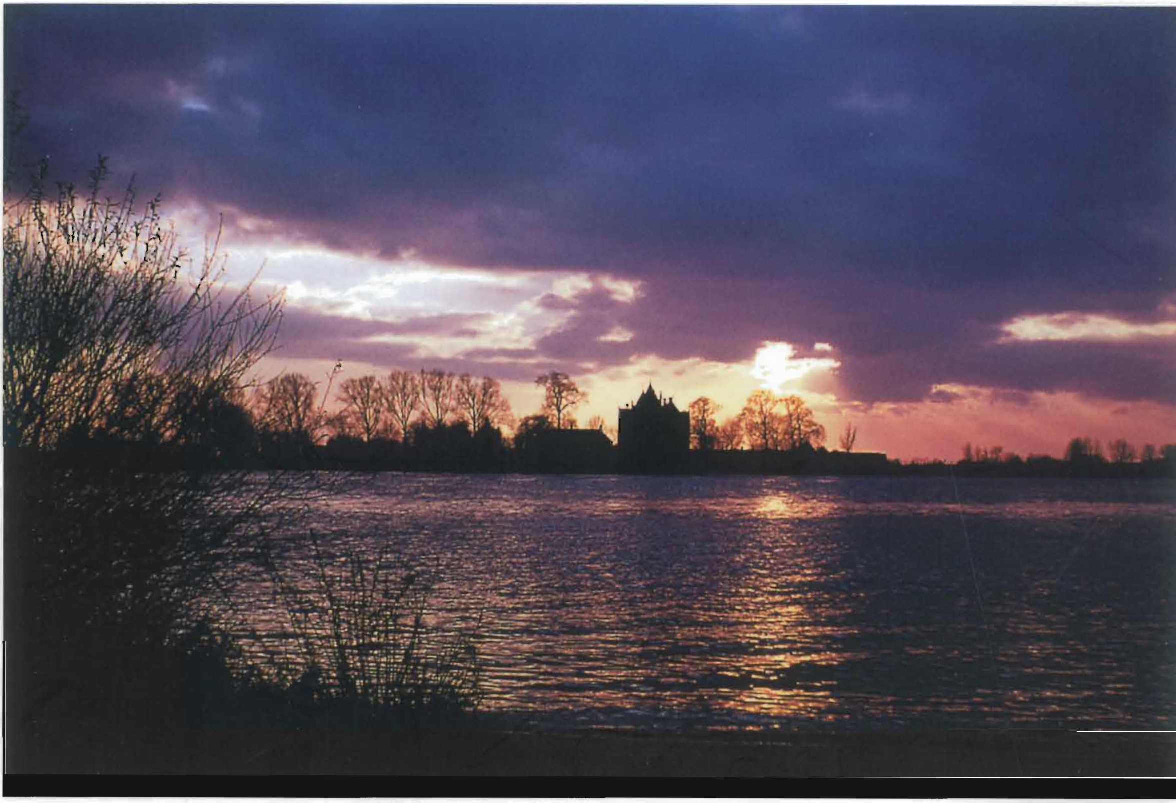

Water in the Netherlands

managing checks and balances

Water in the Netherlands

managing checks and balances

The voice of the water

Thinking of Holland
I see broad rivers
languidly winding
through endless fen,
lines of incredibly
tenuous poplars
like giant plumes
on the polder's rim;
and sun in tremendous
open expanses,
the farmsteads scattered
across the plain:
coppices, hamlets,
squat towers and churches
and elms composing
a rich domain.
Low leans the sky
and slowly the sun
in mist of mother
of pearl grows blurred,
and far and wide
the voice of the water,
of endless disaster,
is feared and heard.

H. Marsman 1936

Translated by James Brockway
From: A Sampling of Dutch Literature
Dutch Radio World Service 1962

Netherlands Hydrological Society (NHV)

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CIP-DATA

Water in the Netherlands,
managing checks and balances

Pieter Huisman, Delft University of Technology
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Colophon

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The Rine branch Waal during high water. Photo: Frans Klijn, WL|delft hydraulics

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Preface

The poem of Hendrik Marsman on the title page not only depicts the serene Dutch landscape but also expresses the struggle for life in the Netherlands. This country is the result of human interventions in the natural conditions over centuries. As an illustration: without dikes, the sea and rivers would regularly flood 65% of the land. In dry summers, however, parts of the country are short of fresh water. Living with floods and droughts requires a ceaseless checking of flood control and water management systems as well as balancing of all water-related interests.

The internationally renowned Dutch polder model refers to the centuries-old decision-making process which defines the water level after establishing the current situation and balancing all concerning interests. Checks and balances in the subsiding Netherlands with rising sea and river levels have defined its present geographic shape, institutional structure and legislation. The oldest, democratically rooted organization in the Netherlands' balancing interests, the water board, is more than 700 years old. This institution is still serving the local and regional flood defence and water management. Some 500 years ago the democratic supervision on water issues by provinces was started. The national responsibility for water is rather young. The Rijkswaterstaat, the present national agency of the Ministry of Transport, Public Works and Water Management, began its activities in 1798.

In the course of time, the Rijkswaterstaat has focused on the improvement of the state-managed rivers, promotion of the navigation system by construction of canals and harbours, and improving water discharge in wet periods as well as water supply in dry periods in the different Dutch regions. Since the 1960s pollution is an important issue not only for the Rijkswaterstaat but also for all interested parties. The fight against pollution required and still requires mutually co-ordinated efforts at every governmental level and in all socio-economic sectors. Enlarging the discharge and storage capacity of the state managed rivers, creating and reserving storage for water in urban areas, and preserving and improving nature management are the current issues. These topics are the challenges in the national water arena. Moreover, according to law, every citizen can participate in the decision-making process about water-related issues.

The key to understanding the geography and institutions of the Netherlands and the Dutch behaviour can be found in the country's flood defence and water management.

In the scope of international activities, I have observed a recurrent interest in the specific features of the role of water in the Netherlands. In particular, foreigners co-operating with Netherlands experts and scientists in the field of water-related problems ask for more specific information about these man-made lowlands. Therefore I welcome the 2004 revised edition of "Water in the Netherlands" because this booklet gives a good overview of human interventions in natural conditions over time and their impact on the Netherlands society. It also provides information about the challenges for water management in the future. The concept of integrated water management launched in 1985 focuses on the mutual coherence between the quantity and quality of groundwater and surface water at local, national and international levels. It also concentrates on co-ordinating physical planning, environmental quality and management of nature areas. The concept of integrated water management was laid down in the legislation.

In 1986/1987, similar ideas on integrated water management, as formulated by the Netherlands, stimulated all riparian Rhine States to adopt a Rhine Action Plan, comprising a further reduction of pollution and the rehabilitation of the ecosystem of this river. Another important step towards integrated transboundary river basin management was taken in the nineties of the former century. The 1993 and 1995 floods of the Rhine and Meuse forced the riparian states to increase their co-operation on flood protection issues. Meanwhile, common principles and strategies have been formulated for a basin-wide approach to mitigating the flood problem.

Excessive rainfall in 1998 and 2000 caused flooding resulting in particular inconvenience in urban areas. It became necessary to reformulate the requirements of the regional and local water systems. This led to the triplet retain-store-discharge as the leading principle for these systems. In its document "Water policy in the 21st Century", the Government also focuses on raising the awareness of citizens and encouraging their contribution in relation to water threats and problems.

In December 2000 the EU Water Framework Directive came into force. Efforts are underway at every governing level in the Netherlands to achieve the objectives of the Directive in time. The first results about the water basin approach have been published. The Netherlands' Government strives to harmonize the Dutch efforts with those of our neighbours in the basins of the Rhine, Meuse, Scheldt and Ems.

Mrs. Melanie Schultz van Haegen
The Vice Minister of Transport, Public Works
and Water Management

Acknowledgements

In 1986 the Committee on Hydrological Research of the Netherlands Organization for Applied Scientific Research TNO (CHO-TNO) published the book "Water in the Netherlands" to meet the increasing demand, especially from people in other countries, for more information about the Dutch water management. The rapid sales resulted in a revised edition being published in 1989. The Netherlands Hydrological Society and the Netherlands Committee of the International Association of Hydrological Sciences completely revised the book in 1998.

My gratitude to those who enabled the present edition to be published also extends to the authors of the earlier publications: Messrs C. van den Akker, H.J. Colenbrander, W. Cramer, G. van Ee, R.A. Feddes, J.C. Hooghart, P. Huisman, P. Kusse, C.R. Meinardi, H. Salz, E. Schultz, C.J.E. Schuurmans, J.H.A.M. Steenvoorden, A. Volker (†), J. Wessel and F.C. Zuidema. Their contributions were partly used for this revision.

Many thanks go to Mr. Pieter Huisman of the Delft University of Technology, the main author of the 1998 publication. He has updated this edition to include recent developments.

My special thanks go to Mrs. Frances Watkins for editing the English text.

I am grateful to the Netherlands Government for financial support.

G. van Ee
President of the Netherlands Hydrological Society (NHV)

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1 Synopsis

The Kingdom of the Netherlands, Holland, the Low Countries: three names for the same country? No, not exactly. The Netherlands is the correct name of the Kingdom bordering the North Sea in western Europe. Many people, both abroad and in the country itself, also call it Holland. The reason is that in the time of the Republic of the Seven United Provinces (AD 1572 - 1795) Holland was the predominant and most prosperous province of that republic. Before 1572 the 17 provinces covering the present kingdoms of Belgium and the Netherlands were a political unity, sometimes named the Low Countries.
Because of the rise of the ocean from prehistoric times up to its present level, the inhabitants of the low-lying areas in the western and northern parts of the country had to compete with the water. The present country is largely the result of this struggle, showing the balance of successes and failures. Life in the Netherlands is closely linked to water. Its history is full of stories not only about floods and dike bursts, but also of successful land reclamation.
In this century two storm surges changed the shape of the Netherlands. The storm surge of 1916 gave the final push to the closure of the inland Zuyderzee and the reclamation of large polder areas. In February 1953 a tremendous storm surge struck the south-western part of the Netherlands. Many dikes were breached, thousands of hectares were inundated and over 1,800 people drowned. This led to the world famous Delta works. Figure 1.1 shows one of the dike bursts in 1953. The danger comes not only from the sea, but also from rivers, as proved in 1926 and 1995. In 1926 high discharges of the rivers Rhine and Meuse breached some river dikes, inundating large areas. Heavy rainfall during several weeks produced high discharges in 1995, threatening the river dikes. It forced the authorities to evacuate more than 250,000 people within 36 hours. Fortunately the dikes held.

This publication describes the events that occurred over many centuries and the Dutch experience in conquering water over that time. It also pays attention to other issues, such as water management, water quality and hydrological research.
It starts with a description of the geography, climate and hydrology of the Netherlands (Chapters 2 and 3). Next, Chapters 4, 5 and 6 give a historical overview of the development of the man-made environment in the Low Lands near the sea. Extensive attention is also paid to water-related interests, which increased during the last decennia, and to their mostly negative impact on the quality of the water systems. In this respect the required rehabilitation efforts are described. The growing importance of water as an international issue is illustrated in Chapter 7. The seriousness of disastrous events with respect to pollution of the Rhine has led to government initiatives in the Rhine States.

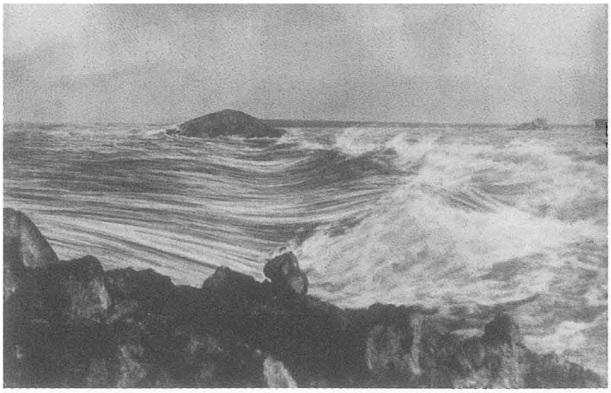


Figure 1.1 Dike burst in 1953

Chapter 8 reports on the long process of co-ordinating and integrating water management, including the recent progress in the international context, as a condition for the sustainable development of water systems. This approach is based on the philosophy that three elements always define the concrete situation of a water management system, namely, the natural features of waters, the water-related interests and functions, and the administrative system and legal framework.
Chapter 9 deals with the institutional and legal aspects from former times up to the present.
The European Union is playing an increasing role also in day-to-day water management practice. Chapter 10 presents the development of the EU water policy and pays attention to the implementation in the coming decades of the recently adopted EU Water Framework Directive .
Over the centuries many Dutchmen have dedicated their efforts to water engineering works and lowland development abroad. Chapter 11 presents an overview of these activities.
Finally, Chapters 12 and 13 illustrate the crucial role of science and education in water affairs, nationally as well as internationally. Among other trends in the Netherlands, hydrological research is described.

This publication will be of interest to a wide variety of people abroad, such as hydrologists, water management engineers, administrators and laymen working on water-related issues.

2 Geography

This chapter deals with the situation of the Netherlands in north-west Europe. It pays attention to the geological structure and the soils. Land use is also an important issue in this geographical description.

2.1 Situation and elevation

The Netherlands, having a land area of approximately 34,000 km^2, is situated along the North Sea in north-west Europe (Figure 2.1). The total territory, including inland lakes, estuaries and territorial sea, amounts to 41,160 km^2. The Netherlands comprises the deltas and former flood plains of the rivers Rhine, Meuse and Scheldt (Figure 2.2).

The western and northern parts have an elevation varying between slightly above and about 6 m below mean sea level (m.s.l.) and have little relief except for the coastal dunes. The lowest point, east of Rotterdam, is 6.7 m below m.s.l. About 25% of the land area lies below mean sea level. In the absence of dunes and dikes more than 65% of the country would be flooded at high sea and high river levels (Figure 2.3). In general the Netherlands slope from south-east to north-west. The highest point (322 m above m.s.l.) is found in the hilly region of the south-east where the national boundaries of the Netherlands, Belgium and the Federal Republic of Germany meet. The central part of the country north of Arnhem is slightly hilly with a maximum altitude just over 100 m above m.s.l.

2.2 Geology and soils

Throughout much of the country Tertiary and Mesozoic deposits are situated at great depth. The only outcrops occur at shallow depths in the south-eastern and eastern areas. The marine clay layers of Tertiary age are found at a depth of about 400 m and act as an impermeable base to the groundwater aquifer system. Nearly everywhere the Tertiary and Mesozoic formations are covered by Pleistocene and Holocene deposits. This is illustrated in Chapter 3 (Figure 3.6), where a geological profile is presented.

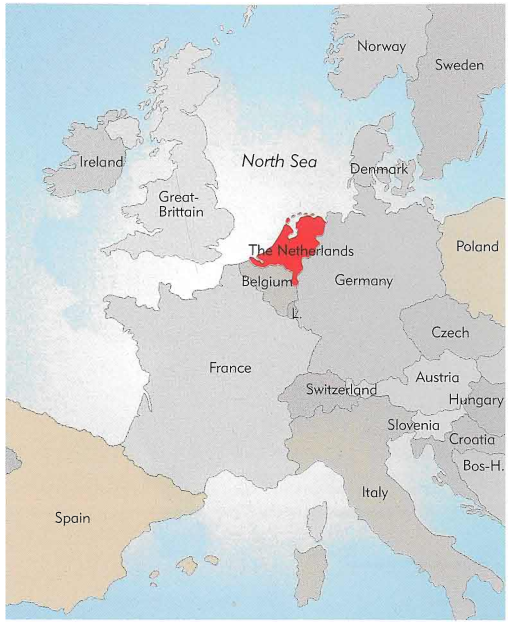


Figure 2.1 The Netherlands, part of Europe

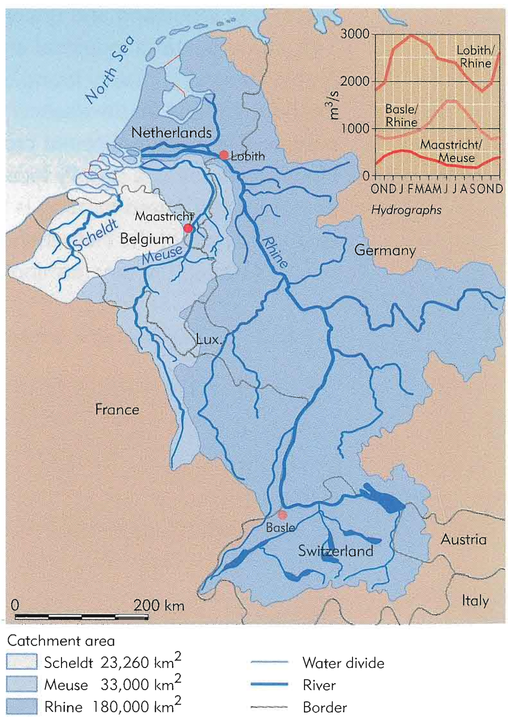


Figure 2.2 Catchment areas of the rivers Rhine, Meuse and Scheldt

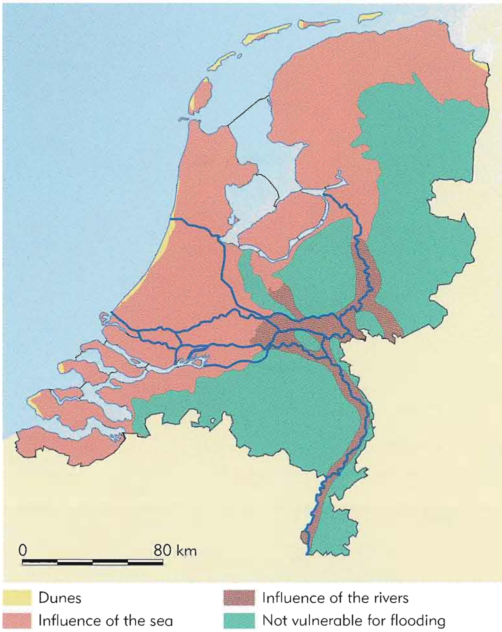


Figure 2.3 The vulnerability of the Netherlands for flooding

At the surface in the south-western, western, northern and central river districts, mainly loamy and clayey material of marine and fluviale origin dominates, together with some peat soils (partly covered with marine and fluviatile sediments) and fine sands (see also Figure 3.3). In time the drawdown of the groundwater table by drainage works has caused shrinkage and oxidation of the clay-peat soil by several metres in the western, northern and river areas. This makes the Netherlands vulnerable to storm surges and river floods. The soils in the eastern and southern parts of the Netherlands consist mainly of fine loamy sand (cover sand), medium and coarse sand (often gravel). In the south, silt and silt loam (loess) occur.

