Water in the Netherlands

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Water in the Netherlands

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Preface

The present geographical shape of the Kingdom of the Netherlands is the result of human intervention in the natural conditions over centuries. Without dikes 65% of the land would regularly be flooded. In summer periods, however, parts of the country are short of fresh water. The key to understanding the Netherlands geography of the present can be found in its water management.

In the scope of our international activities we observe a recurrent demand for knowledge about the specific features of the role of water in the Netherlands. In particular, foreigners cooperating with Netherlands experts and scientists in the field of water-related problems ask for more as well as specific information about the man-made lowlands.

In 1986 the Committee on Hydrological Research of the Netherlands Organization for Applied Scientific Research TNO (CHO-TNO) published 'Water in the Netherlands'. In our opinion it was an excellent idea of the Netherlands Hydrological Society and the Netherlands Committee of the International Association of Hydrological Sciences to revise this publication. We welcome this revised edition, because several national and international events since 1986 have had an important impact on the scene.

The publication gives a good overview of human intervention in natural conditions over time and its impact on the Netherlands society. It also provides information about the state of the art and the future of water research.

The consideration and evaluation of investigations and research activities provide the base for the concept of integrated water management. This concept 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 harmonizing physical planning, environmental quality and management of nature areas.

Recent legislation has considerably improved the administrative and legal framework. The Water Board Act updated the regulations for this over 700-year-old institution. The Flood Protection Act and the Water Management Act aim to support sustainable development of the national water systems.

In the 1980s, similar ideas on integrated water management, as formulated by the Netherlands, stimulated all riparian Rhine States to adopt a Rhine Action Plan containing a further reduction of pollution and the rehabilitation of the ecosystem of this river.

Another step towards integrated transboundary river basin management was taken in 1995. The 1993 and 1995 floods of the Rhine and Meuse rivers forced the riparian states to enlarge their cooperation on flood protection issues. Meanwhile common principles and strategies have been formulated for a basin-wide approach to mitigating the flood problem.

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WATER MANAGEMENT,

Mrs. T. Netelenbos

THE STATE SECRETARY OF TRANSPORT, PUBLIC WORKS AND
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Mrs. J.M. de Vries

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See research topics 13.1 to 13.15.

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Contents

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 seventeen 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 Deltaworks. Figure 1.1 shows one of the dike bursts.
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. 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.

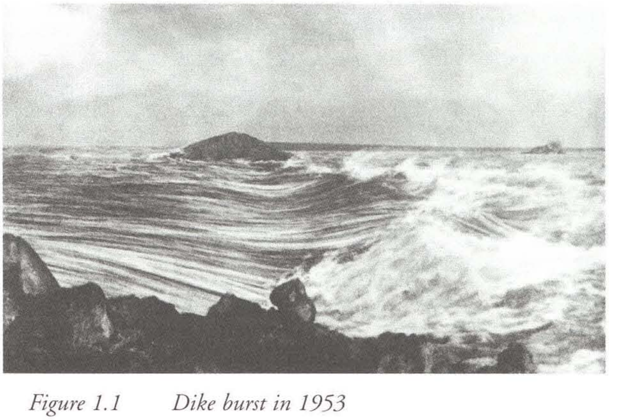


Figure 1.1 Dike burst in 1953

Chapter 8 reports on the long process of harmonizing 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.
Over the centuries many Dutchmen have dedicated their efforts to water engineering works and lowland development abroad. Chapter 10 presents an overview of these activities.
Finally the cluster of Chapters 11, 12 and 13 illustrates 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.

We are certain that 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 m.s.l. 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*

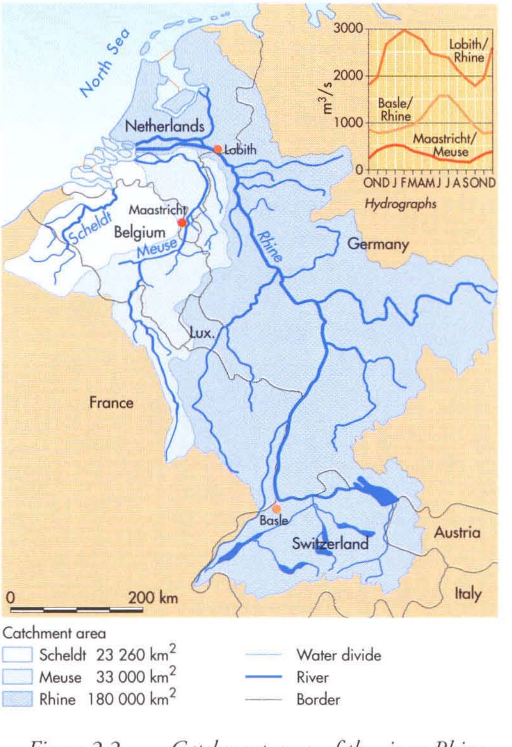


Figure 2.2 *Catchment areas of the rivers Rhine, Meuse and Scheldt*

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 fluviatile 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 mainly consist 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 more than 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 13% and urban and industrial areas for almost 17% of the total land area. Arable farming is mainly found on the fertile, well-drained marine clay soils in the north 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 1994 (Central Bureau of Statistics)*

	land area (km^2)	%
Cultivated land	23 833	70.2
Woodland	3 041	9.0
Uncultivated land (heath, dunes, etc)	1 438	4.3
Built-up areas (incl. roads, etc)	5 595	16.5
Total land area	33 907	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

The population of the Netherlands amounts to 15.7 million (1997) 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 has an average of 460 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 1997 the total working population amounted to 6.8 million of which 6% 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 1993 the figures were 4%, 25% and 71% respectively.

The national income of the Netherlands amounted in 1997 to more than NLG 717 160 million (NLG = Netherlands Guilders). The distribution of this amount among the various sectors is given in the Table. The national income per capita amounts to NLG 46 000.

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 are 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 1997 the total value of imported goods amounted to NLG 295 980 million, whereas the value of exported products amounted to NLG 321 420 million. This resulted in a surplus of NLG 25 440 million.

The breakdown of the national income (market prices) over the various sectors in 1997 (National Bureau of Statistics)

	sector	in NLG x10^9	%
1	agriculture, forestry, fishing	20.0	2.8
2	mining and quaring, manufacturing	156.6	21.8
3	construction	35.5	5.0
4	trade, tourism	96.0	13.4
5	transport, communication	47.9	6.7
6	government, defence, education	65.5	9.1
7	service sector	252.2	35.2
8	taxes	62.9	8.8
9	interest	-27.7	-3.9
10	foreign income	8.2	1.1
	national income	717.1	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 and 10 °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 1961-1990.

Table 3.1 *Some climatological characteristics for the meteorological stations De Kooy and Twente Airbase, based on observations for the period 1961 to 1990*

	De Kooy (coastal station)	Twente Airbase (inland station)
Mean temperature (°C)		
January	2.7	1.5
July	16.2	16.4
Mean daily temperature amplitude (°C)		
January	4.2	4.9
July	5.9	9.9
Mean relative humidity (%)		
January	88	90
July	81	79
Mean annual duration of sunshine (hr)	1 581	1 377
Mean annual wind speed at 10 m over flat open terrain (m/s)	7	4
Mean precipitation (mm)		
annual	757	769
driest month	40	46
wettest month	91	76

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

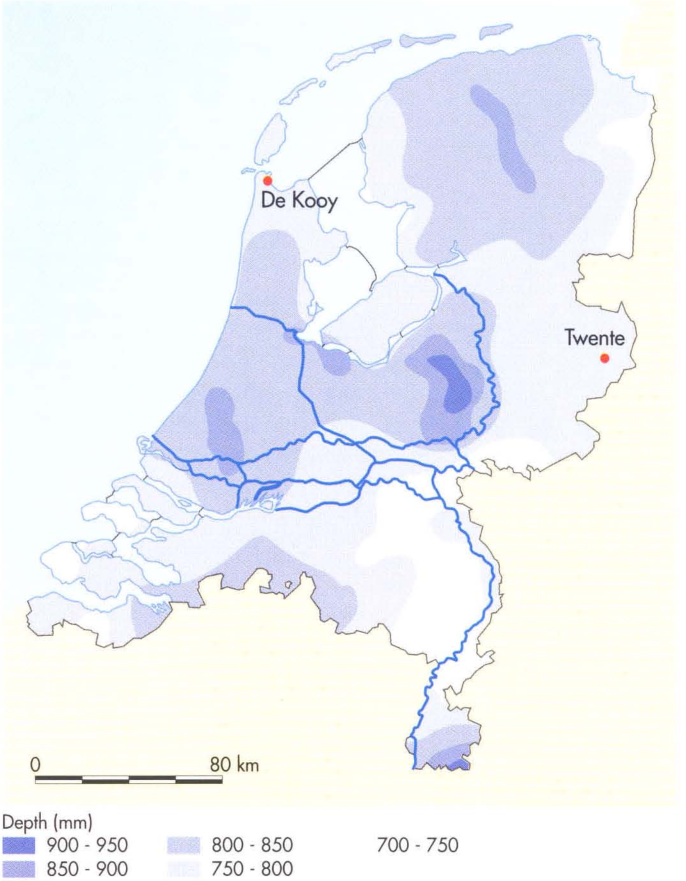


Figure 3.1 *Mean annual precipitation in the Netherlands*

climate 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 750 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.

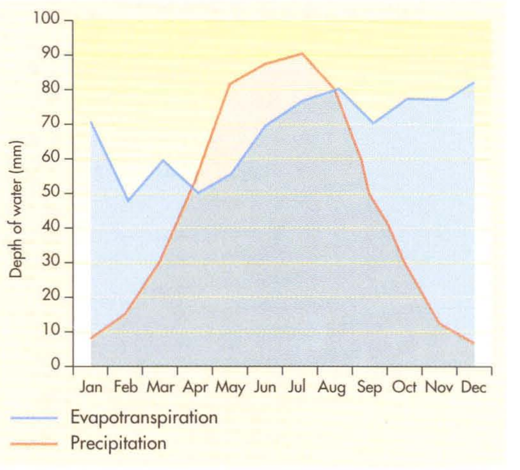


Figure 3.2 *Mean monthly precipitation and the reference crop evapotranspiration*

3.3 Evapotranspiration

Moisture conditions are not only determined 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 of 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 550 mm, with values closer to 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 750 mm precipitation is small in comparison to the much larger amounts in mountainous areas or the tropics. Also the duration of rain at 6 to 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 3 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 1961-1990, 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 nearly 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 remaining relatively low and wet areas 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.

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.

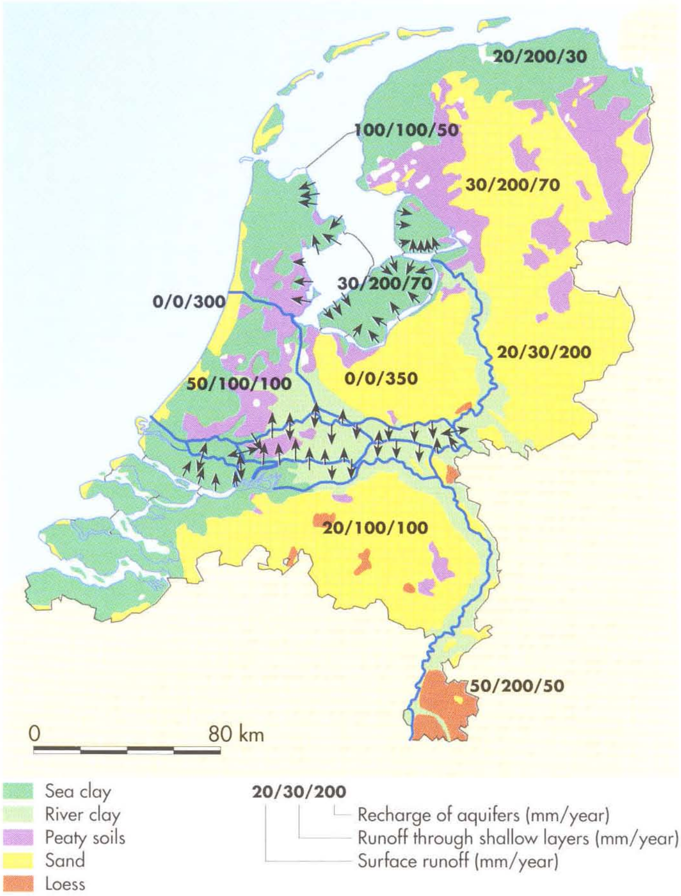


Figure 3.3 *The major soil types of the Netherlands and mean annual runoff*

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 an 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.

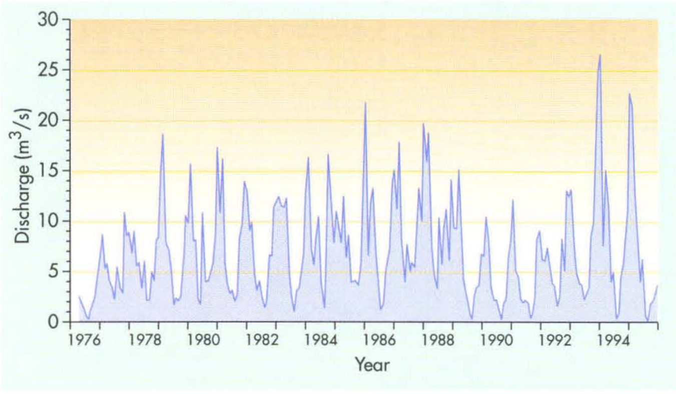


Figure 3.4 Mean monthly discharge of the river Aa

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 controlled by a forced discharge, but on higher grounds the drainage of water is mostly by gravity.
The smaller water courses 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. Figure 3.4 shows the variation in discharge over the period 1976 to 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 to 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 to 1995) and Meuse (1911 to 1995)

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, 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 assumed dangerous levels, causing considerable economical damage. On the other hand, the river water is used for different purposes at present. Water is now 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 use. Projects aimed at bringing Rhine and Meuse water to the higher lying sandy regions suffering from water deficits have been realized or are under construction.

