE RHINE IN THE NETHERLANDS

The branches of the Rhine — the Bovenrijn, the Pannerden Canal, the IJssel, the Nederrijn/the Lek and the Waal — form by far the most important river system in the Netherlands. At Pannerden, five kilometres downstream of Lobith, the Nederrijn is divided into the Waal and the Pannerden Canal, which in turn divides into the Nederrijn and the IJssel near Arnhem. The branches of the Rhine form a coherent system. Changes in capacity or

River branches in the Netherlands.



Rhine branches with cross-sections and grain size of the bed material per section.



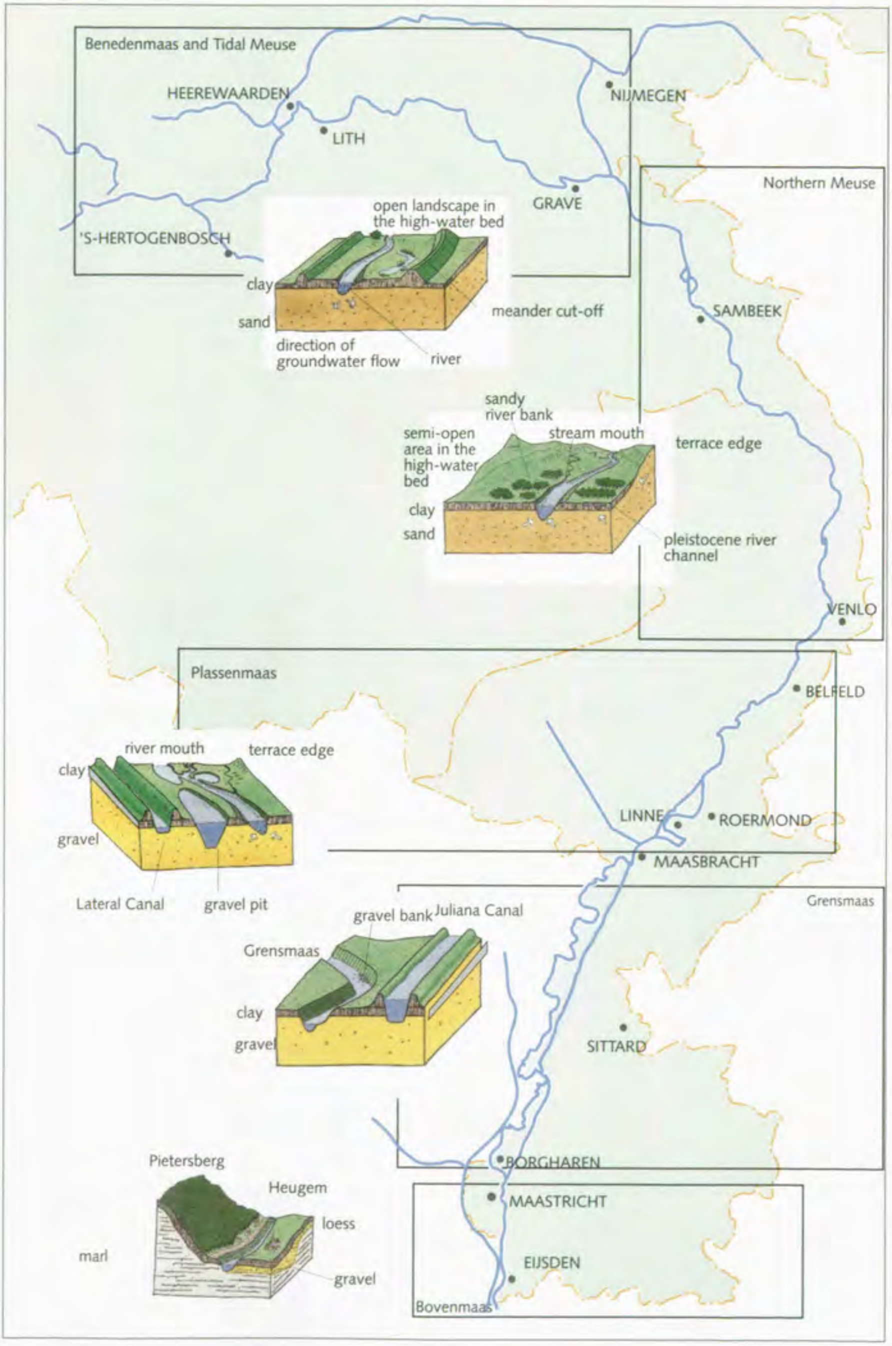
Schematic cross-section of the high-water bed from an embanked river.

water discharge in one branch can affect other branches. Nevertheless, the individual branches do differ from one another considerably. The Waal is a broad, free-flowing river; it regularly inundates its flood plain, within which there has been large-scale gravel and sand extraction. The IJssel, by contrast, is narrow; in places its flood plain has yet to be excavated and is several kilometres across. Canalized along almost its entire length, the Nederrijn is wider than the IJssel, but not as wide as the Waal.

In terms of flow, the Waal is naturally the most important branch of the Rhine. The weir at Driel divides the river water between the Nederrijn and the IJssel, ensuring that, when water levels are low, a sufficient proportion flows into the IJssel. In total, the flood plains on the Rhine branches cover some 28,000 hectares of Dutch soil. In many places, the river's main channel is bounded by low summer embankments, protecting the flood plain from summer flooding. In addition to the flood plains, the river system includes pools, clay ponds and old cut-off arms of the river.

Land use in the embanked flood plains of the rivers (percentages)

	Rhine branches			Meuse branches		
	Bovenrijn-Waal	Pannerden Canal - Nederrijn-Lek	IJssel	Grensmaas	Meuse with weirs	Tidal Meuse
Floodplain forest (nature)	4	1	1	5	5	3
Brushwood/marsh	5	2	1	6	3	2
Grassland (nature)	1	5	3	5	4	5
Water	19	11	11	14	8	17
Production forest	0	1	1	5	4	1
Arable land	4	4	8	30	31	14
Production grass	61	69	72	23	33	50
Built-up area	5	5	3	11	12	4
Other landuse	1	1	1	1	1	2
Total nature	29	20	16	30	19	28
Total non-nature	71	80	84	70	81	72



Meuse sections: schematic representation of cross-sections and composition of the sub-soil per section.

Differences between the Rhine and the Meuse

Considerable differences exist between the Rhine and the Meuse. First, far more water flows down the Rhine: an average of 2,300 cubic metres of water a second enters the Netherlands at Lobith. Flow in the Meuse is not only much lower (230 cubic metres a second on average at Eijsden) but exhibits much greater seasonal variance. The Meuse's maximum flow is 150 times greater than its minimum flow, whereas the difference between the minimum and the maximum in the Rhine is "only" a factor of twenty. In terms of catchment size, the Rhine is Europe's fourth biggest river, after the Volga, the Danube and the Vistula. In terms of length and flow, however, it is the third biggest. The Meuse lags significantly behind, in ninth place.

Water levels in the Dutch Meuse are more or less permanently controlled by weirs, in order to make the river navigable. Since the Waal and the IJssel are free-flowing, there is a marked contrast between the Meuse and the Rhine branches. The Rhine branches are diked along their entire length, whereas only the lower stretches of the Meuse have dikes. Behind the dikes, the land between the Rhine branches is mostly low-lying polder. So, if the dikes were to fail, the consequences would be disastrous. Large parts of the provinces of Gelderland, Utrecht, South Holland and North Brabant would soon be covered by metres of water. Strikingly, the Meuse has no dikes upstream of Mook. In this part of the country, the river flows along a valley whose sides slope gently upwards, forming natural dikes. There are no polders which need to be protected against flooding. Consequently, high water levels along this stretch of the Meuse are not a threat to life. Nevertheless, the consequences of flooding across the intensively used high-water bed in the Meuse Valley should not be underestimated.

THE MEUSE IN THE NETHERLANDS

The Dutch Meuse is 250 kilometres long and has a drop of about forty-five metres from the Dutch-Belgian border to the North Sea. Between Eijsden and Maastricht (nine kilometres) and between Borgharen and Stevensweert (47 kilometres), the Meuse forms the border between the Netherlands and Belgium. For this reason, these parts of the river are known as the Grensmaas or Gemeenschappelijke Maas (literally, Border Meuse and Common Meuse, respectively). From Maastricht to Maasbracht, the Meuse meanders over shallow gravel banks; this stretch is uncanalized, fast-flowing and virtually unnavigable. There is consequently no shipping along this part of the river, and barge traffic goes via the parallel Juliana Canal.

Near to Maasbracht and Roermond, the numerous ponds that line the Meuse form another distinctive feature. The ponds — many directly connected to the river — were formed by the extraction of gravel.

The Gestuwde Maas — the canalized stretch of the Meuse between Maasbracht and Lith — is easily navigable. This part of the river is intensively used for transport, agriculture and recreation. In the future, the canalized Meuse will form an important link between large areas of natural habitat, such as the Grensmaas, Fort Sint Andries, the Biesbosch and the Gelderse Poort. In Limburg, down to near Mook, the Meuse is not diked. The section of the Meuse Valley which is liable to flooding counts as part of the river's high-water bed.

The last stretch of the river, the Getijde Maas (Tidal Meuse) downstream of Lith, is not canalized at all, and the water is allowed to flow freely. Being linked to the sea by the Nieuwe Waterweg, the river exhibits tidal influence as far upstream as Lith.

In 1800, Johann Gottfried Tulla started with the standardisation (fixation of the main river bed) of the Upper Rhine. The maps present the Upper Rhine at Breisach before and after Tulla's correction around 1828 and after the last canalisation in 1963. As a result of canalisations less space was left for the river Rhine.

THE LOWER RIVERS

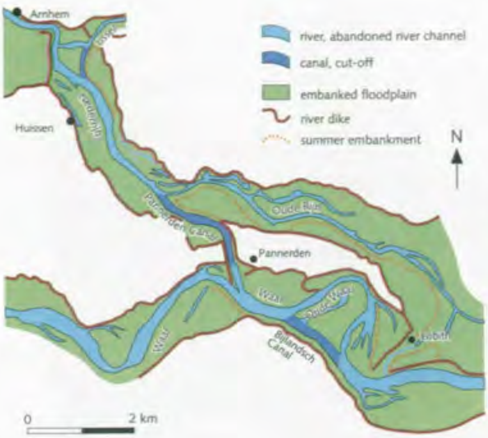
In their lower reaches, the Lek, Waal, Merwede and Meuse increasingly experience under the influence of the sea. Flow and water levels are affected by the tides; extremely high water levels can occur during storm tides. At high tide, a wedge of salt water enters the Nieuwe Waterweg and, if the flow in the river is low, gradually makes its way upstream. The southern part of the lower river area is protected from the North Sea by the Haringvliet Dam.

The IJssel flows into the IJsselmeer, which in turn drains into the Waddenzee via a sluice in the Afsluitdijk (the sea dike closing off the IJsselmeer). Water levels in the lower reaches of the IJssel are determined partly by the water level in the IJsselmeer. Also the wind can hamper discharge from the river.

RIVER MANAGEMENT IN THE NETHERLANDS: A BRIEF HISTORY

Mankind has been seeking to control the great rivers since Roman times. In about

Until the nineteenth century, the rivers were wide and shallow, with islands and sandbanks. Groynes were built in order to reduce flow along the banks so that land could be reclaimed at the water's edge. The presence of the groynes led to the creation of sandbanks as silt deposits built up; these then became covered by vegetation. Old maps show the efforts that were made to modify the river bed in previous centuries. In places where the river bank was being eroded, groynes were used to divert the current and to speed up the formation of usable land within the river's flood plain.

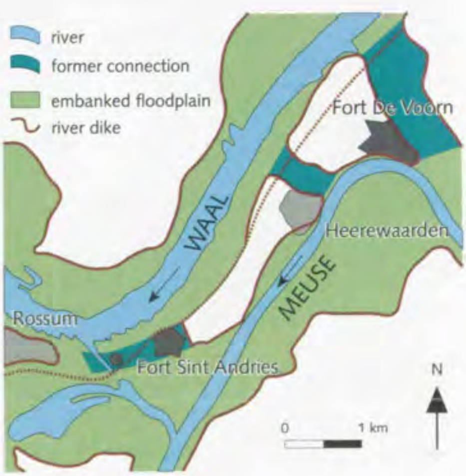


Bifurcations of the rivers Rhine, Waal and IJssel, and the cut-off canals which are dug in the 18th century.

10BC, the Roman governor Drusus built a dam at the point where the Bovenrijn divides to form the Waal and the Nederrijn. Drusus's Dam was designed to reduce the amount of water flowing into the Waal and increase the amount entering the Nederrijn, thereby giving the Batavi, who were Rome's allies, a more defensible border with the Germani.

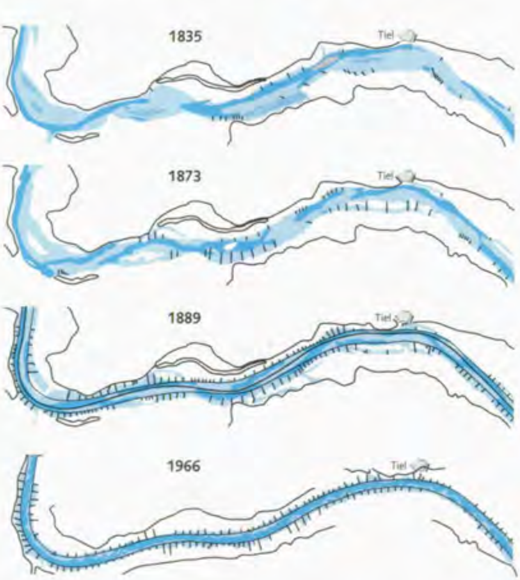
The oldest dikes on the Dutch river system were built in the tenth century. Raised more or less at right angles to the river, these early flood defences were local structures, upstream of village polders. They worked by diverting surplus rainwater and river water back into the wide main channel. Systematic diking of the rivers was not possible, however, until the country developed strong systems of government and water management. Only when the first water authorities were created in the twelfth and thirteenth centuries did the process of systematic enclosing the rivers within dikes begin, and with it the formation of polders. By 1450, the great rivers had been more or less completely diked.

For centuries, people have been trying to ensure that, where the rivers divided, water was well distributed between the branches. Such efforts were motivated not only by the need for flood protection, but also by military, trade and navigational considerations. During the fifteenth century, silt accumulation became an increasing problem in the IJssel, interfering with the commercial traffic on which the Hanseatic towns along the river depended. Mutual rivalries nevertheless prevented the towns from coordinating countermeasures. The silting was so severe that, during the Eighty Years' War, the Spanish army was able to cross the river on foot. Not until the late sixteenth century, when the Republic of the Seven United Provinces was formed, did water management become a political issue. Improved water distribution between the Rhine's branches was required to create a more defensible eastern border. In 1701, the States General ordered the con-



Former connections between the Waal and the Meuse. When the Waal discharge was high, water spilled from the Waal into the Meuse.

struction of a "retrenchment" — a defensive embankment and moat — between the Waal and the Nederrijn to the west of Pannerden. In 1707, the moat was further excavated to create the Pannerden Canal, improving water distribution between the river branches. However, there was no centralized water authority in the Netherlands until the Batavian Republican period. The "Rijkswaterstaat" — a national body responsible for water management and river improvement, the forerunner of the modern Directorate-General for Public Works and Water Management — was established in 1798.

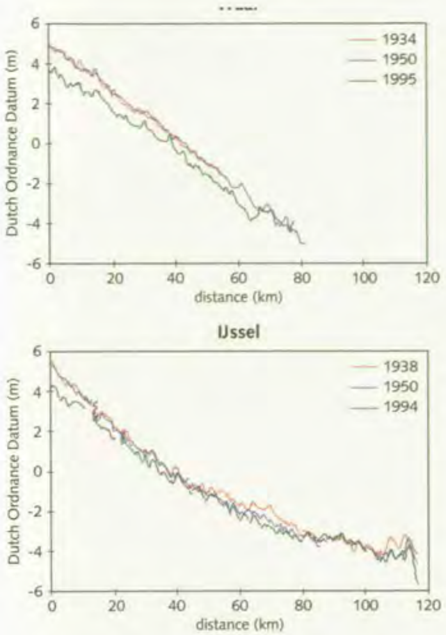


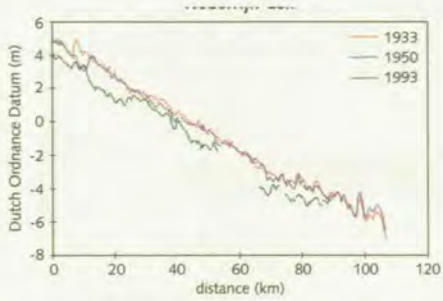
Normalisation of the river Waal in the 18th century. The width of the main channel was reduced from more than 500 metres to 260 metres, islands and sandbanks were removed, and the banks were protected from erosion by regular arrays of groynes.

The Waal has been linked directly to the Meuse since Roman times. When the Waal was running high, the connecting canal at Heerewaarden diverted water into the Meuse. Unfortunately, the Meuse was not able to contain the extra water and repeatedly broke its banks. Furthermore, the reduced flow in the Waal encouraged sedimentation, causing higher water levels in the lower reaches. Below Gorinchem, the two rivers merged, but the Merwede lacked the capacity to cope with all the water.

Until the last century, the rivers' main channels were wide and shallow, with islands and sandbanks. As a result, the rivers were sometimes difficult to navigate and there was a serious risk of ice and even ice jams forming and associated dangers.

To address all these problems, extensive river improvement schemes began around 1850. Main channels were systematically fixed and narrowed, the navigation channels were dredged, islands and sandbanks were removed and the rivers straightened at various points. Groynes and training moles were created to fix the river banks, which were also reinforced with riprap. In 1856, a lock was installed that separated the Waal and the Meuse at Heerewaarden, while the Nieuwe Merwede was cut at Gorinchem in 1876 to improve discharge from the Waal. The Bergse Maas was built in 1904, thereby creating a shorter route to the Amer and the Hollands Diep. Between 1918 and 1929, the Meuse was canalized from Grave to Maasbracht, with weirs and locks at Grave, Sambeek, Belfeld, Roermond and Linne. In 1935, the Juliana Canal was opened, linking Borgharen (where a weir was installed) with Maasbracht, thus bypassing an almost unnavigable forty-seven kilometre stretch of the Grensmaas. During the thirties, the meander cut-off shortened the course of the Meuse downstream of Grave by nearly 30 per cent.





Level of the bed of the main channels of the rivers Waal, IJssel and Nederrijn-Lek in this century.

Erosion of the main channel

Measures designed to improve discharge have led to stronger currents. As a result, the Rhine's main channel has been eroded considerably over the last hundred years along its upper reaches in the Netherlands. Eroded material is deposited in the river's lower reaches. The resultant silting may be controlled by dredging, but little can be done to prevent erosion upstream. Consequently, the Rhine's channel at Lobith degrades one to two centimetres each year. This in turn threatens the stability of the groynes and banks.

RIVER PROCESSES

Although the Netherlands' great rivers are nowadays largely controlled by man, the age-old processes of water flow, erosion and sedimentation that have shaped the country in bygone centuries still act between the primary river dikes.

The transportation of sediment

Large volumes of water flowing down a river generate enormous forces which dislodge and entrain huge quantities of sand and gravel from the river bed. The smaller a particle is, the more easily it is transported. And the faster the river flows, the greater the force on the material forming the river bed; so, if the current is strong, bigger particles of sand and even pebbles of gravel will be transported. Along fast-flowing stretches of river bed, therefore, only the largest pebbles and grains will be left undisturbed. Grains of sand are initially moved rolling along the bed of the river. At stronger currents, however, they are lifted from the bottom and carried short distances before falling back to the river bed, thus gradually making their way downstream. The stronger the current gets, the bigger the "jumps" become, until, in very fast-moving water, sandy particles actually remain in suspension. Fine particles of sediment are nor-

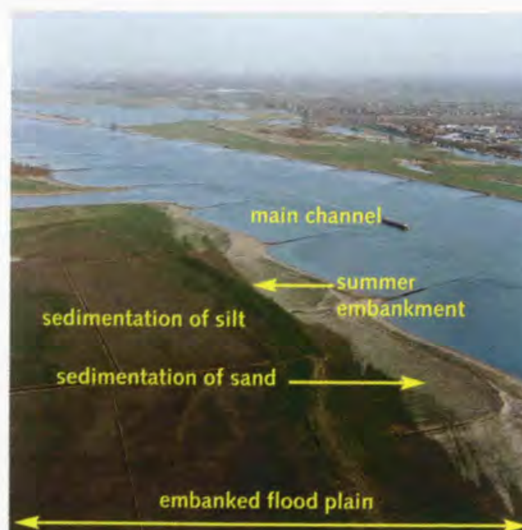
In the sand-bed Rhine branches, roughly equal amounts of material are transported in suspension and along the bed. In the fast-flowing, gravelly Grensmaas, however, sediment transport is mainly bed load. Where the river bed consists of a mixture of fine and coarse material, complex processes are at work. Fine particles are being eroded, while the coarse material remains behind. Thus, in the Grensmaas, the river bed is completely covered by coarse gravel — the so-called armour layer. If one digs a trench in a dried-up section of the river bed, the armour layer is clearly visible, overlying much finer sediment.

mally carried in suspension, giving the river water a turbid colour.

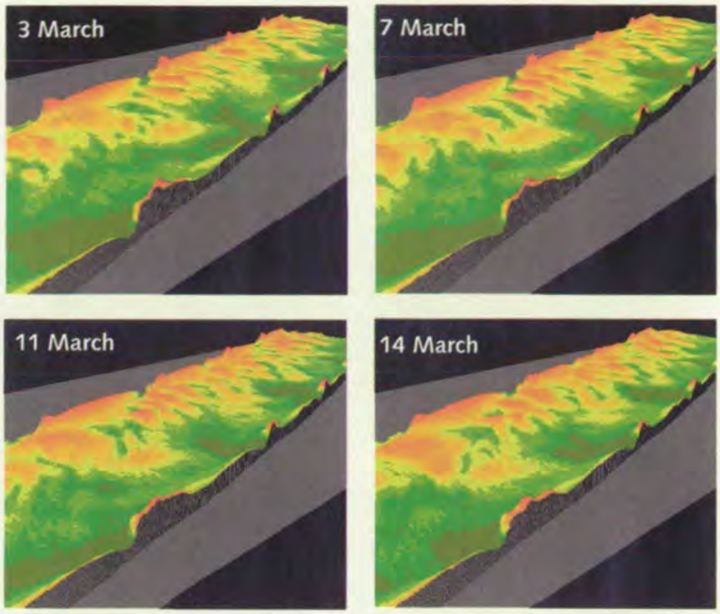
On its way towards the sea, a river gradually slows down and loses its energy to move the sediments. So first the coarse particles and later the finer grains settle to the bottom or cease to move; as a result, the river bed becomes covered with finer sediment further downstream. Local differences in current strength also occur within the main channel, particularly between inner and outer bends. In the outer bend, the river flows more fast. Here, the currents are too strong for the finer grains to settle to the bed, which therefore, is made up of coarse particles. In addition, a current along the bed towards the inner bend moves these finer grains from the outer to the inner bend where they can settle.