2.3 Land use

As shown in Table 2.1 nearly 70% of the total land area consist of cultivated land, of which almost two thirds are pastures and the remainder is used as arable land and for horticulture.
Since 1950 the area of cultivated land has decreased. Woodland and uncultivated land together account for no more than 14% and urban and industrial areas for 17% of the total land area.
Arable farming is mainly found on the fertile, well-drained marine clay soils in the northern and south-western parts of the country and in the recently reclaimed polders. The most important crops are cereals, potatoes, sugar beet and corn. Livestock farming is usually located on clay and peat soils where dairy farming predominates. Mixed farming is traditionally practised on the sandy soils in the east and south of the Netherlands. Many of these farms specialize in pig and poultry farming (factory farming).

Table 2.1 Land use in the Netherlands in 1996 (Central Bureau of Statistics 2003)

	Land area (km^2)	%
Cultivated land	23,508	69.4
Woodland	3,233	9.5
Uncultivated land (heath, dunes, etc.)	1,379	4.1
Built-up areas (incl. roads, etc.)	5,793	17.0
Total land area	**33,873**	**100.0**

Horticulture is practised in many areas. Most well-known are the bulb fields behind the dunes around Leiden and Haarlem, although nowadays bulbs are grown in many other regions too.

The greenhouse area, located between Rotterdam and The Hague, is quite famous and produces a wide range of vegetables and flowers. The Aalsmeer region, south of Amsterdam, is famous for its flowers. Fruit-growing is concentrated in the south-west, the south-east and in the areas between the large rivers and the new polders around Lake IJssel.

Demography
(Central Bureau of Statistics 2003)

The population of the Netherlands amounts to 16.1 million (2002) against a mere 5.1 million at the turn of the century. Over the past decade the annual natural increase averaged 4 per 1,000. The present population density is on average 472 people per km^2. Fifty percent of the people live in the very densely populated western part of the country, the so-called Randstad.
In January 2002 the total working population amounted to 7.4 million, of which 4% were unemployed. The number of people working in the various sectors of the economy has changed drastically since 1900. In that year 31% worked in the agricultural sector, 34% in industry and 36% in the trade and service sectors. In 2002 the figures were 2%, 25% and 73%, respectively.

The national income of the Netherlands amounted in 2002 to more than €432 billion. The distribution of this amount among the various sectors is given in Table 2.2. The average national income per capita amounts to €26,800.

The economy of the Netherlands has a long standing and pronounced international orientation. For centuries the interest has lain in foreign trade and the transfer of knowledge to industry.
It has to be stated that the discovery and exploitation of natural gas have been particularly important for the Dutch economy.
Until 1970 the trade balance was negative. However, this was transformed by the large export of natural gas from 1970 onwards. In 2002 the total value of imported goods amounted to €218,330 million, whereas the value of exported products amounted to €241,339 million.
This resulted in a surplus of €23,009 million.

Table 2.2 Breakdown of the national income (market prices) over the various sectors in 2002 (National Bureau of Statistics 2003)

	Sector	$€10^9$	%
1	Agriculture, forestry, fishing	10.1	2.3
2	Mining	10.6	2.5
3	Industry	59.8	13.9
4	Public business	7.2	1.7
5	Building industry	24.3	5.6
6	Foreign trade, tourism	61.0	14.1
7	Transport, communication	29.4	6.9
8	Services	108.4	25.1
9	Government, defence, education	47.9	11.0
10	Health, recreation	51.1	11.8
11	Saldi taxes, interests, depreciation, foreign income	–21.8	–5.0
	National income	**431.6**	**100.0**

3 Climate and hydrology

This chapter gives the characteristics of the climate, surface water and groundwater in the Netherlands. The transboundary rivers Rhine and Meuse play an important role in the hydrology of this country.

3.1 General characteristics

The Netherlands is located in the temperate zone, but due to strong maritime influences its climate is much milder than average conditions at the 52°N latitude. The annual average temperature in the centre of the country is between 9.0 and 10.4°C, while the annual average temperature at the 52°N latitude is close to 4°C. Apart from this large-scale maritime, or rather oceanic effect, there is also a small-scale effect caused by bordering the North Sea. This results in marked gradients in most climatological characteristics within the first tens of kilometres from the coast. In a sense the climate of this transition area may be called the coastal climate, as distinct from the inland climate, where gradients are generally small. In Table 3.1 some climatological characteristics of the coastal and inland climate of the Netherlands are compared. Data are based on observations during the years 1971 - 2000.

Table 3.1 Some climatological characteristics for the meteorological stations De Kooy and Twente Airbase, based on observations for the period 1971 - 2000

	De Kooy (coastal station)	Twente Airbase (inland station)
Mean temperature (°C)		
- January	3.2	2.1
- July	16.6	17.0
Mean daily temperature amplitude (°C)		
- January	4.4	5.0
- July	6.4	10.2
Mean relative humidity (%)		
- January	88	89
- July	82	78
Mean annual duration of sunshine (hr)	1,648	1,443
Mean annual wind speed at 10 m over flat open terrain (m/s)	6.0	3.5
Mean precipitation (mm)		
- annual	742	758
- driest month	35	42
- wettest month	92	79

As expected, the coastal area is milder in winter and cooler in summer, in comparison to the inland area. This means that the yearly amplitude of temperature in the coastal areas is smaller than in the inland area. The same applies to the daily temperature amplitude. The differences between the coastal and inland climate

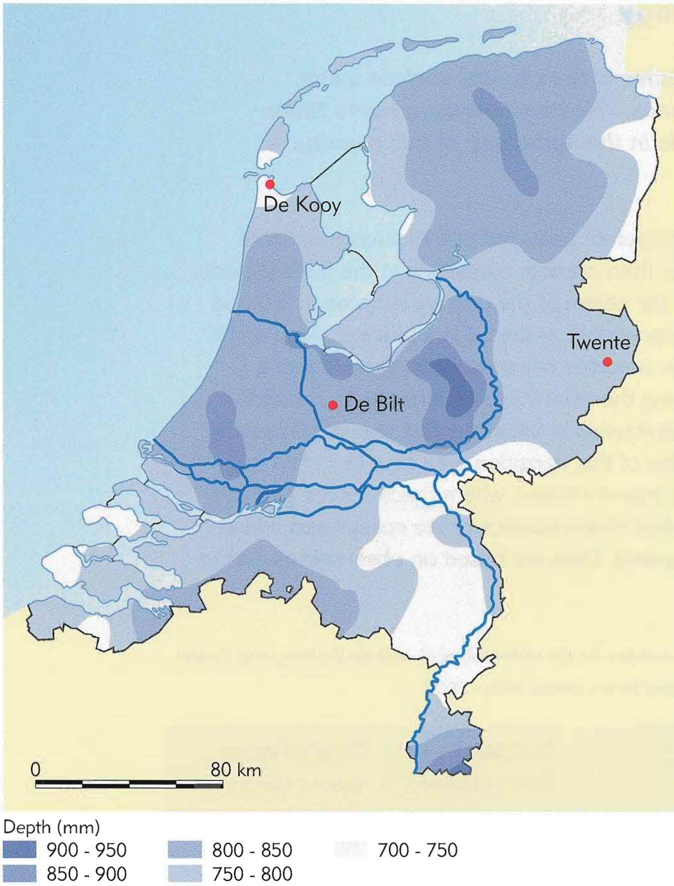


Figure 3.1 Mean annual precipitation in the Netherlands

are most pronounced in wind velocity and duration of sunshine. The more sunny climate of the coastal areas is of course attractive, but as one can see in Table 3.1, it is only at the cost of a much higher wind speed. Relative humidity is nearly the same in both areas.

3.2 Precipitation

According to the data given in Table 3.1, the coastal climate is drier on an annual basis, than the inland climate. However, such a conclusion is not generally valid. First of all, precipitation amounts are highly variable, even at time scales of 30 years. This means that a difference of some tens of millimetres in the annual mean amounts might well be oppositely directed in another 30-year period. In fact we have no indication of a systematic difference in precipitation amounts between the coastal and inland areas. As Figure 3.1 shows, the pattern of mean annual precipitation is somewhat more complex. Unfortunately, the figure is limited to the area within the borders of the Netherlands, which makes the delineation of certain features more difficult. In general the wettest areas coincide with the most hilly regions of the east-central and far south of the country. It may be concluded that these maxima are due to the orographic enhancement of precipitation. Other local maxima of precipitation are less easy to interpret. In some cases in the western part of the country, the large cities of Rotterdam and Amsterdam might be the cause. The areal average annual mean precipitation in the Netherlands is 795 mm and nowhere in the country do values deviate from this by more than 10 - 15%.

While the areal variation in precipitation amounts is small, the seasonal variation is more pronounced (Figure 3.2). Early spring is the driest season in all parts of the country. The wettest months are in the summer and late autumn, but again a clear distinction has to be made between the coast and the more inland part of the country. The heaviest showers occur in the inland in summer when surface warming is greatest. In the coastal areas the maximum is clearly shifted to the months October and November, due to showers developing over the relatively warm water of the North Sea.

As far as the temporal variation in precipitation is concerned the following characteristics may also be of importance. Interannual variability is quite large with the lowest annual amounts as low as about 400 mm and the highest nearly 1,200 mm. Daily and hourly amounts are usually mentioned according to their return periods. The 24-hour values that are exceeded on average once a year and once every 100 years are 34 and 73 mm, respectively. For hourly values and the same return periods these figures are 14 and 39 mm.

Finally it may be mentioned that about 70% of all precipitation in the Netherlands falls with wind directions between south and north-west. Some 10% falls in the form of snow.

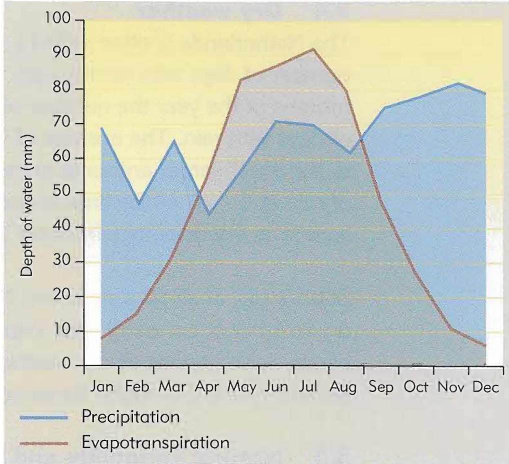


Figure 3.2 *Mean monthly precipitation and the reference crop evapotranspiration in De Bilt*

3.3 Evapotranspiration

Moisture conditions are determined not only by the amount of precipitation, but also by evaporation. Evaporation is governed by a number of meteorological factors, such as solar radiation, temperature, humidity and wind speed. The coastal areas with more solar radiation and higher wind speeds have higher evaporation rates than inland areas, even though in summer temperatures are usually lower. Evaporation is difficult to measure and estimates of actual evaporation are based on theoretical formulas concerning potential evaporation or rather evapotranspiration, since loss of water to the atmosphere is composed of evaporation from water surfaces or other wet surfaces and transpiration from vegetal covers (grass, arable crops, trees). According to the surface considered, evaporation or evapotranspiration may vary considerably. For example, open water in the Netherlands may evaporate as much as 700 mm per year, while annual losses from grass covered areas are several hundreds of mm less. Evapotranspiration from other crops is often smaller and paved surfaces have been found to evaporate only in the order of one or two hundred mm per year.

The mean annual evapotranspiration for the whole of the Netherlands is of the order of 560 mm, with values of 600 mm in coastal areas and 500 mm inland. As shown in Figure 3.2, the seasonal variation of evapotranspiration is very large, due to its dependence on solar radiation and temperature. The values in Figure 3.2 are based on the estimation of the so-called reference crop evapotranspiration, E_r.

The seasonal cycles of precipitation and evapotranspiration give rise to a water surplus in winter and a moisture deficit in summer. At least this has been the case in most years. On average, in the period between October and March, a surplus of about 300 mm is built up; the maximum deficit which accumulates on average in the months April to September is of the order of 100 - 150 mm. In individual years conditions may be worse, however. In exceptionally dry years the maximum summer deficit may be as large as 300 mm.

3.4 Dry weather

The Netherlands is often called a rainy country, probably because of the large number of days with (some) rain. Indeed, everywhere in the country and in all months of the year the number of dry days is equal to or less than the number of days with rain. The average of 795 mm precipitation is small in comparison to the much larger amounts in mountainous areas or the tropics. Also the duration of rain at 6 - 7% of the time is certainly not significant. The point is that rainy days as well as dry ones usually occur in groups.

Statistically, at all stations in the Netherlands, periods of 10 consecutive days of dry weather occur every year. Every 5 - 6 years dry periods of at least three weeks occur. Such periods of dry weather are convenient for all types of activities and only seldom cause a drought; these occur less than once in every ten years.

3.5 Natural variability and climate change

Apart from the effects of urbanization on climate other more large-scale changes due to human activities are possible and are, in fact, expected. Here we refer to global warming as a result of the increasing greenhouse effect. We cannot exclude that the climate data for the period 1971 - 2000, used here, have already been affected by this process. On the other hand, we will never be able to prove that such is the case, due to the natural variability of the climate. To give an example: when comparing the precipitation amounts at the De Bilt station in the centre of the country with comparable figures for the 30-year period 1931 - 1960 one can conclude that the climate has become wetter by some 40 mm. However, in view of the very large interannual variability of precipitation (standard deviation of about 150 mm) even 30-year averages in an unchanged climate are expected to vary considerably (standard deviation of nearly 30 mm). So a difference of 40 mm between 30-year averages is not unlikely and far too small to be considered as an indication of systematic climate change.

3.6 Landscape, soil and drainage

The general features of land and water in the Netherlands are characterized by the shaping of soil and landscape in geologically recent times. Sedimentation during the Pleistocene resulted in a vast and predominantly flat fluvial plain with mainly sandy soils, gently dipping to the north-west. Depending on the transport capacity of the subsurface, a stream pattern developed in the course of time, which is still draining the excess water in large parts of the southern and eastern regions.
The presence of ice sheets during glacial periods strongly influenced the landscape of the northern half of the country. Deep valleys were scoured, either by melt water, or by the ice itself. Many of these valleys can be recognized in the present stream patterns. The sandy material removed by the ice was pushed into ridges; the low hills resulting are at present important groundwater recharge areas. Because of a coarse textured soil and deep groundwater levels, these hills are less suited for agriculture.
They have mostly been planted with forest, and are now nature reserves and recreational areas. The glacial valleys were subsequently often filled with poorly permeable sediments, yet relatively low and wet areas remain where peat layers could develop. Sea levels rose by several tens of metres in the Holocene age,

which led to the deposition of clayey sediments on top of the Pleistocene sand in a broad coastal zone. Marshy areas originated more inland because of the rising groundwater levels, those areas being at the origin of large raised bogs with peaty soils.