Table 3.3 The water balance of the Netherlands for an average year and a very dry year (1976) (in mm and in 10^6 m^3)

	Average year		Dry year (1976)	
	mm	10^6 m^3	mm	10^6 m^3
In				
precipitation	750	29 100	535	20 800
Rhine (at the border)	1 775	69 000	1 065	41 500
Meuse (at the border)	215	8 400	90	3 500
other river inflows	75	3 000	40	1 500
Total	2 815	109 500	1 730	67 300
Out				
evapotranspiration	550	21 400	528	20 500
different uses	55	2 100	154	6 000
river outflow	2 210	86 000	1 048	40 800
Total	2 815	109 500	1 730	67 300

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

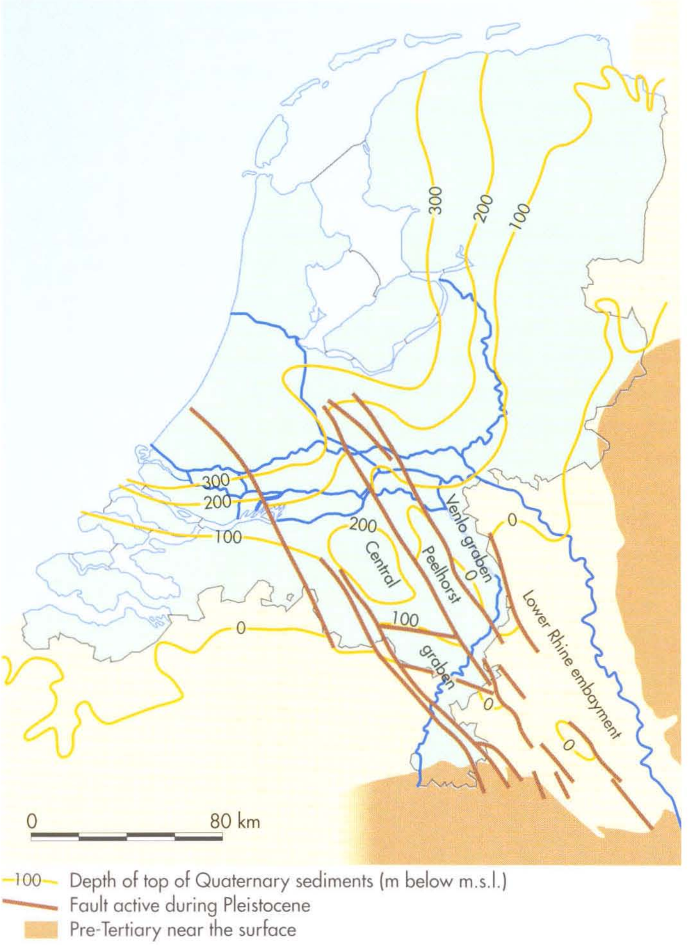


Figure 3.5 Depth of the top of Quarternary sediments

land surface at the eastern border, there being no exploitable aquifers at all in 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 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 so far 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.

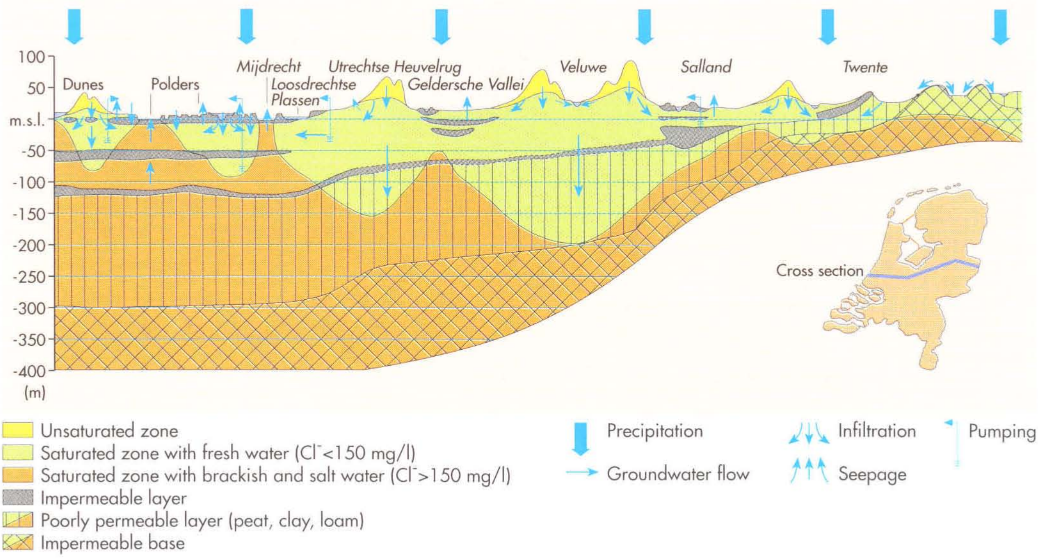


Figure 3.6 *West to east hydrogeological cross section of the centre of the Netherlands*

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 they 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 in 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 the 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

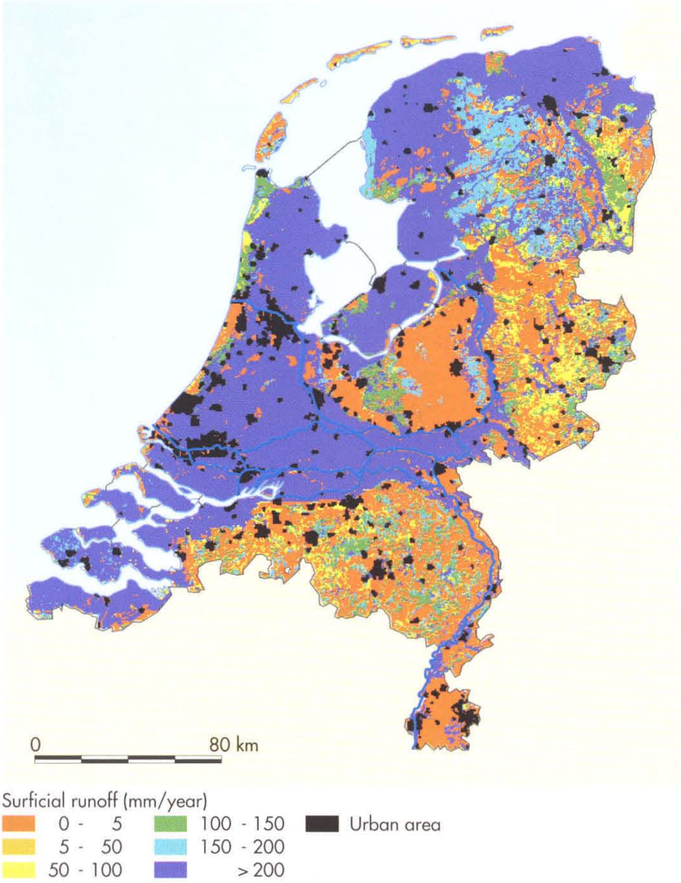


Figure 3.7 *Surficial runoff*

gully beds where the soil 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 topographical situation. 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 (Figure 3.3 and Figure 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 3.3 and 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 mean sea level (m.s.l.). The deep polders are the focal points of regional groundwater flows.

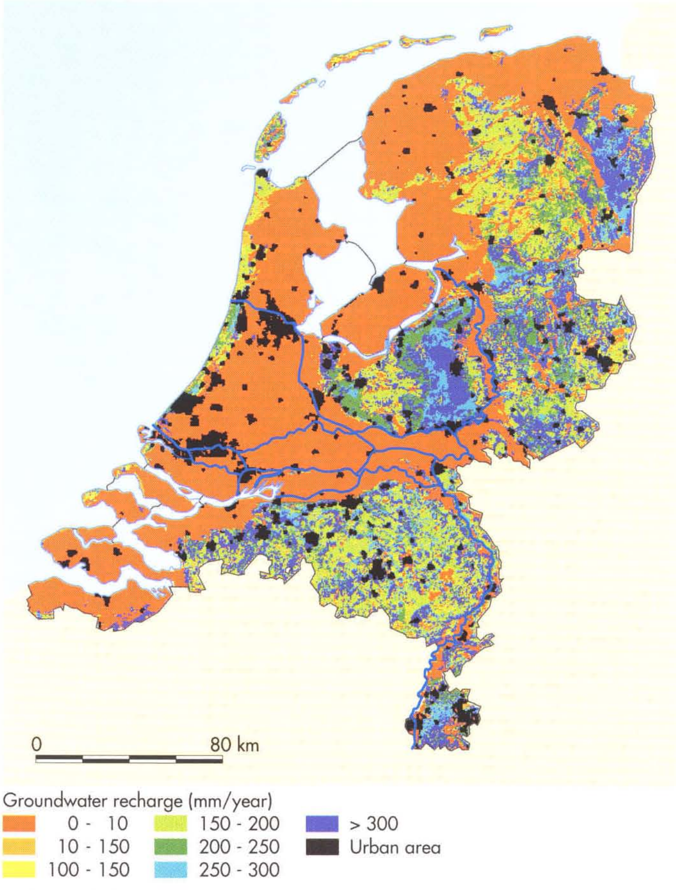


Figure 3.8 Groundwater recharge

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

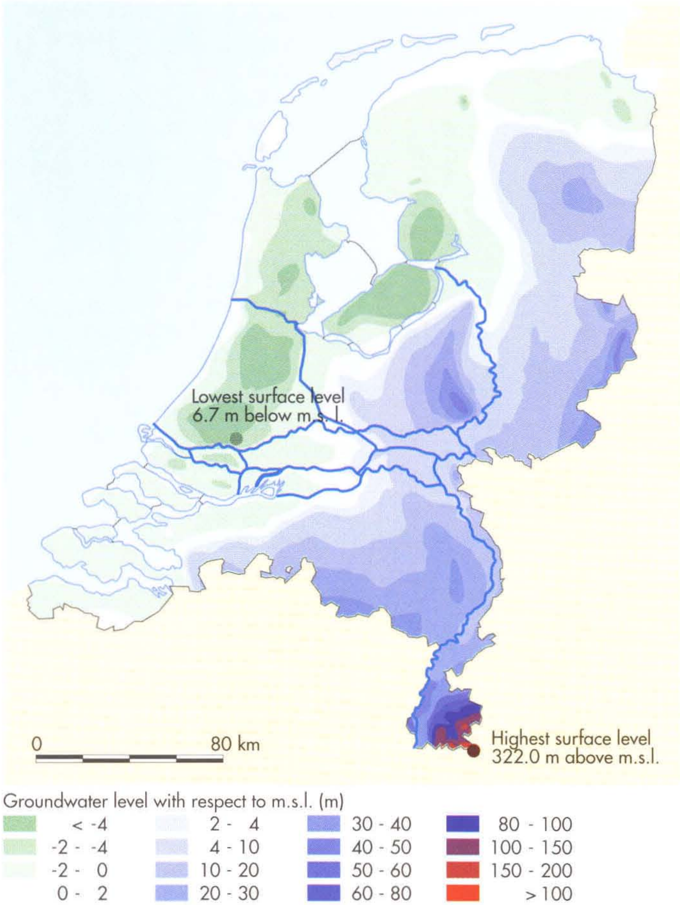


Figure 3.9 *Groundwater levels*

penetrating deeper, saline. 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 freshwater. 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 or through 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.

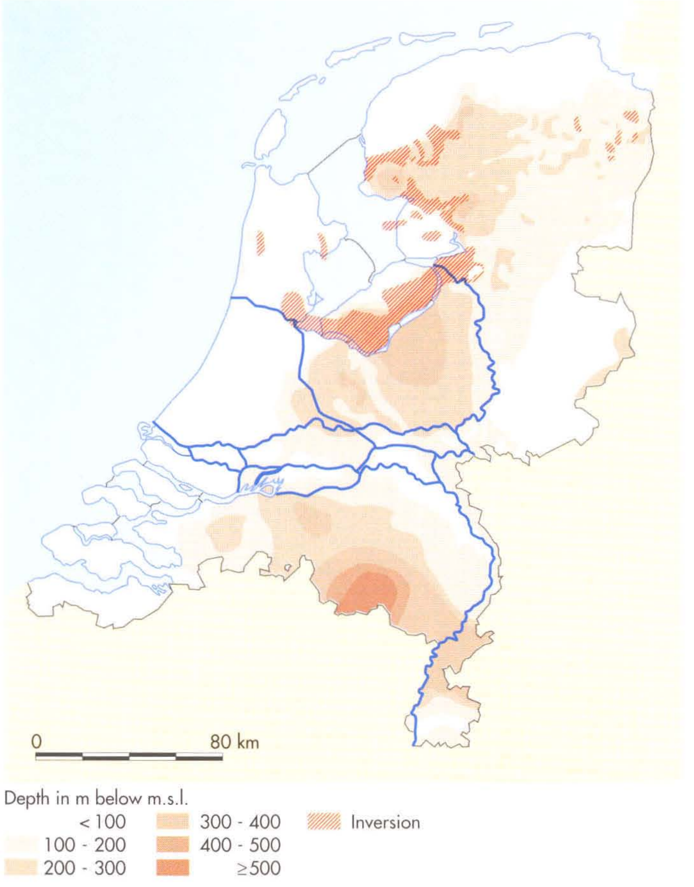


Figure 3.10 *Depth of the fresh/brackish interface in groundwater, brackish means > 150 mg Cl^-/l*