Sedimentation

Approximately a third of the sediment transported by the Rhine reaches the North Sea. The rest is deposited in the river's lower reaches, where the current is not strong enough to carry the particles any further. Sediment also settles in the slow-moving stretches between weirs. However, most of this sediment is re-eroded when the weir gates are opened at times of flood. When the river's main channel overflows, material is also deposited on the flood plain, where the water moves much more slowly, allowing sediment to settle. The reduction of current velocities is most apparent where the water overflows the natural levees along the main channel: most of the sediment transported from the main channel towards the flood plain therefore, settles on



During flood periods, sand is deposited by the river on its natural levees. Deposition of silt and clay occurs behind the summer embankment.



Migration of river dunes on the main channel bed of the river Waal during the 1997 flood. The river bed topography of a 1 kilometre reach is shown for 4 successive time steps between the 3rd and 14th of March 1997. Dunes up to 2 metres high have been observed. The river flows from right (behind) to left (front).

Sand dunes on the river bed

During periods of flood, when flow increases, the sediment of the shifting river bed becomes rippled within a few days. Ribs of several meters long and decimetres high are formed. Gradually, "sand dunes" several metres high are built up under the water. Over time, these ridges creep downstream and new ripples form on and move across them. The gentle slope on the upstream side of a ridge is constantly eroding, while sediment is being deposited on its steep downstream edges. It is this process that causes the ridges to edge their way downstream. Movement of the dunes can be tracked by taking precise depth measurements when the river is running high. As well as affecting the water depth, these underwater ridges are a source of drag, slowing the river considerably. If dune accumulation during flood is particularly great, the water level can actually continue to rise even after the flow has started to fall.

these levees, which is the reason behind the presences of these levees in the first place. Smaller particles, which sink more slowly, are deposited further away from the main channel. After periods of serious flooding, the river can leave up to ten centimetres of sediment along its banks. A few millimetres per flood cycle is deposited on the rest of the flood plain. A layer of sedimentary clay more than a metre thick has been built up over the centuries. Sandy particles from the banks can be dispersed by the wind, locally forming dunes on the flood plains. These dunes sometimes support unusual flora and fauna, with particularly wide varieties of insects.

3 FLOODS!

Floods !

People living near the Netherlands' great rivers have always had to be alert to danger. It is a fact of life that the rivers sometimes run high, and there is rarely much warning. Down through the centuries, the river dikes have repeatedly been made higher and stronger and metres of sediment have accumulated on the flood plains. Today, the prospects of raising the dikes even further is no longer seen as appropriate. Alternative strategies are therefore being sought, such as increasing the absorptive capability of the river basins and the storage capacity of the rivers and adjoining water bodies. The central pillars of the Netherlands' water management policy are creating space for the rivers and increasing the "flexibility" of the river systems so that they can cope with floods.

THE PAST

Down through the centuries, people living near the rivers have had to live with the possibility of flood disaster. Dikes have repeatedly failed, and not only at times of floods. Drifting ice would damage the tops of the dikes and often led to the formation of ice jams, which raised the water levels and increased the risk of dikes overflowing. Such problems were compounded by the fact that, in periods of poverty or war, dike maintenance was neglected. And the advance of many an invading army was hindered by breaking through a dike to flood an area of land.

A historic disaster occurred in 1926. On New Year's Day, discharge in the Meuse at Borgharen reached the previously unrecorded level of three thousand cubic metres a second. Meanwhile, at Lobith, a record figure of 12,600 cubic metres a second was registered on the Rhine. River dikes failed at various places, leading to flooding the land behind.

THE CAUSES OF FLOOD

For a well planned river area and prevention of flooding, insight is needed into the characteristics of the rivers. The strength of currents in a river depends on various factors, such as channel geometry (width, depth, straightness) and bed roughness. The amount of water

Untill the end of 1900, dike breaches occurred several times. Large areas were flooded. Where the dike broke, the floodwater usually eroded a scour hole of several meters depth. After the flood, a small pond remained as a dike-breach scar. These ponds are called 'wielen' or 'waaien'.

The last big flood disaster in the river area caused by a breach of a dike occurred in 1926.

flowing down the river is determined by climatological conditions, the characteristics of the basin and human activity.

Climate

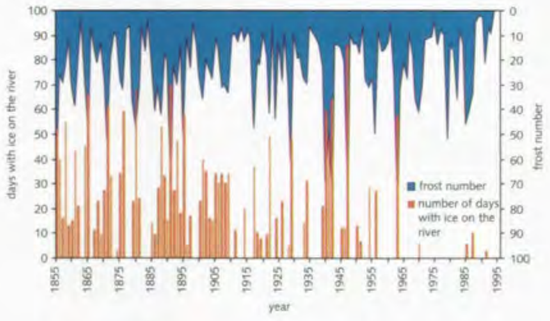
Rivers are part of the natural water cycle. The amount of water in a river primarily depends on the amount of precipitation — rain and snow — in the river basin. Snow, however, may lie on the ground before melting and draining into the river. And not all rain falling on the catchment area enters the river: some is absorbed and subsequently transpirated by vegetation. Precipitation soaks into the soil, and increases soil-moisture. That precipitation which is not retained in the soil either evaporates or drains into water courses. Evaporation rates are influenced by meteorological factors, such as radiation, temperature, humidity and wind.

Characteristics of the river basin

One of the main factors influencing the retentive capacity of the river basin is the type of the soil: whether it is rocky or sandy, for example. And the steeper the valley slope, the more quickly rainfall will drain into the river. If the apparently variability of water flow in the Meuse is studied, the effect of these factors is clearly discernible. Rain falling in the Ardennes (Belgium) can reach Maastricht within twelve hours. The rocky soil of the hillsides does not retain much water, so precipitation soon drains down into the river valley. Soil saturation is particularly rapid in the winter, when there is virtually no evaporation. Furthermore, if the soil freezes, it loses its ability to retain water altogether, and the rainfall runs off the surface, straight into the water courses.

Human activity

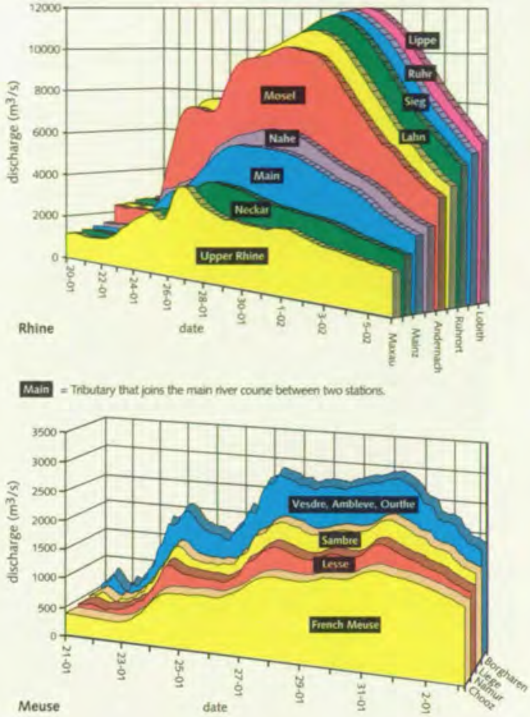
Changes in land use affect the volume of precipitation is absorbed and evaporated by vegetation cover. The ability of the soil to absorb water can also be affected. Where woodland is cleared for agriculture, does more precipita-



In the past, many dike failures were caused by ice jams. However, thermal pollution and the normalization activities undertaken since 1850 have reduced the risk of ice-floe formation considerably. The graph shows that cold winters (high frost number) still occur, but that the number of days with ice per year on the rivers has dropped considerably this century.

Floods 1993 - 1995: Signs of climate change?

The rivers rose to extremely high levels in 1993 and 1995. At the end of 1993, discharge in the Meuse hit a previously unrecorded rate: 3,120 cubic metres a second. About ten thousand people were evacuated from their homes in the province of Limburg, with the water level six metres higher than normal. Similar events were seen in 1995, and this time the Rhine was also very high. The discharge at Lobith reached approximately twelve thousand cubic metres a second — the second highest recorded figure ever. In the province of Gelderland, some two hundred thousand people were evacuated from areas close to the rivers. At Borgharen, discharge in the Meuse peaked at 2,870 cubic metres a second in January 1995. Prolonged rainfall kept the water at these extraordinary levels for five days.



Flood on the Rhine and Meuse in 1995.

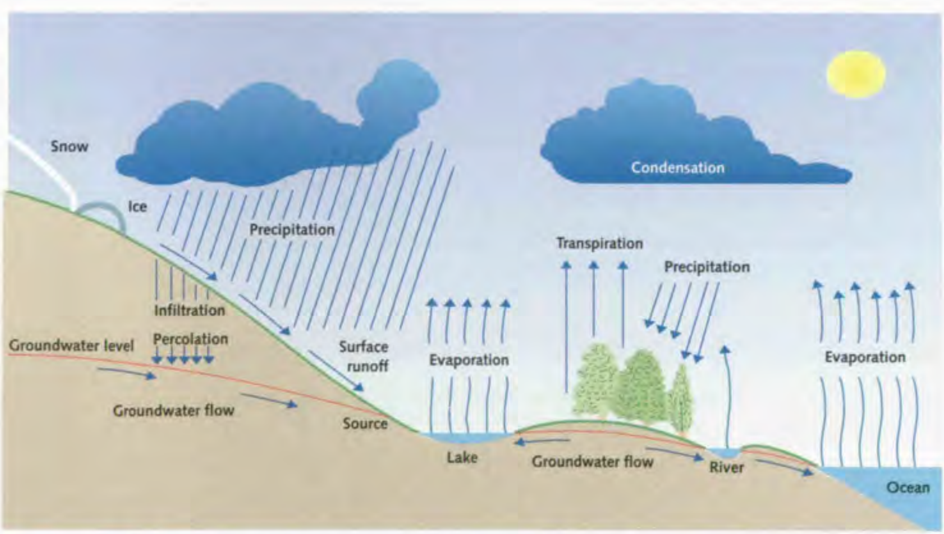
The main reason for these floods were the warm, wet winters of 1993/1994 and 1994/1995. Persistent depressions over the North Sea caused extremely heavy rainfall in the Rhine and Meuse basins. In early January 1995, snow fell across much of the Rhine basin; when a thaw set in on the tenth, the meltwater filled the pores in the soil and the ground became saturated. Starting from January 21 th, mild westerly air currents brought heavy rain: twice the monthly average within ten days. At the same time, much of the snow melted in these mild conditions, swelling almost all of the Rhine's tributaries to an abnormal degree. Simultaneous peaks in discharge from the Mosel, the Sieg, the Ruhr and the Lippe caused a wave of extreme flood in the Netherlands.

The mild, wet winters of 1993/1994 and 1994/1995, together with the hot, dry summers of recent years are consistent with the type of climate change that the 'greenhouse effect' is be expected to bring about. However, subsequent flood events are historically not uncommon. Records show that similar events took place in 1824-1825, 1844-1845, 1918-1920, 1925-1926 and 1982-1983. Hence, it is not possible to say whether we are already witnessing the greenhouse effect in action. Nevertheless, the extreme flood levels seen in 1993 and 1995 can occur in the future.

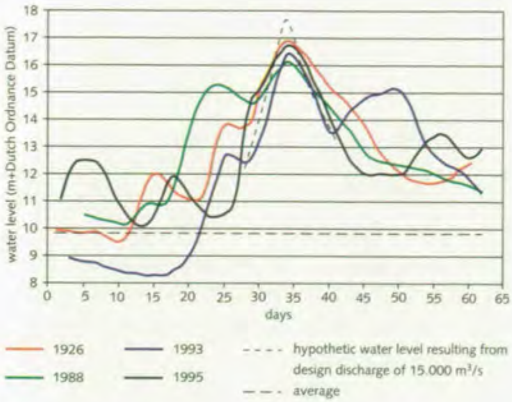
tion reach the ground, and water drains more easily from the soil into the rivers. As a result, less precipitation finds its way into the groundwater reservoir which reduces the low discharges. Urbanization has a similar but more marked effect. Precipitation falling on a built-up area drains immediately into the sewer system and reaches the water courses even more quickly.

Changes in land use mostly affect floods of moderate magnitude. Extremely high flows will only be influenced locally. And even then, only when peaks are generated by heavy summer rain. Deforestation certainly cannot be blamed for the very high river levels seen in recent years, since the area of woodland along the Meuse has actually increased by 8 per cent since 1830. The effect of increased urban development is clearly visible at the local level during heavy summer rainfall episodes. However, under the type of conditions seen in the winters of 1993/1994 and 1994/1995, soils throughout the river basin become saturated, and all further rain runs virtually straight off, so it makes no difference whether it falls on open countryside or paved streets.

People have also modified the water system itself, by canalizing rivers and building weirs and storage reservoirs. These activities can have considerable impact when the rivers are running high. Furthermore the impact is by no means limited to the part of the river which is modified. This has certainly been the case with the canalization and diking of the Upper Rhine between Basel and Maxau, which involved the loss of 60 per cent of the original flood plain area. Once the canalization and diking work was complete, flood waves propagate more quickly along this stretch of river. Such waves also became steeper, since canalization reduced water storage along the river, which previously tended to have a dampening effect. Discharge peaks along the Rhine increased sometimes over 20 per cent.



Rivers are a link in the water cycle. The amount of water flowing through the rivers depends on the climate (precipitation, evapotranspiration, snowmelt) and on basin characteristics.



Comparison of the flood waves on the Rhine in 1926, 1993 and 1995.

FLOOD PROTECTION ACT

Today, strict safety regulations apply to primary flood defences, such as dikes, dams, weirs, dunes, storm tide barriers, locks and inlets. The 1996 Flood Protection Act linked the level of protection required to the nature of the flood threat and the seriousness of the potential consequences in a given area. The maximum acceptable risk for each area is specified separately. So, for example, the risk of flooding in the low-lying and densely populated "Randstad" (the Netherlands' western conurbation) must be limited to one event in ten thousand years. Given that the danger to the Randstad is posed by sea water at storm tides, for which little warning can be given, there is a relatively high risk that, in the event of flooding, casualties would be suffered. The economic importance of the area is also felt to warrant a high level of protection. Population density along the rivers is lower than in the Randstad, and river floods can be predicted far enough in advance to allow for the evacuation of threatened areas. The land along the rivers is also less significant in economic terms. Taking these factors into account, the safety standard for the riverside areas was set at an average of one flood event per 1,250 years.

The highest water level which a defence should be able to withstand is referred to as the design hydraulic load (DHL). The DHL is assessed every five years by the Minister of Transport, Public Works and Water Management. From the DHL, the requirements such as dike height, stability, dressing and so on are derived. The law obliges the agencies responsible for primary flood defences — the Directorate-General for Public Works and Water Management and the water authorities — to check that the structures meet the relevant safety requirements. Compliance has to be demonstrated every five years. If compliance cannot be demonstrated, the structure in question has to be brought up to standard.

High discharge through the river Waal. The polders here are like bathtubs behind the river dikes. A polder will be flooded within a day in case a river dike breaches. The inundation depth, then, will be several meters.

Bart Parmet, RIZA hydrologist:

"Reducing the uncertainties involved in the calculation of design discharges."

The design discharge is the maximum discharge which, in theory, should be exceeded on average once every 1,250 years. In other words, a discharge for which the risk of occurrence in a given year is one in 1,250. 'The design discharge has to be calculated from historical data. Unfortunately, the measured data on discharges at Lobith goes back less than a hundred years, which is not enough for direct calculation of the design discharge. A discharge for which the risk of occurrence is one in 1,250 therefore has to be extrapolated from the available data using statistical distribution techniques.'

However, calculation of the design discharge is fraught with difficulties. 'First, we have to consider the extent to which the last hundred years is representative for a longer period of time: the sort of period for which one really needs data to work out the design discharge. Second, the data set needs to be homogeneous — a statistician would say that the data has to come from the same population. Unfortunately, our data isn't really homogeneous, because there have been all sorts of changes to the river and the river basin in the last hundred years. Then there is a third problem: selecting the appropriate statistical distribution model. Using a different model would produce a different result.

'We can 'homogenize' our data set by correcting for the influence of changes in the river and the river basin. Then we make calculations using several different distribution functions to try and come up with a realistic design discharge. All the same, the figure we finally arrive at is an estimate with a wide margin of uncertainty.'

With a view to reducing the uncertainty, a special computer model, known as a 'stochastic precipitation generator', is being developed in collaboration with the Royal Dutch Meteorological Institute (KNMI). 'The model simulates thousands of years' rainfall across the Rhine basin, enabling us to build up a data set covering a longer period than the measured data relates to,' explains Parmet. 'And we are working with colleagues in Germany to develop a hydrological model which will predict the discharges associated with the simulated precipitation levels. In this way, we intend to create a large body of data applicable to the present situation, which will also solve the homogenity problem. The precipitation generator will also provide information on the nature of the flood wave, which will help us calculate the duration of flood events. This is important because the longer water is in contact with a dike, the more likely the dike is to become saturated and collapse.'

DESIGN DISCHARGE

A DHL is associated with a particular level of river flow, known as the design discharge. The high-water beds of the Rhine and Meuse have to be able to contain the design discharge without flooding in the areas behind the dikes. Design discharges for the Rhine and Meuse are calculated from measured data on discharges at Lobith and Borgharen, respectively. However, the data sets only go back to 1901 for the Rhine and 1911 for the Meuse, so they do not provide a complete picture of the rivers' high-water behaviour. It is particularly difficult to calculate the water level that on average should occur only once every 1,250 years. Prior to the events of 1993 and 1995, statistical data for the Rhine indicated that the design discharge at Lobith is 15,000 cubic metres per second, while the comparable figure for the Meuse is 3,650 cubic metres per second. But when the design discharges are next reviewed, the record will include 1993 and 1995. As a result, the derived design discharge for the Rhine will rise by about 1,000 cubic metres a second, and that for the Meuse by about three hundred cubic metres a second. This in turn will require modification of many flood defences.

Using mathematical river models, it is possible to calculate design water levels along the river branches in the Netherlands. Consideration has to be given not only to the flow of the water, but also to waves on the surface. Waves are induced by the wind. In the lower reaches of the river, the models also have to incorporate tidal influences. The developers are currently seeking to determine the "band width" of the calculations, which are linked to the degree of uncertainty inherent in the model. The more we know about the uncertainties associated with the safety standards, the less likely we are to be taken by surprise.

Researchers indicate that, between now and the year 2050, climate change could cause the design discharge to rise by about 5 per cent in the Rhine and about 10 per cent in the Meuse. Reviewing design discharges is not simply a question of studying historical data. Policies intended to provide safety in the future must take account of climate change and the effects of modifications of the river and its basin.

FLOOD CONTROL IN THE UNDIKED SECTION OF THE MEUSE VALLEY

Along the stretches of the Meuse without dikes, floods bring different problems to those experienced along diked rivers, where it is assumed that the river will periodically flood the land between the outer defences. The undiked section of the Meuse Valley is in intensive use and contains numerous villages and hamlets. Consequently, even moderate discharges can cause damage and inconvenience as the river waters floods the high-water bed. Following the flooding of 1995, low ring dikes were built around the main settlements along this stretch of river. Within these defences, the risk of flooding in any given year is one in fifty. Thus, the ring dikes offer much less protection than ordinary river dikes, but can substantially reduce the damage caused by moderate flood. Once the engineering works planned for the river Meuse have been completed, the annual probability of flooding will drop to one in 250. At times of extreme flood, however, evacuation will still be necessary. River levels can be predicted with reasonable confidence, certainly downstream of the Grensmaas. Hence, the risk of flooding-related casualties is low even when the river is running extremely high. In general, there is sufficient time to remove people and some of their possessions from threatened areas.

Flooding along the river Meuse. Large parts of the Meuse valley have been flooded. In this part of the Meuse valley, low areas will inundate slowly when the river water rises. The old river terraces along the Meuse are higher and are not flooded.

FLOOD FORECASTING AND WARNING SYSTEM

When a flood is expected, a flood warning system goes into operation. RIZA calculates the anticipated water levels at Lobith and Borgharen (the places where the Rhine and the Meuse, respectively, enter the Netherlands) so as to predict the advance of flood waves. In this way, about half a day's notice of high water levels can be given for the Meuse and a few days' notice for the Rhine. Using the forecast data for Lobith and Borgharen, the Regional Directorates calculate water levels along the river branches. The earlier imminent problems are detected, the more damage can be prevented by setting up dike watches, closing culverts, taking ferries out of service and, where necessary, evacuating people and livestock. Water level information and flood warnings are posted on the Dutch Teletext (pages 720 and 725).

Water levels on the Rhine are considered to be high if they are more than 14.00 metres above Dutch Ordnance Datum at Lobith and a further rise of at least one metre is anticipated. On the Meuse, flood is defined as any discharge greater than 1,500 cubic metres per second. To produce such a discharge, at least thirty to forty millimetres of rain per day must fall on the river basin for several days. RIZA issues flood warnings for the Meuse if the level at Borgharen reaches 44.00 metres above Dutch Ordnance Datum and is expected to rise further.

The information- and warning centre of RIZA.

For the Rhine, flood can be predicted much further in advance than for the Meuse, whose water level responds more quickly to rainfall in the river basin. The size of the Rhine's basin means that rainfall often takes two days or more to reach Lobith.

FLOOD CONTROL IN THE FUTURE

Breaking a vicious circle

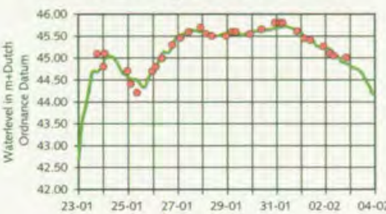
By embanking the rivers within dikes, mankind has created a vicious circle. Dikes limit the space occupied by a river and thus its discharge capacity; they also restrict the area over which silt can be deposited. As a result, ground levels in the flood plains between the dikes have risen by several metres in the last few hundred years. And, as flood plain heights have risen, so inevitably have high water levels. To contain the higher water, the dikes have repeatedly been increased in height. Meanwhile, the land behind the dikes has become drier and consequently sunk. As a result the height differential between the river and the polders has gradually increased. It is therefore imperative that this vicious circle of higher flood plains and higher dikes is broken.