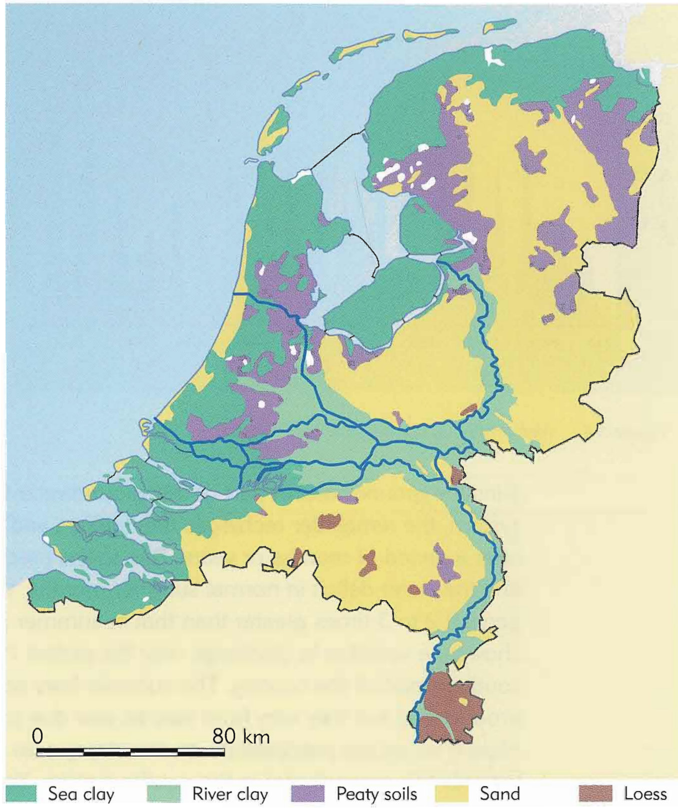


Figure 3.3 The major soil types of the Netherlands

The three major zones in the Netherlands, characterized by their top soil (Figure 3.3), are:

- elevated sandy areas, geomorphologically formed during the Pleistocene;
- areas of the most recent coastal accretions, largely covered by clayey soils;
- a relatively low transition zone with peaty soils.

The detailed drainage system in the lowlands of the Netherlands is almost entirely artificial and based on the discharge of excess water by pumping. Most of the surface peat layers have been excavated to supply fuel. Large lakes were created by this peat mining in the coastal regions. Many lakes were later reclaimed and made into polders, having a clayey soil (see Chapter 4). The excavated raised bogs in the higher regions were directly turned into agricultural land, drained by a system of ditches and canals. The soils of the latter land consist mainly of sand, but still with a large organic component.

The sandy regions were used for extensive agriculture, leading to a degradation of the soils, such that vast heathlands and bare soils with shifting sands developed. The situation changed after the introduction of fertilizers some 100 years ago. Heathlands were turned into pastures and only the most infertile soils were planted with trees. Land reclamation in the sandy regions continued up to the middle of the 20th century, including extension and deepening of the natural stream systems to drain the lowlands. The development still continues with the installation of tile drainage systems.

3.7 Surface water

Surface water plays an important role in the discharge of excess water, although in the relatively elevated regions with sandy soils this role is different from that in the coastal zones. Almost everywhere in the low polder areas water levels are artificially

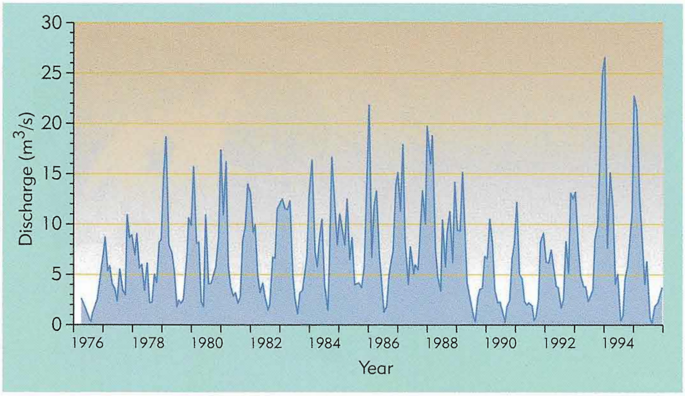


Figure 3.4 Mean monthly discharge of the River Aa

controlled by a forced discharge, but on higher grounds the drainage of water is mostly by gravity.

The smaller watercourses in the sandy regions will even fall dry in normal summer periods, whereas most ditches in the polder areas remain permanently filled. A varying but mostly small portion of the precipitation excess flows directly to the streams of the sandy regions; the majority of it infiltrates into the soil and joins the groundwater. A part of this groundwater flows quickly to the drainage system, the remainder recharges the aquifers and reaches the draining streams only after a period of months or years. Due to the precipitation excess in winter periods and the water deficit in normal summer months, the mean winter runoff is in general 2 to 3 times greater than that in summer periods. As an example Figure 3.4 shows the variation in discharge over the period 1976 - 1995 for the river Aa in the southern part of the country. The summer lows and winter peaks are quite pronounced but they vary from year to year due to the differences in precipitation. Almost no excess precipitation on the clayey soils of the coastal zone will percolate towards the groundwater in the aquifer system. Yet, an opposite flow of seepage water will reach the surface water of the deep polders in the western and central parts of the Netherlands to a maximum of 1 - 2 mm per day. This seepage water originates from groundwater which is recharged by a regional flow from the sandy areas or by infiltration from higher lying river beds or other surface water. The pumping stations, and formerly the windmills, of the polders have to pump the excess water of the winter periods, as well as a possible seepage flow having more permanent features.

Table 3.2 The highest, mean and lowest observed discharges of the Rhine (1901 - 2003) and Meuse (1911 - 2003)

River	Upstream catchment area (km^2)	Discharges at the Dutch border (m^3/s) highest	mean	lowest
Rhine	180,000	12,500 (1926)	2,200	620
Meuse	33,000	3,100 (1993)	230	0

The rivers Rhine and Meuse are of great importance to the hydrology of the Netherlands. The characters of these two rivers are, however, quite different.

The Meuse is a typical rain-fed river, with relatively high peak flows in winter and generally low flows in summer, whereas the Rhine has a mixed character being partly fed by rain and partly by snowmelt from the Swiss Alps. This produces two significant seasonal flow peaks: one in the winter and a much lower one in the summer originating from snowmelt. The ranges of observed discharges of these two rivers are shown in Table 3.2.

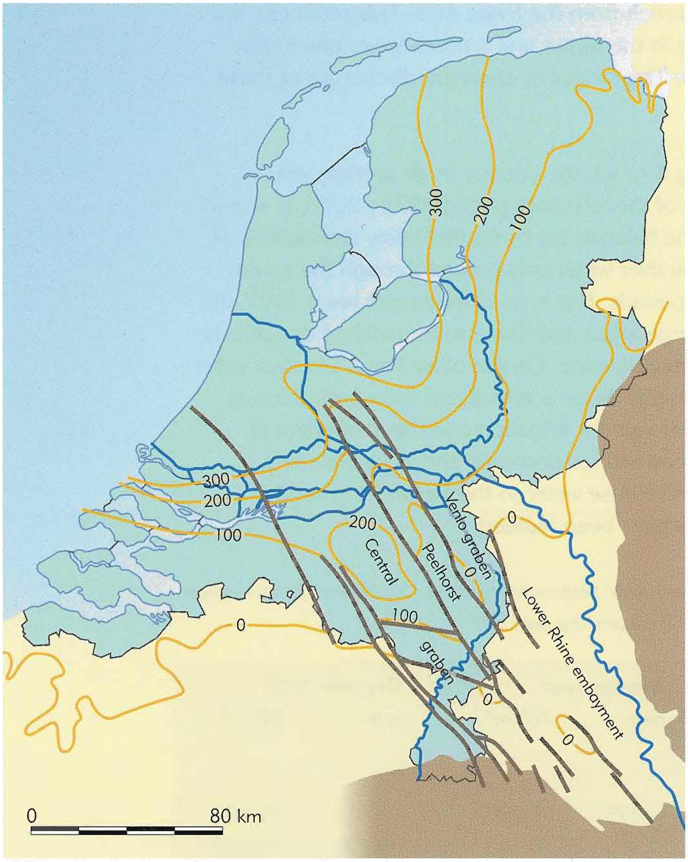
A water balance of all water passing through the country in an average year, as well as in the very dry year 1976 of the reference period 1971 - 2000, is shown in Table 3.3. The largest terms in the balance are by far the inflow and outflow of the River Rhine. In former times, the river water only passed through the country, being a nuisance during high level periods. But even in the recent years 1993 and 1995, the River Meuse inundated large areas and Rhine water reached dangerous levels, causing considerable economic damage. On the other hand, the river water is used for different purposes at present. Water is abstracted from both rivers at a rate of some 16,000 million m^3 per year for irrigation and the abatement of salt-water intrusion in the polder areas and for domestic and industrial uses. Projects aimed at bringing Rhine and Meuse water to the higher lying sandy regions suffering from water deficits have been realized.

Table 3.3 The water balance of the Neterlands' fresh-water mainland (36,750 km^2) for an average year (period 1971 - 2000) and the very dry year 1976

	Average year		Dry year 1976	
	mm	10^6 m^3	mm	10^6 m^3
In				
precipitation	795	29,200	535	19,700
Rhine (at the border)	1,915	70,400	1,130	41,500
Meuse (at the border)	200	7,400	95	3,500
other river inflows	90	3,300	40	1,500
Total	3,000	110,300	1,800	66,200
Out				
evapotranspiration	565	20,700	528	19,400
different uses	60	2,300	163	6,000
outflows	2,375	87,300	1,109	40,800
Total	3,000	110,300	1,800	66,200

3.8 Groundwater

The groundwater hydrology is controlled by the presence and the lithology of unconsolidated sediments, deposited in a subsiding basin. The axis of the basin dips to the north-west (Figure 3.5), resulting in the largest thicknesses of the Pleistocene and Holocene formations in the north-western part of the country. Thick aquifer systems are present in the north-western part. Aquifers are less important at the margins of the basin. Tertiary and even older sediments are near land surface at the eastern border, there being no exploitable aquifers at all in



100 Depth of top of Quaternary sediments (m below m.s.l.)
Fault active during Pleistocene
Pre-Tertiary near the surface

Figure 3.5 Depth of the top of Quarternary sediments

some areas. Lower Pleistocene aquifers along the southern border only reach a shallow depth. Where Quaternary deposits thin out, Upper Tertiary sand layers may form exploitable aquifers. However, except for the Upper Tertiary layers in the southern part of the country, the older strata are not exploited for public water supply. In recent years, the hydrogeology of the deeper soil layers has been investigated to assess its potential for the disposal of hazardous waste and for other human activities. Also, the deeper strata of the subsurface contain groundwater, but the permeability of deeper layers is normally low and the groundwater is brackish. The South Limburg region occupies a special position, in that shallow aquifers of Cretaceous limestone are present, which are covered by aeolian loesses of the Pleistocene formation.

The Pleistocene consisted of a succession of cold and warm periods. The climatic conditions, along with important sea-level changes and tectonic movement, gave rise to an alternation of coarse and fine sediments (Figure 3.6). Thick layers of coarse sand form good aquifers. Finer sediments were deposited during interglacial periods, subdividing the aquifer system over large areas.

In the last cold period, the Weichselian stage, most parts of the country were covered by aeolian cover sands and loesses, which may now act as semi-confining layers. Also the boulder clay, deposited underneath the ice sheets of glacial periods, forms a semi-confining layer. Tectonic activity influenced the geological situation of the southern part of the country. Fault zones affected the presence and magnitude of aquifers and confining layers in the subsurface. After the Middle Pleistocene period, the rising Peel horst hindered a further deposition by the major rivers in western North Brabant, implying that the shallow layers are largely of a Lower and Middle Pleistocene period, often covered with relatively thin layers of younger deposits of a local origin.

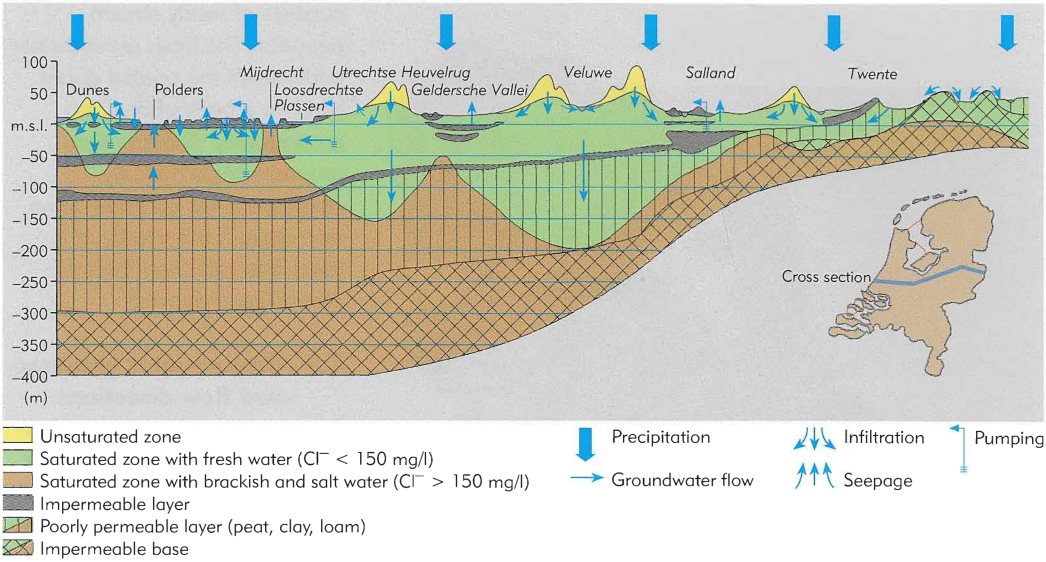


Figure 3.6 West to east hydrogeological cross section of the centre of the Netherlands

The Holocene sediments consist predominantly of clay and peat layers, deposited in a lagoonal and deltaic environment, due to the post-glacial sea-level rise. They are present in a broad coastal zone and can reach a thickness of more than 20 m near the coast (Figure 3.6).
A dune ridge has originated at the coast with an aquifer system underneath containing a fresh-water lens. The shape of the lens is determined by the width of the dune zone and the rate of groundwater recharge. Land-inward, the Holocene layers thin out; they are almost absent in the eastern and southern parts of the country.

The whole subsurface consisting of Quaternary sediments acts as one inter-connected aquifer system, although intercalated clay layers within the Pleistocene sand layers may constitute semi-confining layers over large areas. These clay layers can exert a considerable hydraulic resistance, but they will never be fully impermeable. Transmissivity values resulted from the interpretation of a large number of pumping tests executed in all parts of the country. Transmissivities of more than 10,000 m^2 per day were determined at the deepest part of the Quaternary basin in the province of North Holland. Transmissivities are lower at the margins of the basin. Near the eastern border, values are of the order of some hundreds of m^2 per day. The shallow aquifers along the southern border have transmissivities in the order of 1,000 m^2 per day. The aquifers in the sandy regions are recharged by the local precipitation excess.

In areas covered by Holocene deposits, the same Pleistocene aquifer system is present in the subsurface, but confined by shallow clay and peat layers. The groundwater recharge in the coastal regions consists of a lateral inflow of groundwater arriving from the higher sandy areas, often in combination with a local recharge by water infiltrating from actual river beds or from former river and gully beds where the soil

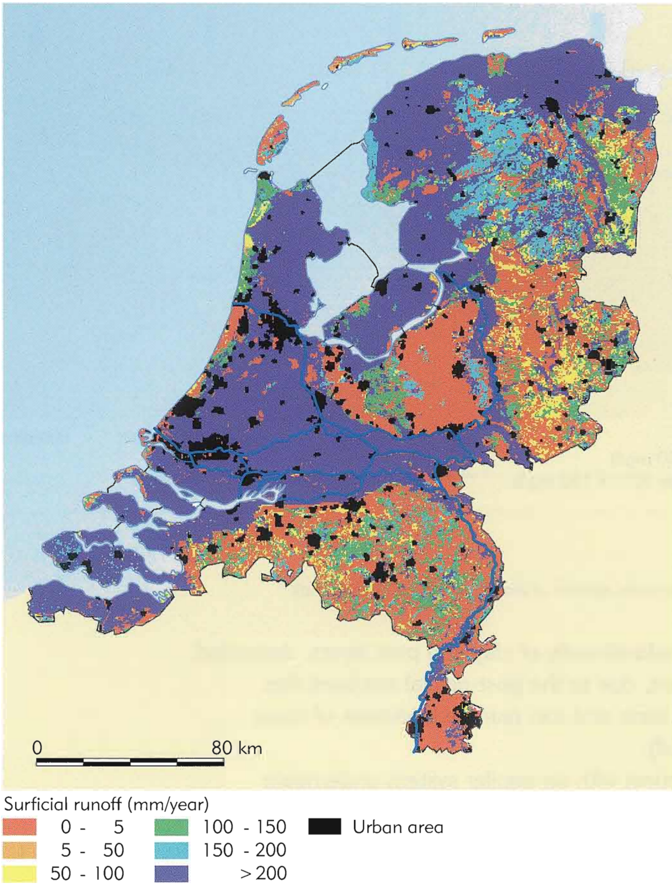


Figure 3.7 Surficial runoff

consists of sandy stream deposits. The fresh groundwater underneath the coastal dunes rests on a body of brackish groundwater. The brackish groundwater is not fully stagnant; it will generally move land-inward, but mostly at a lower flow rate than the fresh groundwater above it.