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

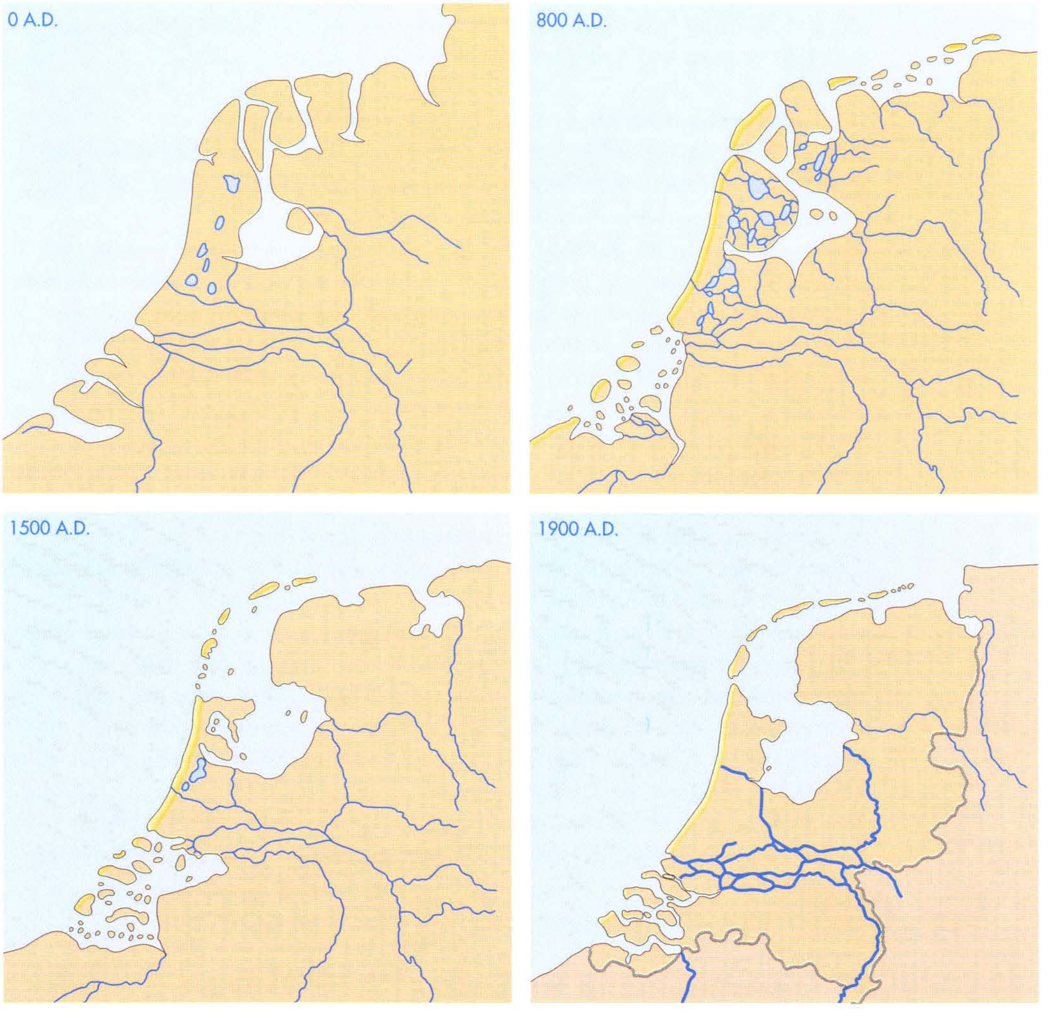


Figure 4.1 The shape of the Netherlands around 0, 800, 1500 and 1900 A.D. respectively

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. 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

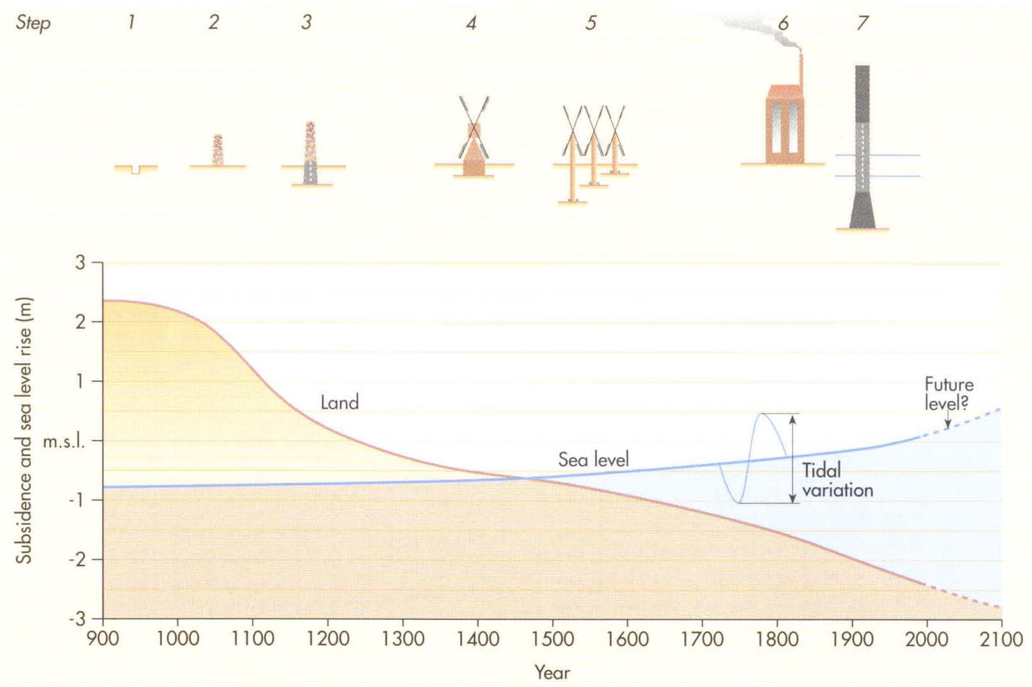


Figure 4.2 Stepwise response to the increasing subsidence of land and sea level rise over time

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 tide. In the 13th century local embankments were connected by dams closing the tidal creeks and inlets 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).

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 m.s.l.; 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 tidal inlet or creek (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.

Figure 4.3 *A series of windmills for draining a deep polder*

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.).
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 (step 6 in Figure 4.2. and Figure 4.4).
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 7 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 m.s.l (up to 6.7 m). Without dikes and dunes 65% 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 m.s.l. 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.

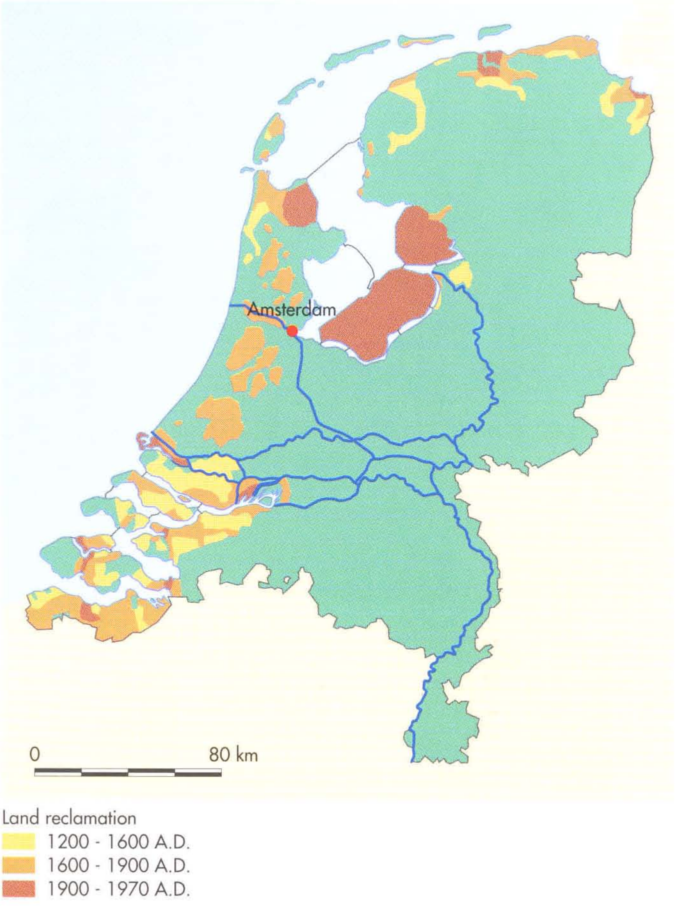


Figure 4.4 Land reclamation in the Netherlands

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

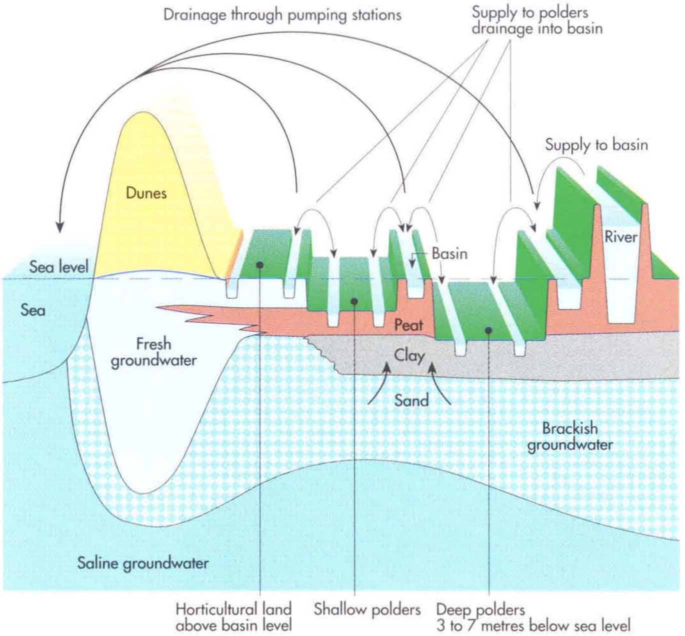


Figure 4.5 *Drainage and flushing of polders*

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 tidal inlets and creeks. The drainage area behind the dam often enclosed many counties, parishes and villages. 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 counties and parishes 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 soon recognized the water boards as the competent water authorities. Generally the water boards received charters from these local rulers. 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.

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, 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 riverbed 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 till 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.

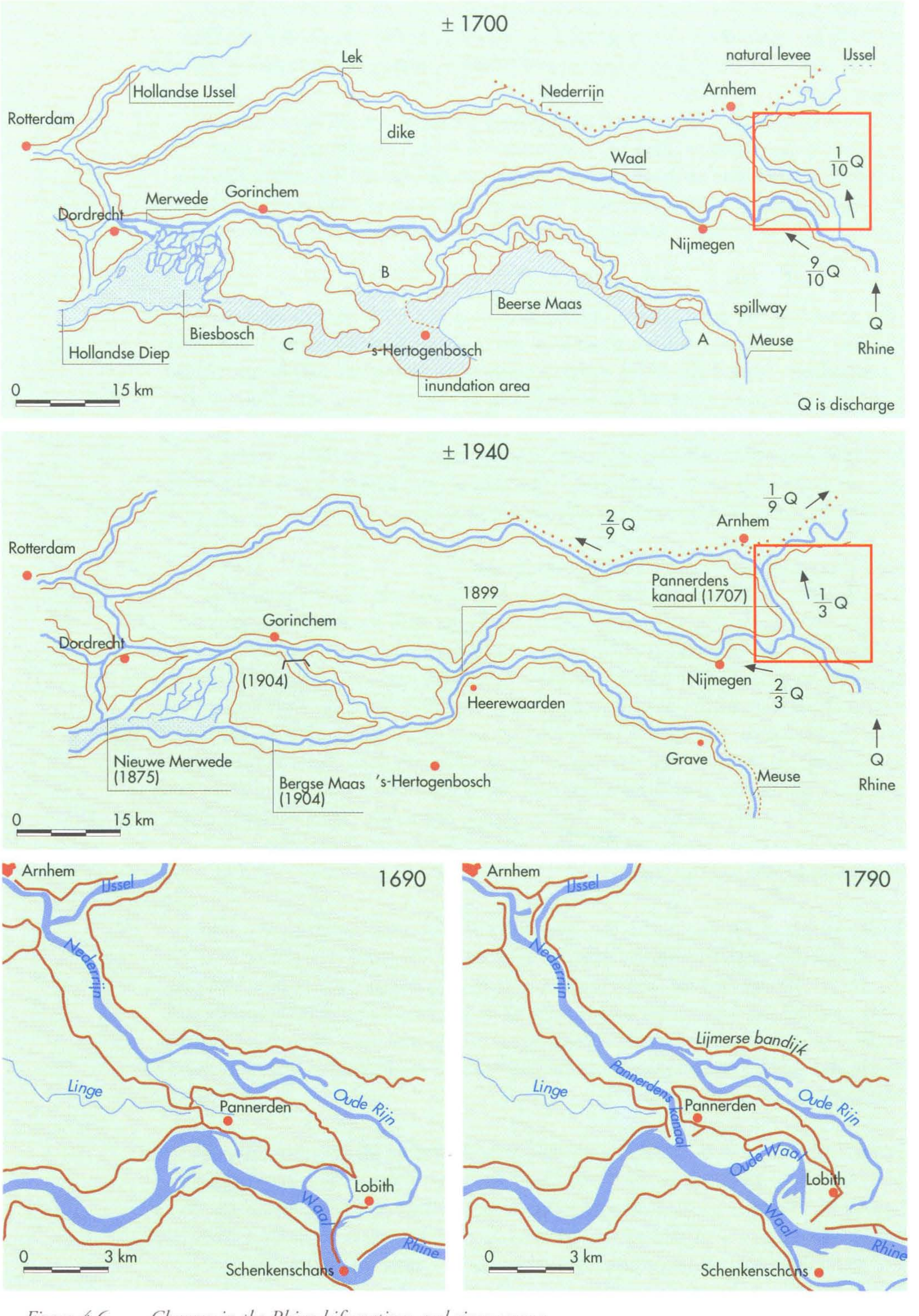
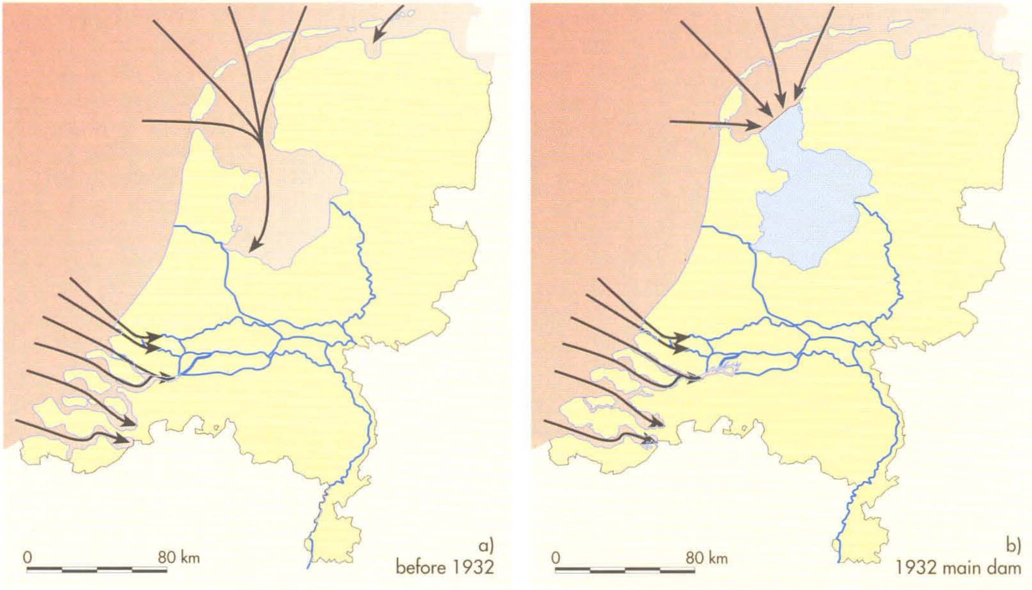


Figure 4.6 Changes in the Rhine bifurcations and river courses



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).