Action plans have been drawn up for both the Rhine and Meuse basins, aiming at limiting

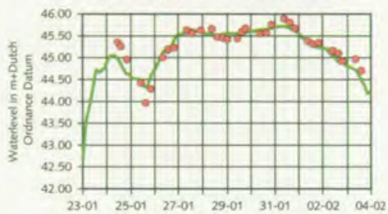
Several-day predictive models

The waterlevels of the Meuse at Borgharen are forecasted using a set of models. A statistical model of the French Meuse and runoff models for tributaries in the Ardennes provide information on conditions upstream. A hydraulic model is then used to predict how the flood wave will advance along the Belgian Meuse towards the Netherlands; this model uses discharge data from France and Belgium, plus precipitation data and forecasts from the KNMI.

Forecast Borgharen 12 hours before

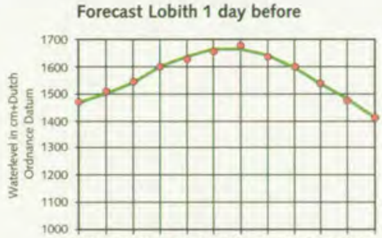


Forecast Borgharen 24 hours before

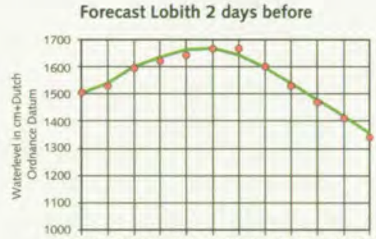


RIZA's several-day forecasts of water levels on the Rhine at Lobith are, by contrast, based entirely on a statistical model. The model's input consists of discharge data from Germany and precipitation data and forecasts from the KNMI. River level predictions generated by this system have proved accurate to within ten centimetres one day ahead and to within fifteen centimetres two days ahead. 3 and 4 days ahead, RIZA restricts itself to trend forecasting (i.e. "Rising" or "Falling"). RIZA is participating in international initiatives aimed at developing of a better model that takes account of the relationship between precipitation and discharge in the tributaries and the advance of the flood wave.With accurate precipitation forecasts for the Rhine and its tributaries, the new model should make it possible to predict river levels three days in advance.

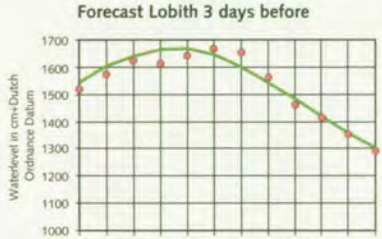
Forecast Lobith 1 day before



Forecast Lobith 2 days before



Forecast Lobith 3 days before

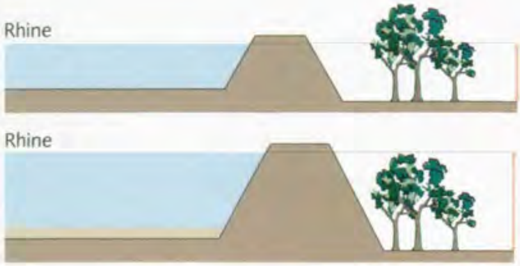


Forecast Lobith 4 days before

Measured   Forecasted

The more days forecasted before, the greater unaccurateness will be in the forecasted waterlevels.

the flood risk in the future. These plans have two key objectives: reducing peak discharges and extremely high water levels, and limiting the potential damage of any flooding which might nevertheless occur.



Dike raising will finally lead to a larger inundation depth, and therefore more damage, when a dike should burst.

Reducing peak discharges

Flood waves can be reduced by increasing the absorptive or storage capacity of the river basin and river system. This involves increasing the infiltration capacity of the soil, reducing drainage rate, and promoting more land use. Such measures are effective mainly on small tributaries.

It is possible to increase the amount of water that can be "stored" in the river system by creating retention basins or overflow areas. Such measures are particularly effective in a river's upper reaches, but the scope for action of this kind in the Netherlands is nevertheless being investigated.

'Make way for rivers'

To supplement the Flood Protection Act, a policy document entitled 'Make way for rivers' was published in 1996 by the Ministry of Transport, Public Works and Water Management and the Ministry of Housing, Spatial Planning and the Environment. This document explains how the authorities intend to give the great rivers more room, so that their flow capacity is retained and, where necessary, increased. This is particularly important, given the possibility of climate change causing higher design discharges in the future. The policy has two key objectives: improving flood defence systems and controlling the impact of any flooding which might nevertheless occur. In principle, therefore, only river-related activities such as shipyards, which need to be sited on the rivers, will be allowed into riverside locations. Activities which have no direct ties with the rivers — recreation parks, for example — will not be approved unless there is special need.
In 'Make way for rivers', particular attention is given to the situation along the undiked part of the Meuse. One of the conditions for future utilization of the Meuse Valley is that it may not result in a reduction of its ability to retain water. This is because reduced water retention in the Meuse Valley means more pressure on areas farther downstream. Furthermore, the valley floor is to be kept as free as possible, anticipate in planning for future flow-improvement for measures within the high-water bed. Consequently, no further residential or industrial development will be sanctioned within the valley. A more flexible attitude is taken towards retention areas: sections of the high-water bed where there is almost no water movement following inundation. Clearly, measures developed to improve flow in the channel proper are less relevant in places where there is no flow.
The policy does not affect life within established Meuse Valley towns and villages, where development is still permitted. However, it is necessary to demonstrate that new projects must not add to the potential impact of flooding. 'Make way for rivers' ties in with international moves to address the issue of flood in the Rhine and Meuse basins.

The capacity of the high-water bed can be increased by, for example, increasing flood plain width, lowering the flood plain and removing obstacles which impede flow, such as pieces of raised ground. The current spatial planning policy is designed to ensure that sufficient space is reserved, both inside the high-water bed and beyond, to enable such meas-ures to be implemented in the future. The policy document 'Make way for rivers' has accordingly been in force since 1996.

Reducing consequences of flooding

It is also possible to reduce the risk of flooding which might occur. First, areas liable to flooding can be left unoccupied wherever possible. This may involve the introduction of planning and building regulations. In addition, improved warning systems and contingency planning can help to reduce the consequences of flooding.

Water retention along the Rhine

Along the Upper Rhine in Germany, retention areas — large polders beside the river, which inundate only at times of flood — are being created. These will be able to store up to 270 million cubic metres of water and are also planned in the state of Nordrhein-Westfalen. About a 100 million cubic metres of capacity is already available, and was first utilized during the high-water episode of 1988. By diverting water into these retention areas, it was possible to reduce the water level by twenty-three centimetres at Maxau and by five centimetres at Cologne — just sufficient to save Cologne's historic city centre from flooding. To create the retention areas, the state government will be clearing approximately four thousand hectares of riverside land in the years ahead — enough to accommodate 170 million cubic metres of water.

WATER DISTRIBUTION 4

Water distribution

Water is not merely a threat to the Netherlands; it is also a valuable resource. Most of the nation's fresh water comes from the Rhine and the Meuse. Given the number of people who use this water, fair and efficient distribution is essential. This is particularly so during dry summer months, when the rivers carry little water, but this demand is at its highest.

THE WATER BALANCE

The Netherlands have a temperate maritime climate, with precipitation occuring throughout the year. Average annual rainfall totals 760 millimetres: in terms of flow, the equivalent of 950 cubic metres a second. This figure is approximately 30 per cent of the total amount of water entering the Netherlands on average. No less than 65 per cent of the Netherlands' fresh surface waters comes from the Rhine and a further 8 per cent from the Meuse. The remainder comes from smaller cross-border rivers. Evaporation from open water bodies varies from zero in the winter to four or five millimetres a day in the summer. In overall terms, there is a precipitation deficit in the summer and a surplus in the winter.

WATER USE

Every year, about sixteen billion cubic metres of water are taken from the Netherlands' two great rivers. This water is used for various purposes, including agricultural sprinkling and "rinsing" silt polders. Such rinsing takes place mainly in the western part of the country, where the groundwater tends to be brackish or saline. River water is also used for the preparation of drinking water — some 1.28 billion cubic metres of it in 1994. Almost as much again (1.2 billion cubic metres in 1990) is used for industrial purposes, excluding cooling at power stations. Water from the IJssel

Approximate water balance of the Netherlands

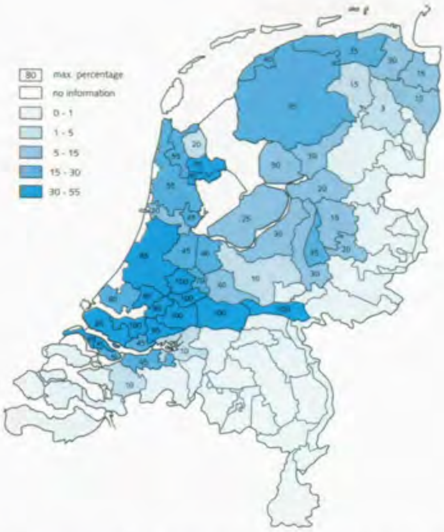
	Average year (10^6 m^3)	**Dry year (1976)** (10^6 m^3)
In		
precipitation	30100	20800
Rhine at Lobith	69000	41500
Meuse at Borgharen	8400	3500
other river inflows	3000	1500
total	110500	67300
Out		
evapotranspiration	19500	20500
various uses	5000	6000
river outflow	86000	40800
total	110500	67300

additionally serves to maintain fresh water levels in the IJsselmeer. Furthermore, the great rivers play a vital role in the prevention of drought in parts of the country with a large summer precipitation deficit.

THE DISTRIBUTION OF WATER BETWEEN THE RIVERS

The Rhine branches

The Netherlands is the Rhine's delta, and the river divides repeatedly on its way through the country. At Pannerden, five kilometres downstream of Lobith, the river splits into the Waal and the Pannerden Canal. The latter divides near Arnhem, to form the Nederrijn and the IJssel. When the Rhine is running high, about two thirds of the flow enters the Waal, while two ninths finds its way into the Nederrijn and one ninth into the IJssel. When the river is low (i.e. the flow is less than 1,300 cubic metres a second), three weirs are closed on the Nederrijn and the Lek. This has the effect of increasing the proportion of Rhine water entering the Waal and the IJssel, while reducing the amount flowing into the Nederrijn. Altering the distribution in this way benefits shipping and ensures that sufficient fresh water reaches the IJsselmeer. When flow rises to between 1,300 and 2,400 cubic metres a second, the weirs at Driel are gradually opened and the amount of water flowing along the Nederrijn increases. At high Rhine flows (more than 2,400 cubic metres a second), the weirs at Driel are opened fully and the distribution of water between the river branches is not subject to active human control. Anymore, the IJssel discharges into the IJsselmeer, from where the water is released into the Waddenzee through discharge locks in the Afsluitdijk (the sea dike closing off the IJsselmeer).

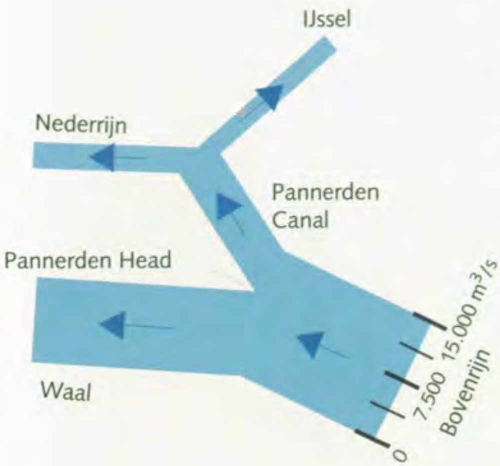


Percentages of Rhine water in the water systems in different regions during a very dry year (1976).

Water distribution over the lower rivers is regulated with weirs and sluices.

The Meuse

Weirs regulate the distribution of water between the Meuse and the canals between Maastricht and Roermond, on the basis of



Distribution of the Rhine discharge over its distributaries.

river flow. When flow at Borgharen is less than 1,200 cubic metres a second, the weir gates are closed and relatively constant level is maintained at each of the seven weirs (at Borgharen, Linne, Roermond, Belfeld, Sambeek, Grave and Lith). This situation prevails almost all year round: the weirs are open for an average of only four days a year. A system of canals enables water from the Meuse to be diverted to agricultural areas and nature reserves. Sometimes, however, there is not enough water in the river to allow optimal distribution to all quarters. At such times, choices have to be made. The aim is always to maintain a flow of at least ten cubic metres a second in the Grensmaas; otherwise, irreparable damage would be caused to natural habitats along the river. Lower flows along the Grensmaas would also lead to unacceptable reductions in water quality, since the waste water discharged into the river would not be diluted sufficiently.

Tidal river area

The area containing the former estuarine stretches of the lower Rhine and the Meuse is known as the tidal river area. This area is directly connected to the North Sea by the Nieuwe Waterweg, but the southern outlet is closed off by the Haringvliet Dam. Since the construction of the dam, the southern part of the tidal river area has become a fresh water basin, and thus a major source of water for agriculture and drinking water supply. The area is also important in relation to the management of water levels in the polders in the west of the country. The lock in the Haringvliet Dam serves as a control valve, which is used to regulate water levels in the tidal river area. When flow in the Rhine at Lobith is less than 1,700 cubic metres a second, the locks are closed. As flow increases, they are gradually opened. In addition, water is distributed in such a way as to ensure that flow in

The weir at Amerongen.

Sprinkling during dry summers.

the Nieuwe Waterweg does not fall below 1,500 cubic metres a second. Otherwise, the incursion of salt water would reach undesirable levels. For the benefit of shipping, water managers try not to let the low water level at Moerdijk drop below sea level. During storms, the locks are closed.

FUTURE TRENDS

Maintaining an adequate supply of water to the IJsselmeer will remain a high priority in water distribution policy, given the lake's importance as a central fresh water basin. Fresh water may in the future become more scarce, if climate change results in hotter summers. Under such circumstances, demands for water are likely to rise, while summer river flows fall.

SHIPPING 5

Shipping

The Netherlands is Europe's biggest inland shipping nation. Nearly half the freight shipped to and from Germany is transported by the river Waal: the busiest inland waterway in Western Europe. To protect the viability of this industry, millions of guilders will be spent during the years ahead on navigational improvements along the Waal and the Meuse. Other important fields of activity will include the communication of water level information, river traffic control at busy points and the provision of emergency warnings.

Transport of goods over the Rhine to the hinterland.

Economic significance

In relation to its size, the Netherlands has more navigable inland waterways than almost any other country in the world: about 4,800 kilometres in total. Located at the mouths of two of Europe's rivers, the Netherlands is a natural access point to a large part of the European mainland. Inland waterways handle about 40 per cent of the nation's international freight traffic (excluding sea shipping) and 20 per cent of domestic freight traffic. An annual total of about 290 million tonnes of freight travels along the inland waterways: fifty-five billion tonne-kilometres a year.

The Netherlands is a distribution land. Transport over water (international), road, rail, by air and via pipelines

	%
inland navigation	46
road transport	39
rail	4
pipeline	11
by air	+ 0

100% = 368 million tonnes

Container transport is the fastest-growing sector: more than a million, or about 35 per cent, of the containers shipped via Rotterdam each year come or go by inland waterway. Of the eleven thousand inland vessels registered in Western Europe — a fleet whose total freight capacity is eleven million tonnes — nearly 50 per cent sails under the Dutch flag. These vessels come in all shapes and sizes, from relatively small three-hundred-tonnes barges to multiple barge sets with six cargo units and a capacity of seventeen thousand tonnes. The latter take bulk cargos, dry goods and liquids.

In terms of cost per tonne-kilometre, water transport is cheaper than any other mode. It is also more environmentally friendly. A six-unit multiple barge set can carry as much freight as 600 lorries. It is also worth noting that, despite decommissioning regulations and recent rationalization, the inland shipping fleet still has a certain overcapacity. This is particularly marked in the dry bulk cargo market, but overcapacity also exists in the tanker sector, as a result of competition from new pipelines, despite the withdrawal of many vessels from service.

In addition to commercial shipping, the IJssel and the Meuse carry a great deal of recreational traffic. Recreation boats are also quite common on the Nederrijn and the Lek, but rare on the Waal, being too dangerous for non-professional traffic.

WATERWAYS

Classification

Waterways are classified on the basis of traffic volumes. Under the Second Transport Structure Plan, the Bovenrijn and the Waal are classed as primary transport axes, also referred to as hinterland links. Other classifications include "major waterway" (the category under which the Meuse falls) and "other waterway". The Waal, the Nederrijn, the Lek and the diked section of the Meuse form east-west freight transport axes, while the IJssel and the undiked Meuse carry north-south traffic.

Vessel types

Inland vessels come in all shapes and sizes, from special cement ships to tankers carrying liquid gas. The capacity of a motor tanker or motor freight vessel varies from 250 tonnes to 3,600 tonnes. Multiple barge sets are in an altogether different category: a six-unit set can transport as much as twelve or even seventeen thousand tonnes. With the cargo units arranged in a long formation, such a set can be three hundred metres from bow to stern; wide formations can be about thirty-five metres across.

Transport of different cargo types per inland ship over the river Rhine.

The Rhine

The Rhine is one of the main transport arteries linking the world port of Rotterdam to the Ruhr and central Europe as far as Basel. The water level in the Rhine is almost always high enough to be navigable for freight vessels, some 165,000 of which pass Lobith every year. About 150 million tonnes of freight a year are carried over the Waal, Western Europe's busiest shipping river. In the next ten years, the annual volume of freight traffic on the Waal is expected to rise to 220 million tonnes.

The Meuse

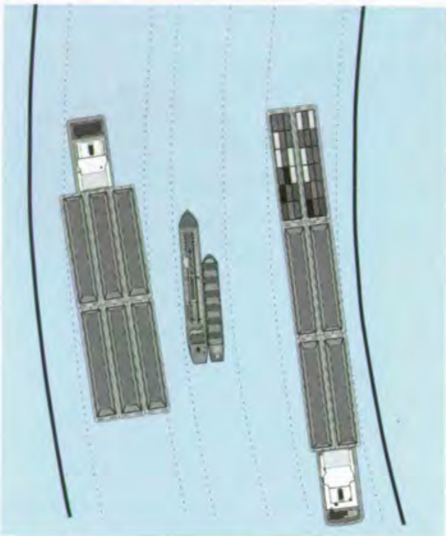
Along with the Waal, the Rhine-Scheldt Canal and the Albert Canal (Belgium), the Meuse is part of a ring of trans-European inland waterways. In the interests of navigability, water levels in the river are permanently controlled by weirs. Because part of the Grensmaas cannot be negotiated by commercial vessels, the stretches either side are linked by the parallel Juliana Canal to make a continuous navigable route. Since canalization of the Meuse and construction of the Meuse-Waal Canal, traffic on the river has increased considerably. In 1930, fifteen thousand vessels with a total capacity of 4.5 million tonnes passed through the Sambeek lock. The combined capacity of the 55,700 vessels passing through in 1996 was 41 million tonnes. Up to the Second World War, coal accounted for 60 per cent of freight on the river; today sand and gravel make up a similar percentage.

Variations in water level

Variations in water level have a major impact on the navigability of the river. When water levels are very high, shipping is not allowed to use the river in Germany, in case the vessels' bow waves and wakes should damage buildings and other structures. When the river is running very low, shippers have to limit their loads to avoid grounding; this in turn increases the transport cost per unit.

Minimum requirements for navigation

The safety, speed and economic viability of shipping on a river depend on the existence of a deep, broad navigation channel. Safe passage for heavy loads must be possible under all conditions: at times of high or low water, during adverse weather, during traffic peaks,



Three lane shipping traffic will be possible over the whole river Waal by 2010.

and in spite of sandbanks or currents. The main channel of the Waal is currently maintained at 150 metres wide, with at least 2.5 metres of water, even when the river is at a specified low water level, known as the Agreed Low River Level (Dutch initials: OLR). On average, the water level is above the OLR 95 per cent of the time; in other words, the navigation channel should exceed the target dimensions 95 per cent of the time.

INFORMATION FOR THE SHIPPING INDUSTRY

RIZA's Inland Waterway Information Centre provides the shipping industry with information about water levels on a daily basis. Such information is vital to shippers, who need to know about bridge clearances, maximum vessel draughts, navigational conditions and the applicability of regulations, such as those covering multiple barge sets and the operating times of locks and bridges.

The Information Centre makes use of data from various sources, including the KNMI and over about seventy river stations in the Netherlands and abroad where water levels are measured on a daily basis. The Directorate General for Public Works and Water Management also has its own automatic Water Monitoring System (Dutch initials: MSW). Real-time data on water levels and, in some cases, river flows, is sent in digital form to a central computer. Data on the Rhine is provided by Germany's Rhine Water and Shipping Directorate in Duisburg, which collates water level figures from thirty measuring stations in Germany and one in Switzerland. Information regarding levels on the Belgian and French sections of the Meuse is provided by the Navigation Office in Liege and the Flood Warning Centre in Nancy.

The RIZA centre operates an information line, that can be called to obtain details not only about water levels and river flow, but also, where relevant, regarding obstructions, emergencies, flood events, ice formation and the

Navigation guide centre at Tiel.

Navigation accident.

navigability of inland waterways during periods of persistent frost. The same information is also posted on Teletext, the Internet and a bulletin board. In addition, written Shipping Information Notices are published every working day. Another function of the Information Centre is providing expert advisers in the event of serious pollution incidents or inland shipping accidents. If necessary, water samples can be analysed at the RIZA laboratories.

WATERWAY IMPROVEMENT

To facilitate inland shipping, the waterway network will be modernized. The navigation channels need to be deepened and widened, and action is required to make it easier for shipping to negotiate weirs, locks and bridges. Effecting these changes will involve various river engineering measures and traffic control initiatives, and they also require major dredging work. So far, the limited scope for disposing of heavily polluted dredge spoil has been an obstacle to progress. However, in 1999 a new depot capable of handling harbour spoil is due to open in the Ketelmeer.

The Waal Project

In the period up to 2005, the Directorate-General for Public Works and Water Management is to invest nearly five hundred million guilders modernizing the Waal as Western Europe's busiest inland waterway. The Waal Project is highly innovative in both river engineering and management terms. Measures such as the construction of bottom vales to widen bends and the closure of groynes to extend the navigation channel have not previously been employed. Through the project, the Directorate hopes to fully use the potential of the river system. However, a commitment has been made that extension of the navigation channel will not be at the cost of the environment. Important natural habitats will be left undisturbed.

The aim is to create a navigation channel that is wide enough and deep enough for two six-unit multiple barge sets and one twin-vessel

Ships sail in convoy through floating ice.