3.9 Groundwater recharge and flow directions

The recharge of groundwater in the Netherlands is complicated because it depends on the local topography. Infiltration of rainfall is the predominant form of recharge in the sandy areas. Important recharge areas are the ice-pushed hills, the Drenthe Plateau and the Peel region.
A part of the rainfall excess in the sandy regions is discharged by surface components, as overland flow, interflow and tile drainage. Factors affecting the flow rates of surface discharge (Figures 3.3 and 3.7) are the occurrence of shallow, less permeable layers, such as the boulder clay in Drenthe and loam deposits in the southern regions and also a shallow depth of the groundwater table, overcome locally by the installation of tile drains. The fast runoff of part of the excess precipitation results in a smaller amount of water being available for groundwater recharge of aquifers (Figure 3.8).

The recharge in the sandy regions is increased locally by sprinkling from surface water. Abstraction by wells may lead to a decrease in surface discharge and, hence, an increase in groundwater recharge.

The aquifer system in those coastal regions covered with clay or peat layers receives a relatively very small or even no recharge from local precipitation. Practically the full excess precipitation is discharged by surface flow to nearby open water courses, except for the sandy dunes. Parts of the coastal dunes have become important sites for artificial recharge by surface water transported from the rivers Rhine and Meuse to the dunes and infiltrating from ponds or canals.
The groundwater flow pattern can be shown by isohypses, representing lines of equal heads. Regional isohypses valid for the Netherlands indicate the large-scale

directions of the horizontal groundwater flows (Figure 3.9). Discharge areas can take the form of a river zone, where the shallow groundwater will have an upward direction and seep into open water courses. The deeper groundwater may continue to flow in the direction of draining water courses farther away and even into the coastal zone. Some of the polder areas in the western and central Netherlands discharge incoming groundwater flows, which originated in sandy areas far away from the polder. However, much of the groundwater in those polders is recharged by surface water, infiltrating at nearby river beds or coming from other surface waters. Prominent examples of areas receiving large amounts of seepage water are those in Figure 3.9, where the groundwater levels are 4 m below m.s.l. The deep polders are the focal points of regional groundwater flows.

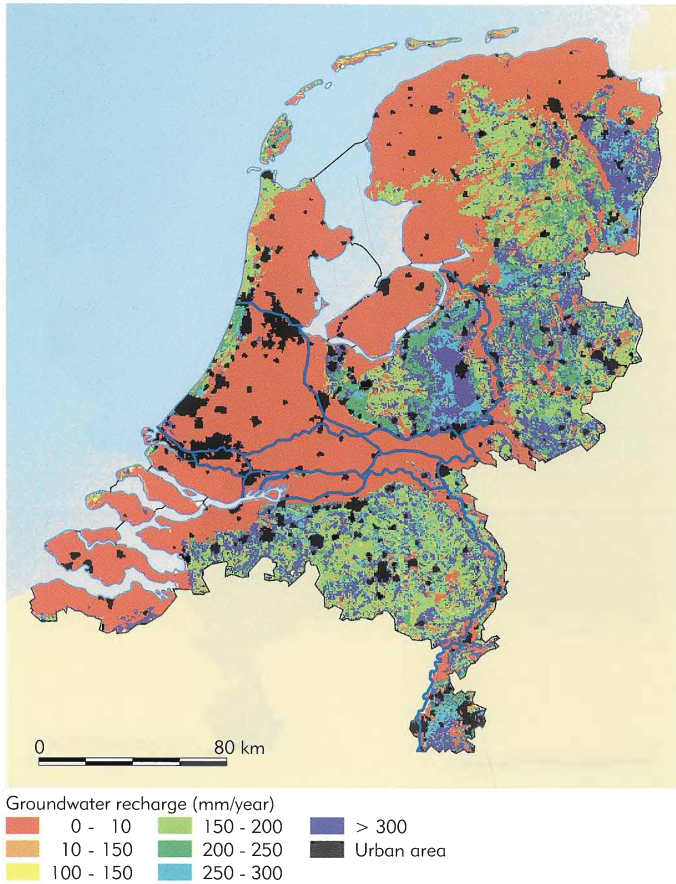


Figure 3.8 Groundwater recharge

3.10 Groundwater composition and the presence of saline and brackish groundwater

In the Netherlands the chloride content is an important natural component when considering groundwater composition. In recent years components such as nitrate and phosphate increased in the fresh groundwater reserves due to human activities. Consequently attention is nowadays paid to those chemical components as well.

The salt brought in by the various floodings of the sea during the Holocene period can still be recognized in the shallow soil, but the chloride concentration in the groundwater is relatively low, if compared to the chloride levels of sea water.
The salt content in the shallow subsurface was redistributed by the creation of high and low polders in the coastal region, resulting in the intensification of groundwater flow and changes in flow patterns. Shallow groundwater in the coastal zone is often brackish, but the groundwater in the sandy regions will generally be fresh.
So, in general, the chloride content of the groundwater in the Netherlands increases with depth. Hence, below a certain level all groundwater is brackish, or when penetrating deeper, saline.

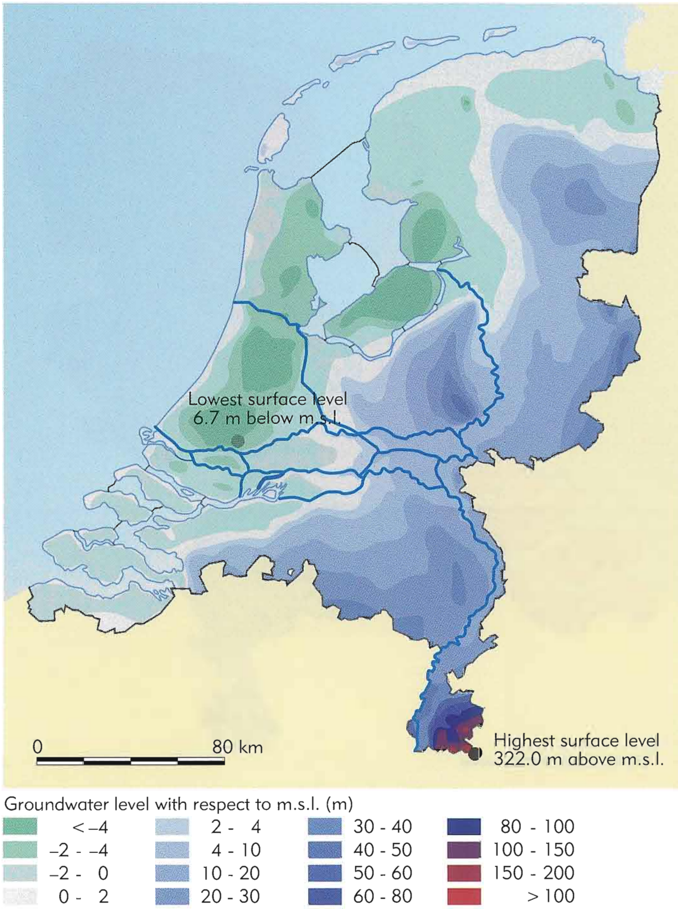


Figure 3.9 Groundwater levels

The depth of the transition from fresh to brackish and saline varies. In the western part of the Netherlands fresh groundwater forms only a thin layer over the underlying brackish zone. Towards the east the thickness of the fresh-water layer increases and hence the amount of available fresh groundwater increases. The interface between fresh and brackish groundwater is represented in Figure 3.10. The chloride content in the groundwater originates from the great number of marine deposits. Chloride distribution in the deeper aquifers is still influenced by lateral dispersion and groundwater flow. As a result of relatively recent (Holocene) marine transgressions and regressions in some specific locations, brackish water occurs in aquifers overlying fresh water. This phenomenon is called inversion.

3.11 Nature and water

A considerable proportion of the indigenous plant life in the Netherlands is characteristic of moist to wet conditions. Indeed, about 35% of the indigenous plant species are groundwater dependent, so-called phreatophytes, which grow in sites where they obtain their water supply directly from the saturated zone orthrough the unsaturated zone. In addition, more than half of the vegetation types occuring at the level of alliances are exclusively or largely phreatophytic. These vegetation types and plant species are susceptible to water management measures that significantly alter the quantitative and qualitative groundwater regime of their habitat.

Moreover, there is a high variability in the origin of soils, soil moisture and the availability of groundwater and surface water. These properties affect the natural conditions in the various areas.
Recognition of the value of ecological qualities for human welfare has increased awareness of the consequences of intensive land use on the natural environment. It is realized that water management plays an important role in this context.
As a result of the many cases revealing the severe impacts of water management

on wild animal and plant life in the period 1975 - 1985, the Government was urged to encourage eco-hydrology, a less traditional field of hydrological research. Ecohydrology is the study of the interaction between hydrology and natural vegetation, with the soil as an important interface.

Having unravelled the general mechanisms of ecohydrological systems it can be stated that local water management measures may have remote impacts on nature areas through regional hydrological systems linking land units within catchment areas. It has also become evident that the sensitivity of vegetation to changes in the hydrological regime is related firstly to the impairment of chemical buffering capacities, then to increases in the soil nitrogen supply and lastly to changes in availability of soil moisture.

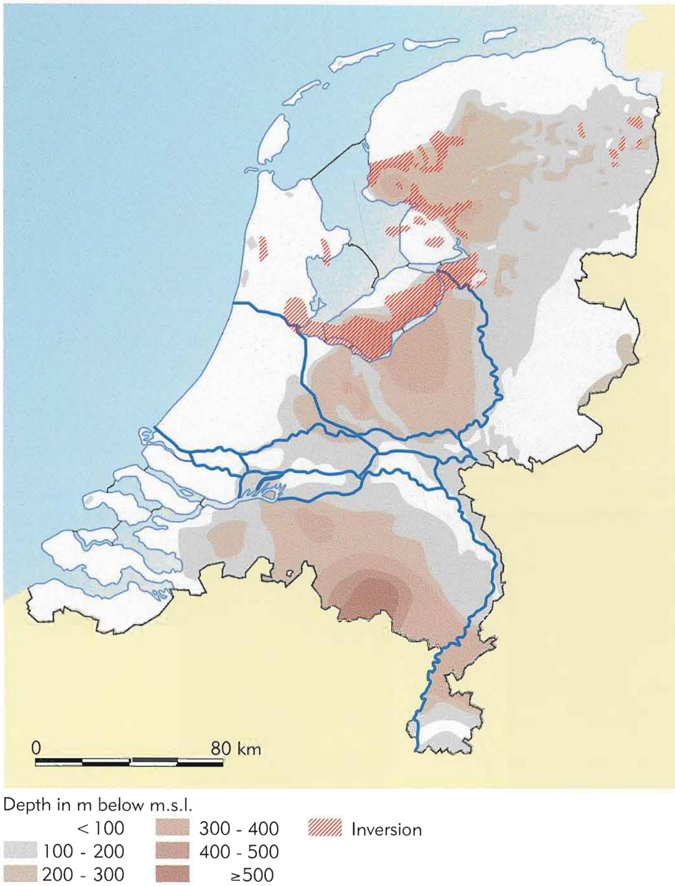


Figure 3.10 Depth of the fresh/brackish interface in groundwater, brackish means > 150 mg Cl^-/l

4 Genesis of the man-made environment

This chapter describes the essentials of human intervention in the Netherlands. Continuous lowering of the groundwater table in the peat and clay areas caused, and still causes, irreversible subsidence. Intervention to protect subsiding areas against flooding and (in the coastal regions) salination has grown in scale and impact over the course of time. Man-made developments have also defined the institutional and administrative structure of the country.

4.1 Natural circumstances

Over the course of time the position of the Dutch shoreline has varied with the rate of sea-level rise and the rate of sedimentation. During the glacial era the coastline of the North Sea was approximately 200 km further north-west than its present position. In the warmer Holocene era, the sea level rose and the North Sea flooded the western and southern part of the Netherlands. Sand ridges (called old dunes) were formed parallel to the present coastline. In about 1000 AD 'young dunes' developed on the west side. Although the latter eventually dominated the old dunes, the sea occasionally invaded the land, cut streams and formed lakes in the eroding peat area that had developed behind the dunes.
Lake Flevo in the heart of the country, originally a fresh-water body, was transformed into an inland sea. Figure 4.1 shows this inland sea, better known as the Zuyderzee, at different epochs of history.
The first settlers in these 'low lands', some 5,000 years ago, found themselves in a poorly drained flat delta or flood plain intersected by creeks, tidal inlets, and small and large rivers. Their dwelling places were on the high ridges or artificially raised hills along these water courses. Life was not comfortable, as the Roman Plinius described: "There the ocean throws itself, two times a day, daily and nightly, in a tremendous stream over a wide country, so one doubts if the ground belongs to the land or to the sea. There lives a miserable people at the highest known levels of the tide and here they have built their huts living like sailors when the water covers their environment and as if shipwrecked when the water has gone."

4.2 Irreversible subsidence caused by permanent drainage

In these areas people lived by hunting and fishing. Archeological finds show that small dikes and flumes were built at the beginning of our era to create conditions appropriate for agricultural activities on a very local scale.
Developments after the Roman times are unknown due to a lack of written and archeological information. A marked increase in the population of Western Europe took place about 1000 AD. To increase rye and wheat production the land was systematically cultivated. In the marshy land consisting of peat and clay, at that time lying 2 or 3 m above m.s.l., field drains and ditches were dug to lower the groundwater table and make agriculture possible (step 1 in Figure 4.2). The drop in the groundwater level subsided the peat and clay layers. Moreover the peat oxidized. The subsidence forced the people to deepen the drains and ditches further and to dig canals to lower the groundwater table in order to keep the land suitable for agriculture. This of course led to further subsidence of the surface. The permanent need to lower the groundwater table provoked an irreversible subsidence process.

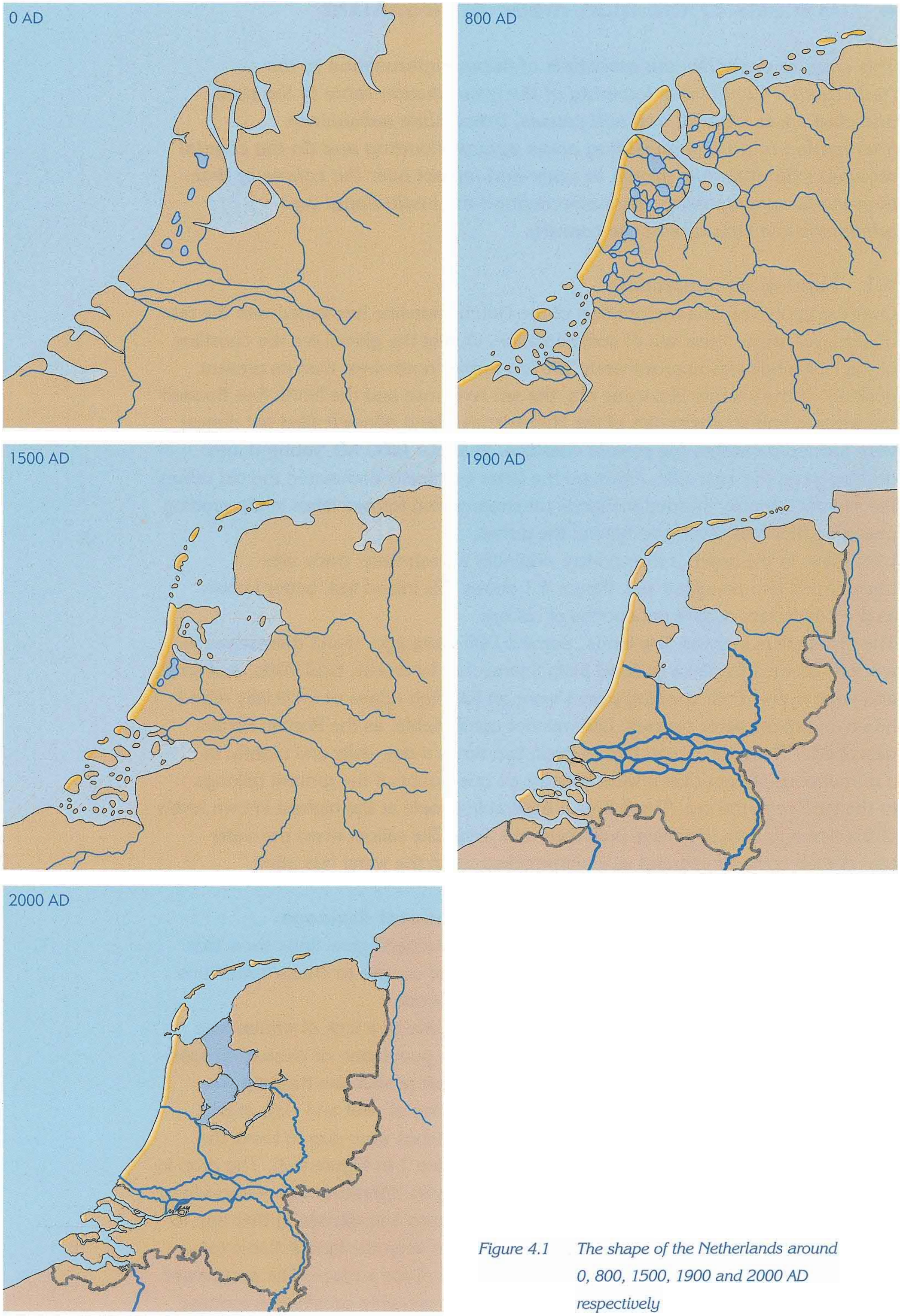


Figure 4.1 *The shape of the Netherlands around 0, 800, 1500, 1900 and 2000 AD respectively*