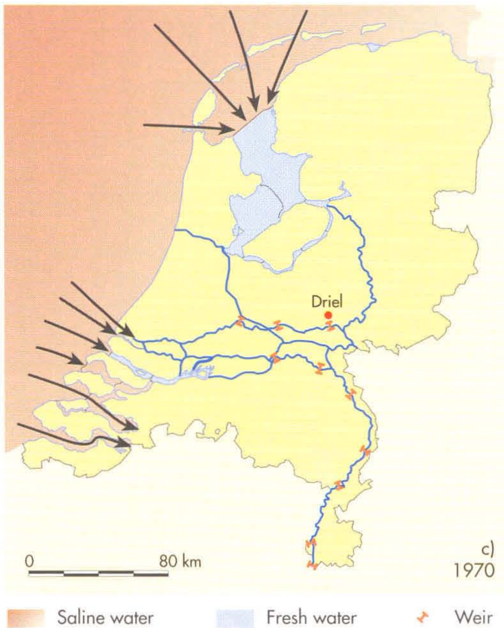


Figure 4.7 Protection against storm surges and salinization in the 20th century

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 realise 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 (Figure 4.7b and Figure 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.

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

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

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 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.
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.
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 4 200 million NLG 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 along the Antwerp-Rhine navigation route. As required by navigation and water management, the dam has been provided with locks and sluices.

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)*

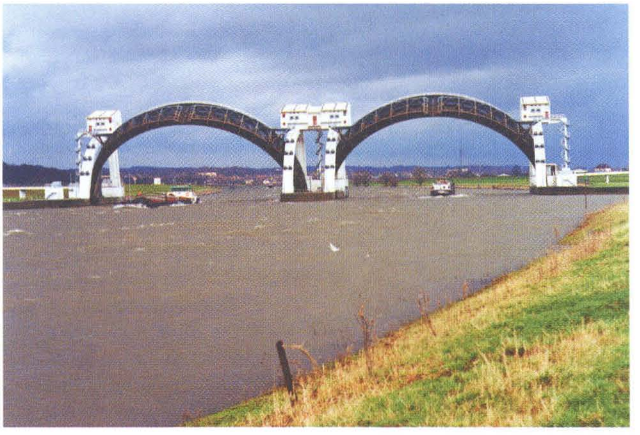


Figure 4.12 *The weir in the lower Rhine at Driel, the major valve for Dutch water management*

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.

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 manipulated 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 to flow the Rhine and Meuse water to many locations in the Netherlands, Figure 4.13.

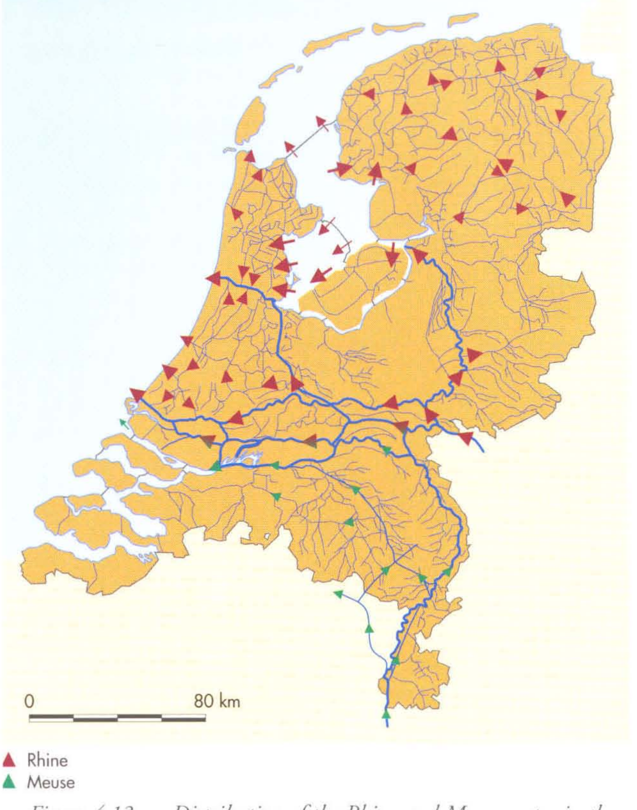


Figure 4.13 *Distribution of the Rhine and Meuse water in the Netherlands*

In the 1960s the increasing demand for fresh water by households, industry, agriculture and navigation, and for flushing to prevent salt water intrusion, showed 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.

5 Water-related interests

The Netherlands is a sinking country bordering the rising sea. Water courses intersecting the country are vulnerable to pollution. That is the reason 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 fell primarily under the responsibility of the water boards. The provincial government and the 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 item.

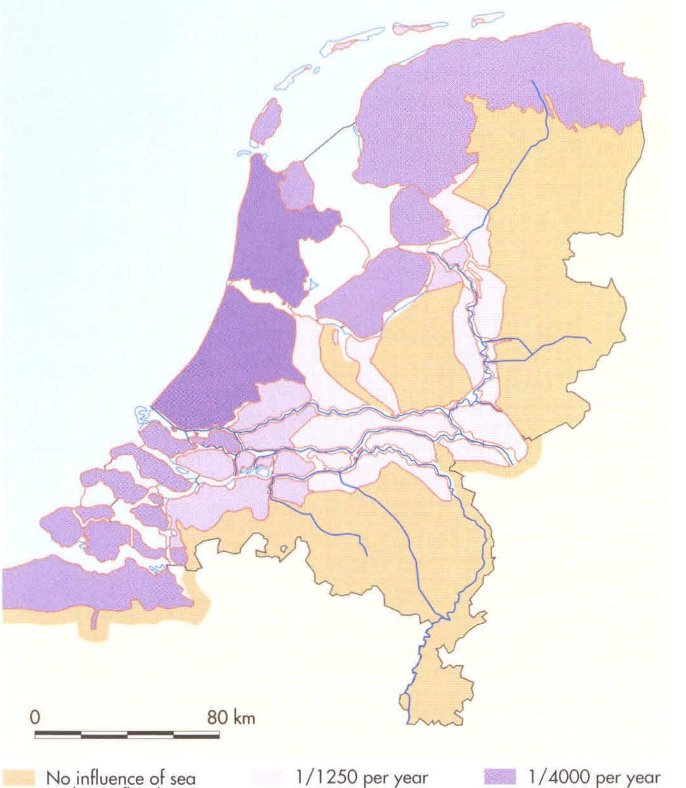


Figure 5.1 Safety standards for the different dike areas

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 on the average. They accept(ed) inundations by storm surges exceeding this safety

Figure 5.2 River flood of 1995

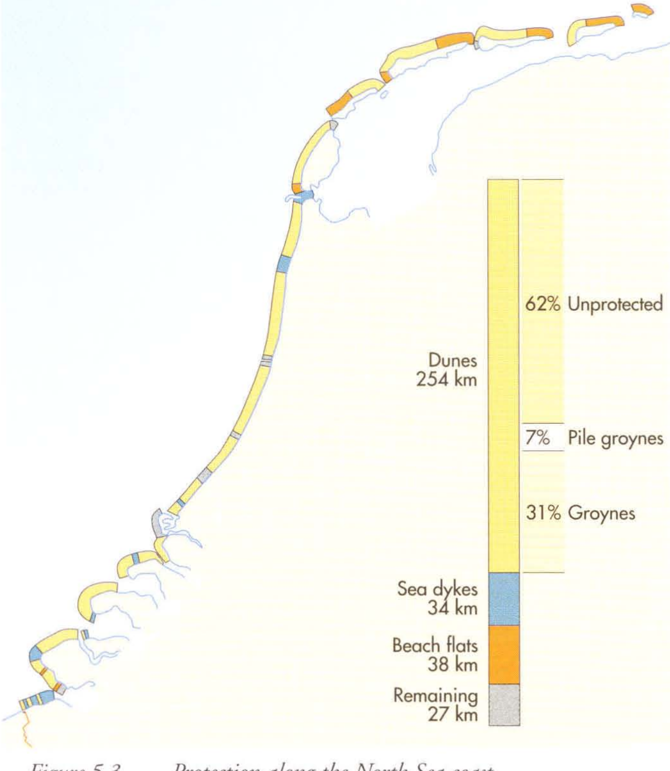


Figure 5.3 Protection along the North Sea coast

standard. For the north and south-western parts of the Netherlands and some Wadden Sea islands, dikes and dunes have to meet the safety standards of 1/4000 and 1/2000 per year. 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 1/1250 per year 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 the tidal currents which cause deep channels in the dike's gap.

Figure 5.4 Artificial beach replenishment

After the completion of the Deltaworks, the strengthening of the river dikes began in the 1980s at full speed. As the last big river flood dated back to 1926, there was strong opposition from environmentalists who where 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. Out of the 1 800 km of river dikes two thirds meet the required safety standards, one third has to be strengthened.

The protection against storm surges concentrates on man-made structures, but the longest protection facility along the North Sea coast are the dunes (Figure 5.3). During the centuries large parts of the dunes were taken by the sea as a result of sea level rise and currents. Where the dunes disappeared they were replaced by dikes. In the frame work of the Delta Project the competent authorities strenghtened weak dunes by artificical sand supply or by application of bank protection works. To encounter 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 assures the preservation of the coast (Figure 5.4). 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 and warnings. The emergency services for coasts and rivers inform the water boards and the public about the expected water levels (Figure 5.5).

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 5.5 *The early flood warning system*

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

Figure 5.6 Reservoirs for drinking water in the Biesbosch

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, whereafter 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.

The water production by water supply companies amounted to 1 280 million m^3 in 1994. About 740 million m^3 are used in households (132 litre/day/capita) 290 million m^3 in small businesses, 160 million m^3 in industry and 90 million m^3 for other purposes. Groundwater provides two thirds of the drinking water production.
In the western part of the country the groundwater is brackish or salty. Here drinking and industrial water is produced from the Rhine and Meuse rivers. Large reservoirs were created in the former tidal area of the Brabantse Biesbosch. When the water quality of the Meuse is good the water is pumped into the reservoirs (Figure 5.6). The Hague also uses Meuse water, but Amsterdam withdraws water from the Rhine. The Hague and Amsterdam pretreat the water before it is stored in the dunes. The dunes filter and improve the quality.
The water companies expect a shift from groundwater to surface water because of the 'verdroging' (see section 6.5 for definition).
The price of drinking water varied from NLG 0.95/m^3 to NLG 2.65/m^3 with an average of NLG 1.70/m^3 in 1994. In the coming 20-30 years the price will increase substantially due to the quality and environmental costs and the ecotax.

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 x 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 this use of surface water.

Besides surface water groundwater is also extracted by industry. In 1990 this amounted to approximately 200 x 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. 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 why 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, like 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 only be maintained if sufficient water is available from external sources like 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 part of the Netherlands, the diluvial part which 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 equiped 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 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.

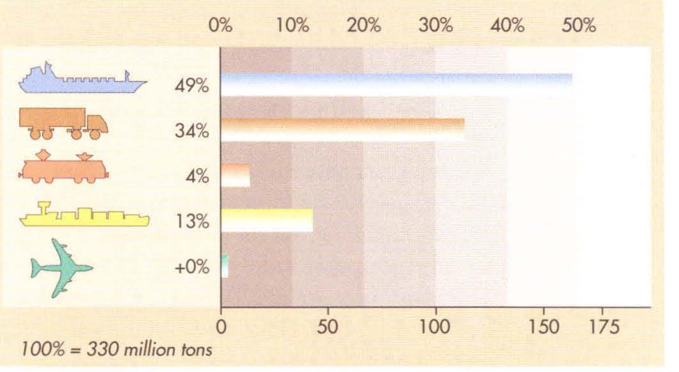


Figure 5.7 *Transboundary transport in 1992*

Figure 5.8 *Push barges*

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. In 1992 inland navigation carried 250 million tons, 18% of the total inland transport.
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 5.7 shows

that almost 50% of the transboundary transport, 330 million tons in 1992, is carried out by the inland water navigation system. The Dutch flag is carried by 6 200 vessels; the inland fleet in Western Europe totals 11 000 ships.
The dimensions of the ships vary from small vessels of 300 tons up to push barges of 17 000 tons (Figure 5.8).
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, congestions, accidents, etc to minimize the 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 the waterway network with culturally and historically interesting cities.

The total number of recreation anglers above the age of 15 years amounts to 1.3 million, which is almost 10% of the total population. Total spending in the fishery sector amounts roughly to NLG 0.35 billion which is the equivalent of some 1 900 man-years of employment. Roughly 340 000 ha of surface water is in use for recreative 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 tons, 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 all kinds of supply firms and retailing) the total turnover is about NLG 2.3 billion (1995). About 14 000 people are employed in this sector. The tourist 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 1990-1995 was estimated to be 6.2%.

5.8 Fishery

In former days inland fishery was an important sector; today it is a minor sector with a turnover of NLG 70 million. The construction of weirs, sluices and reservoirs has created obstacles for migratory fish. The salmon fishery in the Rhine

Figure 5.9 Fish passage

has mainly disappeared due to these obstacles (see also Figure 7.1 and Figure 7.2). The changes in water quality and overfishing did reduce 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 5.9) attempts to improve the situation for migratory fish.
Contrary to the inland situation, fishery in the salty surface waters is important. The turnover amounts to more than NLG 1 000 million. 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.

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 NLG 1 billion a year on rehabilitation projects. This effort is illustrated by the Baakse Beek Watershed (see box).

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.

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 urbanized 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. Chapter 13 deals with these topics.

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 is 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.