Extension of groynes

Bottom vales

Closing of a groyne

Bend-way weirs

The Waal project. Different strategies to improve the waterway of the Waal for inland navigation.

set to pass one another at any point. To make this possible, the channel will have to be enlarged from the Pannerden bifurcation to Zaltbommel, so that, even when running low, the river is at least 170 metres wide and 2.8 metres deep. Downstream of Zaltbommel, the channel already meets these new specifications.

A deep navigation channel enables shippers to carry more loads even when water levels are low. This in turn reduces transport costs per unit load, thereby saving the industry at least 25 million euro (rate 1999) a year. Consider the following illustration. A standard cargo unit lies one centimetre deeper in the water for every 8,200 additional kilos carried. If a four-unit set is able to use an additional thirty centimetres of draught, its carrying capacity is increased by 4 x 30 x 8,200 = 984,000 kilos.

The Waal Project will also provide additional safe mooring places away from the main channel at intervals of about thirty kilometres. By ensuring that shippers have no need to anchor their vessels close to the busy navigation channel, this initiative should further improve safety. Between 1984 and 1993, 30 per cent of accidents which resulted in serious damage involved anchored vessels. Even if they do not cause accidents, vessels moored at the edge of the waterway hinder the free movement of other boats and reduce the available width of the navigation channel. The government ultimately hopes to prohibit anchoring on the main river channel.
Traffic control provisions are also to be extended. Radar systems are to be installed to monitor the bends on the Waal at St. Andries and upstream of Nijmegen. At St. Andries, there will be a remote radar station, operated from the Tiel traffic control centre. On the stretch above Nijmegen, several unmanned radar stations will be built and linked to the Nijmegen traffic control centre. Since 1998, traffic control systems are in operation at all problematic points along the river.

Modernization of the Meuse route

The Meuse Route Modernization Project (known by its Dutch acronym, MOMARO) has been set up with the aim of making the Meuse and its canals suitable for larger vessels. Ultimately, the entire Meuse route should be able to take vessels up to 190 metres long and 11.4 metres wide: the typical dimensions of a twin-barge set. Sets of this kind need a navigation channel at least 3.5 metres deep; any less and they cannot be fully loaded. The authorities therefore want a channel which is between 3.5 and four metres deep. At present, the effective depth of the Meuse channel is only three metres. The locks along the river form the main obstacle to increasing the channel depth, since the sill depths are all between three and 3.5 metres.
The Momaro Project involves increasing the channel depth by raising water levels, correcting bends and modifying engineering structures. There is to be a second lock at Lith; clearance under the bridges over the Juliana Canal at Echt and Roosteren is to be increased and the lock approaches are to be modernized. Particular emphasis is being placed on safety and ease of passage. It is anticipated that the project — which is due for completion by 2010 — will lead to a considerable increase in freight traffic along the Meuse.

PROSPECT

The expectation is that, on the Waal, the total volume of freight moved per vessel will rise considerably over the next few years. Particularly strong increase is foreseen in container traffic. Vessels using the waterway are likely to get faster and substantially larger; the average freight vessel tonnage is expected to rise from the existing 1,155 tonnes to 1,500 tonnes by 2015. In the last 25 years, vessel dimensions have steadily increased, while the size of the fleet has halved to around five thousand units with a total capacity of six million tonnes. By 2015, the number of vessels will probably have dropped to four thousand, but their output, measured in tonne-kilometres, will continue to rise.

The Netherlands is a major distribution centre, and growth in inland waterway traffic is desirable both from an environmental viewpoint and as a means of relieving the pressure on the country's crowded road network. By 2010, the government hopes to see 5 per cent of road freight transferred to rail and water. To achieve this, the inland waterways must tempt twenty million tonnes of freight traffic off the roads, in addition to any autonomous growth. A modal shift of this kind depends not only upon improving the waterways themselves, but also upon having efficient transfer facilities, especially for the growing traffic in containers.

At present, two thirds of vessels are in operation only by day. However, in the twenty-four-hour economy, more and more night-time shipping will also be necessary. Much of the traffic growth foreseen in the next twenty years will be based upon a shift towards round-the-clock shipping.

New markets and technologies

Within the rapidly growing container transport market, the shipment of containers by inland waterway is a relatively new activity. Another growth area for the waterways is waste transport. Rapid passenger transport by water also looks to be a promising option. The shipment of refrigerated cargos for onward distribution to urban destinations could be viable as well. Within the freight transport market, certainly the container sector, there is a trend towards bulk transport between nodes, using large multiple barge sets. It is worth noting that not all sectors of the inland water transport market are growing. In recent years, increasing use of pipelines has had a major impact on the tanker sector. Nevertheless, the waterways retain a strong position when it comes to the shipment of goods which arrive in or leave the Netherlands by sea. Meanwhile, shipbuilders are seeking ways of making new vessels lighter, because every tonne less in the weight

Climate change

Climate change is expected to cause more frequent and prolonged periods of low water in the late summer and autumn. During the winter, on the other hand, the chances of extreme flood will be greater. Such variations in river flow could have implications for transport along the Rhine route between Rotterdam and Germany. In the summer, it is more likely that shippers will not be able to fully load their vessels; it is even possible that there will be times when the rivers become impassable for heavy commercial traffic. The improvements planned along the Waal and on the Rhine in Germany will not be able to fully offset the potential effects of climate change. Shipping on the Meuse is less sensitive to low flows, since the river is largely rendered.

of a vessel is another tonne of freight that can be carried.

The waterways would also benefit from the creation of larger harbour facilities, more industrial sites with docks and terminals for the transfer of goods between water and road.

New technology is likely to make its effect felt primarily in the fields of modal transfer and rapid passenger transport. Meanwhile, advances in navigational and communications technology are enabling water transport to develop into a truly reliable link in the transport chain.

Dirk Van Der Graaf, Senior Waal Project Manager, East Netherlands Directorate for Public Works and Water Management:
"JUST-IN-TIME TRANSPORT"

'Information provision will become increasingly important in the inland shipping industry. The waterways used to have a rather old-fashioned image, but that is changing fast, and rightly so. Within the transport industry, the just-in-time concept is constantly advancing, and the use of electronics has gained enormous ground. In the future, containers may even be electronically labelled, so that their whereabouts can be checked at all times. It may also be that clients simply specify where a container must go to and when it must arrive, leaving decisions about the transport mode and so forth up to the shipping contractor. As congestion increases on the roads, the waterways become more attractive, and more and more road-water transfer terminals are being built. Traffic control is continually being improved as well. Faster vessels could nicely lead to the development of water taxi services, which would be nice. On a hydrofoil that does forty miles an hour, you could get from Dordrecht to Rotterdam in no time.'

WATER QUALITY 6

Water quality

Clean water is important to everyone who uses the river, and to the plants and animals of the river environment. After a long history of serious pollution, water quality in the Rhine has recently improved considerably, due to international treaties and clean-up initiatives. Similar improvements have yet to be effected on the Meuse. Pollution control initiatives are now being implemented.

Source of pollution.

DECADES OF POLLUTION

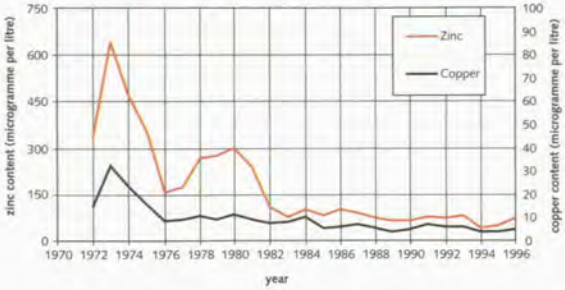
For many years, the Rhine was Europe's prime example of a polluted river. Water quality deteriorated particularly sharply in the post-war era, when the Rhine basin was the scene of extensive reconstruction and industrial development. Between 1960 and 1975, summer oxygen levels in the foaming, stinking water often fell below three milligrammes per litre: much too low for many fish species. Fish stocks consequently plummeted to the point where the Rhine virtually became a dead river. The Meuse was also heavily polluted in this period. Water supply companies found it increasingly difficult to make river water fit to drink. At times of flood, large quantities of polluted silt were deposited on the flood plains, while the river beds in the tidal area became seriously polluted as well. The situation was so serious that exposure to Rhine water proved immediately fatal to water fleas during laboratory experiments carried out in the late seventies. Today, however, these animals are able to breed successfully in both of the Netherlands' great rivers.

WATER QUALITY PROBLEMS

Environmental policy is based on standards and limits calculated on ecotoxicological principles. The concentration limits applied are generally derived from maximum acceptable risk (MAR) data. The MAR for a given substance is the highest concentration which is not toxic for 95 per cent of the species potentially present in the ecosystem. MARs are calculated using published ecotoxicological data and regularly reviewed. The main water quality problems in the great rivers are summarized below.

Heavy metals

From around 1930 right up to the sixties, heavy metal concentrations in the Rhine rose almost constantly. Only during the Second World War did metal pollution fall slightly. In the seventies, concentrations were between five and twenty-five times higher than the current limits. Thereafter, concentrations fell sharply until 1985. Since then, they have been



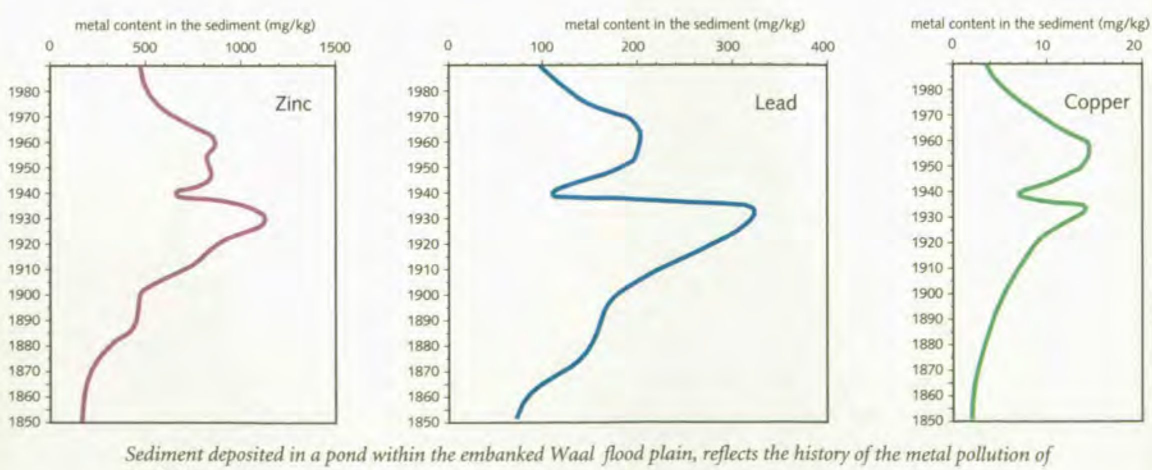
Copper- and zinc contents in the Meuse at Eijsden.

more or less stable, albeit at levels in excess of the long-term targets. Heavy metal concentrations in the Rhine are now hovering around the specified limits, but remain above the applicable threshold levels applied in the Meuse.

Heavy metal pollution is still a problem in the sediments of the river bed. This is because metals attach (adsorb) themselves to suspended clay and silt particles, which settle to the bottom in slow-moving stretches of water. Consequently, heavy metal concentrations in dredge spoil are often so high that the spoil cannot be freely disposed of. Cadmium and mercury levels present a particularly serious problem, while spoil from the Meuse is also badly contaminated with copper and zinc.

PAHs, PCBs and dioxins

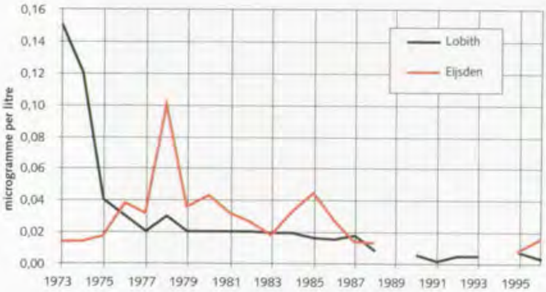
Significant organic micro-pollutants include PAHs (polycyclic aromatic hydrocarbons) and PCBs (polychlorobiphenyls). The history of micro-pollutant concentrations has followed a similar course to that of heavy metal concentrations: rises in the fifties, sixties and seventies, followed by a gradual decline until the early nineties. Because micro-pollutants also attach themselves to silt particles, changes in their concentrations are reflected in the beds of water bodies such as the Ketelmeer, the Hollandsch Diep and the truncated river at Haringvliet, where PAH levels in particular are often well in excess of the recommended figures. Dioxins also represent a problem, especially in the sedimentation areas of the great rivers (the Biesbosch, the Hollandsch Diep, the Nieuwe Merwede and the deeper silt layers of the Ketelmeer).



Sediment deposited in a pond within the embanked Waal flood plain, reflects the history of the metal pollution of the Rhine.

Crop protectors

Organochlorine crop protectors such as DDT, lindane, aldrin, endrin and dieldrin cling to silt particles, which ultimately settle out to form the river bed. Current concentrations of many organophosphates, chloro-phenoxycarbonic acids and triazines are in excess of the limits. Over the last ten years, a number of new, readily water-soluble crop protectors have come onto the market. Rather than attaching themselves to silt particles, these substances are transported downstream almost entirely in solution. In this form, these substances are much more toxic than earlier crop protectors. Thus, while insecticides account for only 4 per cent of all discharges, some 79 per cent of the overall toxic risk to the water system is attributable to them.



Concentration lindane (pesticide) in the river Rhine (Lobith) and Meuse (Eijsden).

Unidentified toxic compounds

The chemical analysis of river water tends to focus on readily identifiable individual substances or small groups of substances. However, anything up to 80 per cent of the total toxicity of water or silt can be attributable to unidentified pollutants. To obtain information on total toxicity, the effects of water and silt are studied in bio-assays: laboratory tests in

Contents of different PAK's in sediment cores from IJsselmeer and the Rhine.

which organisms such as bacteria, water fleas and mosquito larvae are exposed to polluted water or silt, then their population growth and development observed. In such bio-assays, the effects suffered by the organisms often prove to be anything between twice and ten times the desirable levels; yet only 10 to 30 per cent of the toxic effects tend to be attributable to identifiable substances. It is therefore important that future pollution control policies address the question of unidentified toxic compounds.

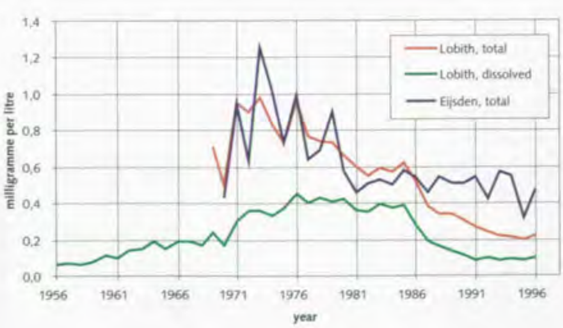
Phosphate and nitrogen

Phosphates and nitrogen compounds are nutrients, whose presence in the river causes excessive algae growth in the upper water strata. The abundance of algae in turn reduces oxygen concentrations in the water. Since the construction of sewage treatment plants in the seventies, less organic waste and consequently less phosphate and nitrogen are being discharged into the rivers. However, discrepancies are emerging between the various nitrogen compounds. Ammonium concentrations are falling, for example, while nitrate levels are rising. This is because the breakdown processes in sewage treatment works result in the release of ammonium, which is then converted into nitrate (nitrification). To address this problem, denitrification procedures are to be introduced at the plants.

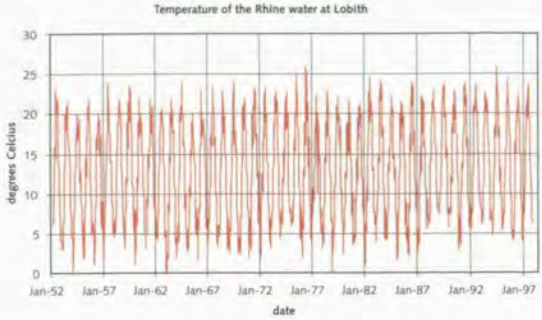
Eutrophication (nutrient build-up) is a serious problem on the Meuse. As a result, algal blooms regularly occur, especially in the very slow-moving water behind weirs. The nitrogen and phosphate responsible for the eutrophication have three main sources: unpurified domestic waste, discharged into the Meuse from Belgian towns such as Liege; discharges into the Meuse's Dutch tributaries from sewage treatment plants; and drainage from the intensively worked agricultural land.

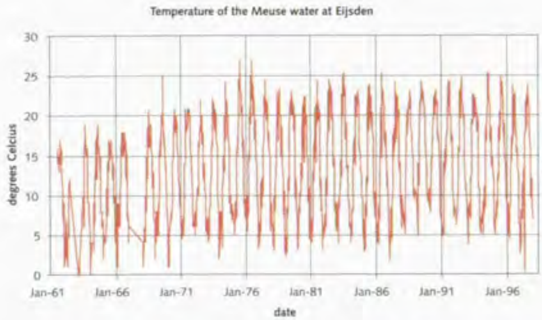
Temperature and salinity

In the last hundred years, the rivers have become warmer and more saline. As a result, a range of warmth and salt-loving organisms now live in the rivers, which were not found there in the past. Since the war, the temperature of the Rhine has risen almost half a degree centigrade every decade, mainly as a result of cooling water discharges from power stations and industrial plants. The river now freezes over less often than it once did, allowing colonization by various new species of water organism which could not previously have survived. Power stations also discharge cooling water into the Meuse, often making t much too warm at times of low flow in the summer.



Phosphate contents in the rivers Rhine and Meuse.





Water temperature of the Rhine and Meuse over the past decennia .

The natural chloride or salt concentration in the Dutch Rhine is around ten or fifteen milligrammes per litre. Present-day concentrations average 150 milligrammes a litre, however, having briefly reached two hundred milligrammes a litre in the early seventies. So much salt damages drinking water pipes, while agricultural and horticultural land is affected by silting. About a third of the river's salt burden originates from the French potassium mines in the Alsace, which are due to close in 2004. Other major sources of salt include the tributaries, industrial plants in Germany, mines and sewage treatment works. Although the salt concentration in the Meuse is also artificially high, it is considerably lower than in the Rhine: the average figure at Eijsden is about eighty milligrammes a litre.

The Rhine Action Programme

In 1986, a blaze broke out at the Sandoz chemicals plant in Basel. Heavily contaminated water from the fire-fighting operation flowed into the Rhine, killing huge numbers of fish and posing serious problems for the drinking water production companies. The incident made the countries along the Rhine realize that the established Rhine water quality protection programmes needed to be accelerated and improved. A new policy was accordingly formulated and formally adopted on 1 October 1987 in the guise of the Rhine Action Programme (RAP). The RAP has three objectives:

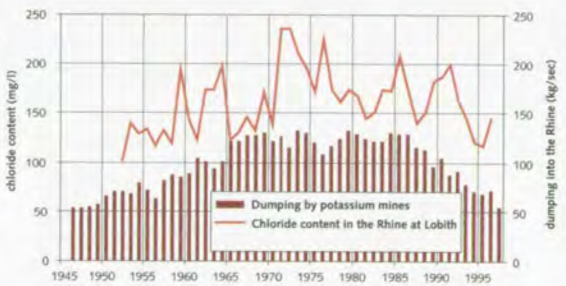
- To bring about the return of higher animal species lost to the Rhine, such as salmon
- To secure immediate and long-term drinking water supplies from the Rhine
- To reduce the pollution of river silt by harmful substances.

These objectives had to be realized by 2000, through implementation of the following measures:

- Bringing discharges of forty harmful substances down to half of their 1985 levels by 1995
- Ensuring that harmful substances are not released into the Rhine when accidents occur
- Conducting research and acting to improve the design, accessibility and water quality of the river as an environment for higher and lower organisms

WATER QUALITY MONITORING

The quality of the water in the Rhine is constantly monitored at numerous automatic stations. Monitoring enables scientists to establish whether environmental initiatives are effective and to act quickly in the event of pollution incidents — warning drinking water companies which withdraw water downstream of the incident site, for example. In addition, the companies responsible for pollution are nowadays increasingly inclined to report accidental releases of harmful substances themselves.



Salt dumping and chloride contents in the river Rhine.

Oxygen, salts, nitrogen compounds, tritium and four metals are directly measured — constantly, daily or twice a day. Concentrations of several dozen substances are estimated every day using a single-stage analytical procedure which, while not extremely precise, enables significant increases to be detected quickly.

In addition to the chemical tests, biomonitoring activities are undertaken. These activities involve exposing bacteria, algae, mussels, water fleas and fish to continuous flows of river water in special tanks. Behaviour is electronically monitored and an alarm raised in the event of any abnormalities. A close-knit network of chemical and biological monitoring systems was installed along the entire length of the Rhine in 1986.

Over the last ten years, the number of pollu-

The water quality is measured 24 hours a day at different stations along the rivers Rhine and Meuse. The picture presents the monitoring-station at Lobith.

tion incidents detected on the Rhine has fallen substantially, but the situation on the Meuse is less favourable. Activity levels among water fleas in the biomonitoring tanks at Eijsden drop sufficiently to trigger the alarm several times a year, after which the animals often die off in huge numbers. It is likely that other invertebrate species suffer a similar fate in the river itself. Following the Sandoz disaster, it was about a year before the affected species recolonized the polluted Rhine. For the Meuse, however, the intervals between pollution incidents are sometimes too short to allow similar recovery.

INFERIOR QUALITY OF MEUSE WATER

The quality of the water in the Meuse is not as high as that in the Rhine. Much of the pollution responsible for the poor water quality originates outside the Netherlands. Nevertheless, the river is further contaminated from sources within Dutch borders. Among the chief pollutants are phosphates and nitrogen (from agricultural land and sewage treatment works) and crop protectors. Because of the levels of organic pollution, oxygen levels in the Grensmaas and other sections of the Meuse are frequently very low, particularly in the summer. With the oxygen concentration sometimes less than three milligrammes per litre, the prospect of encouraging salmon back into the river seems remote. In addition to having a serious eutrophication problem and carrying a heavy organic pollutant burden, the Meuse is affected by high concentrations of heavy metal aromatics. PAH levels were steady or almost unchanged over the period 1990 to 1996. The Meuse is also contaminated with a wide variety of agricultural crop protectors, many of them in high concentrations. Nor is the bacteriological quality of the Meuse what it should be. Mainly as a result of unpurified domestic discharges further upstream. As measured at Eijsden, the river's bacteriological quality has remained consistently poor over the last ten years.

Such poor water quality results in heavily polluted silt. This in turn means that the bottoms of the Limburg and Brabant canals, and of the river's high-water bed, are badly contaminated. Frequent accidents constitute an additional and major problem, especially as more and more water is drawn from the Meuse for the production of drinking water.