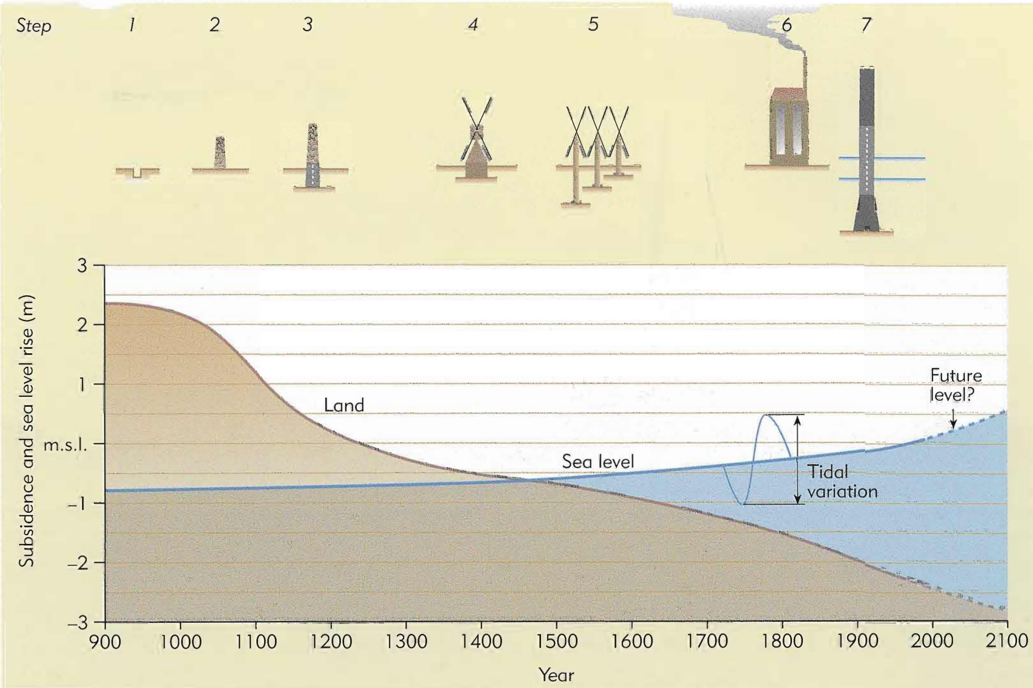


Figure 4.2 Stepwise response to the increasing subsidence of land and sea-level rise over time

By about 1100 AD the subsidence had increased to such an extent that large areas bordering the sea were flooded during high tide. Besides the man-made subsidence, the natural sea-level rise also affected the drainage problem.

Their combined impact resulted in an increase in the scale of mitigating intervention over the course of time. The measures, such as digging ditches, construction of dikes and dams, creating polders with artificial drainage, reclamation of former water areas, large-scale drainage by intermediate storage and closure of estuaries and the inland sea, are presented in Figure 4.2. This figure is the key to understanding the basics of the consecutive intervention in the natural (water) systems in support of the growing socio-economic interests and the development of the institutional structure of the Netherlands.

4.3 Dikes and dams to prevent flooding

Dikes were built to protect the land against the threatening sea water (step 2 in Figure 4.2). They protected the embanked areas against high water levels from outside. In north-west Europe precipitation exceeds evaporation. To avoid high water levels inside the embanked areas, excess water was released through outlets at low water levels outside the dikes.

In the 13th century local embankments were connected by dams closing the natural water courses intersecting the peat and clay regions. Many names of towns and cities are reminders of these events, e.g. the cities of Amsterdam and Rotterdam were developed around the dams and sluices in the tidal inlets of the Amstel and Rotte rivers about 700 years ago (step 3 in Figure 4.2).

Figure 4.3 A series of windmills for draining a deep polder

4.4 Embankments, polders and windmills

The considerable subsidence and the sea-level rise could not have been stopped. The surface behind the dikes and dams dropped below mean sea level; gravity discharge of the superfluous water from the embanked regions was hampered and became impossible. Behind the dikes and closure dams the embankment of small areas was started. From these small inner areas, called polders, the excess water was artificially removed and brought to the former natural water courses (step 4 in Figure 4.2). It was released from these water courses by sluices into closure dams at low water. The former inlets and creeks were and are still being used as intermediate storage areas (called 'boezem') during high water levels. This stepwise drainage system is very typical in the Netherlands.
The first artificial drainage tools were hand- and horse-driven mills; their capacity was very limited. Fortunately windmills became available for artificial drainage on a larger scale in the 13th century (Figure 4.3). The invention of turning the sails of the mills into the varying wind directions has been vital for the survival and development of the Netherlands.

4.5 Reclamation of large water areas

In the 16th century the drainage techniques reached such a high standard that it became possible to reclaim shallow lakes. The practice was to dig a canal around the lake or pond, constructing the enclosing dikes on both sides along the canal with the removed ground. Windmills drained the polder. Sometimes it was necessary to place a series of windmills in order to overcome the difference in level (up to

6 m) between the former tidal inlet and the new polder (step 5 in Figure 4.2 and Figure 4.3).
Since the 14th century the sea-states Holland and Zeeland have become centres of trade, industry and traffic. The sea and the navigable rivers played an important role. Thanks to this situation more capital became available. In the 16th and 17th centuries the Amsterdam merchants earned a lot of money and looked for investment projects. At the beginning of the 17th century the money was invested into the enlargement of the agricultural area, as there was a high demand for agricultural products due to the strong growth of Amsterdam and other towns in Holland. This was partly due to many refugees who found a new homeland in the Netherlands. In the course of time large areas have been reclaimed, in total 600,000 ha (Figure 4.4).

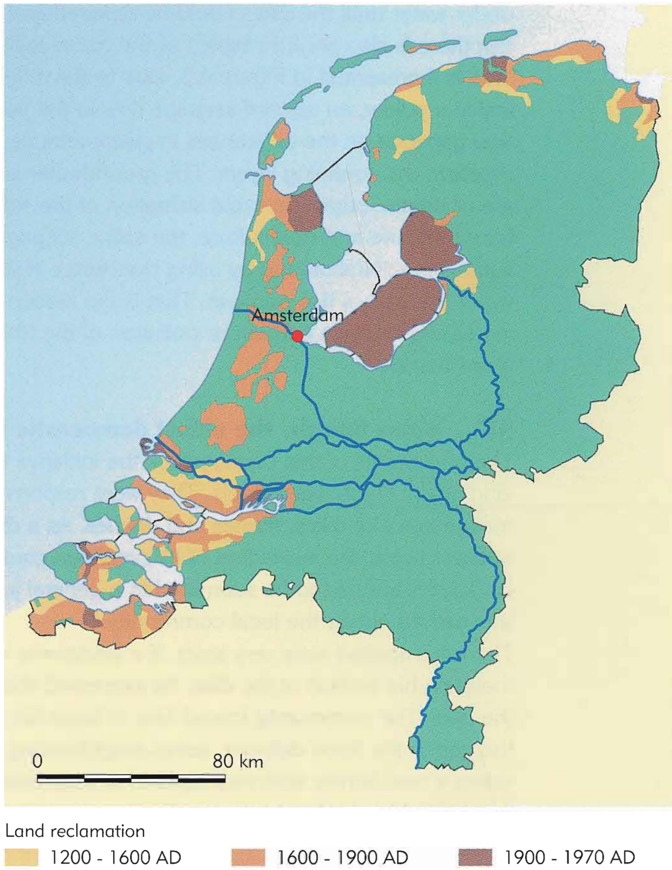


Figure 4.4 Land reclamation in the Netherlands

Industrialization, started in the 19th century, created new possibilities. Instead of many windmills draining large polders, steam-driven pumping stations became available. The artificial release of water from the boezem became possible too (step 6 in Figure 4.2.).

4.6 Increasing vulnerability to floods and saline water

The history of the Netherlands in the last ten centuries is particularly characterized by flood disasters, reparative works and reclamation.
The continuing subsidence of the surface in the polders and the rise in sea level have resulted in about 25% of the Netherlands now being situated below mean sea level (up to 6.7 m). Without dikes and dunes 65% of the land would be flooded daily (Figure 2.3). This situation makes the Netherlands vulnerable to storm surges and river floods.
Dikes may collapse during high storm surge levels or extreme river discharges and large areas could become inundated. In many countries the water drains away without manual assistance when the surge or flood is over, because the land lies above the sea and river levels. If dikes or dunes in the western part of the Netherlands were to collapse, large areas would be flooded and would remain

under water until the dikes could be repaired and the water artificially removed. But there is also another aspect of the vulnerability of living below mean sea level. This is represented in Figure 4.5. Due to the difference in water levels outside and inside a polder, an upward seepage flow in the polder will occur. The velocity of the flow depends on the differences in piezometric levels and the resistance the flow meets in the confining layers. The groundwater is brackish because the deposits are of marine origin. To avoid salination of the soil and to create good conditions for agriculture and horticulture, the saline seepage water is flushed to the sea by surplus precipitation and by using river water in dry periods. It is mainly the Rhine water that serves this purpose. That is the reason why the Netherlands reaction to increasing chloride content or pollution of the Rhine is so sensitive. Chapter 7 gives more details.

4.7 Water boards, the oldest democratic institutions in the Netherlands

The inhabitants of this country took the initiative to cultivate and protect the land against high water levels. They were responsible for the construction and maintenance of dikes, flumes and ditches. As a dike's strength depends on its weakest point, the inspection of its condition could not be entrusted to an individual landowner but had to be submitted to a general judgement. Therefore the inspection was carried out by the local community.

The rules applied were very strict. If a landowner was not able to fulfil his duty to maintain his section of the dike, he expressed this fact by putting his spade into the dike. The community forced him to leave his property forever. In order to close the gap in the flood defence, seven neighbouring farmers would come together and select a new farmer who was capable of maintaining the dike according to the rules formulated by the local community.

In the 13th century local embankments were connected by damming off the natural water courses intersecting the peat areas. The drainage area behind the dam now enclosed many local communities. It soon became very clear that maintenance of sluices and dams could not be realized by individual landowners and the inspection could not be exercised by local communities. Regional meetings were organized to discuss the common problems and interests. The local communities involved began to elect representatives to these meetings. The conventions about personal and financial involvement in the formation of the water control and maintenance activities of the communities concerned led to the still existing institutions, namely the water boards. The rulers of the different parts of the Rhine-Meuse delta stimulated this process and recognized the water boards as the competent water authorities. The water boards received charters from these rulers detailing their competencies. The water boards exercised the inspection of dikes, dams and sluices. For these activities a levy had and still has to be paid. The levy is proportional to the extent of 'interest' the possession of land expressed in hectares. Participation and the voting system for this authority are based upon the levy paid. The basic rule of the water boards is interest-payment-say.

The oldest existing written charter was given by the Count of Holland in 1255. The name of this water board is 'Rijnland' situated around the former main tidal branch of the Rhine. As the water boards were based on voluntary participation principles these organizations can be considered as the oldest democratic organizations in the Netherlands.

According to the Constitution of the Netherlands, the water boards are still the competent authorities for local and regional flood protection and water management issues. The institutional and administrative structure is defined by law. The provincial authorities formulate the tasks of every water board within their territory by establishing the 'reglement', the statutes of the water board. The law defines that water boards are administered by the assembly, the executive board and the chairman.
The assembly makes the important decisions on matters such as budget, taxation, orders and regulations. The executive board, composed of a small number of members of those entitled to attend the assembly, is responsible for day-to-day administration and implements the decisions of the assembly. The chairman chairs both the assembly and the executive board and has certain powers of his own.

The growth of the population and urbanization in the 20th century increased the number of interested participants in local and regional flood protection and water management. According to the 'interest-payment-participation' rule house owners and residents are members of the water board.
In the 1970s the water boards were also charged with water quality issues. The 'polluter-pays' principle, led to taxes having to be paid by polluters. According to the device 'no taxation without representation' the polluting categories (households and firms) have representatives on the water boards. For more specific information, see Chapter 9.

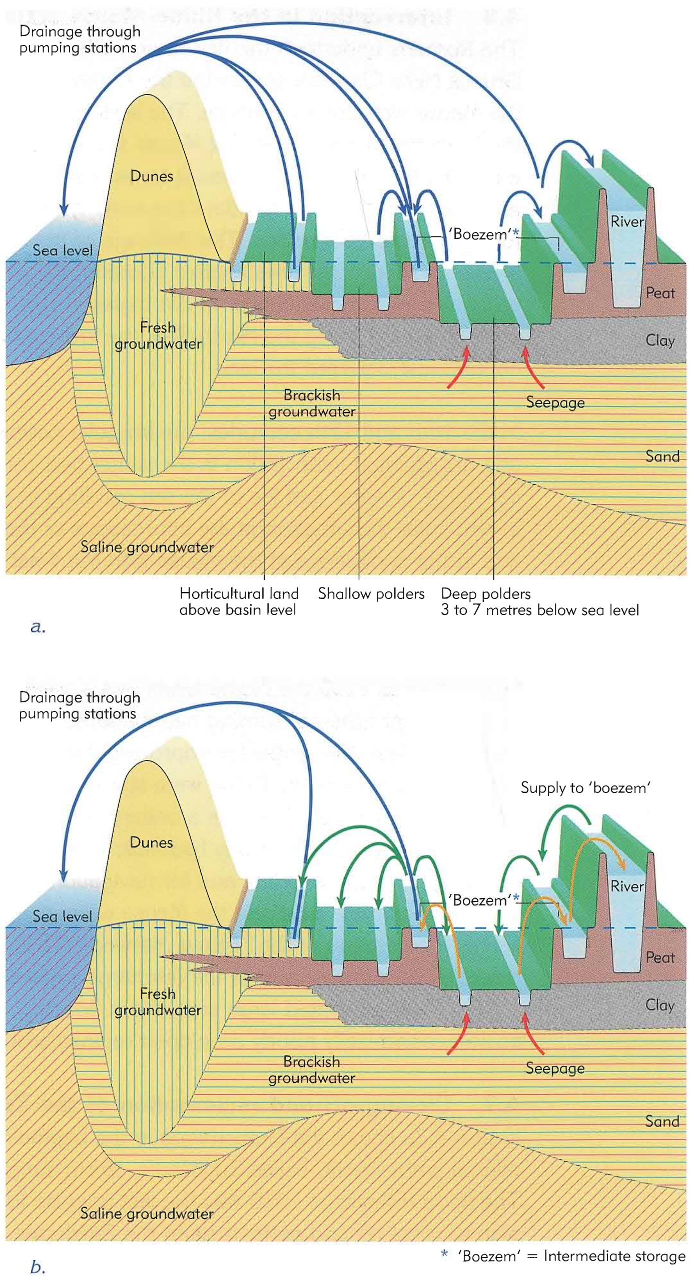


Figure 4.5 *a. Drainage of polders in wet periods;*
b. Supply, flushing and drainage of polders in dry periods

4.8 Intervention in the Rhine-Meuse system

The Romans undertook the first large-scale intervention in the Rhine-Meuse system. Drusus Nero Claudius connected the Rhine with the IJssel and General Corbulo the Meuse with the (Old) Rhine. The systematic intervention in the areas along the branches of the Rhine and Meuse started in approximately 1100 AD, about a century later than in the coastal areas. People originally living on high ridges and river banks, began to adapt the lower lying areas between the delta branches for agricultural production. The drainage of the land caused subsidence of the clay layers. To protect the area against flooding, the inhabitants began to construct inner embankments perpendicular to the higher ridges. Later they began building dikes. As in the areas along the North Sea, the irreversible process of subsidence continuously lowered the land.

In the 16th and 17th centuries, the irregular course of the summer river bed and unregulated intervention in the winter bed considerably hampered the safe discharge of water and ice to the sea resulting in dike breaks and inundations. In particular the situation at the bifurcations of the Rhine and its delta branches and at the confluence of the Meuse with the Waal caused problems. It took almost two centuries for the first large-scale improvements to be made because the institutional situation was so complicated.

From 1579 to 1795 the Netherlands was a confederation of seven sovereign states. In 1707, after time-consuming negotiations, four states decided on an overall approach. The river works for improving the unequal water distribution over the bifurcation points of the Rhine were started in 1707 (Figure 4.6). After 1795, when the Netherlands became a unitary state, the national water authority, the Rijkswaterstaat, realized many hydraulic works to improve conditions for the discharge of water and ice, and for navigation.
The Rhine branch Waal and the Meuse were given new, shorter routes to the sea by the creation of the Nieuwe Merwede (1875) and Bergse Maas (1904), respectively. Improvement of the discharge capacity of the Lower Meuse in the period 1930 - 1940 prevented large areas from flooding, creating better conditions for the socio-economically poorly developed regions around 's-Hertogenbosch (Figure 4.6).