6 Impact on and improvement of water systems

Large amounts of waste water discharged into the water systems have an undesired impact on water quality and aquatic life. Since the last decennia efforts are being undertaken to improve the water quality by reducing pollution. Hydraulic installations serving human interests have undesired side effects on the terrestrial and aquatic environment, too. The different administrative levels try to cope with these side effects by mitigating measures. This chapter describes the impacts and the efforts to improve the water systems in the Netherlands.

6.1 Waste water and its treatment

For centuries surface waters removed the waste water produced by the population. The size of the population was limited and so was the pollution. The self-purification capacity was sufficient to maintain good water quality. This situation began to change in the second half of the 19th century. The growing population and industrial activities produced large quantities of waste water which was discharged untreated into the surface waters.

During the last four decennia the pollution of the surface waters by oxygen consuming substances drew much attention. In many surface waters the oxygen balance was in disorder. Poisoning of fish and bad smells (odour) created problems in local and regional water systems. The polluted Rhine and Meuse were of little use in flushing the regional and local waters because the other regions in the basins had to cope with the same problems. The authorities developed sanitation plans. Favoured by the regulations and finance system of the Pollution of Surface Waters Act (1970), the pollution was reduced. The increasing efforts to reduce the pollution by households and industries can be seen in Table 6.1.

Table 6.1 *Pollution by oxygen-consuming substances and sanitation of surface waters in the Netherlands (in million inhabitant equivalents)*

	1969	1975	1980	1985	1990	1995
Households	12.5	13.3	14.3	14.5	14.9	15.4
Industries	33.0	19.7	13.7	9.8	9.7	10.2
Total	45.5	33.0	28.0	24.3	24.6	25.6
Elimination in wastewater treatment plants	5.5	8.7	12.6	14.5	17.0	18.6
Discharge into the surface waters	40.0	24.3	15.4	9.8	7.7	7.0

From these figures it can be concluded that pollution with oxygen-consuming substances is a problem, which nowadays is under control.

Table 6.2 Decrease of chlorinated hydrocarbon pollution from industry

	1975	1980	1985	1990	1995
Organochlor (EOCl) in tons/year	1 000	5 300	60	50	40

Under the power of the above mentioned Act industrial pollution by dangerous substances began to decrease with the introduction of new production methods, recycling and new purification techniques. Table 6.2 and Figure 6.1 represent the industrial discharge of chlorinated hydrocarbons and heavy metals in time. The agreements of the Rhine and North Sea States to strengthen the depollution efforts have contributed considerably to this development.

6.2 Pollution from diffuse sources

The pollution of groundwater and surface water from diffuse sources is a point of major concern. This can be observed in Figure 6.1; the industrial discharge of heavy metals has been reduced by a factor of 20. Pollution from non-point sources did not halve in the same period. Diffuse sources are responsible for some objectives that were formulated for the Rhine and North Sea not being achieved. The substances concerned are nitrogen, some heavy metals, polycyclic hydrocarbons and insecticides. It is difficult for the water authorities to get a direct grip on the diffuse sources. Changes in the behaviour of consumers and producers as well as intervention by other authorities can contribute to the reduction of diffuse pollution. This can be illustrated by the eutrophication problem in the North Sea.

The most important sources of nitrogen and phosphate are agriculture, households and industry both in the Netherlands and abroad. Eutrophication can lead to excessive growth of algae, some of them toxic. The dying off in the autumn often causes shortage of oxygen in stagnant waters and in the North Sea. Both phenomena can result in the death of fish and other animals. The Rhine and North Sea States agreed upon reduction objectives of 50% for phosphate and 70% for nitrogen in the period 1985-1995. The objective for phosphate will be achieved. The replacement of phosphate in detergents, mainly forced by consumers was particularly important. Within some months they were buying only non-phosphate containing detergents. The removal of phosphate in wastewater treatment plants also contributed to the 50% reduction. The objective of nitrogen reduction will not be achieved. Wastewater treatment plants remove nitrogen produced by households and industries. Reduction in the agrarian sector, however, is difficult.

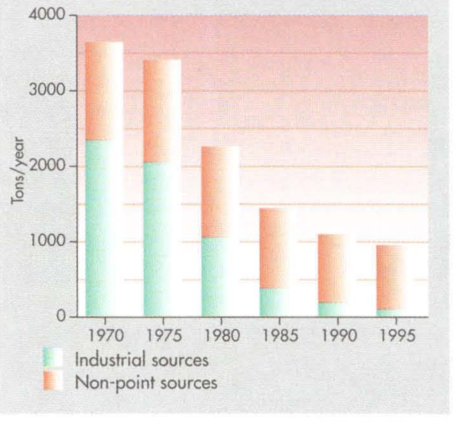


Figure 6.1 Discharge of heavy metals by different sources in the Netherlands

6.3 Groundwater pollution

In this century the explosive socio-economic and technical developments have led to a serious assault on the quality of soil and groundwater. Today, all over the world, a variety of problems is encountered: physical, chemical and biological degradation of soils, soil erosion, overdrawn aquifers, salt water intrusion and groundwater contamination.

Many activities hold a potential threat for soil and groundwater pollution. Hence, it is not surprising that cases of pollution have been reported for quite some time. At first, these were seemingly only local pollution, caused by point sources like waste disposals, and accidental spills of chemicals, and were of minor importance for the state of the subsurface environment at regional or national scales. However, in the 1970s it gradually became clear that soil and groundwater were being treated rather carelessly not only in the Netherlands, but also in many other countries. Numerous human activities appeared to have significant and large-scale effects on soil and groundwater quality, in spite of the natural protection provided by the physical, chemical and biological properties of soil and groundwater.

The discovery of some serious cases of soil pollution in urban areas at the end of the 1970s, led to nationwide inventories of suspect sites of soil and groundwater pollution. The result is a long list of approximately 100 000 sites.
Since 1983 a large operation has been in progress to clean up these polluted sites, with a yearly governmental budget of about NLG 275 million and another NLG 250 million coming from polluters, owners and users of specific sites. The objective is to clean up all urgent cases before the year 2010.

Another serious impact on soil and groundwater results from the intensification of agriculture. The use of fertilizers, pesticides, sewage sludge and animal waste produces a substantial and widespread deterioration of soil and groundwater quality. Several groundwater pumping stations in agricultural areas are threatened by high levels of nitrate, heavy metals and organic micropollutants. It is expected that in the near future a quarter of the extracted groundwater will be in need of extra treatment. Atmospheric deposition (e.g. acid, heavy metals and organic micropollutants) caused by industry, traffic and agriculture is another diffuse threat to the quality of soil and groundwater.

6.4 Polluted sediments, a mortgage on use

The water sediment is polluted. The degree of pollution differs from place to place and varies from slight to severe. The risks for the environment are mainly due to the absorption into the biological food chain and the spreading of polluted sediment into vulnerable regions, such as the lower reaches of the Rhine and the North Sea. The water and port authorities dredge up quantities of 25 to 30 million m^3 in situ annually. About 5 to 10 million m^3 of nautical dredging spoil is so polluted that relocating it threatens the environment. Treatment and storage in depots is necessary. To safeguard the North Sea against polluted sediments from the Port of Rotterdam a large storage depot was realized in 1985 (see Figure 7.5). To solve urgent regional problems, authorities created small depots for polluted sediments. In 1997 two large-scale depots for inland water sediments will become available to store polluted sediments from both state and regionally managed waters. Research for treatment and reutilization techniques are underway to reduce the quantities to be stored.

6.5 Unbalanced hydraulic design and excessive use

The regulation of brooks, canalization of rivers, reclamation of land, closing estuaries, etc. have had undesired side effects. The annually recurring phenomenon of fish such as salmon, sea trout etc. migrating up-river, has disappeared from the Netherlands as a result of hydraulic works and the abrupt changes from salt to fresh water.

Spawning grounds have become inaccessible, shore plants and organisms have disappeared. Hard constructions along the river banks disfigure the landscape and make the banks unsuitable for terrestrial animals and recreation. It is not only a problem in the Netherlands. Unbalanced hydraulic design occurs basin-wide as described in Chapter 7.

Other intervention has lowered the water levels and groundwater tables. Agriculture and urbanization require accelerated drainage in wet periods. Improvement of field drainage and the regulation of water courses have had the required effect on high water levels. However, the drained quantity fails in dry periods. Drinking and industrial water supply extract groundwater in considerable quantities. In dry periods agriculture also extracts (ground)water to cope with the increasing evaporation by the selected and intensified crops. In rural areas an average drop in the groundwater level of 35 cm could be established since the 1950s; in areas with permanent extraction the drop is more than one metre. The lower groundwater tables have adversely affected the moisture content, mineralization, seepage and the influence of precipitation. Nature areas, forests and the landscape became dried out. This chain of causes and impacts is defined as 'verdroging'.

In Figure 6.2 the nature areas affected by 'verdroging' are illustrated. In these areas the terrestrial and aquatic species which depend on water have (almost) disappeared.

Figure 6.2 Inventory of 'verdroging' in 1996

6.6 Impacts on regional water systems

In the past decades high priority was given in rural water management to the realization of good conditions for agricultural production. Many

measures were taken to improve the water management of agricultural soils. The construction of deeper and wider canals and ditches lowered surface water levels, especially in winter and spring. In addition pipe drainage was installed to drain the land in wet periods and allow subsurface infiltration in dry periods. These efforts enabled the farmers to work in the fields in early spring and to sow crops at an early stage of the growing season. In dry periods water mainly from the Rhine and Meuse was transported to agricultural areas. This water is rich in nutrients causing eutrophication in stagnant water courses. Moreover cheap mineral fertilizers and pesticides increased agricultural production, worsening the water quality.
The increasing water demand of the population also led to larger groundwater abstractions especially in the higher diluvial parts. In these regions the shortage of water for agriculture was met by groundwater extraction too. Unfortunately there was little coordination between the different authorities, resulting in unwanted side effects such as 'verdroging' and a waste of money. For example, in one region measures were taken to improve the agricultural drainage, while at the same time groundwater abstraction for public water supply was permitted. Together, both activities caused undesired drops of the groundwater level. The combined effect resulted in conditions too dry for agriculture and caused ecological damage. In the past little knowledge was available to quantify the effects of these measures and impacts on other interests.

6.7 Rehabilitation efforts

The rehabilitation of the water systems started with discussions about the impacts of the storm surge barrier in the Eastern Scheldt in the early 1970s. If the barrier had been built as planned, the mussel and oyster catches and the marine environment would have completely disappeared. The barrier would have created a fresh water reservoir supplied by polluted Rhine and Meuse water with all its negative impacts. There was strong opposition which succeeded in convincing the Government to look for other solutions. Three alternatives were considered. Finally Government and Parliament decided on the alternative of an open Eastern Scheldt, closed only during high storm surges. Thus rehabilitation started with the preservation of the existing environment.
In the early 1980s it became necessary to rehabilitate the water systems; some small scale projects were realized. The rehabilitation plan of the International Rhine Commission created the overall framework for large-scale projects. These projects are of national interest and therefore financed by the Government. In order to support the efforts of the provinces, municipalities and water boards the Government also decided to co-finance small rehabilitation projects for improving the situation at local and regional levels. Since the late 1980s many rehabilitation projects have been realized and the efforts are still in progress. The projects concerned combating eutrophication and 'verdroging' by isolation and regeneration measures, biomanipulation to restore the ecological equilibrium in lakes, introduction and repair of fish corridors and environment-friendly shores, zoning, etc.

A number of ecohydrological studies, carried out in the 1980s, improved the knowledge of the function of ecosystems in relation to water management. Nowadays ecohydrological knowledge is involved in nearly all policy plans dealing with water management, nature management and environmental protection. Both

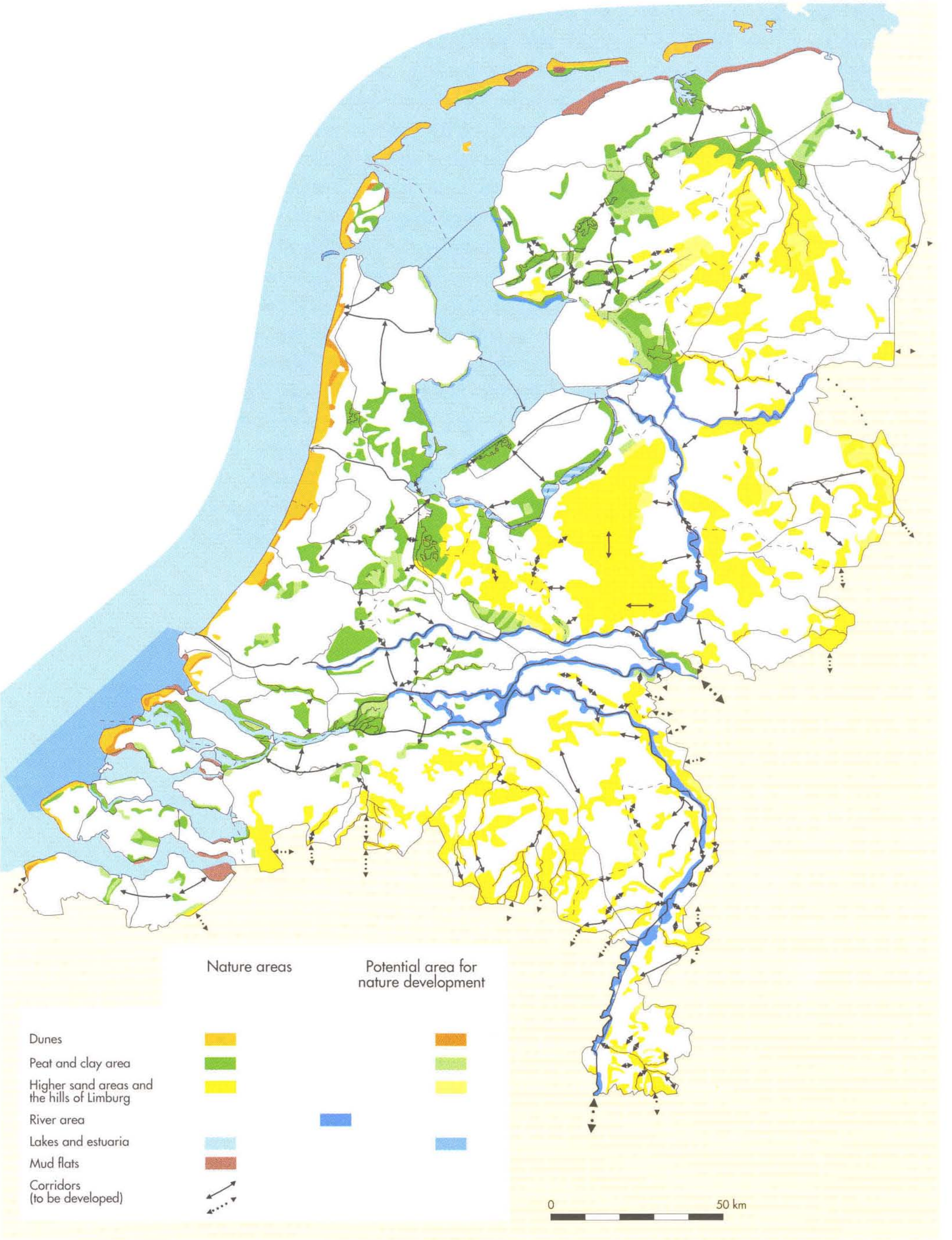


Figure 6.3 Ecological Main Structure of the Netherlands

local, regional and national scales are covered. Until recently most studies, using either sophisticated models or more knowledge-based approaches, were carried out to evaluate the impact of prospective measures of water management for policy plans.