POLLUTION CONTROL PHILOSOPHY

The way water quality in the Rhine has been improved is undoubtedly a success story. Following implementation of the Pollution of Surface Waters Act (Dutch initials: WVO) in 1970, numerous sewage treatment works were built, with the result that there is now sufficient oxygen in the river water. Pollution producing companies switched to cleaner processes and adopted new purification methods in order to avoid heavy environ mental levies. A range of regulations and

Meuse Action Programme

The International Commission for the Protection of the Meuse is working to improve water quality and promote ecological recovery of the Meuse. In the Flemish-speaking part of Belgium, for example, numerous sewage treatment works are to be built, which should reduce eutrophication in the Meuse considerably. Meanwhile, plant closures and the introduction of new clean-up measures can be expected to bring down heavy metal discharges from industrial sources. Crop protector use will then be left as the major threat to river water quality.

provisions was also introduced through the EC to prevent water pollution. The result of all these measures was that the quality of the Rhine improved spectacularly between 1970 and 1980. Progress slowed after 1980, until new impetus was provided by the Rhine Action Programme, started in 1987. In the context of this successful international programme, the countries along the Rhine committed themselves to halving discharges of numerous substances by the year 2000. In fact, the concentrations of various pollutants have been cut by well over half, although the targets for certain others (mainly diffuse discharges from the use of fertilizers and agricultural crop protectors) have not yet been met.

Pollution from diffuse sources — i.e. sources which do not discharge pollutants from a particular point — is much harder to tackle than that from industrial and domestic sources. Most diffuse sources are agricultural, but others include road traffic, shipping, private individuals and the atmosphere. A reduction in contamination by crop protectors is very important in relation to drinking water preparation.
In contrast to the situation for the Rhine, the progress being made towards improved water quality in the Meuse is based entirely on national initiatives. To reach MAR levels by 2000, discharges of various substances will have to be cut by between 65 and 90 per cent.

Stricter standards

The Dutch government has introduced stricter water quality standards in line with the Third Policy Document on Water Management (1989) and the Evaluation Document on Water (1993). The EC has also issued directives in this area. The new, stricter standards take more account of ecological considerations. Under the policy now in force, discharges must be prevented as far as possible and activities which affect water quality are subject to stringent legislation.

ECOLOGICAL RECOVERY

As the river water becomes cleaner, so plant and animal species driven away by pollution gradually return. The number of fish species in the Rhine is now back to what it was at the start of the century, although the recovery is not the same for all the species. Encouraging fish species to return is not only a question of providing cleaner water, however. The river must also be designed so as to give the fish places to spawn and to mature, and access must be improved by building fish passes to bypass weirs and locks. The macrofauna —

Fish passage along the river Meuse near Roermond. Through such fish passages, fishes can pass along a weir or sluice.

invertebrates large enough to see with the naked eye, which contribute to the river's ability to keep itself clean — is also recovering. Since 1975, the development of macrofauna living on rocks along the side of the IJssel has been closely monitored. Between 1975 and 1983, the density — especially of Chironomid larvae — increased significantly, probably as a result of reduced insecticide concentrations and higher oxygen levels. Since 1978, the sensitive caddis worm has also returned to the IJssel.

Both the density and the diversity of the macrofauna in the river environment are increasing. About twenty-five or thirty immigrant species have colonized the Rhine, encouraged by the warmer, saltier water. In the IJssel, the number of new species seems to have fallen recently, after years of increase; this may indicate the establishment of a new equilibrium. Newcomers benefit not only from the environmental changes, but also from links between river basins. Since the construction of the Main-Danube Canal, for instance, many species traditionally found in the Danube have migrated into the Rhine.
Being canalized and suffering from serious eutrophication, the Meuse is not particularly rich in the plants and animals normally found in river environments. Water plants grow only in the parts of the river where the water is not moving; species typical of moderate to rapid-flowing gravel-bed rivers are rare. Only the most resilient invertebrates, such as mosquito larvae and isopods, are able to survive. None of the typical river invertebrates are found. A similar situation is seen where fish are concerned: general species such as roach, bream and silver bream predominate, while those associated with flowing water — barbel, chub, beaked carp and dace — are found only in the Grensmaas, and not in any great abundance even there. Typical river species such as salmon, sea trout, sea lamprey and burbot have more or less disappeared. To address this situation, measures similar to those taken on the Rhine — the construction of fish passes and the creation of spawning and schooling areas — are being put in place. Recovery of the macrofauna depends on reducing flow variations and improving water quality, however. Ducks, geese, grey herons and even ospreys are nevertheless seen along the Meuse, while the cormorant also winters beside the river.

One of the obstacles to ecological recovery along the rivers is the amount of toxic material that has built up over the years, particularly in the deeper sedimentary layers. For example, in the Biesbosch, a notorious spot for the accumulation of polluted sediment, cormorants and tufted ducks breed less successfully. Species which are sensitive to micro-pollutants are either rare (as with the mayfly) or absent (as with the otter). Although it is unlikely that toxic substances will have a dramatic effect on plants and animals living beside the river, the possibility should not be ignored. Furthermore, the biological availability of toxic substances can vary considerably, depending on the land use. So, for instance, the situation in a dry area can be very different from that in a wet area of flood plain. On wooded land, trees can draw pollutants from lower soil strata towards the surface, creating conditions which do not exist in areas of pasture.

THE FUTURE

As more is done to remove localized sources of contamination, a greater proportion of the pollution in the waters of the Netherlands' great rivers will be due to diffuse discharges. Nevertheless, water quality can be expected to improve in the next ten years, especially in the Meuse. By 2030, water quality should no longer be an obstacle to ecological recovery. Even now, there are some attractive areas of natural habitat, in which numerous plant and animal species are evidently able to thrive, despite the unclean water.

René Breukel, RIZA environmentalist

"CROP PROTECTORS AND NUTRIENTS ARE STILL PROBLEMATIC"

'In information technology, there is a saying that 80 per cent of project costs go on achieving the last 20 per cent of quality improvement. The same principle applies to water quality. A great deal has been invested in reducing pollution from domestic and industrial sources, and spectacular progress has been achieved. Now great effort is being put in to completing the final phase: modifying purification plants to remove more phosphate and nitrogen. Nitrogen and phosphate removal is very expensive in relative terms, and yields comparatively small quality improvements. Installing the necessary equipment at the country's existing sewage treatment works will cost more than a billion guilders. Processing the sludge from the plants will cost a further 427 million, according to the Fourth Policy Document on Water Management. Still more will have to be spent to clean up the polluted river and lake beds.'

'The pollution of surface waters with crop protectors and nutrients is presently a major obstacle to ecological recovery. More pollution may now come from agricultural sources than from domestic sources. Although the agricultural industry does not use crop protectors in the same quantities as in the past, water quality has not improved as much as one might expect, because more effective modern products are being used. The present concentrations of crop protectors in the river water remain too high for many organisms.'

'When crops are sprayed, considerable quantities of spray are not absorbed by the plants, but drift away on the wind or land on the ground. These chemicals are subsequently washed into the rivers. To a large extent, the crop protectors in the river water come from sources in the Netherlands, rather than abroad. A great deal could be done to improve the situation by using improved spraying techniques, selecting more appropriate crops and using disease-resistant varieties.'

NATURE DEVELOPMENT 7

Nature development

Agricultural use of the flood plain and centuries of engineering work have deprived the rivers of their natural character. Also, human activity has caused pollution. Today, however, ecological recovery is an important item on the policy makers' agenda. Being long, unbroken ribbons through the landscape, the rivers offer unique opportunities for nature development; they are the backbone of the national ecological network. Provided that safety and the interests of the shipping industry are not compromised, nature is nowadays allowed much more freedom within the river area. Various nature development projects have now been established. Plant and animal species associated with natural river environments are being reintroduced and given the chance to re-establish themselves.

THE RIVER ECOSYSTEM

River engineering, agriculture and water pollution have affected nature badly. Nowadays, the rivers' flood plains are designated largely as agricultural land. Some 3 per cent of the flood plain along the Rhine branches is urbanized, and 7 per cent along the Meuse. Only 15 per cent of the land is taken up by natural ecotopes: areas of countryside which are not subject to intensive human interference. Dredging and the construction of groynes have made the rivers' main channels quite a bit deeper than they would be otherwise. Few natural river banks are left intact, and there are almost no floodplain forests or secondary channels anymore. As a result, typical river species such as brown galingale, black poplar and barbel have virtually disappeared from the river environment.

The river Allier in France: an example of a natural river.

Nevertheless, the countryside along the rivers can be rich in animals and plants — which pay little attention to the national borders established by man. Numerous wild species are able to move freely along the rivers, linking natural habitats from Switzerland to the IJsselmeer, from the Vosges to the Haringvliet.

Without man's interference, the rivers would be extremely dynamic. Flood plains would be alternately inundated and drained, sediment would be deposited then moved on again, floating ice would erode the high-water bed. Beside the rivers, dense floodplain forests would grow. Sandy river dunes would support a characteristic flora and a wide variety of insects. In secondary channels off the river, fresh water fish would spawn, while all sorts of insects, molluscs and shrimps would live on

Secondary channel.

dead wood rotting in the water. Islands in the river would provide birds with safe brooding areas. Still more creatures would inhabit little pools dotted along the river's course; regular flooding of these pools would refresh the water and allow larvae to spread from pool to pool or into the river itself. At times of high water, there would also be massive invasions by macrofauna from upstream areas. The strength of the current in the river's main channels and secondary channels would have a major effect on the local ecosystems. In a secondary channel open only at one end, for example, the almost still water would support very different animals and plants from those found in free-flowing secondary channels.

REPLANNING THE LANDSCAPE OF THE RIVER AREA

Today's highly normalized rivers allow little scope for natural processes such as erosion/ sedimentation and vegetation succession. For the greater part, the river banks are lined by carefully managed, species-deficient meadows and large pools created by sand extraction. Major changes are planned for the years ahead, however. The area of natural habitat along the Rhine branches and the Meuse is to be increased from the 10,000 hectares occupied in 1995, to about 28,000 hectares by 2010.

In large parts of the river system, the planning of the landscape is being revised to include free-flowing secondary channels, muddy banks, pools and marshes. Grasslands and riverside floodplain forests will be created, complete with beavers, ospreys and black poplars. River dunes will be allowed to develop and some of the old river arms and floodplain channels are to be reconnected to the main channels. At various points, the summer embankments will even be dismantled. Measures such as these will be implemented in nature development projects planned for the

The river IJssel around 1830. The map shows the original topography very well.

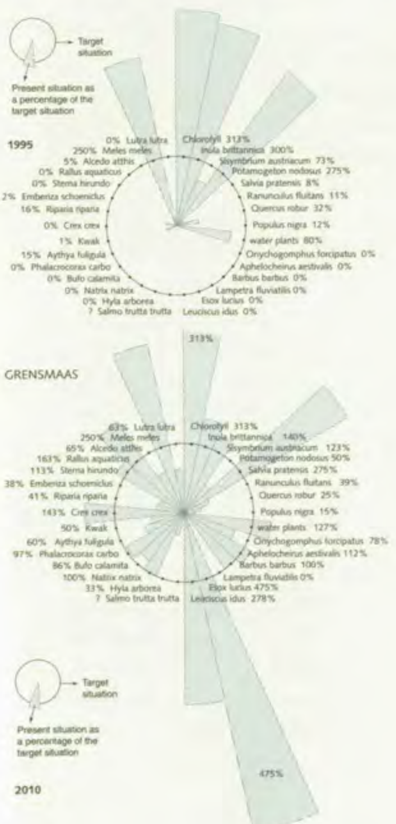
Duursche Waarden beside the IJssel between Wijhe and Olst, for the Blauwe Kamer at Rhenen, along the Nederrijn and the Lek, for the Waal at St Andries, for the Gelderse Poort between Lobith and Nijmegen and for the Grensmaas and Zandmaas in Limburg. The first real free-flowing secondary channels have already been created in the Waal's flood plain at Opijnen and Beneden-Leeuwen.

Natural bank with sand deposits and willows.

NATURE DEVELOPMENT, BUT WHAT KIND OF NATURE?

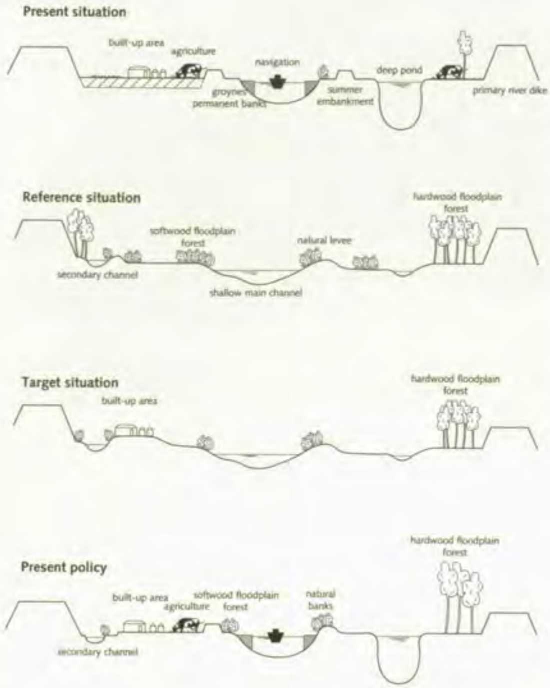
Before new areas of natural habitat can be developed, one must decide what these areas should be like. To this end, it is instructive to look back at the environment that, having evolved over thousands of years, existed

Amoebe as an ecological indicator



"AMOEBE" is an acronym based on a Dutch phrase which means "general method for describing and evaluating ecosystems". An amoeba is also a microscopic water animal, whose tentacles can take on weird shapes. However irregular the form of nature's amoeba may be, the perfect AMOEBE of academic theory is circular. Around its edge, various characteristic animal and plant species are indicated, together with the numbers in which one would ideally expect them to be found. If all the species were present in a given area in the right numbers, an ecological equilibrium would exist. In practice, however, local studies generally find that some species, such as algae, are over-represented, while others, such as black poplars, are under-represented. By extending or reducing the corresponding segment of the AMOEBE diagram to reflect the degree of over- or under-representation, one ends up with a graph with tentacles of different lengths. An AMOEBE diagram shows at a glance how far an area is away from ecological equilibrium.

An amoebe is an unicellular animal that keeps changing its shape.



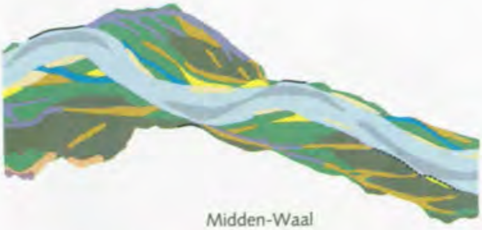
Cross section of the high-water bed in the present situation, according to the reference situation, the target situation, and by continuation of the present policy.

before mankind's intervention. Policy-makers and river managers can assess their achievements by comparing the actual environment against this "reference situation".

Old books, maps and pictures give an impression of the river landscape in previous centuries and the type of environment we should ideally be seeking to re-establish. So much has been changed along the great rivers, however that it is not feasible to try and turn the clock back. The Nederrijn, for example, has been canalized for the last thirty years. Without the weirs, the environment along the river would have developed in a very different way, with dunes and natural levees. And, for safety reasons, primary river dikes have to remain. Re-establishing the reference situation is therefore no longer a viable proposition. An ecological target situation has accordingly been defined: a sort of cross between the reference environment and the present circumstances. While the target situation protects safety and provides for shipping by retaining primary river dikes and weirs, it also restores some of the river area's natural contours. Since the construction of summer embankments and groynes, sedimentation has increased the height of the high-water bed by about a metre — and even by two metres in places. Under the target situation, these layers of sedimentary clay would be removed, so that the lie of the land returned to what it once was. The target situation has been defined by reference to several European rivers which are still in a fairly natural state, including the Allier in France, the Tisza in Hungary and various Polish rivers. These rivers provide pointers to the direction of natural river development and to the conditions which must be created for the re-establishment of riverine processes.

YARDSTICK OF PROGRESS

Water managers need to measure the progress of achievements. Are the steps taken to improve water quality effective, for example? And what is the ecological condition of the water systems? One way of answering questions such as these is to establish whether all the animal and plant species normally associated with a particular type of environment are actually present. If, for instance, an area appears ideal for river birds such as the night heron, but the creatures do not breed there, it is likely that something is wrong with the water quality or that the area is too intensively used for recreational purposes. Alternatively, the birds may have died out all across the



Midden-Waal

Midden-IJssel

Peelhorst-Meuse

region in question, and may be unable to re-establish themselves independently. Clearly, however, the absence of the species serves to alert those responsible for the area that something is wrong. Many species are in a similar position to the night heron, and this complicates the task of measuring the ecological condition of a given locality. To facilitate the assessment of progress towards abstract ecological objectives, the AMOEBE method has been developed. This method involves dividing an ecosystem into a number of characteristic species, representative of its various sections.

WHICH ECOTOPE SHOULD GO WHERE?

Water policy is aimed at creating the conditions in which a healthy ecosystem can develop and sustain itself more or less independently in the long term. Within certain limits, natural processes are being allowed to re-establish themselves, enabling new plant and animal species to spread across the river area. Different species thrive in different conditions. To link the variations in physical and ecological conditions within the river area to the needs of a range of species, the term "ecotope" has been introduced. An ecotope is a geographically distinct area which is not only characterized by certain physical factors, such as typical flood period length, groundwater level, height and degree of erosion or sedimentation, but is also managed in a particular way, which might involve grazing by cattle, mowing, forestry, etc. Differences in these characteristics mean that ecotopes differ from one another in terms of the composition and structure of their vegetation. Important river ecotopes include shallow main channel, softwood floodplain forest, marsh, river dune, brushwood, secondary channel, pond and arable land.

The physical differences between the Meuse, Waal, Nederrijn and IJssel affect the way ecotopes are distributed over the flood plain. First, the four rivers differ in terms of water flow and sediment burden. In the canalized

The needs of the night heron

Night herons are characteristic inhabitants of inaccessible, marshy floodplain forests and riverside willow and poplar woods. They are stocky birds, with big beaks and relatively short legs. As their name suggests, night herons rest during the day, coming down from the trees to go about their business only under cover of darkness. Night herons brood in colonies (preferably in willows), around which they forage at distances of up to ten kilometres in the sort of shallow water found at the edge of clay ponds and floodplain channels. They are opportunistic feeders, eating mainly fish and amphibians, but also small mammals, worms, spiders and other such creatures.

At present, the Netherlands' entire night heron population consists of no more than five pairs. The bird has completely disappeared from the Biesbosch, traditionally an important breeding area. Night herons are particularly sensitive to the presence of heavy metals and organic micro-pollutants (PCBs and pesticides) in the environment, so the level of contamination in the Biesbosch stands in the way of their return. They are also very shy, fleeing from any human activity within a radius of more than four hundred metres.

The study entitled "A stream of nature" indicated that, under optimal conditions, a hectare of softwood floodplain forest can accommodate a colony of fifty pairs of night herons, each of which then needs a further hectare in which to forage. Theoretically, all sorts of water bodies can provide suitable feeding grounds, provided the banks are densely covered and that there is plenty of fresh water, no more than twenty centimetres deep, with a firm and not too silty bottom to support the birds.

Meuse and Nederrijn, there is very little water flow for a large part of the year. By contrast, the Waal and the IJssel are free-flowing rivers, carrying large quantities of sandy sediment. The IJssel developed meanders; its discharge was a lot higher than it is today and it was strong enough to change its course quite frequently. As a result, natural levees were able to form. Today, however, flow in the IJssel is much lower than it once was. With its artificial ripraps on the banks and reduced dynamism, the river is barely able to build up natural levees any longer.
Differences in flood plain height are also significant. The Waal flows through flat land and has a relatively low flood plain, which would be even lower if the excess sedimentary clay and the summer embankments were removed. The Meuse, on the other hand, has cut a deep channel through its own sediment. On the relatively high Meuse terraces, which rarely inundate, the natural vegetation is therefore more wooded than that along the Waal.

The rivers' upper reaches also differ from their lower reaches. Further downstream, the tidal and saline influence of the sea become increasingly greater.

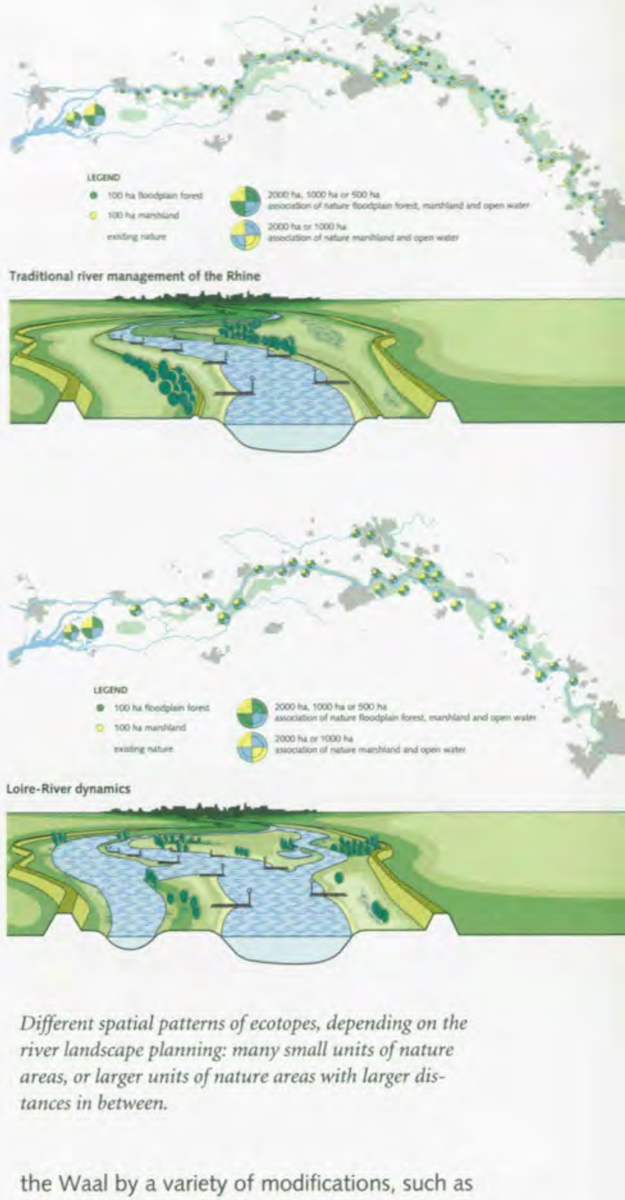
Within an area of flood plain, local differences in height determine how often a particular piece of land is flooded, and how quickly flood water flows over it. Old maps have been used to study the original contours of the flood plains, including the old channels and natural levees. Using computer models, it is possible to determine the pattern of current velocities across a flood plain with known topography.