4.9 Closing-off and reclamation of the Zuyderzee

Figure 4.7a shows the Netherlands at the beginning of the 20th century. In the central embayment, called Zuyderzee, storm surges caused many inundations. The flood disaster of 1916 was the last impulse for carrying out the long-cherished plan to close off and partly reclaim the Zuyderzee. There were four main reasons to realize this plan: flood protection, the fight against salination, water supply in dry periods and land reclamation to increase food production.

The closure dam with large discharge sluices was completed in 1932 creating Lake IJssel (Figures 4.7b and 4.8). The IJssel, the northern flowing branch of the Rhine, supplies the lake. The lake was gradually transformed into a fresh-water reservoir by receiving the IJssel input, supplying the northern parts of the Netherlands with fresh water during dry periods and discharging the surplus through sluices into the sea. The sluices were designed based on the situation prevailing at the beginning of the

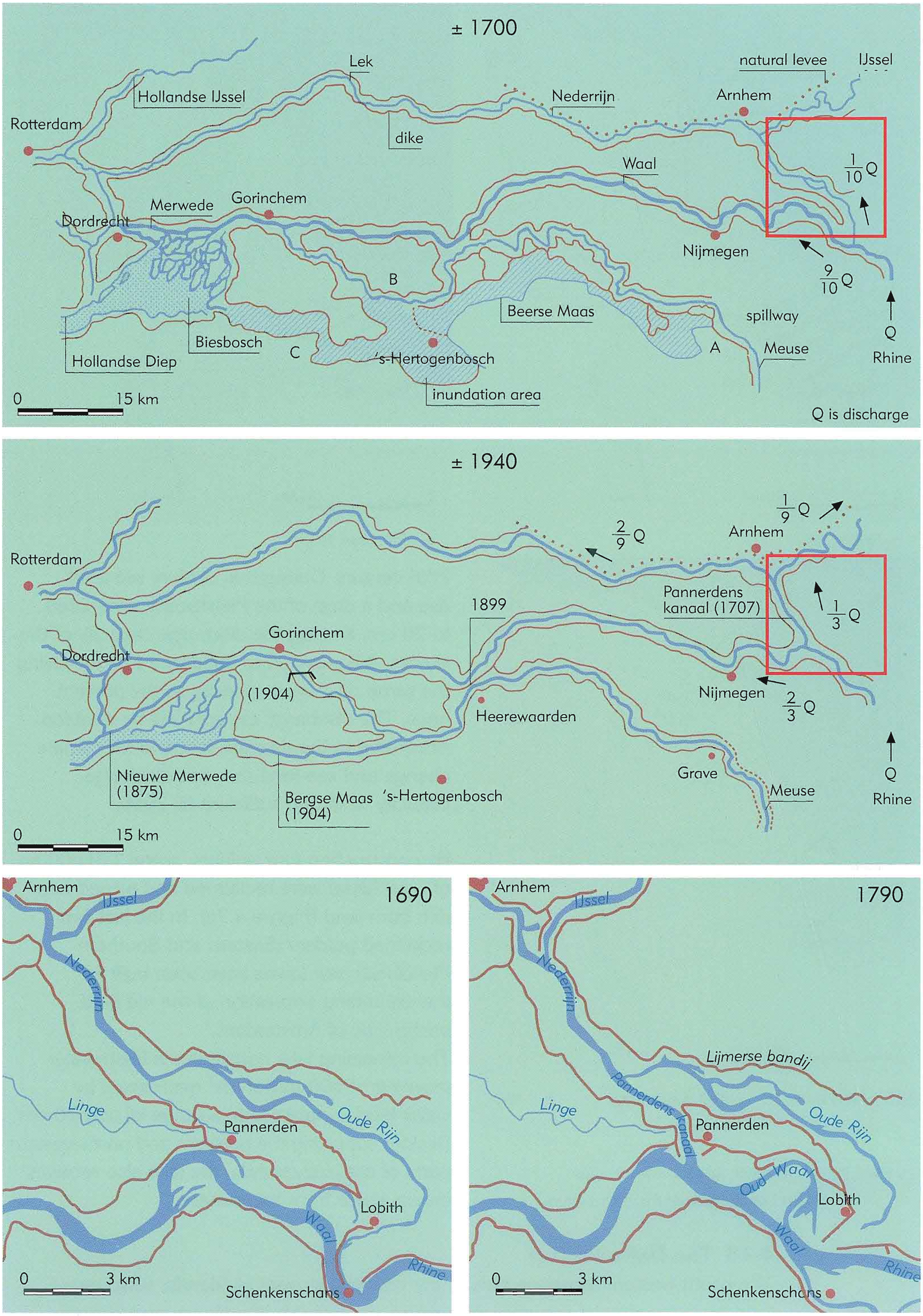
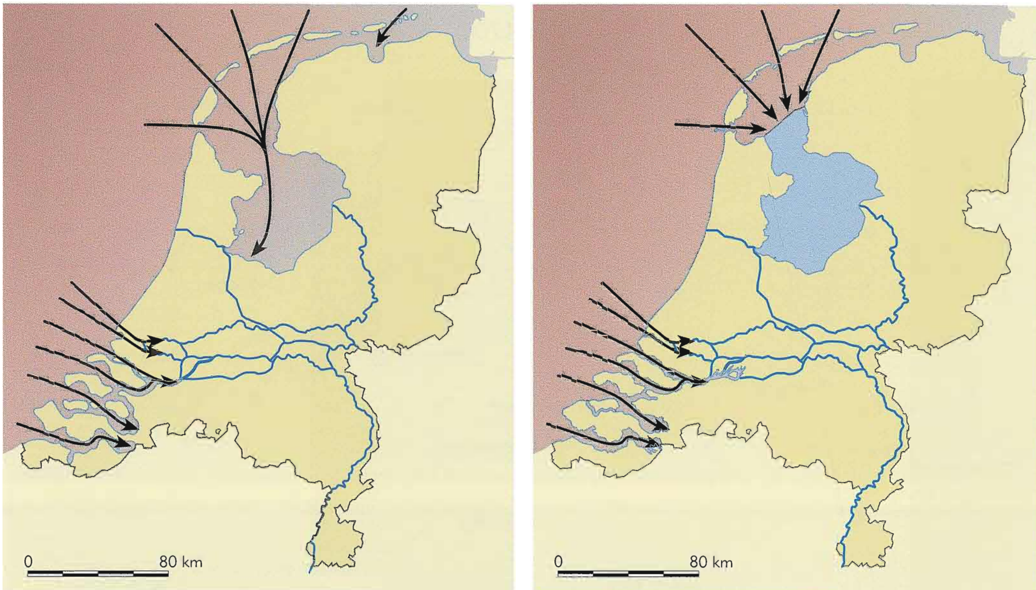
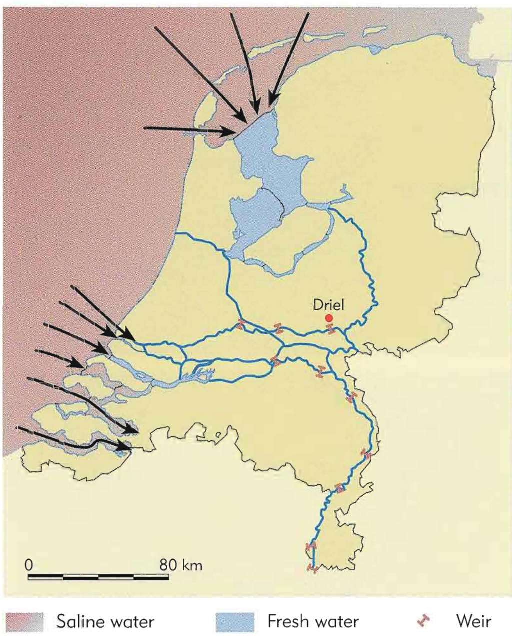


Figure 4.6 Changes in the Rhine bifurcations and river courses



a. Before 1932

b. Main dam 1932



c. 1970

Figure 4.7 *Protection against storm surges and salinization in the 20th century*

20th century. During this century sea level rise and a drop of the Pleistocene amounted to 20 cm, limiting the discharge capacity of the sluices. It is planned to build new sluices having the same discharge capacity as the present ones. The discharge capacity will be doubled. According to the average scenario for climate change and sea-level rise, this discharge capacity would be sufficient till 2050.

By constructing four polders, some 170,000 ha of Lake IJssel were reclaimed and turned into rich farm land (Figure 4.7c). In the last two reclaimed polders (Eastern and Southern Flevoland) new towns have been built for the expanding population of the old land, particularly of Amsterdam.
The remaining lake constitutes a fresh-water reservoir of 500 million m^3 maintained by water-level control within a range of only 20 cm. Besides supplying the northern and north-western parts of the Netherlands, the lake also receives excess water from these areas.

4.10 The Delta Project

The south-western estuarine area of the country consists of islands, surrounded by deep tempestuous estuaries, into which the Scheldt, the Meuse and 90% of the Rhine discharge. The storm surge of February 1953 breached the dikes in

900 places, large areas became inundated and many people and livestock drowned. It gave the final impulse to the Delta Project with the aim of damming the estuaries in the south-west to provide protection against storm surges and to fight the salination by the sea. The Rotterdam Waterway and the Western Scheldt were excluded from the scheme because of their importance as entrances to the ports of Rotterdam and Antwerp. Safety along these water courses would be achieved by substantial reinforcement of the dikes.

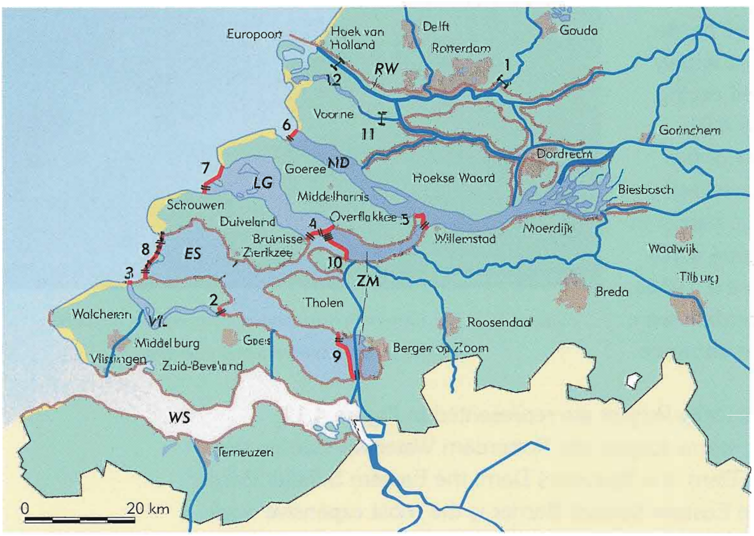
Figure 4.8 *The 32 km long main dam (Afsluitdijk). Left: Wadden Sea (salt water), right: Lake IJssel (fresh water)*

The original Delta Plan has been adapted at two major points: the Eastern Scheldt barrier and the Veerse Gat Dam. The Eastern Scheldt was to be closed by one of the largest dams ever built in the Netherlands. In 1975 environmental considerations led to the decision to build a storm surge barrier, that leaves the tidal movement largely unmodified, but can be closed during storms and high tides (Figure 4.9).
Due to the rapid development of the port of Rotterdam, it proved necessary in 1987 to build a storm surge barrier in the Rotterdam Waterway (Figure 4.10). In contrast to the situation in the 1950s, the deepest harbours of Rotterdam were given a separate obstacle-free entrance to the sea in 1975.

Figure 4.9 *The Eastern Scheldt barrier, compromise between protection and environmental interests*

The main features of the final Delta Project are represented in Figure 4.11.
Six primary elements oppose storm surges: the Rotterdam Waterway Barrier, the Hartel Barrier, the Haringvliet Dam, the Brouwers Dam, the Eastern Scheldt Barrier and the Veerse Gat Dam. The Eastern Scheldt Barrier is the most expensive work, having cost the equivalent of €2,000 million in 1986. The cost increased by 30% compared with the 1976 estimate. Secondary dams were necessary to allow construction of the primary dams. The Volkerak Dam divides the northern and the southern delta basins. The northern basin is important for national water management.
Secondary dams in the southern basin are the Grevelingen Dam, built primarily for the temporary function of moderating tidal currents during the construction phase of the project, and the Philips Dam which, together with the Oyster Dam, helps create the fresh-water basin 'Zoommeer' in the otherwise salty southern system. The Zoommeer serves agricultural interests and increases the safety of shipping

Figure 4.10 The first test closure of the storm surge barrier in the Rotterdam Waterway, May 1997



Characteristics of water courses due to the Delta works

RW	Rotterdam Waterway:	tide, brackish
ND	Northern Deltabasin:	few tide, fresh
LG	Lake Grevelingen:	stagnant, salt
ES	Eastern Scheldt:	reduced tide, salt
ZM	Zoommeer:	stagnant, fresh
VL	Veerse Lake:	stagnant, brackish
WS	Western Scheldt:	tide, salt

- Dike
- Dam
- Sluice
- Barrier

Chronology of the major Delta projects

1	Hollandse IJssel barrier with lock	1958
2	Zandkreek dam with lock	1960
3	Veerse dam	1961
4	Grevelingen dam, sluice and lock	1965
5	Volkerak dam, sluices and locks	1970
6	Haringvliet dam, sluices and lock	1970
7	Brouwers dam with sluices	1972
8	Eastern Scheldt dam, barriers and lock	1986
9	Oysterdam with lock	1986
10	Philipsdam with lock	1987
11	Hartel barrier with lock	1996
12	Rotterdam Waterway barrier	1997

Figure 4.11 The Delta Project (south-west Netherlands)

along the Antwerp-Rhine navigation route. As required by navigation and water management, the dam has been provided with locks and sluices.

The fresh water of the northern delta basin is supplied by the Rhine and Meuse.

The Haringvliet Dam is equipped with drainage sluices that keep salt water out at high tide and discharge surplus fresh water into the sea. At normal and low flows the sluices control the water level in the basin by directing part or all of the river flow to the Rotterdam Waterway. This limits the salt-water intrusion and improves the fresh-water balance in the northern delta basin. However, the sharp transition between the fresh-water and salt-water environments also has negative impacts on the ecology in the northern delta basin. That is why measures to allow limited salt-water intrusion are being considered today.

4.11 The main infrastructure

Due to the improvement of the fresh-water situation in the south-west of the country, it became possible to assure a larger supply of water to the northern and north-western parts of the country in dry periods. The diversion of water from the west to the north, to Lake IJssel, has been realized by the canalization of the lower Rhine. The weir built furthest upstream, at Driel (Figure 4.12), is the major valve through which the main water management system can be controlled in dry and normal periods. Other elements of the main system are the sluices in the Amsterdam-Rhine Canal/North Sea Canal, the Haringvliet, the Closure Dam (Afsluitdijk) (Figure 4.8) and the pumping station at IJmuiden. Regional and local water management works allow control of the flow of the Rhine and Meuse water to many locations in the Netherlands (Figure 4.13).

Figure 4.12 The weir in the lower Rhine at Driel, the major control valve for Dutch water management

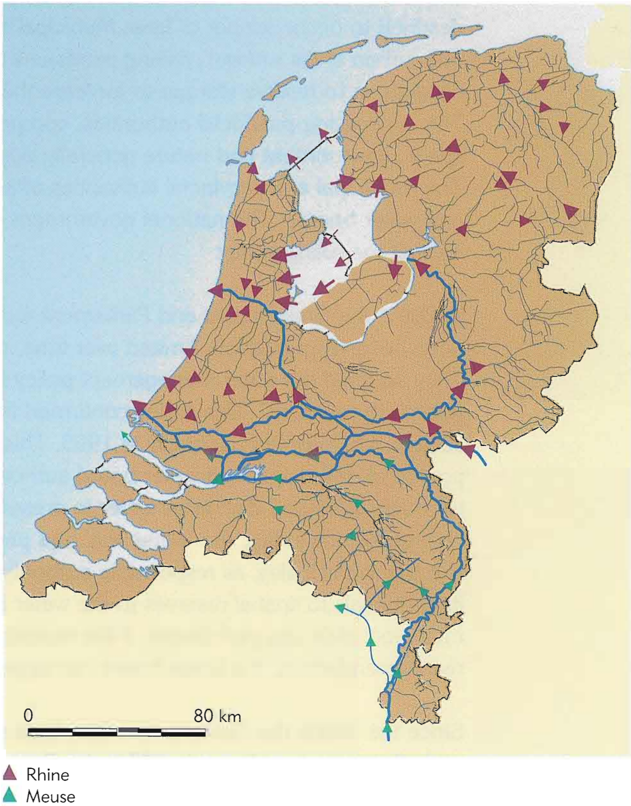


Figure 4.13 Distribution of the Rhine and Meuse water in the Netherlands

In the 1960s the increasing demand for fresh water by households, industry, agriculture and navigation, and for flushing to prevent salt-water intrusion, indicated the need for a coherent policy. The planning instrument entered the water scene. In the first policy document on water (1968) the Government formulated the principles and measures at a national level to achieve efficient, long-term water management. However, the approaches for water quantity and water quality followed different tracks in the period 1970 - 1985. Reduction of pollution at source dominated the water quality approach (see Chapter 6). Water supply for all interests in every corner of the Netherlands prevailed in the water quantity approach. The second policy document on water (1985) defined the water distribution over the Netherlands during dry periods taking into account environmental aspects. The third policy document (1989) fully integrated both approaches. The fourth policy document (1997) reinforced, deepened and enlarged the integrated approach.