Since 1990 national nature policy plans changed from a defensive to a more offensive policy after policy makers became aware of the serious 'verdroging' (Figure 6.2) and acidification of nature reserves. This gave birth to the Ecological Main Structure of the Netherlands, which among other things, is founded on ecohydrological patterns in the landscape and which is part of a strategy to create new chances for nature (Figure 6.3). Ecohydrological and environmental scenario studies are carried out on a national scale using national data bases, to decide on optimal hydrological and environmental conditions for the sustainability of ecosystems.

Regional authorities stimulated studies in physical planning where both knowledge-based and model-based ecohydrological approaches are involved in decision making. Numerous local nature restoration projects have been launched and ecohydrological systems analysis has become a basic requirement in the planning of measures to restore a sound water management for nature area development. Monitoring networks have to be generated and standardized in the near future to evaluate the effectiveness of measures to reset and restore ecosystems.

7 Water, an international issue

International cooperation in transboundary river problems often starts with issues of common interest, i.e. the promotion of navigation. The promotion of opposing interests, such as the fight against pollution in transboundary river basins and seas, is more difficult. The pollution problems in north-west Europe have shown that international cooperation on this subject is a time consuming process. It took several decades to reach a mutual understanding of specific problems in the countries of the Rhine basin and the North Sea area as well as to take measures to reduce pollution. The first ministerial conferences, in 1972 on the pollution of the Rhine, and in 1984 of the North Sea, marked the transition from mutual understanding to taking concrete measures.

7.1 One-sided promotion of interests harms the ecosystem

As a result of its hydrological characteristics the Rhine has become an important navigation link in north-west Europe. International cooperation on navigation started in 1815 with the creation of the Central Commission for the Rhine Navigation, was promoted in every country and contributed considerably to trade and industry in this part of Europe. The river authorities of the Rhine States succeeded in eliminating obstacles which hindered navigation. Improvement works affected other interests. For example the concentration of river discharges into one channel in the section Basle-Karlsruhe caused a lowering of the river bed by 2-7 m. Consequently the groundwater table dropped by several metres. It seriously affected the landscape and agricultural use. The vegetation died off and spawning grounds were lost. At the end of the 19th century hydropower was introduced and plans were developed to serve both hydropower and navigation interests. Today more than 450 dams, weirs, sluices and locks in the Rhine and its tributaries serve these interests. However, they prevent migratory fish from reaching their spawning grounds. Moreover these hydraulic structures produce higher water levels which change the velocity and sedimentation processes. In the Netherlands the Closure dam and Delta dams created barriers for the migratory fish, too. Figure 7.1 gives an impression of the physical obstacles for migratory organisms in the Rhine basin.

Figure 7.2 shows the impact of these interventions for the salmon supply to Dutch and German fish markets. This amounted to some 100 000 salmon a year, before 1900. After 1915 there was a sharp reduction. In 1940 the salmon has almost disappeared from the Rhine. Only few salmon reached their spawning grounds because of the weirs and dams. This happened in spite of the Salmon Agreement of 1885, by which the riparian Rhine States agreed to preserve the salmon stock and to protect the spawning grounds along the Rhine and its tributaries. But navigation and hydropower got higher priority than fishery interests. Spawning areas became inaccessible or disappeared in higher water levels. After an inventory, made in 1913, it proved that only some larger spawning areas along the High Rhine above Basle and along the river Moselle were left. When the works of the Grand Canal d'Alsace were realized and the canalization of the Moselle began, these spawning grounds also disappeared. The few quantities of salmon surviving in small spawning areas were finally wiped out by pollution.

> Weir with lock — Weir — Reservoir dam

Figure 7.1 *Obstacles in the Rhine basin*

7.2 Chloride, trigger for the Netherlands to tackle the Rhine pollution

Chapter 4 describes the vulnerability of the polders to floods and salt water intrusion because many polders are situated below m.s.l. The saline seepage which collects in ditches and canals has to be flushed away by the surplus of precipitation and by using river water, which mainly originates from the Rhine, in dry periods.

The Rhine water used to be very suitable for this purpose because of its natural low salt content. Before 1900 it had a chloride content of 10 to 20 mg/l. The industrial revolution in the Rhine basin resulted in a strong increase in the salt content originated by industries and mines in the countries upstream of the Netherlands (Figure 7.3). In 1932 the Netherlands Government undertook the first diplomatic steps to stop the increasing chloride content and other activities polluting the Rhine water. This effort, however, was in vain.

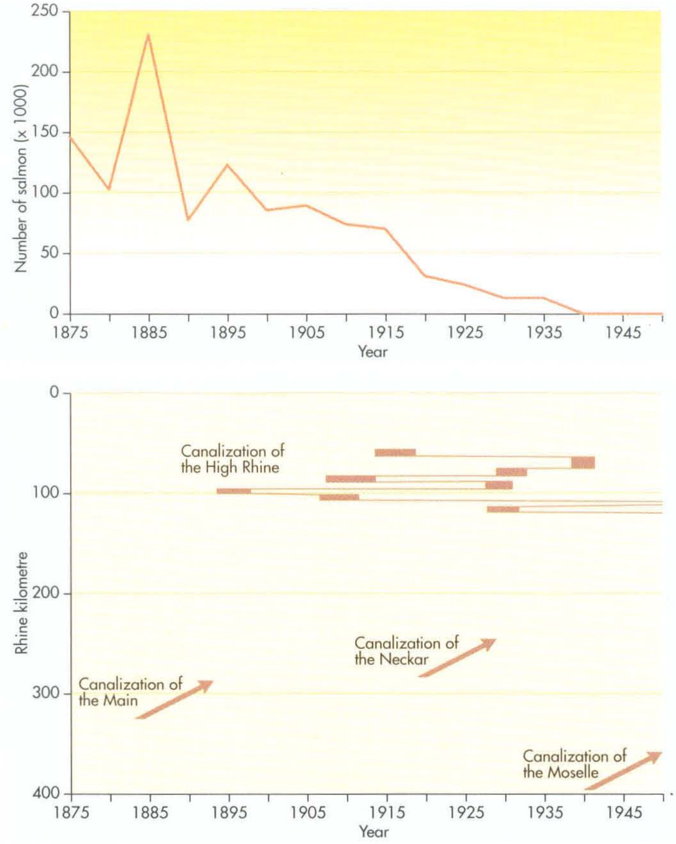


Figure 7.2 *Decrease in salmon caught due to increase in navigation and hydropower structures*

7.3 The international fight against pollution, a laborious process

After the Second World War there was a marked increase in industrial activities. Large quantities of untreated wastewater heavily polluted the Rhine. In 1946 the Netherlands tried again to start international negotiations on the pollution problem. It took until 1950 before the Rhine states: the Federal Republic of Germany, France, Luxembourg, the Netherlands and Switzerland created the International Commission for the protection of the Rhine against pollution (IRC). The creation was based on an exchange of diplomatic notes. The IRC received its legal basis from the treaty of Berne in 1963. Since 1953 the IRC thoroughly investigated the type and the quantity of pollution. With that aim the IRC developed common measurement and analysis methods. Later these efforts also served the water-related activities in other international fora.

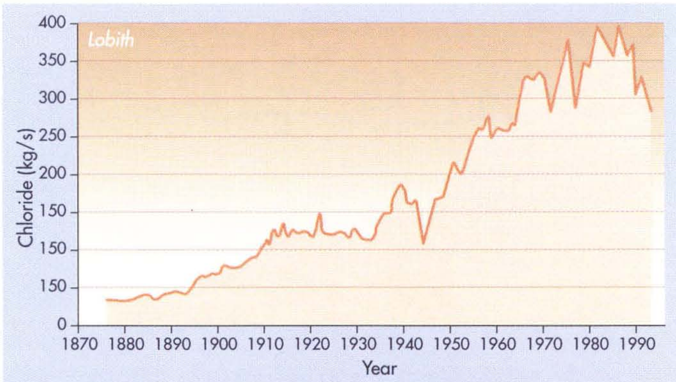


Figure 7.3 *The chloride load of the Rhine at Lobith on the Dutch-German border*

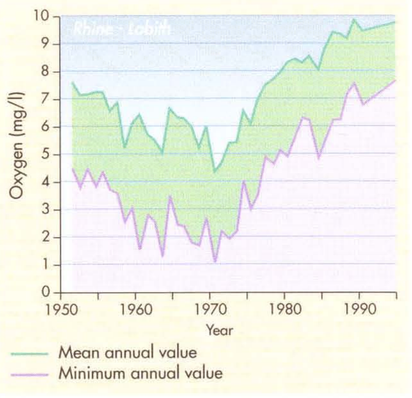


Figure 7.4 *Oxygen content of the Rhine at Lobith on the German-Dutch border*

However, the negotiations in the IRC did not lead to concrete arrangements to combat pollution. The quantities of organic and inorganic pollutants still increased. Dangerous substances, nutrients and heat were also released without purification or other provisions. The water quality of the Rhine was continuously deteriorating. Figure 7.4 illustrates this by means of the oxygen content. The impact of the pollution reached its worst levels in the autumn of 1971. At that time the Rhine water lacked oxygen in the downstream river sections and accidents had poisoned the river with chemical substances. Oilspills from ships and industry left a black ribbon on river banks and dikes around the mean river level. Carbol dominated the odour of the river. The Rhine was considerably damaged; aquatic life had disappeared. The press and the public began to designate the Rhine as the open sewer of Europe.

7.4 Public opinion forced governments to act

Shocked by the dying Rhine in 1971 and under pressure of public opinion, the ministers of the Rhine Commission States met for the first time in The Hague in 1972. They charged the IRC with elaborate conventions containing the main objectives for the fight against chemical pollution and pollution due to chlorides. They also asked the IRC to draw up a long-term working programme for the reduction of all polluting sources (time target 1985). In 1976 the ministers adopted the conventions and the working programme providing concrete arrangements to combat pollution. Taking into account the competencies, the European Union became a member of the IRC.

Table 7.1 *Improvement of the water quality of the Rhine*

Pollution measured on the German-Dutch border in 1972, 1985 and 1993

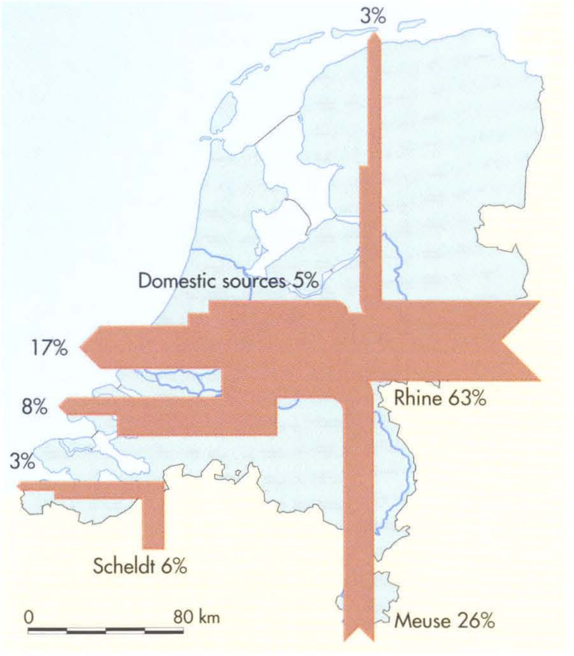
	1972	1985	1993	Reduction 1993 w.r.t. 1972	Natural load/ content
Mercury	99 t	5 t	2.5 t	97%	0.7 t/y
Cadmium	167 t	9 t	2.8 t	98%	1 t/y
Chromium	3 627 t	378 t	251 t	93%	240 t/y
Lead	2 000 t	441 t	346 t	83%	75 t/y
Copper	2 018 t	473 t	314 t	85%	70 t/y
Nickel	-	356 t	219 t	-	-
Zinc	13 800 t	2 995 t	1 724 t	88%	250 t/y
TOC	29 kg/s	13 kg/s	8 kg/s	72%	-
Oxygen	4.4 mg/l	8.0 mg/l	10.0 mg/l	56%	10 mg/l
Phosphate	1.3 kg/s	1.0 kg/s	0.5 kg/s	63%	0.2 kg/s
Nitrogen NH_4	1.0 kg/s	1.4 kg/s	0.5 kg/s	47 %	0.3 kg/s

Figure 7.5 Slufter, storage reservoir for heavily polluted sediment

In 1976 the IRC believed that the emission standards mentioned in the chemical convention could have established the bulk of the point-sources within a few years. However, the work proved to be more complicated and consumed more time than expected. Many substances were involved and eco-toxicological data were available for only a few compounds. The convention prescribed the use of the best technical and best applicable means to reduce the pollution, but the best means of today are outdated tomorrow. The required approval of the proposed measures by the EU produced time-consuming negotiations at Brussels.
In spite of these difficulties sanitation measures for wastewater from industries and municipalities were realized. After 1971 the pollutant loads decreased. The water quality of the Rhine improved, (Figure 7.4 and Table 7.1.) Aquatic life returned. The improvement of the Rhine stimulated the riparian states to continue their efforts.