To determine which locations are most suitable for the creation of particular ecotopes, the rivers have been divided into more or less uniform sections. Aerial photographs have been used to produce maps, on which secondary channels, raised and low-lying floodplain forests, marshes and other geographical features have been delineated, thereby creating ecotopic maps of the rivers as they are today.

TARGET SITUATION

Without human intervention, and depending partly on the grazing pressure, the countryside surrounding the rivers would probably consist mainly of woodland, with patches of brushwood, pools and secondary channels. This reference situation, as it is known, and the ecotopic maps are fascinating for the insight they provide into the natural landscape of the Netherlands, but they do not represent a realistic view of the environment we should presently be striving to create. Therefore, an ecological target situation has accordingly been defined: a vision of the ecologically most desirable environment that can practicably be created.

Differences between the rivers mean that the river area as a whole cannot be uniformly divided into forest, brushwood, meadow and other ecotopes. Along a canalized river such as the Nederrijn, a stable landscape is possible, with patches of marsh here and there. For the Waal, the target situation is very different. Greater dynamism could be promoted along



Different spatial patterns of ecotopes, depending on the river landscape planning: many small units of nature areas, or larger units of nature areas with larger distances in between.

the Waal by a variety of modifications, such as the construction of secondary channels. River dunes and natural levees could also be allowed to develop naturally. Dynamic environments, with escarpments on which birds such as the sand martin and kingfisher might breed, could also be established on the Grensmaas and the IJssel. Along the canalized section of the Meuse, the Nederrijn and the lower reaches of the IJssel, marshes could

Sea trout with transponder.

Sea trout migration routes

Since the massive destruction of fish stocks that followed the Sandoz pollution incident, getting salmon back into the Rhine has become something of an ecological crusade. Achieving this goal is more than simply a question of improving water quality. Fish such as the salmon and the sea trout, which spawn in fresh water but mature at sea, have very little opportunity to migrate back up the Rhine branches or the Meuse. The Nieuwe Waterweg is the only direct link between the river system and the sea; all the other river openings have been closed by weirs and discharge sluices. Further upstream, the way is blocked by more weirs, locks and hazards such as shipping and industrial discharge outlets. These problems are being studied in the Sea Trout Migration Project (the sea trout was chosen, rather than the salmon, because the latter is still almost completely absent from Dutch rivers). The project involves tracking almost two hundred trout fitted with transponders: little transmitters inserted in the abdominal cavity of fish that are ready to spawn. Receiver cables have been laid across the river beds at various points, linked to a detection station. Each time a fish with a transponder passes over one of the cables, the individual is identified and the event recorded. Some 250 crossings have been recorded in about a year. From the data, it is clear that only a handful of fish has been able to negotiate the weirs.

Number station	Location	River/Canal	Amount
1	Genemuiden	Black Water	0
2	Kampen	IJssel	0
3	Schellingwoude	IJ	0
4	Maarssen	Amsterdam–Rhine Canal	0
5	Zuidland	Spui	28
6	's Gravendeel	Dordtsche Kil	47
7	Kinderdijk	The Noord	12
8	Boven Hardinxveld	Beneden Merwede	27
9	Nieuwegein	Lek	43
10	Vuren	Waal	27
11	Capelse Veer	Bergsche Maas	28
12	Stevensweert	Meuse	4
13	Xanten	Rhine	19
14	Spijkenisse	Oude Maas	15
		total	250

The first results: 250 recorded passages.

Location of the detection-stations along the rivers.

develop in places. It is not feasible, however, to create wetlands on more than a few per cent of the land behind the dikes. Riverside marshes are best created within the diked area, in the low-lying flood basins between the rivers, which have been reclaimed and turned into polder over the years. Hardwood floodplain forest might be allowed to establish itself on the higher flood plain surrounding the canalized part of the Meuse.

Hence, there is no universal target situation for the river environment in the Netherlands. Various solutions must be sought to suit the different rivers and river branches.

ECOLOGICAL NETWORKS

Efforts to bring about the ecological recovery in the rivers are based upon self-sustaining ecosystems, which are not reliant upon constant human intervention. However, the restoration of habitats that have been damaged or destroyed does not guarantee the return of displaced species. Assuming they

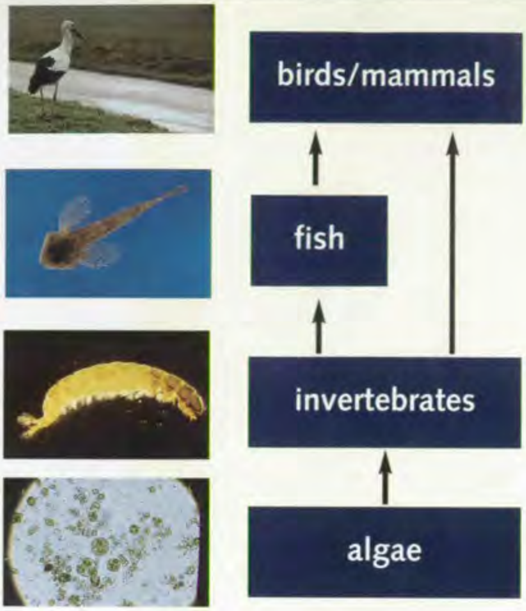
The Biesbosch.

The Haringvliet sluices and the Biesbosch

Since completion of the Haringvliet Dam in 1970, the formerly saline Haringvliet has become a fresh water body. In addition, the difference between the high water level and the low water level has gone from two metres to a few decimetres. Although there is a fish pass around the sluices, the movement of migratory fish has been impeded, partly by the abrupt change from saltwater to fresh water. Areas which were sometimes under water and sometimes exposed, providing feeding grounds for birds, have disappeared. Waves constantly breaking at the same height have eroded such patches of land, and the mud flats have gradually gone from outside the dikes. Bank defences have now been constructed to prevent further erosion, shallows have been created where fish can spawn, and the needs of brooding birds are taken into account when depositing sand.

Natural processes in the tidal river could be restored to a certain degree by partial opening of the Haringvliet sluices. The sluices could be used simply for discharge purposes, or opened only when the river runs high (normally in the winter). Alternatively, the sluices could be open at all times except when the river flow is very low, or when a flood tide is imminent. A certain degree of tidal influence would make the environment more attractive to various plants and animals, while also allowing better access for migratory fish. The now very rare biocommunities in Europe associated with brackish water would be given a chance to re-establish themselves as well. Furthermore, partial opening of the Haringvliet sluices could assist the recovery of the Biesbosch as a unique tidal fresh water habitat.

The presence of brackish water could, however, have adverse effects on agriculture and drinking water production in the Haringvliet area. A carefully balanced policy therefore needs to be developed.



An example of a food chain in a secondary channel.

have not died out, the natural occupiers of the habitats need to have access to the newly prepared locations. Weirs, roads and fences form serious barriers in this context. Nature reserves are often small, isolated "islands" in a man-made environment, between which both animals and plants find it hard to move.

Even if recolonization is achieved, the long-term success of the returning species depends on the existence of habitats large enough to support viable populations. Small, isolated populations run the risk of degeneration through inbreeding, or local extinction. Often, a species will only survive if its habitat is part of a coherent ecological network, across which the species can disperse. Animals with large territorial requirements, such as black storks and ospreys, require networks of european proportions.

Some species thrive where natural habitats are large and well separated, while others prefer an environment with a patchwork of scattered and small habitats. Individual nature development areas are more likely to prove successful if they are created in the context of a strategy for the river system as a whole. Many animals are dependent upon several ecosystem components for their survival: water from which to obtain food, and woodland in which to nest, for example.

Marshes and floodplain forests have become scarce in the river area. It is therefore very important that these ecotopes are well distributed, not only on a macro-level (nationally or internationally along the length of the river), but also on a regional level (along the course of a river) or on a micro-level (within a particular area of flood plain).

The concept of ecological networks is now being implemented right across the Dutch Rhine and Meuse river system.

FOOD WEBS

One of the characteristics of a healthy ecosystem is an intact food chain. Individual species depend on others to live, each eating and/or being eaten by another. If one link in the chain is missing or predominant, the natural balance can be destroyed.

In natural river environments, the shallow main channel and the flood plain provide much of the biomass for the food chain. A lack of suitable habitat for the provision of this vital link has a knock-on effect all the way along the chain. Hence, the strength of the food chain depends, for example, on adequate exchange between the main channel and the flood plain.

Before the rivers were dredged or canalized, their main channels were relatively shallow and scattered with islands. In shallow running water carrying sand and silt, enormous primary algae production takes place. The algae are then filtered from the water by a wide variety of invertebrates living on trees that have fallen into the river and branches that overhang it. The invertebrates are in turn food for fish fry, birds and other higher organisms. The recreation of shallow, flowing water bodies lined with trees would restore a valuable link in the lower food chain, thereby providing better opportunities for birds, fish and other species higher up the chain.

The presence in the water of trees, branches and plants also creates more varied conditions, in which it is easier for fish to find places to spawn and hide. Environmental variety enables a range of fish species to thrive and ensures that the larvae are able to develop to adulthood.

Within the river area, numerous food chains exist, each of which affects the next, with complex interaction between food chains in the main channel and on the flood plain. The maintenance of all links in the food chain is therefore very important.

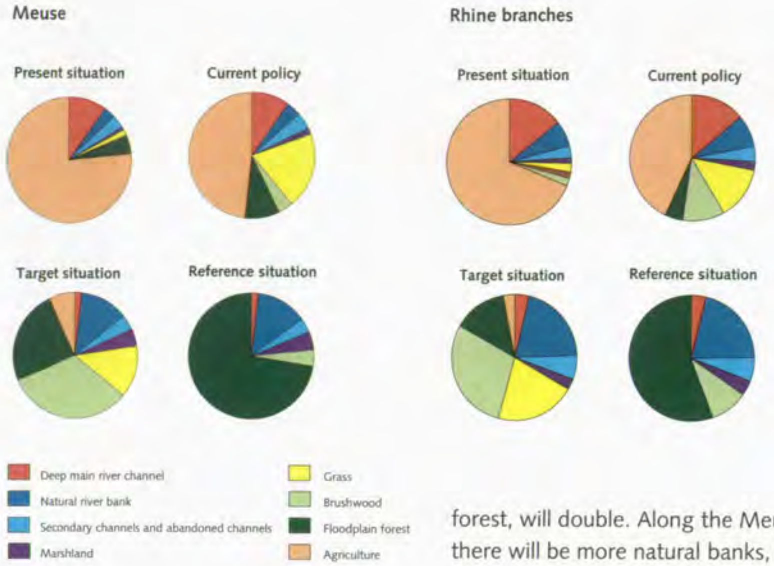
SPECIES TO FIT THE HABITAT

You would expect to find otters in floodplain channels and marshes, but how many? To address such questions, computer models have been developed, which simulate the environmental scope for all kinds of animals and plants. Using data on the areas of suitable ecotope in a given landscape plan, the models project the amount of foraging, nesting or spawning space available for the various AMOEBE-system species, and hence the number of animals of each kind that can be supported. These projections are based on ecological data on the ecotopic, territorial, networking and feeding requirements of the species in question. So, for example, two hundred hectares of marsh and floodplain channels can support ten pairs of otters, since each pair needs a territory of twenty hectares. Similarly, it is possible to work out what sort of habitat other animal and plant species require, and how much room individuals or pairs need. Where a species is no longer found in the Netherlands — as is the case with otters — the basic data is obtained from abroad. The estimated animal and plant numbers are then used to produce AMOEBE diagrams, from which it is possible to see whether the numbers and the breakdown of species provided by a given ecotopic arrangement are consistent with the ecological target situation.

TAKING OTHER INTERESTS INTO ACCOUNT

Nature development is an important and worthwhile activity, but it must not compromise flood protection or the navigability of the rivers. Large areas of floodplain forest, for example, would seriously increase flow resistance at times of high water, thereby increasing the risk of land behind the dikes being flooded.

A cautious approach must also be taken to the creation of secondary channels. If too much water were diverted away from the river proper, sedimentation problems would develop in the main channel, interfering with shipping. It is therefore important that there is sufficient resistance to flow in the secondary channels. For example, the channel entrances should be narrow, so that only small amounts of water enter. This would be ecologically quite acceptable, as the relevant water organisms only



Pie charts of the ecotopes in the high-water bed of the rivers Meuse and Rhine.

need a current of half a metre a second. And, because the erosion of bends at times of high water could undermine adjacent dikes, secondary channels should be well away from the dike walls.

PROSPECT

The ecological target situation differs considerably from the present conditions. Current policy is to increase the amount of natural habitat from ten thousand hectares to 28,000 hectares by 2010. This would represent considerable progress towards the 51,000 hectares envisaged in the ecological target situation. The kilometrage of natural river bank along the Rhine branches is set to rise considerably in the next few years. Meanwhile, the proportion of "dynamic natural habitat", complete with floodplain channels, secondary channels and softwood floodplain forest, will double. Along the Meuse, too, there will be more natural banks, but there are no plans to improve ecological conditions in the Meuse canals significantly. Along the IJssel and the canalized sections of the Meuse, the area of hardwood floodplain forest will not reach the full natural potential, and no extension of shallow main channel is planned. If the navigation channel must remain deep, the only way of offsetting the ecological consequences and re-establishing viable river ecosystems is to create numerous secondary channels. Characteristic riverside trees such as the black alder are unlikely to increase significantly along these stretches of river under the present policy. Policy-makers therefore need to focus particular attention on these parts of the river system.

In many places, the soil of the rivers' flood plains is badly polluted. Disposing of and cleaning up contaminated clay excavated in the course of nature development projects is therefore very expensive.
Concrete plans for nature development and the assessment of these plans will ultimately be based on the collective factors referred to above: the target situations, the ecotopic

maps, the territorial requirements of individual species, the spatial networks formed by the various ecotopes, the food webs and non-ecological considerations, primarily safety and the navigability of the rivers.

Using AMOEBE diagrams, it is possible to determine whether ecological conditions are improving. It will be interesting to learn, for example, whether all the anticipated species of animal and plant return to the Millingerwaard following its relandscaping. If they do not, the policy for the area will have to be reviewed.

Marks of a beaver in the Biesbosch.

Jaap Goudriaan, Rivers Project Manager, Limburg Directorate for Public Works and Water Management:
'THE BEAUTY OF THE MEUSE'

Along a forty-five-kilometre stretch of the Grensmaas, about a thousand hectares of nature development is planned as part of a scheme which also involves the extraction of around thirty-five million tonnes of gravel. "Green for gravel, a fair exchange" is the motto of the project, started in 1992. Since establishment of the project, flood protection has become one of the primary objectives.

"In the Meuse Valley, it obviously isn't easy to 'make way for the river', because the land is in intensive use. Nevertheless, we feel that parts of the flood plain could be taken out of agricultural use and allowed to return to nature. It is also important to keep the flood plain as clear as we can, so as to maximize the flow capacity at times of high river discharge. That is not to say we are planning to throw farmers off their land in order to create nature reserves; everything is to be done on a voluntary basis. So we think it will be about 2035 before we reach a point where perhaps 40 per cent of the flood plain is designated natural habitat."

"The opportunities around the free-flowing Grensmaas are particularly exciting. Originally, the Grensmaas ran along a number of braided channels, with natural variations in height and low islands, which were frequently flooded. The river transports not only gravel, sand and silt, on which pioneer vegetation could gain a foothold, but also all sorts of plant seeds. The gravel banks that have developed support only poor, sparse vegetation, especially in locations that are liable to regular flooding. These extreme environments take years to acquire any reasonable plant cover. This results in more variation in the landscape. Depending on the way the land is managed, softwood floodplain forest can be established in spots that often flood, while hardwood floodplain forest can be allowed to develop on higher, drier areas."

"Along stretches where there are no settlements nearby, the river will soon be allowed to erode its banks once more. Additional bank defences will only be built to protect villages. And we plan to re-create a few islands, and to allow them to develop naturally at certain other spots, as the river deposits gravel, sand and

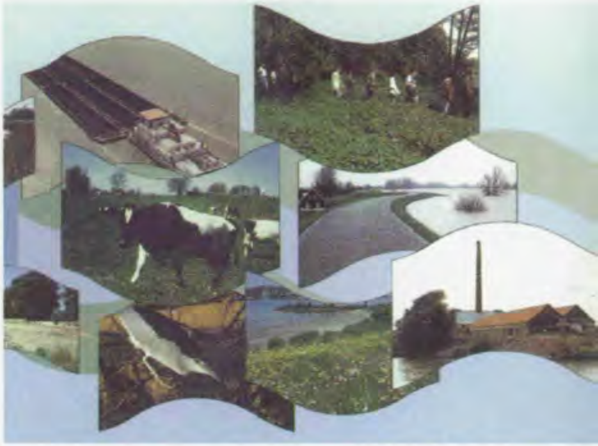
LANDSCAPE PLANNING 8

Landscape planning

Flood defence, transport, ecological recovery, the preservation of cultural and historical values, recreation, flood plain agriculture. Clay and sand extraction, dredging and spoil disposal. The provision of water supplies for agriculture, industry and drinking water preparation. How can all these functions simultaneously be accommodated in the finite space along the rivers? Can the rivers' high-water beds be landscaped in a way that is fair to all? And how should the different interests be weighed up? What can reasonably be done, and what cannot? By using our knowledge of the river system to create mathematical models, it is possible to explore various landscape planning alternatives. Modelling allows researchers to see what the consequences of a given proposal are for river processes and river functions. A suite of models and decision support systems (DSSs) have therefore been developed.

WEIGHING UP DIFFERENT INTERESTS

Before long, a great deal is set to change in the river area. In line with the commitment to 'make way for rivers', alternatives to further dike reinforcement are being sought, since continually making the defences higher is not seen as a sustainable approach. Efforts are also being made to develop natural habitats and to improve the navigational situation and recreational facilities, while respecting the cultural, historical and aesthetic values of the present landscape. Under such circumstances, decision-making necessarily involves weighing up the various interests at stake. Sometimes,



Try this and that with the river functions.

these interests conflict with one another. Intensive agriculture, for instance, is hard to reconcile with the promotion of truly natural habitats; large-scale afforestation within the flood plain is inconsistent with the need to make way for the river; and the creation of ecologically attractive secondary channels could lead to navigational problems. Furthermore, the Dutch' rivers form a coherent system. Changes on one branch of the Rhine can have consequences for others; changing the navigation channel or flood plain on one stretch of river affects water levels, flows and river-bed conditions elsewhere.

To enable studying the potential impact of proposed measures and weighing up the different interests at stake, models and decision-support systems (DSSs) are used. DSSs are computer programs which simulate the implications of planned measures for river processes. They also provide insight into the conse-

1 = narrowing of the main channel
2 = lowering of the groynes
3 = dredging
4 = redumping of sediment
5 = permanent layer
6 = natural bank
7 = removing summer embankment
8 = digging a secondary channel
9 = lowering of the embanked flood plain
10 = nature development
11 = removing of raised areas
12 = dike reinforcement
13 = dike repositioning
14 = retention (outside the high-water bed)
15 = obstructing lateral inflow
16 = dike raising

Possible landscaping measures along the river.

quences of a given landscape planning option for the various groups who make use of the river. The availability of such tools means that planners are no longer limited to examining individual themes in isolation; a range of river properties and functions, and their interrelationships, can be analysed together. At present, the models are being used to study each river branch in its entirety, with projections as far ahead as 2010 and 2050.

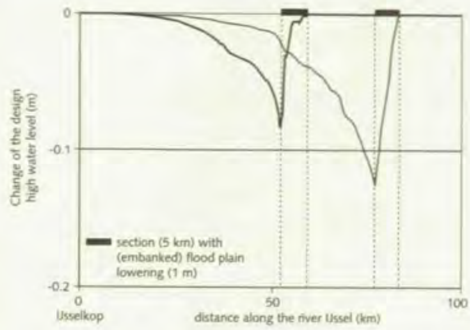
LANDSCAPE PLANNING MEASURES

A wide range of landscape planning measures is available for the improvement of river functions. Widening the river bed, for example, is one way of increasing long-term capacity. High water levels could be reduced considerably by lowering the flood plain and moving the dikes further apart to widen the high-water bed. Both of these measures are fairly drastic and — certainly where the second option is concerned — only suitable for certain locations. Deepening the main channel to increase the river's capacity in the short term is a particularly attractive (albeit expensive) option for the Meuse. Other, potentially more beneficial ways of providing more room for the river include the creation of secondary channels and the removal of summer embankments and raised pieces of land beside the main channel. These measures would result in the flood plain being under water more often and for longer, which would have ecological spin-offs as well.

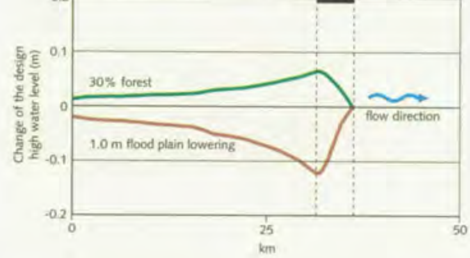
Reduction of the design flood water levels when the embanked flood plain is lowered by 1.0 m.

From an ecological point of view, measures worthy of consideration include creating secondary channels, converting agricultural land into natural habitat, re-establishing floodplain forests, promoting greater exchange of water and sediment between the main channel and flood plain, and allowing river dunes to develop. Modifications to the main channel would improve conditions for inland shipping. The scope for initiatives of this kind has been demonstrated by the Waal Project. Yet farmers benefit from summer embankments and raised flood plains, because agricultural land needs to be protected from inundation during the growing season. And, in areas of special cultural or historical interest — where, for example, there are ancient fortifications, houses or farms, or where the natural contours of the flood plain show how it has evolved — it may be best to leave things as they are.

Sometimes, a measure can serve several purposes at once. For instance, lowering the flood plain not only reduces the risk of flooding for areas behind the dikes, but also allows marshes and other wetland habitats to develop. At the same time, such an option may conflict with other important considerations. Making a flood plain lower could, for instance, involve the destruction of a culturally or historically valuable landscape, and is liable to disadvantage farmers, whose land will be flooded more often.



One Rhine branch, different effects. Even along a single river, reaches with wide and narrow floodplains occur, resulting in varying flow velocities along the river stretch. As a result, the same measure will have a different effect on the flood water levels on different locations.



Local measures may have regional impact. Reforestation leads to higher floodwater levels, whilst lowering the embanked flood plain reduces them. The effects of measures taken within a single floodplain section can be observed over a much longer stretch in the upstream direction.