4.12 Adaptation of the local and regional water infrastructure since 1998

Excessive rainfall in 1998 and 2000 confronted large areas in the Netherlands with flooding in urban areas. Streets, cellars and ground floors became inundated. Although the situation did not threaten society, as did the 1916 and 1953 storm surges and the 1926 and 1995 river floods, it caused much inconvenience for residents, businesses and traffic. Citizens and, in their turn, governments were upset. How this could happen in modern times?
In the course of time, public opinion had changed. Fifty years ago citizens took their own measures to prevent or mitigate damage by water inconvenience. Today many citizens do not take precautions, but blame the governments when a disaster occurs.
On the other hand, governments had systematically ignored the warnings of water scientists and water boards about the consequences of urbanization. Urbanization makes surfaces impermeable. To avoid inundation, space to store water, or enlargement of the discharge capacity of the water system are required. Without adaptation of the local and regional water systems, inundation was destined to occur sooner or later. Municipal authorities often decided to enlarge their urban areas without making provisions to compensate for the loss of storage capacity or to reserve storage to increase the discharge capacity of a watercourse. The supervising provincial authorities, competent for decision making on water, space, environment and nature generally, approved the municipal decisions. The municipal and provincial authorities often sidelined the arguments of scientists and water boards. The national government did not formally notice opposition against the ruling policy.

In 2001, the Government and Parliament recognized that the space for water had been becoming gradually limited over time, particularly during the 20th century. They adopted the water management policy for the 21st century entitled "A Different Approach to Water". This policy confirmed the space-making policy for rivers (see section 8.6) adopted nationally in 1995. This document also instructed the provincial, municipal and water board authorities to reserve and create space to retain, store and discharge water in present and future situations in this order. To enforce this policy, the 'water test' was prescribed by law. According to the water test the municipality, as responsible authority for final spatial reserves, has to submit its proposals fo spatial reserves to the water board. The water board can reject the municipal planning permission; if the municipality ignores the water board's recommendations, the water board can appeal to higher authorities.

Since the 1950s the Government has made many efforts toward mitigating flooding and other waterproblems. In 2001, the Government and Parliament observed a lack of understanding and acknowledgement among individuals and social interest groups with regard to water problems. People are often unaware of any looming threats and show little understanding for measures being taken by the authorities. Therefore, the policy document also stressed the responsibility of individuals to contribute to the prevention of water damage and inconvenience.

5 Water-related interests

The Netherlands is a sinking country bordering the rising sea. Watercourses intersecting the country are vulnerable to pollution. That is why flood protection and the preservation of sound water systems predominate all other interests. The Dutch Constitution charges the competent authorities "to ensure the habitability of the country and to preserve and improve the environment". These predominant interests define the conditions for living in this country. When flood protection and sound water systems are not ensured, the promotion of any other interest makes no sense. The other water-related interests, such as drinking and industrial water supply, navigation, water for agriculture, recreation, nature and power generation, depend highly on the multifunctionality of the land and water systems. Preservation of these systems is the main goal of the Netherlands water policy. In the following sections the different water-related interests are explained.

5.1 Flood protection

The previous chapter explained the continuous struggle against storm surges and river floods over time. Before the disaster of 1953, flood protection was primarily the responsibility of the water boards. The provincial government and parliament supervised flood protection requirements and defined the dimensions of the dikes around the low-lying areas and polders. The national Government could only intervene when dikes were neglected. It is responsible for the safe discharge of water, ice and sediment from the large rivers to the North Sea. After the disaster of 1953, the national Government and Parliament found that the definition of acceptable risks against flooding had become a national issue.

Based on the size of the population and the economic conditions in the 1950s, the Government and Parliament decided that the dikes and dams in the densely populated Holland have to resist a storm surge occuring once in 10,000 years

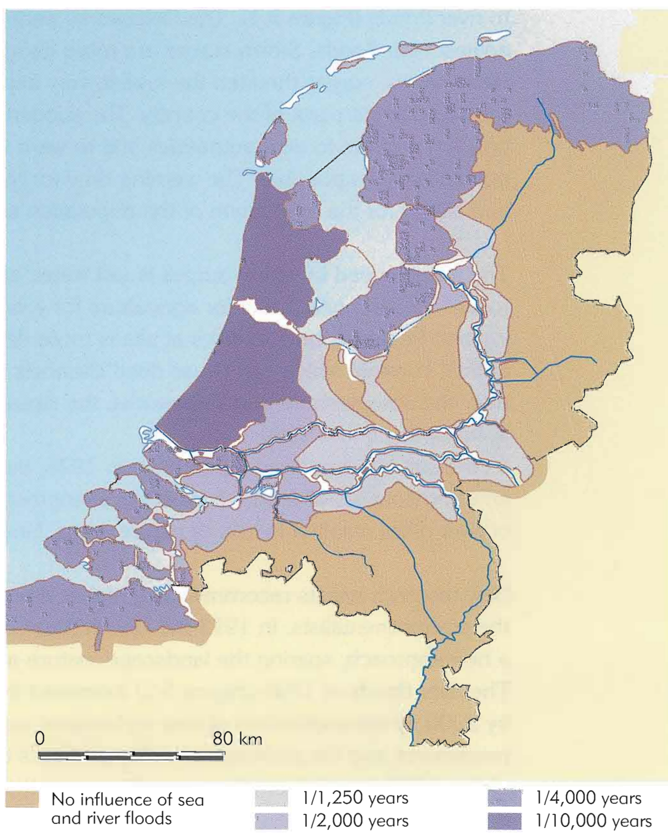


Figure 5.1 Safety standards for the different dike areas

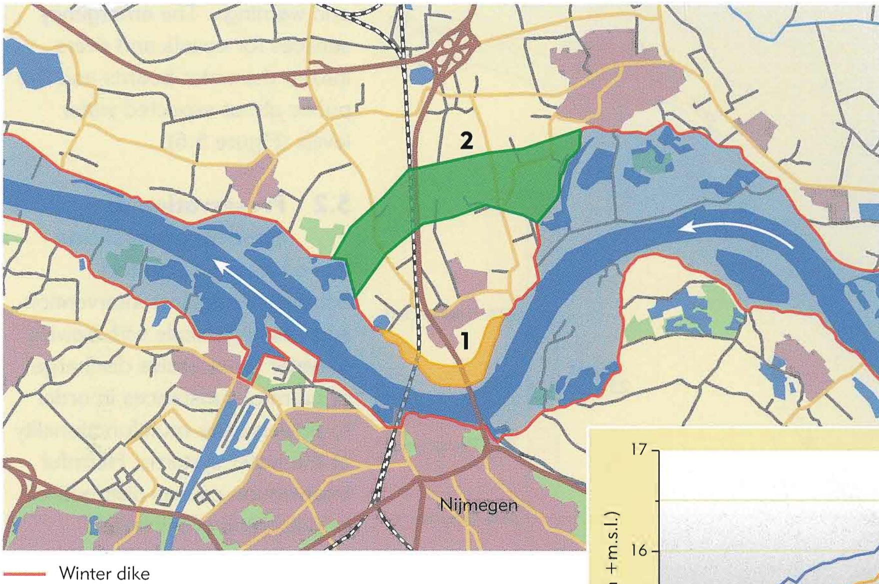
Figure 5.2 River flood of 1995

on average. They accept(ed) inundations by storm surges exceeding this safety standard. For the northern and south-western parts of the Netherlands and some Wadden Sea islands, dikes and dunes have to meet the safety standards of 1/4,000 and 1/2,000 years. The Deltaworks are designed according to these standards.

Frightened by the storm surge disaster of 1953, the authorities and population in the regions along the rivers Rhine and Meuse concluded that the protection against river floods was insufficient. They asked the Government to present guidelines and to provide funds to strengthen the river dikes. The Government set a standard of one flood in 1,250 years for areas vulnerable to river floods (Figure 5.1). The Deltaworks were given priority over protection against river floods. Storm surges are more dangerous than river floods in the Netherlands: surges threaten the lowest, very densely populated and economically most important parts of the country. The sudden occurrence of storm surges leaves only a few hours to alert authorities and to warn the population. Evacuation of the population is impossible. The warning time for river floods can be counted in days and allows for the evacuation of the population as demonstrated in early 1995.

The threat posed by storm surges is salt water; salt water destroys vegetation and makes the land unsuitable for agriculture for years. River floods do not have that impact. Repairing broken dikes at sea is more difficult than along rivers because of tidal currents which can cause deep channels in the gap in a dike.
After the completion of the Deltaworks, the strengthening of the river dikes began at full speed in the 1980s.
As the last big river flood dated back to 1926, there was strong opposition from environmentalists who were against the strengthening programme. The strengthening of river dikes resulted in loss of nature areas, landscape and sites of cultural value.

New research results recommending higher dikes increased the resistance of the environmentalists. In 1993 the Government and Parliament agreed upon a new approach, sparing the landscape, nature areas and places of cultural value. The river floods of 1995 (Figure 5.2) increased the pressure to realize the works by 2000 by the application of new techniques, acceleration of administrative procedures and the provision of sufficient funds by the Government. In 1995, out of the 1,800 km of river dikes, two thirds met the required safety standards and one third needed to be strengthened. Today, the river dikes meet the requirements of the 1993 recommendations.



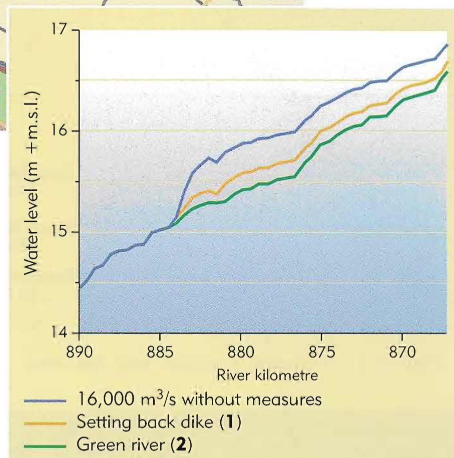


Figure 5.3 Situation at Nijmegen

However, Government and Parliament realized that the current policy of allowing any discharge-limiting activity in the river bed area, even if it was being compensated for, was too restricted in that it did not anticipate higher discharges that might occur due to climate change. The new policy allows only river-bound activities (i.e. in the winter river bed) by water-related interests (e.g. construction of bridges, weirs and boat yards). Licenses for such activities still include regulations on the compensation necessary for lost discharge capacity. Further, Government and Parliament have adopted a policy for creating storage areas and measures reducing high water levels. Figure 5.3 shows two alternative measures lowering the future water level by inland relocation of the winter dike of the Rhine branch Waal at Nijmegen.

The protection against storm surges concentrates on man-made structures, but the longest protection facility along the North Sea coast are the dunes (Figure 5.4). During the centuries large parts of the dunes were taken by the sea as a result of sea-level rise and local currents. Where the dunes disappeared they were replaced by dikes. In the framework of the Delta Project, the competent authorities strengthened weak dunes by artificial sand supply or by construction of bank protection works. To counter the slow erosion process along the sandy coast, the Government decided in 1990 to preserve the coast in its position of that year. Artificial beach replenishment ensures the preservation of the coast (Figure 5.5). The preservation of the North Sea coast completes the protection concept in the Netherlands.

It is not only a question of defining and maintaining the flood protection standards. Adequate protection and limitation of damage highly depend on actual information

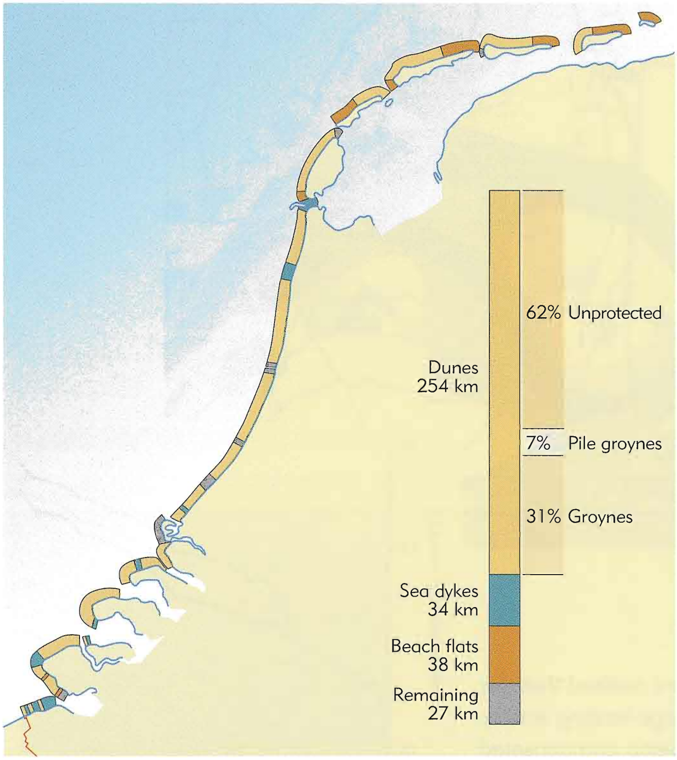


Figure 5.4 Protection along the North Sea coast

Figure 5.5 Artificial beach replenishment

and warnings. The emergency services for coasts and rivers inform the water boards and the public about expected water levels (Figure 5.6).

5.2 Preservation of aquatic ecosystems

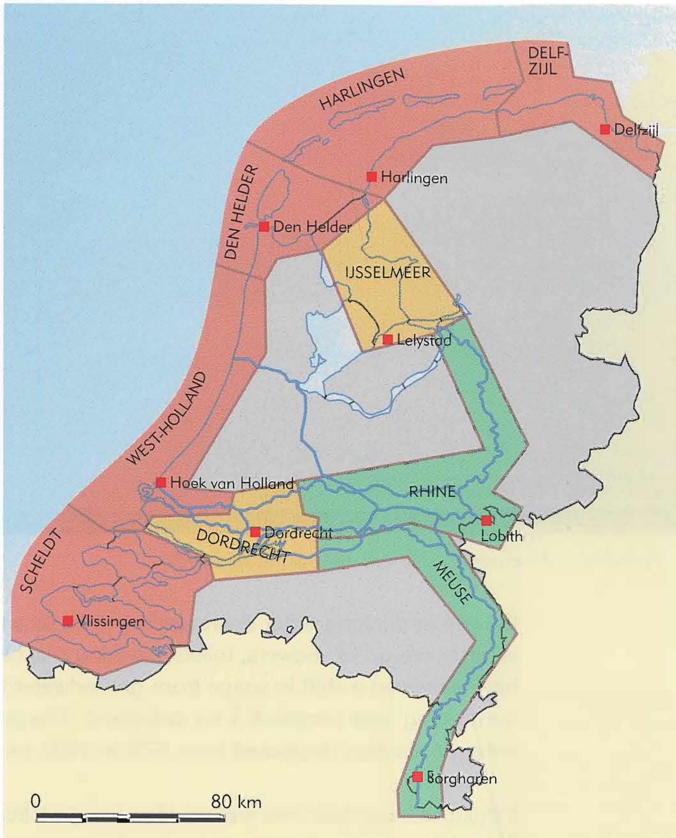
It is necessary to protect ecosystems against intervention such as large-scale withdrawals of water or excessive discharge of harmful substances in order to preserve the multifunctionality of the water systems. Harmful intervention causes disfunction or poisoning of the water systems, as proved in 1971, when the Rhine was heavily polluted and poisoned by accidents. Thus, without sustainable, sound aquatic ecosystems, the promotion of human and nature oriented interests is limited or impossible. To preserve the aquatic environment and promote other water-related interests, the Government formulated general quality standards for inland surface waters. In the Netherlands all surface waters have to meet these standards. For every substance the standard has two levels based on risk assessment: the maximum admissible level (above this level the risk is unacceptable) and the target level (below this level the risk is negligible). Moreover the surface waters may not smell or look visibly polluted. The general quality provides conditions to support biotic communities such as some fish species, birds, and mammals which consume water animals.

Additional standards are applied for certain uses by man such as recreation, bathing, use for arable farming and cattle-breeding, angling, fishery, and disposal or re-utilization of dredged material.

5.3 Drinking and industrial water supply

Private and public water supply, the latter started from the 1850s onward, were and are predominantly based on groundwater. The water companies prefer groundwater because of its constant quality (the aquifer is protected against incidents by covering layers) and purification is simpler than for surface waters.

Initially, public water supply encountered problems only in the coastal areas where the supply of fresh groundwater was limited. Fresh-water lenses below the dune ridge were heavily exploited until 1940; since then, an ever increasing proportion of the dunes was converted into important sites of artificial recharge with river water. The effects of pumping, and thereby lowering the groundwater table, on agricultural production, natural vegetation and land subsidence have to be taken into account in exploiting well fields (see Chapter 6). This has led to the need for careful planning of all groundwater abstractions, controlled by a delicate balance between the economics of groundwater use and the environmental effects.