7.5 Contaminated water and sediment threatens north-west of Europe

In the stagnant waters of the Netherlands sand and silt settle down. For centuries sand and silt have been dredged and used to raise the land and as natural fertilizers because of their nutrient content. Dredged material was a wanted product. To ensure sufficient navigation depth to the Port of Rotterdam, large quantities of dredged sediment from the Rotterdam Waterway were dumped into the North Sea without a quality licence. This is no longer the case. In the late 1970s, in the new housing and agricultural areas where dredged material was used, it became clear that dangerous substances had heavily contaminated the soil. The authorities advised the



Source	Quantities		Destination	Quantities	
Rhine	6000 t/y	63%	Sedimentation	2600 t/y	27%
Meuse	2400 t/y	26%	Deposited on land	3900 t/y	41%
Scheldt	600 t/y	6%	Deposited in sea	3100 t/y	32%
Domestic sources	500 t/y	5%			
Total	9600 t/y	100%	Total	9600 t/y	100%

Figure 7.6 *Pollution of the Netherlands by seven heavy metals in 1984-1985*

population about the health risks of consuming vegetables from their own gardens. That is the reason why nobody wants the dredged material that has been removed from channels and harbours. The sediments of the polluted river beds are an unwanted heritage. But what can be done?
As the first step to avoid irreversible effects on the marine environment, the Government decided to stop the dumping of polluted sediment into the North Sea. The polluted sediment must be stored under controlled conditions. For that reason a reservoir was built near the coast (Figure 7.5). The cost is high and the storage capacity limited till 2005. In that year the quality of dredged sediment has to meet the standards which will allow dumping in the sea or using it on land without repercussions for the environment.

The Netherlands brought this problem to the international fora at the beginning of the 1980s, and pointed out that most of this material was imported from abroad, as illustrated by Figure 7.6. The Dutch pleaded for further measures to be taken to reduce this pollution. These demands implied that not only did the water have to be cleaned but efforts should be oriented to the quality of the sediments. As this would be a costly matter, the Netherlands did not succeed initially in convincing other states and organizations about the threat posed by the polluted sediments.
The Netherlands pressed for consideration of the pollution issues not only on a river basin scale, but also at the level of the recipient marine environment. The (recipient) North Sea has its own characteristics influencing the pollution pattern and its impact. Figure 7.7 shows the water and sediment movements in the North Sea. Due to the tidal influence, there is a south-north current along the Dutch coast, transferring polluting fine particles from the Scheldt, Meuse and Rhine to the German Bight. The tidal current from the east of England also carries polluted material to that area. Of course the Weser and Elbe rivers also contribute to the water quality problems, e.g. oxygen deficit, fish diseases and high mortality of seals. As for the Rhine in the 1970s, the most involved country took the lead. The Federal Republic of Germany took the initiative for the First Ministerial Conference on the protection of the North Sea in 1984. Later, more consultations were held at ministerial level resulting in a slow but continuous reduction of the pollution in the North Sea.

7.6 European water policy

The European Union (EU) started its involvement in transboundary water politics in 1972 to avoid unequal competition, particulary between the Rhine states and the other EU countries.Therefore directives were issued to deal with these problems. These rather detailed rules aim to limit the emission of specific substances, to formulate water quality standards within specific parameters, and to monitor and evaluate quality measurements. The directives can be classified into three categories: source-oriented, dealing with the input of pollutants into water; impact-oriented, protecting specific types of water use; and directives combining both orientations.

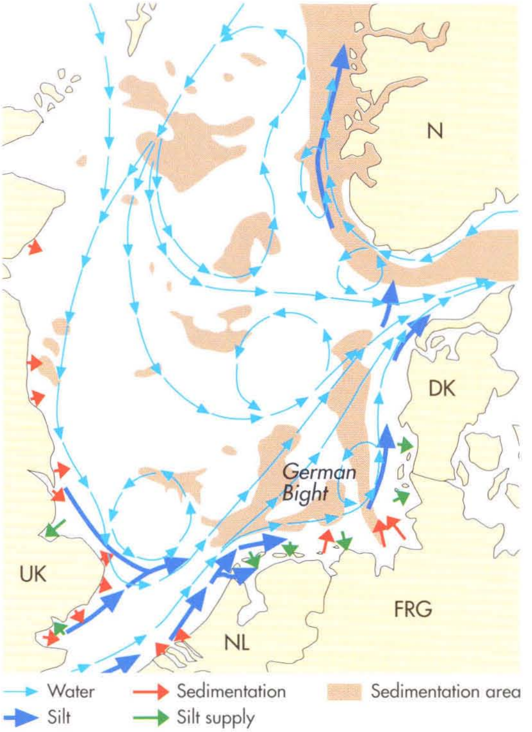


Figure 7.7 Water and sediment movements in the North Sea

The most important source-oriented instrument is the 'Directive on pollution caused by dangerous substances discharged into the aquatic environment of the Community', known under number 76/464. The regulations of this Directive have the same structure and wording as the Convention to protect the Rhine against chemical pollution. Based on this Directive, the EU agreed on 7 'daughter-directives' containing emission limits, water quality objectives and monitoring requirements. Four impact-oriented Directives have outlined quality standards for specific uses: the Directive about the use of surface water to produce drinking water (1975) defines three levels of quality objectives corresponding to treatment processes -if the surface water does not meet the objectives, drinking water production is prohibited; the bathing water Directive of 1976 obliges EU members to observe certain quality standards in places frequented by large numbers of bathers-observations have to be reported; and the Directives on fish water and shellfish water (1978 and 1979 respectively) contain quality standards which have to be respected for waters designated by EU members as appropriate for salmonides, cyprinides or shellfish. Originally, Directive 76/464 contained regulations for groundwater. These regulations ceased to apply as the groundwater Directive came into force in 1980. This Directive aims to protect the groundwater against discharges and pollution by substances on the black and grey lists.

The Directive on urban wastewater treatment (1991) obliges all urban agglomerations to be connected to a sewer system, to purify wastewater according to secondary treatment. In vulnerable situations, i.e. when the recipient water is used for drinking water, treatment of phosphates and/or nitrates should be added. The second source-oriented instrument deals with nitrates from agricultural sources. It obliges EU Member States to establish codes for good agricultural management up to a maximum nitrate level of 170 kg per hectare.

In practice the EU legislation has shown a lack of consistency in the Directives. The interrelation between the source- and impact-oriented ones is not always clear. Similarly, this is the case with Directive 76/464 and the urban wastewater directive. It often makes the directives difficult to apply and to enforce. The source-oriented Directives also lacked flexibility. It took much time before emission limits were adopted by the Council of Ministers. The periodical assessment and actualization of the black and grey lists were not foreseen. The diffuse sources were ignored. The importance of these sources grew when the pollution by point sources was decreased by sanitation. Some quality standards of the impact-oriented directives were outdated at the date of their enforcement. Nevertheless the Directives have considerably contributed to the reduction of pollution in the EU member states.

Since the end of the 1980s new orientations in the EU water policy have taken place at a time when many international water agreements have undergone fundamental revisions. New river treaties were concluded, many of them focusing on a river basin approach. They coincided with new orientations of the general EU policy like subsidiarity and transparancy.

In 1993 the European Commission submitted a proposal for a Directive on integrated pollution prevention and control. In June 1994, the Commission presented the proposal for a Directive on the ecological quality of water. Some directives were up-dated. However, neither the Council of Ministers nor the European Parliament were sastisfied. They invited the Commision to present a coherent strategic document on water policy. It should start with the ecological water quality proposal and be based on principles for sustainable water management: the principles of precautionary measures, preventive action, priority for rectifying environmental damage at source, progressive reduction of the use of dangerous substances, and of 'the polluter pays'. Where possible the river basin should be taken as a basic unit for the coordination of planning and management. Special attention should be given to achieving a high level of environmental protection, to regional diversity, to subsidiarity and to the functioning of the common market.

In December 1996 the Commission submitted the proposal of a Water Framework Directive. The proposal was welcomed by the EU members. In June 1997 the Council of Environmental Ministers reached a political agreement on the outline of the proposal. Maybe the deliberations will be concluded in the course of 1998.

8 Integrated water management, essential for sustainable development

This chapter deals with the attempts to analyse systematically the water management problems and to formulate comprehensive policies. The concept of integrated water management resulted. This concept had a great influence on the working methods and organization of the water management authorities. The never-ending process of harmonization of the often opposing interests is being realized by planning as a legal instrument. The process is not limited to the water sector. Spatial, environmental, natural, agricultural and economical issues are also involved. Integrated water management received an international dimension through the Rhine and North Sea action plans. These plans created a coherent framework for national, regional and local activities to reduce pollution and rehabilitate water systems. The 1995 peak discharges in the Rhine and Meuse rivers gave an additional impulse towards integrated water management in transboundary river basins.

8.1 Attempts at harmonization and integration

Against the background of a strongly increasing population in the 1960s, the Government concentrated its efforts on fresh water to meet future needs. In the first Water Policy Document (1968) the Government formulated a coherent vision about the necessary activities. The infrastructure to meet the future demands on drinking water and water for agriculture were considered to be important issues. The document also considered items such as drainage, salination caused by the North Sea, and the Rhine pollution. For water quality problems the document refers to the reduction of oxygen-consuming and other substances by the bill on 'Pollution of Surface Waters' (in force since 1970) and to the negotiations with the riparian Rhine states on this subject. In this period the water management problems were tackled according to four tracks: the quantity of surface water and groundwater, and the quality of surface water and groundwater.

The increasing water demand and the deteriorating water quality of surface waters made the water supply complicated for the interested bodies. Hydrologists of national institutes and provincial water authorities pleaded for an integrated approach to the problems. The study Water Management in the province of Gelderland and the study Policy Analysis of Water Management for the Netherlands (PAWN) tried to relate water demand by different sectors in order to find an optimal solution. The application of the system approach broadened the insight into the interactions between the quantitative and qualitative aspects of groundwater as well as the coherence with physical planning, nature and environment. The document 'Living with water' by the Minister of Transport, Public Works and Water Management (1985) pleaded for a comprehensive approach to water-related problems in their relevant natural, social and administrative environments. Provincial and regional water authorities responded positively to this concept of integrated water management as did the interest groups and nature conservation organizations.

8.2 Impact of integration on organizations

In the 1950s the flood protection and water quantity management tasks were split between 2 500 water boards. These authorities were weak in management power and had small technical support staffs. The 1953 storm surge disaster prompted the reorganization of local and regional water management. The concentration of water boards was necessary. In 1970 the water boards were also charged with water quality management of local and regional waters.
These tasks required larger water boards with financial and managerial strength. Only a few existing water boards could manage the new tasks.

That was the reason why the new water boards dealing only with water quality were created. It led to a dispersion of tasks and competences. Since the mid-1970s a second wave of integration and reorganization of water boards was started. Today 66 water boards take care of flood protection, and quantitative and qualitative water management at local and regional levels. Figure 8.1 represents the territories managed by the water boards in 1997.

In the 1970s the provincial authorities were organized along the lines of departments for water management, environment, spatial planning, etc. Today the water management and environment departments are integrated into one department for water and environment. In some provinces the integration has been enlarged to include spatial planning.

8.3 Water-related issues in spatial, nature and environmental policy

The Netherlands is the most densely populated country in Europe. From 1970 to 1994 the density grew from 384 to 456 inhabitants/km^2. The pressure on land use is high and mutually competing. Urban areas and roads are expected to increase from 8% - 16% in the period 1970-2000. At the same time land use for agriculture will decrease from 70% in 1970 to 60% in 2000. The demand for agricultural area is diminishing by 300 km^2 per year in the 1990s. On the other hand there is an increasing demand for nature areas, water and landscape of high quality and great diversity. The policy document of the government on nature (1989) defined the ecological structure and requirements. These ideas are worked out in national spatial schemes. The preservation and improvement of spatial quality present a challenge for the authorities. Laws define policy planning and decision making about harmonization and realization.

The fourth document on spatial policy and its addendum (1989 and 1993) explain the chosen spatial water-related strategy and specify the quality demands. The Government aims to improve spatial quality by means of three objectives: strengthening of the cohesion between water supply, recreation, tourism, nature and landscape, reinforcement of the interrelation between large water courses, and giving special attention to nature development. This national policy means a change in the approach to rural areas. The mainly agricultural development in these areas can be replaced by other regional policies. The regional spatial policy may vary from the preservation of the present conditions to the marginalization of agriculture and the stimulation of nature development. As problems and opportunities differ from region to region, the provincial, regional and local