THE RIVER RESPONDS

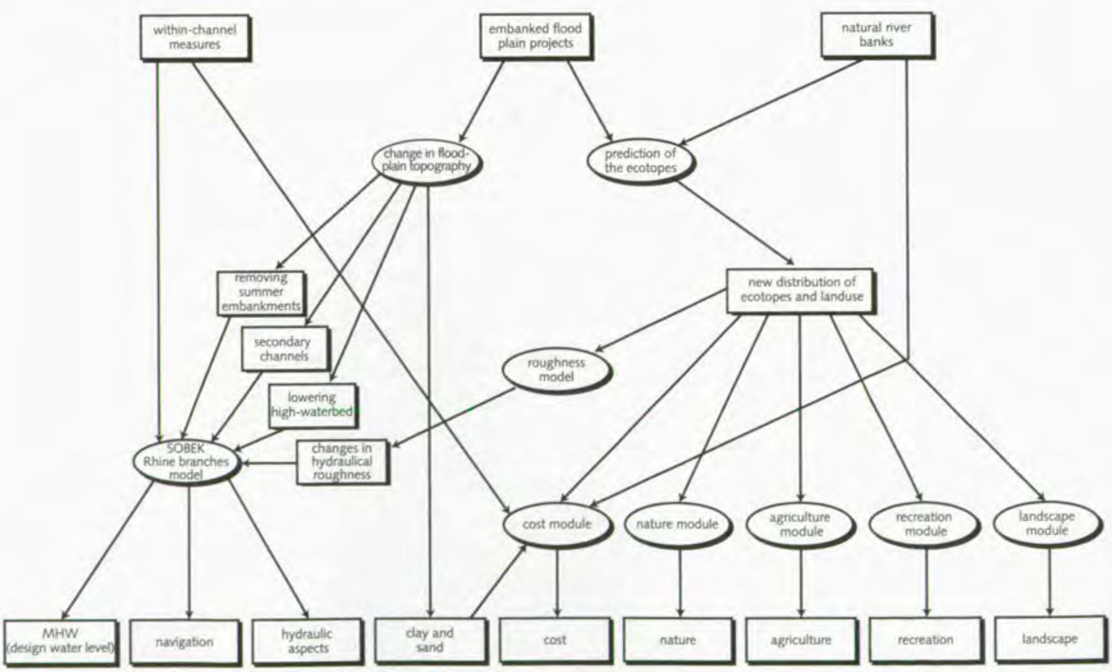
Measures such as those described above are liable to induce a response from the river itself. The transportation of water, sand and silt may be affected, which will in turn have implications for the main channel bed and for the flood plain. Because the Rhine, Waal, IJssel and Meuse differ from one another so much, they will also respond in different ways to nature development measures, excavation and other activities. Along the IJssel, with its narrow main channel and relatively wide high-water bed, more than half of the flow passes over the flood plain at times of high discharge. As a result, the consequences of changes to the flood plain would be more far-reaching than on the Waal, where the main channel is

Decision support system for landscape planning alternatives:

At the heart of the decision support system (DSS) used to assess landscape planning alternatives is a hydraulic and morphological model of the river, known as SOBEK. SOBEK calculates the implications of a proposed option for hydraulic variables such as water levels and discharges, and for morphological processes such as erosion or sedimentation of the river bed.

The DSS also predicts what effect planned measures will have on the flood plain. So, for example, it is possible to calculate how much clay needs to be removed to offset the flow resistance created by a flood-plain forest. The model can also calculate how the river bed will be affected by a given measure. If it appears that a project is likely to have an adverse impact, the plans can be modified — say, by reducing the amount of afforestation or increasing the amount of flood plain excavation — and retested until a solution is found which is acceptable in river management terms. For an option to be deemed acceptable, the design water levels and the associated flood risk must not be exceeded and the water depth during low flow must remain adequate for shipping.

Simulations are also performed to determine the implications of a given plan for agriculture, the environment, sites of special cultural importance and recreational opportunities. In addition, the capital cost and maintenance cost of a project are calculated. Thus, by using the DSS, various landscape planning proposals and visions can be assessed and compared. Because society's priorities are constantly changing, relandscaping is a dynamic process which involves constant policy review. A tool which makes it possible to quickly assess and accommodate new priorities is therefore invaluable.

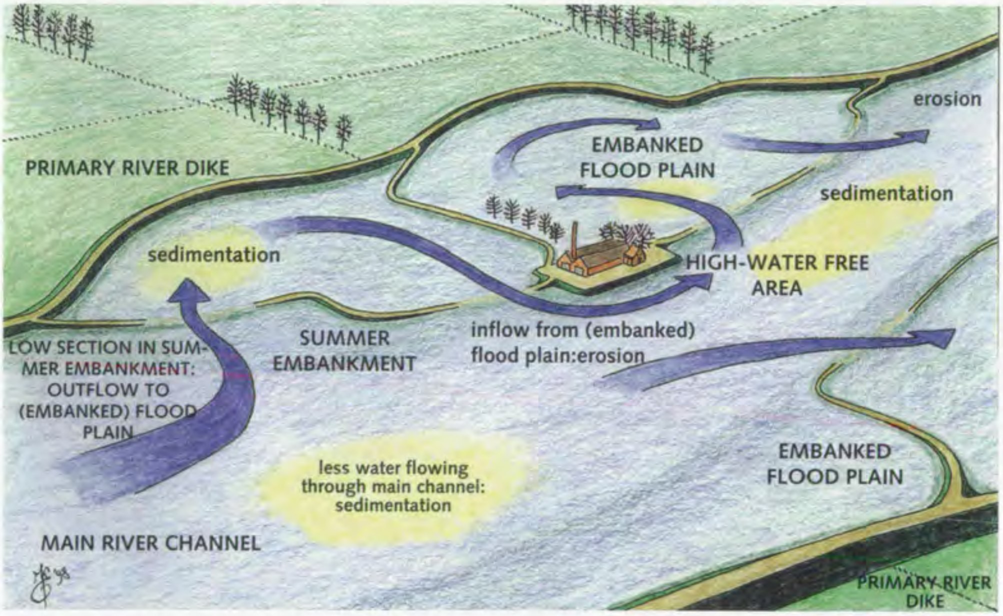


From measures to effects on river functions.

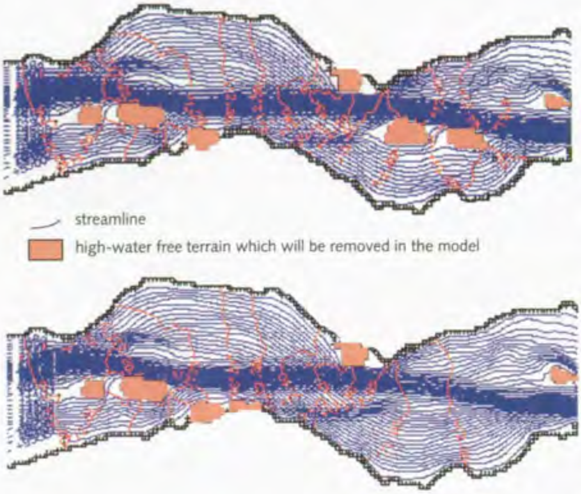
much wider. Considerations such as these need to be taken into proper account when planning landscape modifications.

Secondary channels in the flood plain can cause local sedimentation in the main channel. This results in noticeable rises in the river bed within a year or two, and can ultimately interfere with shipping. A sustainable balance can be established between the navigation channel and the secondary channels by, for instance, making the river's main channel narrower, thereby increasing the current velocities, which then reduces deposition. Alternatively, the main channel can simply be dredged more often. However, deepening the main channel can lead to erosion in the upstream stretches. When a river without weirs such as the Waal is deepened, the water level in the main channel is further reduced, even at low discharge levels. This in turn reduces groundwater levels and consequently dries out the local environment. Channel deepening can also have implications for the stability of groynes, the height of lock sills and pipelines laid across the main channel. In the Meuse, making the main channel deeper would have an adverse effect on nature in the high-water bed, since the water would not reach the banks and low-lying parts of the high-water bed as frequently.

Sedimentation and erosion phenomena can occur on a local scale as well. Where there are no summer embankments, or only low ones, the river carries sediment across the flood plain at times of flood. At times of extremely high water, variations in the width of the high-water bed mean that the river is alternately forced through bottlenecks, then allowed to ease up as it passes through a bulge. Such variations in the distribution of



Measures affect morfological processes.



Computer models are used to calculate how the flow pattern will be influenced after removing high-water free areas and lowering of the (embanked) flood plain surface.

flow between the main channel and the flood plains lead to erosion and sedimentation in the main channel, which can cause problems for shipping when the river is running low. At the same time, an ecologically interesting process takes place: the incoming water brings with it a large quantity of sand, which is deposited on the banks and across the flood plain, leading to the development of river dunes in the medium to long term.

If the flood plains were lowered, the rate of silt and sand accumulation would subsequently rise again, especially if the summer embankments were removed, since inundation by sediment-bearing river water would be easier. Finally, the secondary channels would eventually silt up if they were not regularly dredged or provided with sand traps.

FUNCTIONAL EVALUATION

Using a DSS, it is possible to determine whether a particular landscape planning option will have the desired effect, without having any adverse impact on river functions. For this purpose, a series of criteria has been defined for each function. Flood prevention has the highest priority; a landscape planning measure is considered only if it preserves the required level of protection. Hence, the safety criteria relate to increases in design high water levels and the kilometrage of river which would fall below the safety standard if the option under review were implemented. In cases where a hypothetical plan involves measures which would lead to increased water levels, supplementary measures are added one at a time to compensate for this effect. These compensatory measures might include creating more space for the river, by, for example, reducing the flood plain height or changing the vegetation to reduce flow resistance. To judge the impact of a proposed measure for shipping, the changes in water depth and navigation channel width at the Agreed Low River Flow are calculated. Ecological impact is then assessed by working out what the extent and distribution of the various ecotopes will be, and comparing the results against the target situation. The scope for ecotopes to function as a network is also considered. The proposed measure's consequences for the landscape are estimated by calculating the amount of open country that would be created, and working out the ratio between agricultural ecotopes (arable land and productive meadow) and natural ecotopes (e.g. flood-plain forest, brushwood and marsh). In addition, the area of flood plain with special cultural or historical value that would be affected by the plan is determined. The plan's rep ercussions for agriculture in the flood plain are

Measure	Water depth	MHW (design water level)	Channel slope
secondary channel	-	-	+
lowering the (embanked) flood plain	-	-	+
removing summer embankment	-	-	+
forest development	+	+	-
dredging the main channel	+	-	-
narrowing the main channel	+	+	-
+ increasing - decreasing			

The influence of measures on the water depth, the design water levels (MHW) and the channel slope.

evaluated by calculating the amount of land that would enter or be taken out of production. Measures such as clay removal, the creation of secondary channels and sand extraction result in the release of sedimentary material. The overall annual amount of sediment release is therefore determined, along with the possible quantity of seriously polluted sediment.

Designs

If a proposal is carried forward to the detailed planning stage, more precise projections of its impact within individual areas of flood plain are required. So, for example, calculations have to be made to determine where a floodplain forest should be sited to minimize the associated flow resistance, where river dunes should be allowed to develop, where a secondary channel should be connected to the main channel, and how wide the secondary channel should be. Questions of this kind cannot be answered by the DSS, so some are addressed using two-dimensional models to simulate water flow and sedimentation within an area of flood plain. In addition, field studies are undertaken and the situation is closely monitored after implementation to detect any changes.

CONTROLLING RIVER PROCESSES

Human interventions produce responses from the river. River managers consequently have to ensure that the action undertaken achieves the intended goal, but has no undesirable side effects. To this end, it is very important to control the various river processes when relandscaping the river area.

With a view to maintaining flood defences and protecting shipping interests, existing water and sand management policies are retained as far as possible. Many of the river's morphological responses contribute to high water levels. Apparently minor interventions can have far-reaching consequences in the long term, as a result of disturbances that they cause to river flow in a given locality. And it is not just measures which interfere with the free flow of water that can provoke such responses; measures which reduce water levels, such as sand removal, can have a similar effect. It is not possible to modify the river bed on a once-and-for-all basis; flood defence is an ongoing activity. Morphological effects of the kind referred to can be mitigated by implementing well-designed groups of compensating measures that suit individual river stretches. For example, careful siting of a secondary channel inlet and location of its outer bend within clay soil can substantially reduce the amount of sedimentation caused in the main channel.

Groynes and summer embankments have the great advantage of ensuring that the navigation channel remains deep enough for shipping, but cause constant erosion of the main channel's bed.

IN SHORT....

There are various ways in which the capacity of the rivers can be increased. The Landscape Planning of the River Rhine (LPR) has shown that reducing the height of the high-water bed and moving the dikes further apart are the most effective for reducing water levels along the branches of the Rhine. Over the next few years, more detailed assessments are to be carried out for the individual stretches of river. Knowing that the river will respond to any human intervention, the fundamental principle applied is that a modification at one point must not be allowed to create a problem elsewhere.

It is important that action undertaken in the rivers' upper reaches is coordinated with that undertaken in the lower reaches. Therefore, to supplement the LPR, a number of integrated studies of the tidal river area and the Meuse are being performed to identify which measures for increasing river capacity will be possible and necessary in the future and where such measures should be implemented. Given the cross-border nature of the rivers, international cooperation must also be sought with other countries along the Rhine, Scheldt and Meuse.

FUTURE PERSPECTIVE 9

Future perspectives

As the agency responsible for the Netherlands' great rivers, the Directorate-General for Public Works and Water Management has to pursue policies which take due account of the many activities which are or may in the future be undertaken in the river area. For the decades ahead, the directorate's highest priority has to be ensuring that flood protection is maintained, even in the event of higher design discharges, while also improving the situation for shipping and promoting nature development.

THE PRESENT SITUATION

Mankind has been modifying the river area for centuries, changing a natural landscape into a cultural one. The Netherlands' great rivers are now largely controlled by man and the flood plains are used for agriculture, clay and sand extraction, and all kinds of other purposes, some related to the river, others not. The other side of this coin is that the rivers have become much less natural and lost much of their ability to adapt to changing environmental conditions. Confined within their narrow, silted high-water beds, they have difficulty coping with waves of high water. The dikes are consequently tested to the limit. Furthermore, only a few isolated patches of natural river habitat are left. And, although the chemical quality of the river water is improving, the legacy of the past is heavily polluted river beds and floodplain land.

Many functional aspects of the river environment need improvement. The maintenance of flood defences capable of protecting the populace from higher river flows remains the top priority, but bigger dikes are no longer considered as the best way to ensure safety. For ecological reasons, clean water and river beds are required, as is environmentally sensitive landscape planning in the river area. Recreation — nature-oriented, in many cases — is becoming an integral part of the river scene. At the same time, existing cultural, natural and aesthetic features of the landscape need to be treated with due respect. In the future, the nation will be increasingly dependent on the rivers for drinking water production. Inland shipping is also vital to the Netherlands, and its continued growth depends on modifications to the navigation channels.

AIMS AND PLANS

Flood protection

During the high-water episodes of 1993-1994 and 1994-1995, about half of the river dikes in the Netherlands proved to provide insufficient protection. In 1995, 200,000 people and millions of animals had to be evacuated from areas in Gelderland threatened by flooding. The government subsequently paid out nearly 200 million euro (rate 1999) in compensation to economic flood damage. If the dikes had actually given way, this sum would have been much higher. Following the floods along the Meuse in 1993, the compensation bill was 100 million euro (rate 1999). In response to these events, the Great Rivers Delta Plan was developed. The plan provided for reinforcement of the dikes in Limburg by the year 2000, and for widening and deepening of the Meuse channel in the province by 2015. Given the unpredictability of natural phenomena, no one can be sure just how the rivers will behave in future. So the enhancement of flood protection will continue even once the dike reinforcement programme is completed in 2000. It is now accepted that there is more to ensuring safety than continually making the dikes higher. Additional measures are required to counter the risk of flooding in the long term. The river needs to be given more space, in order to increase the amount of water it can cope with. Obstacles will accordingly be removed, secondary channels reopened and the height of the high-water bed reduced. Activities proposed for the great rivers' high-water beds — including nature development, sand and gravel extraction and hydraulic engineering works — are now assessed on the basis of the policy document 'Make way for rivers', which came into force in 1996. Serious consideration will additionally be given to measures such as building retention areas inside the dikes and moving the primary river dikes further apart along the Meuse and the Rhine branches.

Flood protection initiatives are not confined to the Netherlands. International action plans have been set in motion for the Rhine and the Meuse basins to minimize the damage caused by high water in the future. Under these plans, peak flows are to be reduced by increasing the absorptive capabilities of the river basins, as well as the storage and drainage capacities of the rivers. The plans also provide for measures to reduce the potential for damage in areas at risk of flooding and for the improvement of flood warning systems. At the same time, research is underway across the river basins to ascertain the effect of climate change on high-water peaks, as well as the impact of changes in land use and of engineering and landscape planning initiatives along the rivers. This work is being done on a collaborative ba-sis by research institutes in the various countries in the Meuse and Rhine regions.

Nature

Extension of the rivers' high-water beds will have to be linked to nature development, since the river environment is a vital component of the national ecological network. Nature development depends on clean water and environmentally sensitive landscape planning in the river area. At present, about 17 percent of the land along the rivers is designated natural habitat; the policy objective is to increase this figure to 40 per cent. Nature policy for the fresh water delta, the naturally tidal reaches of the Rhine and Meuse, is aimed at partial restoration of the former estuary. Since completion of the river engineering projects in this

Research into landscape planning measures and alternatives

There are various ways of 'making way for rivers'. An exploratory research project known as the LPR suggested that measures such as reducing flood plain heights, increasing the distance between dikes and removing obstacles all have potential. To be effective, the policy ultimately adopted will have to consist of a carefully balanced combination of measures covering the entire river basin. Active post-implementation management will also be necessary to prevent natural processes such as sedimentation and plant growth gradually reducing the space that has been created.

By combining capacity-increasing measures in various ways, landscape planning alternatives can be developed. Each alternative has its own emphasis, which might be developing natural habitats, or minimizing the amount of contaminated spoil requiring disposal, or preserving the existing land use pattern as far as possible. Differences also exist between the alternatives in terms of cost and the time required for implementation. All alternatives must meet two basic criteria however: they must not have an adverse effect on high water levels and involve only at those locations where other measures are inadequate.

Present land use preserved.

Nature development.

Nature development. Leaving areas of naturally, culturally or historically important landscape intact.

Impressions of the high-water bed of the Rhine according to different landscaping alternatives.

Climate change and sea level rise

The consequences of gradual changes in the earth's climate could ultimately be so far-reaching that landscape planners should already be taking them into account. Climate changes, soil subsidence, sea level rise and so forth are slow but sure processes, which cannot be directly influenced by the water manager. On the basis of measured data sets and climate models, the Intergovernmental Panel on Climate Change (IPCC) has concluded that global rises in temperature and sea level are likely to continue in the years ahead. The KNMI has also made projections for the future Dutch climate. Broadly speaking, these projections point to average temperatures being between 0.5 and 2 degrees higher in 2050 than they are today, and a rise of between 2 and 5 per cent in annual precipitation. The precipitation increase is expected to be most marked in the winter. Episodes of prolonged, heavy winter precipitation could involve anything from 5 to 20 per cent more snow and rainfall than the episodes we are currently used to. During the summer, we are likely to see a shift towards heavy showers.

Climate change has consequences for the water cycle and thus for the amount of water in the rivers. If temperatures in the Alps rise by one or two degrees, the snow line will retreat dramatically in some areas, and meltwater flows will fall sharply. Hydraulic models suggest that the Rhine will become much more of a river with a pluvial regime. In the late summer and autumn, low water will be more likely, if only because the higher temperatures will cause more evaporation. Flow at Lobith on the lower reaches of the Rhine is forecast to drop by 10 to 20 per cent in the summer. In the winter, however, the river will more frequently run high, as a consequence of increased rainfall and the greater likelihood of snow in the Alps melting again soon after falling. Higher rainfall will also increase winter water levels on the Meuse, while average summer flows will fall somewhat. Without intervention, shipping between Basel and Rotterdam will have to contend with low river levels more often. The water supply to regional water bodies (and, therefore, water-level management and rinsing) and the extraction of industrial cooling water could also be affected. River ecosystems should generally benefit from the greater dynamism, although some wetland systems may be damaged by the dry summer conditions.

Although the overall annual volume of water flowing down the rivers will remain much the same, extremely high and low flows will become more common. Design flow in the Rhine may be about 5 per cent higher by 2050 than it is today. In the Meuse — a typical rainfall river, with a rapid response to precipitation events — design flow could be up 10 per cent by 2050. Without countermeasures, this could mean an increase in high water levels of twenty-five to thirty centimetres. What is more, further rises are expected after 2050. If existing safety standards are to be maintained in the twenty-first century, therefore, river capacity will need to be increased.

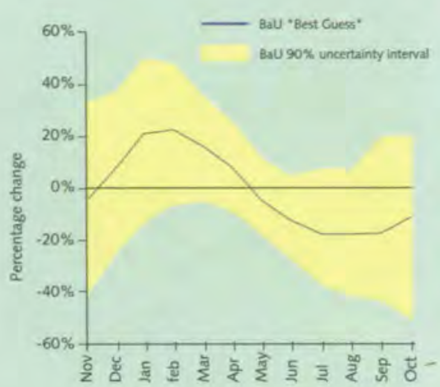
Higher river flows will be accompanied by a twenty-five-centimetre rise in the sea level along the Dutch coast between 1990 and 2050. This will affect not only the movement of water and salt in the tidal river area, but also the morphology of these lower reaches. Greater penetration of salt water, combined with lower river flows in summer, will limit the scope for extracting water from the tidal river area. The extent of the tidal influence will consequently reach further upstream.

area, much of the brackish and tidal environment has been destroyed. More varied ecosystems could be restored by opening the Haringvliet sluices more often, by cleaning up the beds of the water bodies in this area, by creating more natural banks and by allowing polders to return to nature. However, any such initiatives must pay due respect to existing culturally, ecologically and aesthetically important features of the landscape.

Shipping

The volume of goods transported per vessel on the Netherlands' inland waterways will increase considerably in the years ahead. Promotion of water freight transport is desirable not only for environmental reasons, but also as a means of relieving the pressure on the crowded road network. More, faster and, above all, bigger ships are therefore expected. In addition, general round-the-clock shipping is likely to become more commonplace, increasing the volume of night traffic. Rapid passenger transit by water is another realistic prospect. To make these developments possible, the rivers' navigation channels will need to be modified to facilitate quick, safe passage and the use of greater vessel draughts.