	North Sea					Transition zones		Rivers	
Sector	SCHELDT	WEST-HOLLAND	DEN HELDER	HAR-LINGEN	DELF-ZIJL	DOR-DRECHT	IJSSEL-MEER	RHINE	MEUSE
Sector station	Vlissingen	Hoek van Holland	Den Helder	Har-lingen	Delf-zijl	Dor-drecht	Lely-stad	Lobith	Borg-haren
Limited alarm	3.30	2.20	1.90	2.70	3.00	1.80	VAR.	16.00	45.50
Full alarm	3.70	2.80	2.60	3.30	3.80	2.50	VAR.	16.50	46.00

Levels in m above m.s.l.

Figure 5.6 The early flood warning system

In the western part of the country the deeper groundwater is brackish or salty. Here, drinking water and water for industrial uses is mainly abstracted from the Rhine and Meuse rivers. Large reservoirs were created in the former tidal area of the Brabantse Biesbosch to supply the Rotterdam area with drinking water. When the water quality of the Meuse is good the water is pumped into the reservoirs

Figure 5.7 Reservoirs for drinking water in the Biesbosch

(Figure 5.7). The Hague also uses Meuse water, but Amsterdam withdraws water from the Rhine. The water for The Hague and Amsterdam is pretreated before it is stored in the dunes. The dunes filter the treated water improving its quality.

Water production by the water supply companies amounted to 1,168 million m^3 in 2002. About 709 million m^3 are used by households (121 litre/day/capita) 225 million m^3 by small businesses, 177 million m^3 by industry and 67 million m^3 for other purposes. Since 1992 the use of drinking water decreased by 4.4% as a result of water saving due to smarter design of showers, toilets, washing machines, etc. The water companies have observed a shift in usage from groundwater to surface water because of the 'verdroging' (see section 6.5 for definition). The proportion of groundwater in the water production decreased from 67% in 1992 to 57% in 2002.

Industries have their own source of water apart from the water supply companies. Industries mostly use fresh surface water, extracted from rivers etc. In 1990 the total amount of extracted surface water was approximately 1,200 × 10^6 m^3 (excluding the extraction of surface water for power plants). More than 95% of this water is used for cooling purposes. Important branches of industry influencing this matter are the food, paper, chemical and steel industries.
Generally speaking, one could say that the availability of fresh surface water does not constitute a problem in the Netherlands. Hence there is no pressure to develop policies aimed at limiting the use of this water.

Besides surface water, groundwater is also extracted by industry. In 1990 this amounted to approximately 200 × 10^6 m^3. A little more than half of this quantity is used for cooling purposes (mostly once-through cooling). This use of groundwater substantially decreased recently as a result of the implementation of strict water demand management by the provincial authorities and the introduction of the ecotax on groundwater. The responsibilities of provincial authorities concerning groundwater management are laid down in the Groundwater Act. According to this act the provinces are responsible for granting extraction licences (not only for industry, but also for the water supply companies and agriculture). The reason that provinces have implemented a strict licencing policy is that excessive abstraction, in combination with groundwater table management, has resulted locally in fresh-water deficits and the deterioration of conditions in nature conservation areas.

National and provincial policies aim at a further decrease in the extraction of groundwater for industrial purposes. Substitutes, such as the use of partially purified surface water, are being investigated.

5.4 Agriculture

The production of agricultural crops can be hampered by both abundance and lack of water. To maximize their income farmers strive for a situation in which the right amount of water of the right quality is available at the right moment. This means, for example, that the water level in spring, the start of the growing season, should not be too high to create a good bearing capacity for heavy machinery and to allow rapid warming up of the soil. In the Netherlands the growing season is characterized by precipitation shortage (see section 3.3). Therefore in summer time the water level in the ditches is set to increase infiltration into the fields or to have water available for irrigation. The desired high water level during the growing season can be maintained only if sufficient water is available from external sources such as the rivers Rhine and Meuse. The desired water level is different for arable crops, grassland and horticulture. The water boards play an essential role in meeting the demands from the agricultural sector. In the coastal zone, the Holocene part of the country, surface water quality is threatened by brackish and saline seepage. In summer time flushing with water from the River Rhine is essential to prevent the reduction in crop production by salination. Most glasshouses cultivating vegetables and flowers are found in this region. Sometimes this sector has very high water quality demands, which in many cases are met by private water reservoirs with an additional supply from public drinking water sources. In the southern and eastern parts of the Netherlands, the diluvial part that is lying above sea level, surface water quality is usually not a problem. In this area groundwater is an important additional water source for agriculture, but its quality may be a limiting factor for some crops due to too high iron or manganese contents.
The decrease of wetlands by 'verdroging' (see section 6.5) and the increase of nutrients has led to nature conservation measures being introduced. These measures limit the agricultural production in many regions. The input of river water in periods of water shortage is no longer obvious. The use of groundwater for irrigation is being restricted in some provinces.

5.5 Electricity production

The generation of electricity from fossil fuel produces heat. Since the start of this form of production, the heat has been cooled by water. The power stations withdraw large quantities of fresh and salt surface water to cool their installations. The only requirement is the low water temperature. The emission of used cooling water can affect water quality by the rise in temperature and by the additives used for preventing corrosion of the cooling systems.

To limit the rise in temperature, the ministers of the Rhine states decided in 1972 that future power stations have to be equipped with cooling towers, which release the heat into the atmosphere. Another method limiting the rise in temperature is to apply the waste heat in industry and for city heating. The demand for cooling water by electricity generation amounts to 10 million m^3 yearly. The energy demand and the available cooling capacity has concentrated most of the power stations in the

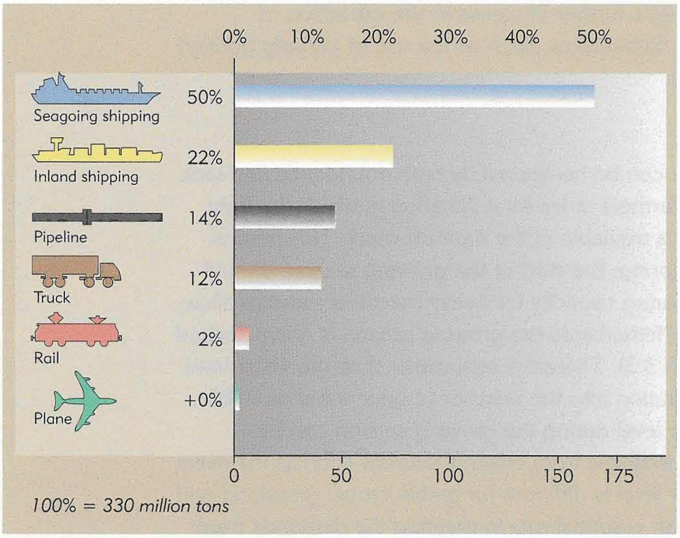


Figure 5.8 Transboundary transport in 2001

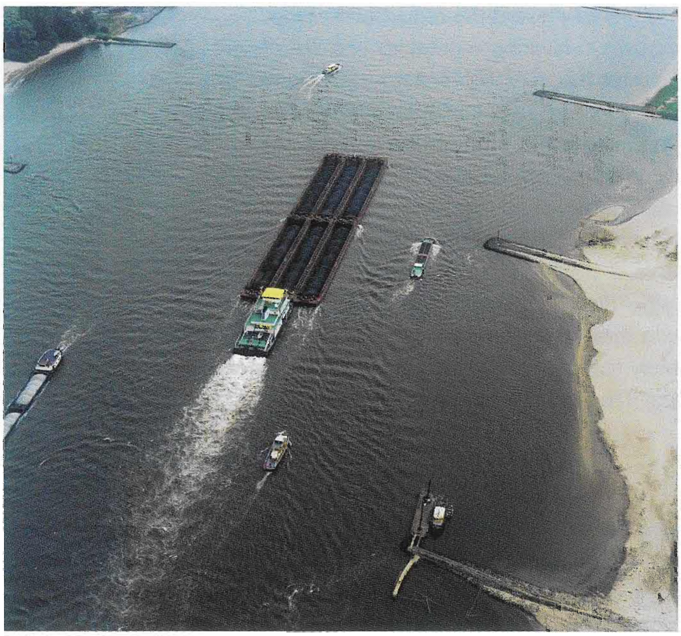


Figure 5.9 Push barges

western part of the country. During periods of high temperature and low river flows, power generation has to be reduced to meet the emission standards. Therefore, future developments for power generation are planned at coastal waters.

5.6 Navigation

The Netherlands is blessed with excellent waterways. The country has a 3,500 km long network of rivers and canals to transport goods by barges. According to the Central Bureau of Statistics inland navigation carried 109 million tonnes, 19% of the total inland transport, in 2001. The Netherlands is the natural entrance to a large part of Europe because it is situated at the mouth of the rivers Rhine, Meuse and Scheldt. Figure 5.8 shows that 50% (850 million tonnes) of the transboundary transport was carried by sea going vessels in 2001 and 22% by inland water navigation.
The Dutch flag is carried by 4500 vessels, nearly 50% of the inland fleet in Western Europe. The dimensions of the ships vary from small vessels of 300 tonnes up to push barges of 17,000 tonnes (Figure 5.9).
The water management system must take care of the depth of navigation channels, the current and the time required to pass the locks. The depth and current in rivers depend highly on the actual discharge, but are also influenced by water withdrawals for other purposes and by the loss of water at weirs and locks.
The authorities use modern communication techniques to inform ships about the services at bridges, locks, weirs, congestion, accidents, etc. to minimize waiting times. The information system also contains the names of the ships, their dimensions and cargo data. These are the preconditions for adequate assistance in case of accidents.

5.7 Water and recreation

The Netherlands is known for the large amount of surface waters and their great diversity. It is therefore not surprising that, in a densily populated country like the Netherlands, recent policy efforts have been aimed at combining the functions of surface waters (e.g. water supply, transport, nature) with recreation and tourism. For recreation the Government has tried to create a linked waterway for pleasure crafts along two main routes. One extends from the Lauwersmeer in the north-east to the delta area in the south-west. The other runs from east to west through the river area. Traditionally the strength of water recreation has been the availability of the huge inland water network, the overall presence of natural scenery, the small scale of the waterway network and the combination of this network with culturally and historically interesting cities.

The total number of recreation anglers above the age of 15 years amounts to 1.5 million, which is almost 10% of the total population. Total spending in the fishery sector amounts to roughly €300 million, which is the equivalent of some 2000 man-years of employment. Roughly 340,000 ha of surface water is in use for recreational fishery, of which 55% have an open connection with the sea. The total amount of fry put yearly into fishing waters is roughly 75,000 tonnes, but the importance of fry input is decreasing as a result of improved fish population management. The total number of boats is estimated to be 25,000. Based upon a broad definition of water recreation as an economic sector (inclusive of all kinds of supply firms and retailing) the total turnover is about €1,200 million (1998). About 15,000 people are employed in this sector. The tourism and recreation potential of several water recreation regions in the Netherlands will be used to improve the market position on the tourism market. The prospects for further development are favourable. The average growth of tourist income in the water recreation areas in the period 1990 - 1998 was estimated to be 6%.

5.8 Fishery

In former days inland fishery was an important sector; today it is a minor sector with a turnover of €30 million. The construction of weirs, sluices and reservoirs has created obstacles for migratory fish. The salmon fishery in the Rhine has mainly disappeared due to these obstacles (see also Figures 7.1 and 7.2). The changes in water quality and overfishing reduced biodiversity in the rivers. Consumption of eel and perch from the sedimentation areas of the Rhine and Meuse was discouraged in the 1970s because of the high concentrations of heavy metals and organic compounds in the fish.

To improve the situation, the European Union formulated water quality directives for salmonides and cyprinidae. But other aspects such as variations in current, level and salinity are also important. That is the reason that many rehabilitation plans for large and small surface waters take these aspects into account. The provision of weirs and reservoirs with adequate fish passages (Figure 5.10) attempts to improve the situation for migratory fish.

In contrast to the inland situation, fishery in the salty surface waters is important. The turnover amounted to more than €570 million in 2001. Water quality is an important condition for fish as was found in 1989 when high mortality of fish occurred in some parts of the North Sea due to the algae bloom.

Figure 5.10 Fish passage

Besides water pollution there is the danger of overfishing. That is the reason why the European Union took steps to assure fish stocks in the long term by the introduction of quotas. It may be that closed areas and other catch techniques can contribute to sustainable use and biodiversity. Research is necessary to answer this question.

5.9 Water for wildlife and landscape

Wildlife and landscape are related to water. Nature conservation in the Netherlands is of international importance because of the country's deltaic character and the presence of a large number of wetlands. However, due to the intensive use of soil and water, environmental values diminished significantly during the past 50 years. Large numbers of plant and animal species are becoming rare. The species that depend on nutrient-poor soils and wet conditions are becoming rarer, whereas the number of those that thrive in well-drained land and fertile conditions increases.

The interrelationship between the abiotic structure of the environment and man-made landscape has been weakened. As a result, characteristic landscapes are disappearing. Since the late 1980s much effort is being put into the conservation and rehabilitation of both terrestrial and aquatic ecosystems. Planning is an important instrument for landscape and nature conservation. The efforts are focused on what is called the National Ecological Network. Priority is given to developing elements with a specific ecological or scenic value, while safeguarding phenomena of more general value. The Government spends €500 million a year on rehabilitation projects. This effort is illustrated by the Baakse Beek Watershed (see box).

Rehabilitation of the Baakse Beek watershed

The Baakse Beek watershed landscape is characterized by a small-scale variation in meadows and fields, hedges, small woods, heaths, rivulets, farms, small towns and estates. Agricultural land use is based on high inputs of fertilizers, animal feed and insecticides. The capacity of the drainage system has been increased enormously for agricultural purposes. The combination of these agricultural and water management practices and the small-scale landscape pattern is responsible for eutrophication and drop of the groundwater level in areas with natural landscape elements. The lowering of water tables since 1950 has been increased by artificial wells for drinking water supply. Water quality, however, is endangered by agricultural practices. Most rivulets and artificial ponds in the estates dry up during summer. These changes have such an impact that variation in landscape declines. Basically these problems are caused by insufficient attunement of the interests of nature, agriculture and drinking water supply.

A better attunement of these interests has been found in both the introduction of new techniques and the spatial rearrangement of land use. An example of a new drinking water supply technique is the use of drainage (surface) water from small watersheds designated solely for nature conservation. Large reservoirs are needed in order to solve the problem of low discharges during summer. For the rearrangement of land use three spatial strategies have been formulated.
In order to evaluate these landscape planning strategies, three scenarios for the Baakse Beek Watershed have been designed and evaluated by state-of-the-art hydrological models. The results indicate that the small nature area watersheds for drinking water supply require the same area of land as the actual protection zones around drinking water wells. Within the nature area watersheds natural ecosystems will not suffer from eutrophication and low groundwater tables, as all agricultural land use is forbidden or no longer a pollution risk due to more rigid environmental constraints than those outside these areas. Water tables within the nature-watersheds will have to rise in order to restore ecosystems and to increase water storage capacity and base flow of rivulets.
The main profit of this strategy is the mutual support of nature conservation and drinking water supply in solving these problems.

The Dutch tradition of landscape planning is based on the consideration that landscape dynamics is a complex process. Its visual manifestation is influenced by changes in almost all land utilization types and water management. Landscape planning therefore needs an integral approach and, in this respect, all interests should be incorporated in such a way that the landscape structure is enhanced or reconstructed. As mentioned before the water system is a major structure in the Dutch landscape. During the last decade this water system approach in landscape planning was developed further.

5.10 Water in urban areas

As in many other countries a rapid urbanization process has been going on in the Netherlands during the last two decades. Pastures and cropland disappear as a consequence of the shift in land use to urban functions and infrastructure. In the lower parts of the country new residential quarters and industrial sites mostly

require that a sandy layer of more than one metre is transferred to the peat or clay soil. New canals and subsurface drainage systems are being built to drain the surplus water.
In that environment new living conditions for human beings as well as for flora and fauna have to be shaped. Open water may fulfil more functions than in the past.
It can be stated that not only in these newly built areas, but also elsewhere, for example in old city centres, the role of water has been changed during the last decennia. Besides the water supply for domestic and industrial use and the traditional functions of drainage, storage and transport, new functions have been established. These are related to the requirements of urban quality of life, such as the recreational, ecological and landscape-ecological functions.
In the field of housing and physical planning the high value and attractiveness of open water have been discovered. Today, urban design pays more attention to open water in residential quarters and business centres, and especially to the recreational potential and ecological quality of water areas.
Such demands require a more integrated approach to water management with special care for the interaction between the water systems in the urban areas and the adjacent rural areas.
Also special attention is needed (and given) to the ecologically sound conditions of surface waters, groundwater levels and water quality in urban areas.
Recently several research projects have been directed towards the relations between sewerage systems, surface water, groundwater, and to the ecological conditions of water systems.