The Waal Project and the Meuse Route Modernization Project (Momaro) have accordingly been established. Account must also be taken of recreational river traffic, which has been growing at an average of 2 per cent a year as prosperity and leisure opportunities have expanded. As time goes by, recreational river users are buying bigger vessels and seeking out the larger water systems. The accessibility and suitability of the river banks need to be improved for the benefit of these pleasure boaters.



Results of the RHINEFLOW waterbalance model: 'best guess' changes in the monthly discharge of the Rhine at Lobith resulting from climate change, and the 90% uncertainty interval according to the IPCC "Bussiness as Usual" scenario.

As a result of climate change the discharges will change. More water in the winter months, less water during summer. The uncertainty interval of the model results, however, is quite wide.

Water and sediment quality

Water quality has improved sufficiently to allow various animal and plant species to recover, or to return to the river environment, even though the concentrations of various substances remain above the target levels. In the years ahead, eutrophication will remain a major problem in the great rivers. The situation with regard to heavy metals is stable and unlikely to improve between now and 2015. Concentrations of crop protectors — currently well above what they should be — are expected to fall by about 30 per cent in response to implementation of the Multi-year Crop Protection Plan and the Surface Water Pollution Act. The pollution picture differs considerably from one substance to another. Unfortunately, it is with the very substances which are most harmful to water organisms that the least progress is being made. Good water quality in

Photo montage of a secondary channel along the river Meuse. The small picture shows the present situation, the large photo presents the future situation.

the future therefore depends on continuation of the work started by the International Commission for the Protection of the Rhine and the Committee for the Protection of the Meuse. Particular attention will need to be given to the beds of the various water bodies. The quality of recent sedimentary layers is considerably higher than the quality of those laid down in previous decades, but pollution remains serious in many places. As a result, essential dredging work will generate many extra costs.

To ensure that everyone who uses the river system is fairly treated, and to weigh up the various interests at stake, a number of decision support tools have been developed in the context of schemes such as the Landscape Planning of the River Rhine (LPR). Similar studies are now being carried out for the tidal river area and for the Meuse. In these integrated studies, different scenarios for the development of the river area are assessed and forecasts of their impact made.

AREAS OF UNCERTAINTY

Despite all that is now known about the rivers, the process of making decisions about their future management and use remains beset by uncertainties. The sources of uncertainty are various. First, much remains to be learned about the river system as it is today. Not enough is yet known about peak flows, the dispersal of pollutants or the flow resistance associated with floodplain vegetation, for instance. Understanding of many natural processes is also limited, and the models used to simulate them are often rather simplistic. Among the processes that could be better understood are the development of ecosystems, the transport of sediment and the exchange of sediment between the rivers' main channels and their flood plains. Many questions about climate change and its possible impact on (extreme) river flows also remain unanswered. The directions in which society will develop represent another area of uncertainty. We can only guess, for example, how future generations will feel about flood protection, the disposal of polluted silt, the relative importance of the environment and the economy, or the value of the river landscape. Nor can one predict with real certainty how shipping, agriculture, industry, drinking water preparation or recreation will develop; changes in the importance of these functions and the requirements associated with them will require the regular reassessment of interests and perhaps ultimately the revision of policy.

The increasing emission of CO_2 has enhanced the natural greenhouse effect, resulting in a global warming.

Many of the changes at work or in prospect will affect not only the Netherlands, but also all the other countries through which rivers

The Zandmaas and Meuse Route Projects

Minimizing flood-related problems, improving the navigation channel and developing natural habitats are the three main aims of the large Zandmaas and Meuse Route Projects. In pursuit of the first aim, embankments were created as part of the Zandmaas Project in 1995. Further measures are planned to increase river capacity and thus reduce high water levels. By 2005, the risk of flooding in the areas protected by embankments should be one in 250 in any given year.
The navigation channel improvements in prospect are intended to make the entire Meuse route suitable for twin-vessel sets. Other important aims are safety and ease of passage for all vessels using the navigation channel.
Without compensatory measures, the work being undertaken along the Zandmaas to 'make way for the river' would affect water levels on the diked sections of the Meuse. The various water authorities, provinces and regional directorates involved are therefore working together to develop appropriate plans for the project area as a whole.

Making way for the Rhine branches

In the coming decades, large-scale initiatives to increase river capacity will be required in the Netherlands. The space available to the rivers will be increased so that greater volumes of water can move downstream without further dike reinforcement being required. The Landscape Planning for the river Rhine Study has accordingly been established to advance sustainable flood protection in the river area. The project involves a planning study, on the basis of which an advisory report on making way for the Rhine branches will be submitted to the Minister of Transport, Public Works and Water Management.
Regional authorities and national government agencies will draw up capacity improvement plans together after weighing up various alternatives. One of the points of departure is that nothing must be done to compromise the stability of the river dikes. Furthermore, the established ecological objectives are to remain in force. Water levels must not be allowed to fall to a level which would disadvantage shipping and proposed measures are not allowed to interfere with the Waal Project.
The planning study is intended to provide a general framework, indicating how extensive the various measures should be, and where they are considered appropriate. The central government will then leave detailed planning to the local authorities and agencies. The capacity improvement proposals developed through the project have to be financially, technically and legally feasible and must enjoy sufficient support from the relevant local authorities and other organizations.

flow. Climate change, new patterns of land use, river improvements and the creation of retention areas are relevant right across the river basins.
Against this background, it is essential that the various sources of uncertainty are identified and the degree of uncertainty associated with each estimated as accurately as possible. If a corresponding degree of flexibility is then built into the decision-making and landscape-planning processes, it should be possible to cope with new developments as they arise. Decision support systems can be very useful in this regard. As the LPR study showed, different visions of river management can result in very different landscapes and produce a wide range of effects on river functions. And, using Decision Support Systems (Dss), it is possible to study the likely repercussions of various scenarios before any action is taken. So, for example, the effects of anticipated changes and possible response measures can be assessed in advance.

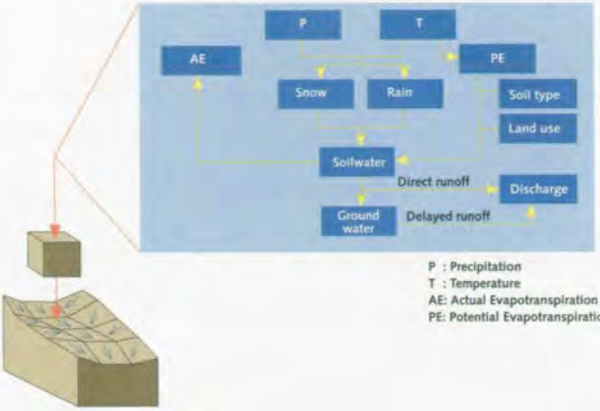
TRENDS IN WATER MANAGEMENT

Water management, nature development and spatial planning are becoming more and more closely linked. A sustainable approach to flood protection necessitates imposing limits on the amount of floodplain land that may be used for purposes which are not directly river-related. Spatial planning of the river area is now based on the assumption that, in the long term (i.e. after the year 2015), more space will be required for increasing the capacity of the river. Land (whether inside the dikes or behind them) which is reserved for possible future capacity-increasing measures will be given reversible and thus "no regret" designations such as natural habitat.

Preparations are being made for the adoption of a new approach to flood protection, based on flood risk ratings for areas enclosed within ring dikes. The Technical Advisory Committee for Water Management Structures (TAW) at the Directorate-General for Public Works and Water Management is coordinating work in this field. Under the new approach, both the likelihood of flooding and the consequences of any flooding which might occur will be taken into account.

Efforts to establish a sustainable flood protection policy, to encourage nature development and to improve navigation routes are most likely to be successful if they tie in with natural processes as far as possible. This does not, however, simply mean sitting back and letting nature take its course. River managers will need to provide a guiding hand where necessary, and an active approach to maintenance and monitoring will be required, making a thorough understanding of river processes vital.

Flow diagram of the RHINEFLOW-model



The effect of climate change on the river discharge can be determined with hydrological models which simulate the hydrologic cycle.

Truly integrated river management has to extend beyond national borders. Like ecological recovery and pollution control, effective flood protection depends on policies implemented across the river basins. The countries along the Rhine, Meuse and Scheldt therefore

The Mars Route: a new approach to flood protection in prospect

With a view to placing flood protection planning on a more solid theoretical footing, the Mars Route Research Programme has been established by The Technical Advisory Committee for Water Management Structures (TAW), which reports to the Directorate-General for Public Works and Water Management. Flood protection policy is presently based primarily on the likelihood of a particular high water level occurring. There will always be an outside chance of the river reaching a level higher than that for which the flood defences are designed. The main aim of the programme is to develop a new approach based on a flood risk rating for areas completely enclosed by dikes (dike rings). This rating will represent the likelihood of flooding multiplied by an index reflecting the amount of damage any flooding might be expected to cause. Dike rings can border on several river branches and can therefore be protected by sections of various dikes. Furthermore, the damage likely to result from inundation will vary from one ringed area to another. Thus, the new approach seeks to ensure that policy is based not simply on the probability of a particular dike overflowing, but on the risk of flood-related damage and casualties in areas ringed by dikes. Nevertheless, the minimization of damage and casualties at times of high water will continue to depend on reliable river level forecasting and information systems.

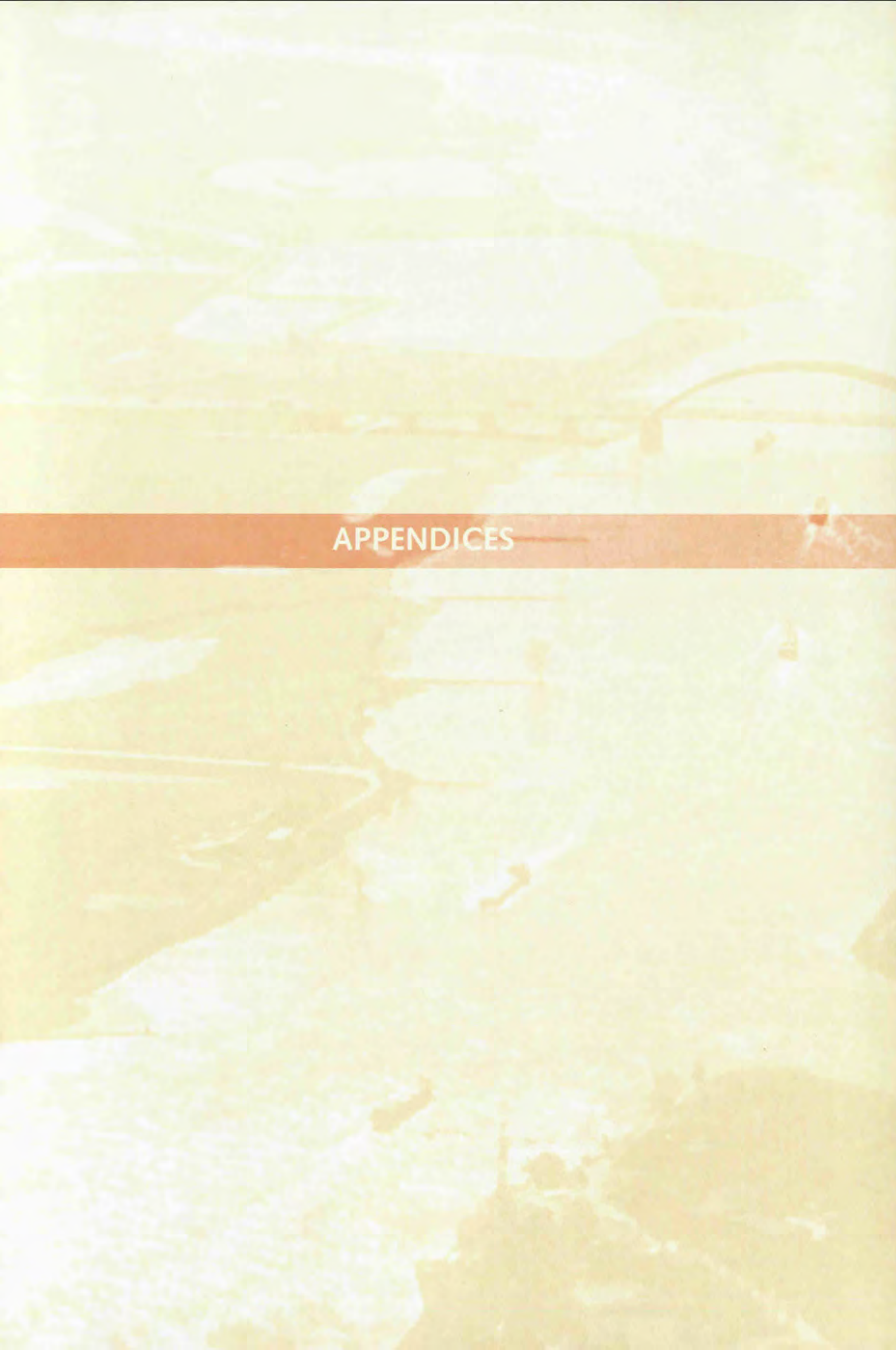
need to work closely together. International flood protection action plans have already been set in motion. The International Rhine Committee has drawn up a Flood Action Plan which includes a series of measures due for implementation along the river, starting in the year 2000. Similarly, a Meuse Flood Action Plan is now in place. To back up these initiatives, decision support systems capable of forecasting the impact of developments and measures throughout the river basins are required. As well as involving a great deal of technical development work on the necessary models, creation of river basin DSSs will call for cooperation between and support from the various countries concerned.

A similar international approach is needed to tackle water pollution problems, particularly those associated with diffuse sources (e.g. agriculture and shipping), which are becoming increasingly significant in relative terms. Continued effort will also be required to tackle discharges from localized industrial sources, by improving operating practices, for example. In the field of industrial pollution control, priority has to be given to long-term solutions, such as environmentally friendly product and raw material selection, clean technologies and closed product cycles.

A solution to the problem of polluted sediment should be based in the first instance on preventing pollution at source. However, the most badly contaminated beds will also need to be cleaned up in due course. Where state-owned water bodies are concerned, this work will take a further twenty-five to forty years.

Social issues are becoming more complex, more dynamic and, in many cases, more extensive. This trend is evident in water policy. Greater coordination is required between the spatial planning and water management disciplines. Developments in the funding of water management and European legislation could lead to the further integration of existing legislation, such as the Rivers Act, the Town and Country Planning Act, the Flood Protection Act and the policy document entitled 'Make way for rivers'. The government wishes to make as much use as possible of the open planning process, in which great importance is attached to consultation with interested groups and the general public.

So it seems that, for the Directorate-General for Public Works and Water Management, the next two hundred years will be just as busy as the last.



APPENDICES

Who is involved in river-related policy development, planning, licensing, management and maintenance (i.e. integrated river management)?

The national government departments involved in integrated river management are the Ministry of Transport, Public Works and Water Management (Dutch initials: **V&W**), the Ministry of Housing, Spatial Planning and the Environment (**VROM**), the Ministry of Agriculture, Nature Management and Fisheries (**LNV**) and the Ministry of Internal Affairs (**BiZa**). BiZa's involvement is in the field of crisis management. At the regional and local levels there are of course the provinces and municipalities and the water authorities and water purification boards. Various non-governmental organizations (**NGOs**) have important roles as well, generally representing the interests of particular groups. Yet another aspect is the involvement of the business community in the implementation of policy.

Across the river basins, international policy is coordinated through organizations such as the International Commission for the Protection of the Rhine (**IRC**), the International Commission for the Protection of the Meuse (**ICBM**) and the Scheldt against pollution, the International Working Group for Flood Protection on the Meuse (**WHM**) and, in the field of shipping, the Central Rhine Navigation Committee (**CCR**). Various bilateral working agreements also exist at national, regional and local level.

The highest level of collaboration is through the European Union (**EU**). Legislation from Brussels, such as the framework directive Water, will in the future become increasingly important.

Major events in the history of river management

The information in this table was originally published in 'Vorm geven aan een duurzame delta' (Sustainable delta design), published by the South Holland Directorate for Public Works and Water Management, 1997, and 'Autonome morfologische ontwikkeling van de Rijntakken' (Autonomous morphological development on the Rhine branches), published by Haskoning, 1990.

Treaties, policy documents and reports		Events
	1870	Rhine normalization, phase 1
	1890	Rhine normalization, phase 2
Rivers Act	1908	
	1916	Completion of Waal normalization
	1926	Disastrous Rhine and Meuse flood
	1928	Completion of IJssel normalization
	1929	Canalization of Meuse
	1932	Closure of Zuiderzee
	1934	Completion of Nederrijn/Pannerden Canal normalization
	1950	Establishment of International Commission for the Protection of the Rhine (IRC)
	1953	Disastrous sea flooding in the provinces Zeeland/South Holland
	1956	Design discharge first calculated
Delta Plan	1957	
Delta Act comes into force	1958	First part of the Delta Works completed: flood barrier on the Hollandsche IJssel
	1962	Establishment of International Commission for the Protection of the Meuse (ICBM)
First Water Management Policy Document	1968	
Surface Water Pollution Act (WVO) comes into force	1970	Completion of Haringvliet Dam
	1970	Completion of Rhine canalization
	1970	Establishment of the International Commission for the Hydrology of the Rhine Basin (CHR)
Publication of *The Limits to Growth* (Club of Rome)	1972	
	1975	Establishment of the River Dikes Committee (Becht)
Salt Treaty	1976	
	1977	Start of river dike improvement programme
	1980	Further normalization of Beneden Waal
Integrated Regional Water Management Regulations (REGIWA) come into force (until 1992)	1982	
Second Water Management Policy Document	1984	
Dealing with water	1985	
	1986	Environmental disaster on Rhine (Sandoz fire, Basel - Switzerland)
	1986	Construction of Slufter dredging depot started
	1986	Introduction of six-unit multiple barge sets on Rhine

Rhine Action Programme	1987	
Stork Plan	1987	
Third Water Management Policy Document	1989	Start of Waal Project (shipping)
	1989	Establishment of Duursche Waarden riverine nature development project
National Environmental Policy Plan Plus	1990	
Nature Policy Plan; introduction of the ecological main structure (EHS)	1991	
Supplement to the Fourth Policy Document on Physical Planning	*1991*	
Further Elaboration for the River Area (NURG)	1991	Start of Meuse Route Modernization Project for inland navigation (MoMaRo)
Green Space Structure Plan	1992	
Living Rivers	1992	
Green for Gravel	1992	First IPCC report (climate change)
Water Authorities Act	1992	Establishment of Committee for the Assessment of River Dike Reinforcement Principles (Boertien I)
Second National Environmental Policy Plan	1993	Flood on the Meuse
	1993	Establishment of Meuse Flood Emergency Committee (Boertien II)
Evaluation Document on Water	1994	Formal opening of Biesbosch National Park
Great Rivers Delta Plan (DGR) and Emergency Act	1995	Flood on Rhine and Meuse
	1995	Meuse works started
Flood Protection Act	1996	
Policy document: *Make way for rivers*	1996	Start of Mars Route Project (inundation risk approach)
The Future for Water, final report of 'Aquatic Outlook' Study	1996	
Document: *Landscape Planning for the Rhine (LPR)*	1996	Establishment of International Working Group for Flood Protection on the Meuse (WHM)
	1997	Storm surge defence on Nieuwe Waterweg commissioned
	1997	Start of Make way for the river Rhine (RvR)
	1997	Start of Landscape Planning of the Lower Rhine and Meuse Delta (IVB)
	1997	Start of Landscape Planning of the river Meuse (VVM)
Policy document: *Active River Bed Management (ABR)*	1997	
Rhine Flood Action Plan	1998	
Fourth Water Management Policy Document	1998	
Meuse Flood Action Plan	1998	
	1998	Bicentenary of Directorate-General for Public Works and Water Management
	1999	Completion of Ketelmeer silt depot
	2000	Completion of river dike reinforcement programme introduced under DGR
	2001	Assessment of design water levels in accordance with Flood Protection Act

List of abbreviations

ABR	Active River Bed Management
BiZa	Ministry of Internal Affairs
CCR	Central Rhine Navigation Committee
CHR	International Commission for the Hydrology of the Rhine Basin
DGR	Great Rivers Delta Plan
DHL	Design Hydraulic Load, associated with a particular level of river flow, known as the design discharge.
DSS	Decision Support System
EU	European Union
EHS	National Ecological Network; nature policy plan
ICBM	International Commission for the Protection of the Meuse
IPCC	Intergovernmental Panel on Climate Change
IRC	International Commission for the Protection of the Rhine
IVB	Landscape Planning of the lower Rhine and Meuse Delta.
KNMI	Royal Dutch Meteorological Institute
LNV	Ministry of Agriculture, Nature Management and Fisheries
LPR	Landscape Planning for the river Rhine Study
MAR	Maximum Acceptable Risk
MSW	Water Monitoring System
NGO	Non-Governmental Organizations
NURG	Further Elaboration for the River Area; landscape planning and policy
RAP	Rhine Action Programme
REGIWA	Integrated Regional Water Management Regulations
RIZA	Institute for Inland Water Management and Waste Water Treatment
RvR	Make Way for the river Rhine Project
RWS	Directorates for Public Works and Water Management
TAW	Technical Advisory Committee for Water Management Structures
V&W	Ministry of Transport, Public Works and Water Management
VROM	Ministry of Housing, Spatial Planning and the Environment
VVM	Landscape planning of the river Meuse Project
WHM	International Working Group for Flood Protection on the Meuse
WVO	Surface Water Pollution Act

Colophon

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Editors H. Middelkoop - RIZA, C. O. G. van Haselen - RIZA

Text M. de Boo, H. Middelkoop

With contributions of
R.M.A. Breukel - RIZA
W.B.M. ten Brinke - RIZA
J. Goudriaan - RWS-DLB
D. van der Graaf - RWS-DON
D. Ludikhuize - RIZA
H. Middelkoop - RIZA
B.W.A.H. Parmet - RIZA
W. Silva - RIZA

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For more information about the Rhine or the Meuse, please contact:

RIZA
P.O. Box 9072
6800 ED Arnhem
The Netherlands
tel. +31 26 368 8911

P.O. Box 17
8200 AA Lelystad
The Netherlands
tel. +31 320 298 411

East Netherlands Directorate for Public Works and Water Management (RWS-DON)
P.O. Box 9070
6800 ED Arnhem
The Netherlands
tel. +31 26 368 8911

Limburg Directorate for Public Works and Water Management (RWS-DLB)
P.O. Box 25
6200 MA Maastricht
The Netherlands
tel. +31 43 329 4444

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The Netherlands

tel: +31 70 378 9880
fax: +31 70 378 9783
e-mail: mlget@sdu.nl

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