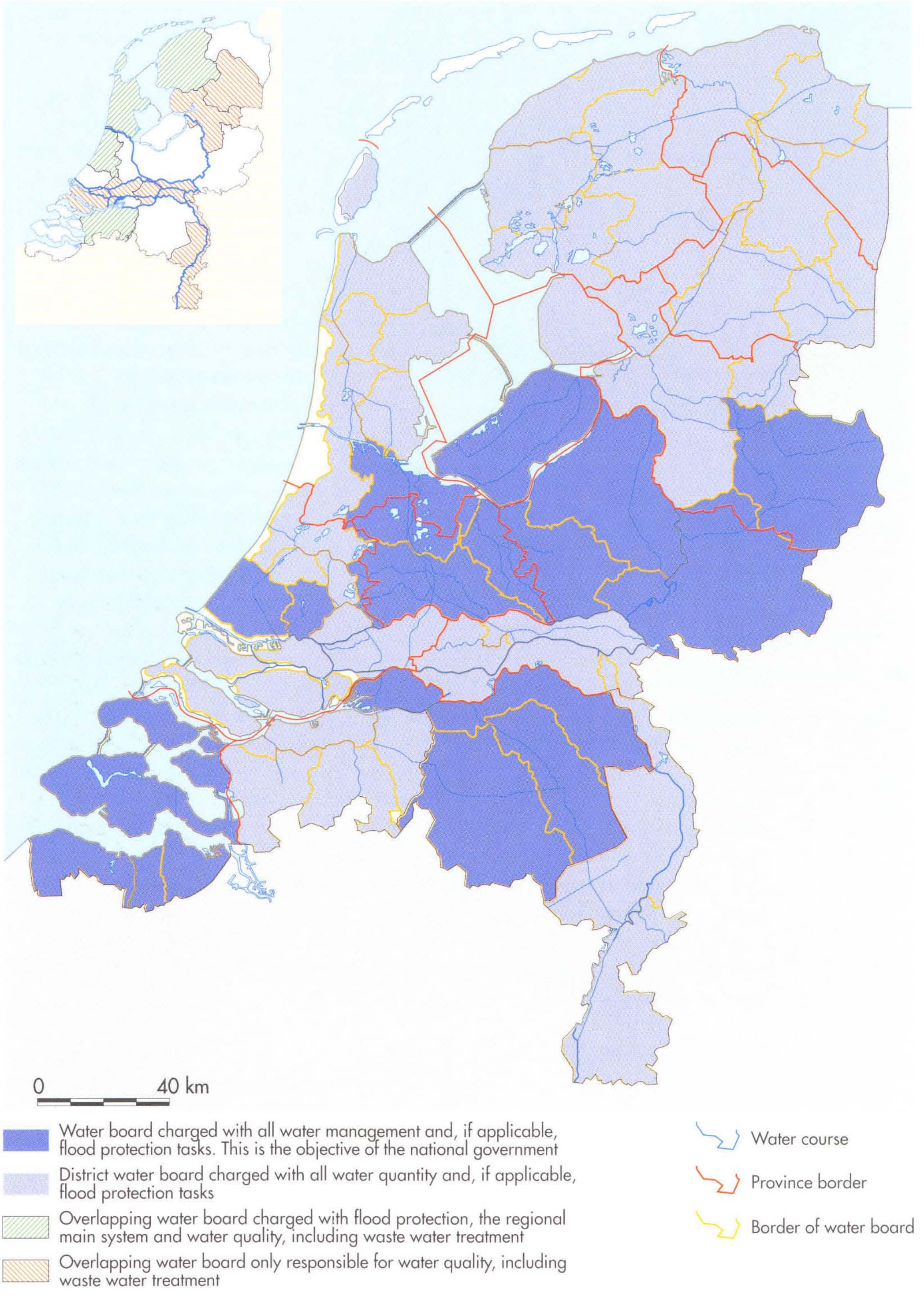


Figure 8.1 The water boards in the Netherlands in 1997

Figure 8.2 *Improvement of spatial quality along the Rhine and Meuse branches and the south-north axis*

authorities have to formulate tailor-made spatial policies.

The spatial quality along the Rhine and Meuse branches (Figure 8.2) and the south-north axis that connects the Delta region with the Lake IJssel region has to be improved. The harmonization of nature development and navigation conditions must be accompanied by water quality measures which are necessary to meet recreational, nature and landscape requirements. The Government and provinces have to work out the water-related requirements in their schemes for spatial structure and in the strategic documents on water. These plans should contain specific assigments for operational water management.

Another important item is the harmonization of the policy areas of environment and water. Environmental policy considers the mutual coherence of three environmental sectors: water, soil and air. Harmonization is a neccessary activity to avoid pollution reduction in one sector increasing the pollution in another.
The elaboration of quality standards for water, soil and air and policy formulation to tackle specific polluting activities therefore take place in the framework of environmental planning. The Government defines the national environmental policy providing the objectives and conditions for the provincial strategic environmental plan.

The Policy Document on Environment also contains operational assignments for the state managed infrastructure. The provincial document on the environment defines the strategic issues to protect the environment and to reduce pollution. It charges the local and regional authorities with realizing the objectives in the scheduled period.

8.4 Present water management

In the Netherlands water management is the responsibility of public authorities and not of private persons or institutions. These authorities have to harmonize the possibilities of the water system to the demands of the socio-economic system. Figure 8.3 relates the steering function of the governing-administrative structure to the water-related demands of the socio-economic interests and the potential of the (natural) water system to meet these demands. This system consists of groundwater and surface water, water quantity and quality and its environment such as river bed, banks and technical infrastructure. The socio-economic system defines the requirements of the interests concerned. The Netherlands' society created an institutional and administrative framework to manage the water resources system in an efficient way. The role of the public authorities stems from the basic objective that water resources -as public property- should be managed in such a way that results in the optimal social benefit. The demands of the various users and interested parties are often competing and/or conflicting. To meet all the demands is impossible and therefore choices have to be made. It is the task of the management to make the choices and then execute them.

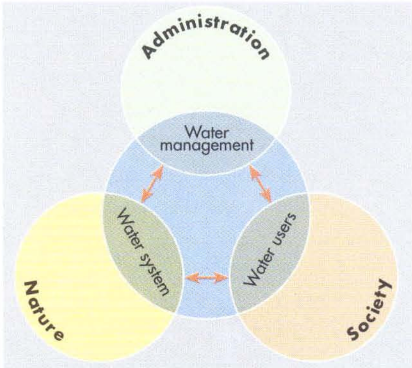


Figure 8.3 *Harmonization of water related functions with the water system by the administration*

Chapter 9 describes the institutional structure for regulating the water resources management at three governing levels. The central Government formulates the main lines for the strategic policy about water issues at the national level. The central Government is also responsible for the operational management of the state managed waters and some major flood protection works.
Within the framework of the national policy, the provincial Government defines the strategic policy for the non-state managed waters and the regional framework for flood protection. The provinces also take care of the operational management of groundwater extraction and in some cases of water courses serving navigation.
The water boards and the municipalities are responsible for the operational management and actual realization of the policy issues. The tasks of the municipalities concern wastewater collection by the sewerage system and drainage in urban areas. The water boards are responsible for the overall drainage in urban and rural areas, water quantity and quality including wastewater treatment as well as flood protection.

8.5 Fire in Basle, occasion for integration in the Rhine basin

In 1986 the store facilities of a chemical factory in Basle caught fire. The fire-fighting water became heavily contaminated by insecticides. The poisoned water was released into the Rhine. The poison wave spreading down the river killed all organisms. The disaster led to several meetings of the Rhine states at ministerial level in the same year.

In addition to the measures to be taken to prevent such accidents, the ministers adopted new long term objectives for the Rhine:
- higher species such as migratory fish should return to the Rhine by the year 2000. The salmon, as the best known species, is to be used as an indicator;
- future use of Rhine water for public water supply must be possible with simple production methods;
- the pollution of sediments has to be reduced to such a low level that sediment can be applied on the land or dumped into the sea without harmful consequences for aquatic organisms.

In the 'Rhine Action Plan' (RAP) the International Commision for the protection of the Rhine (IRC) presented proposals to fulfil these objectives. The adoption of the RAP by the ministers in 1987 implied an integrated commitment of the riparian Rhine states to the further reduction of the pollution and to the rehabilitation of the ecosystem of the Rhine.
Instead of continuing the detailed elaboration of emission standards prescribed by the chemical convention, the ministers adopted the IRC proposal to reduce pollution by selected substances by 50% during the period 1985-1995. This decision allowed the riparian states to define the most effective way of realizing this goal in their territory. It implied that not only the point sources but also the diffuse sources from households, agriculture and traffic etc. could be tackled. This approach was worthwhile. In recent years the detergents containing phosphate have disappeared and wooden products containing polycyclic aromatic carbons have been considerably reduced in the Netherlands.
The states bordering the North Sea adopted the IRC approach in 1990. Some IRC proposals were amended, referring to the ecological impacts of some substances on the North Sea. The objective of 50% reduction was raised to 70% for mercury, cadmium, lead and dioxin.

An integrated approach is necessary in order to meet the objective for the presence of migratory fish such as salmon etc. in the Rhine. The IRC developed such an approach by its masterplan 'Salmon 2000', published in 1991. This plan considers two issues:
- the rehabilitation of the main stream and tributaries as the backbone of the ecosystem for migratory fish;
- the protection, preservation and restructuring of ecologically important Rhine reaches.

Priority must be given to rehabilitation of the spawning grounds to meet the first issue. In this scope the IRC investigations indicated that 250 ha along the Rhine and some tributaries can be restored as nurseries for the migratory fish. But the spawning areas have to be accessible. For that reason the present dams and weirs must be equipped with proper provisions for allowing the fish to surmount these obstacles. Weirs in the Rhine are being provided with fish passages to realize the migration and spawning. The water-release-regime of the sluices in Lake IJssel and the Delta Plan barriers has been adapted to meet the migration demands.

Administrative-legal provisions are required to meet the second issue. Particularly the reaches Constance/Basle, Karlsruhe/Mayence and Duisburg/ Nimegue/Arnhem should be assigned as wetlands subjected to the regulations of the Ramsar Convention. These reaches are the stepping stones for the rehabilitation of the ecosystem of the Rhine. The masterplan envisages an extension of the stepping stones (Figure 8.4). All applications for land use along the Rhine and its valleys must be subjected to an environmental audit to prevent further degradation of the ecosystem.

8.6 International harmonization still going on

In the previous paragraph much attention was paid to the Rhine issues. The Meuse and the Scheldt, however, also play an important role in the Netherlands' water

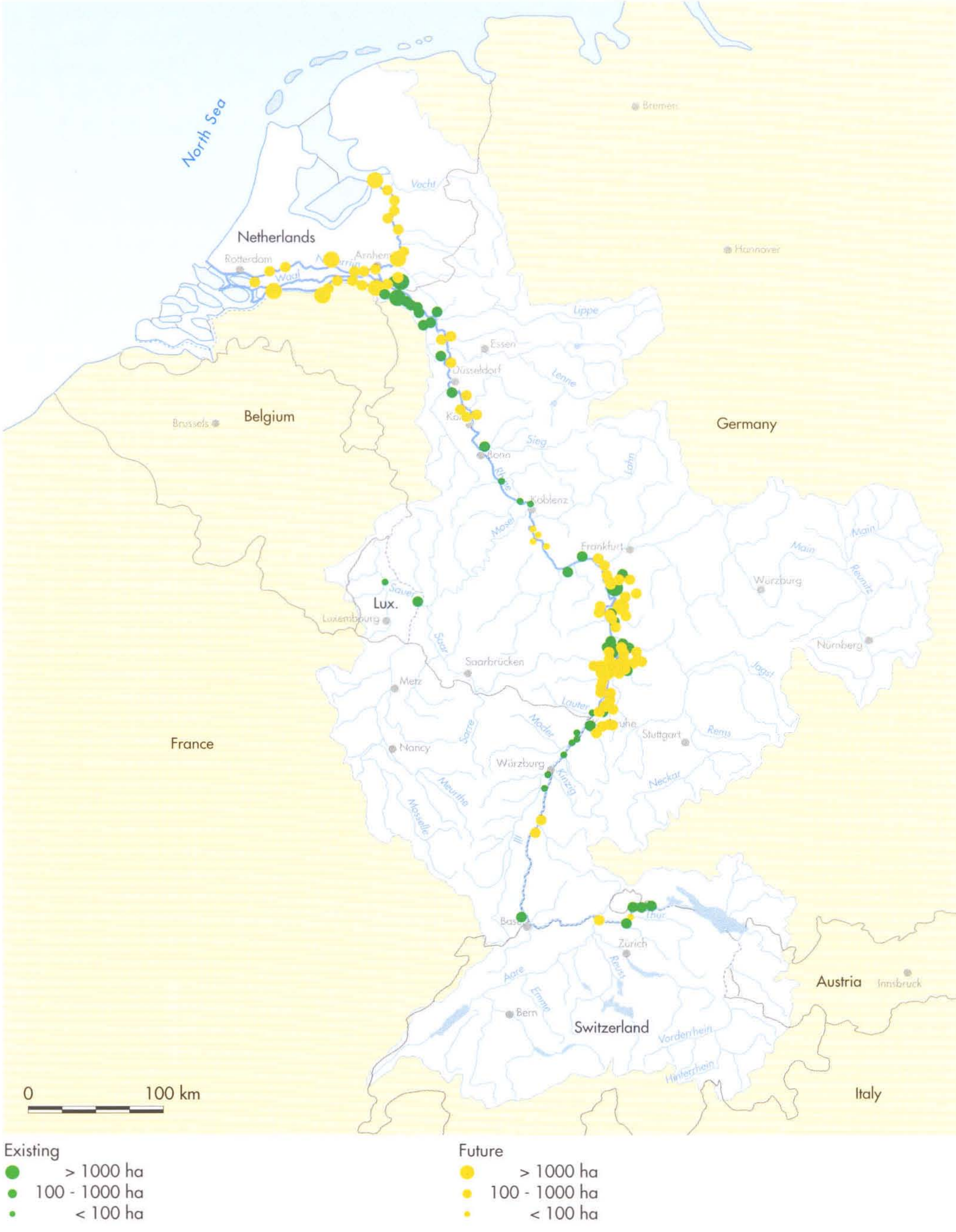


Figure 8.4 *Stepping stones of the masterplan to rehabilitate the Rhine ecosystem*

management. In particular, the use of the Meuse for the production of drinking and industrial water for Rotterdam and The Hague has to be stressed.
After many years of deliberations, the Netherlands, France, and the Belgian regions of Flanders, Brussels and Wallone signed respective treaties in 1994.

The flood problems in the Rhine and Meuse (January/February 1995) brought a further step: the ministers of the riparian states declared in Arles, France that measures have to be taken to reduce the future risks imposed by high water levels in the rivers Rhine and Meuse.
They asked for special attention to be paid to land use, water management and spatial planning. Land use defines the impact of agriculture, forestry, nature management, urbanization and recreation on runoff. Water management can influence buffer zones, dikes and embankments, and flow management in the floodplain. Basin-wide spatial planning is necessary to realise the proposed measures.

To expedite matters, the ministers decided to make maximum use of existing structures and research institutes. From this starting point they charged the IRC with developing a flood prevention plan similar to that applied in the RAP for the reduction of pollution and rehabilitation of the ecosystem. For the Meuse and Scheldt the action plans should follow the steps of the IRC.
The developments in the last decade illustrate the truth of the title of this paragraph. The adaptive capacity of the institutions (national and international) is a prerequisite for sustainable water management.

8.7 Planning, an important instrument for water resource management

The harmonization of the natural characteristics of the water system and the water-related interests requires a structural and actual weighting mechanism.
The objectives of the interested parties are partly complementary and partly conflicting. The trade-offs between each of them are not always clear. This fact demands careful selection of management objectives and allocation of resource measures in time.
Policy making and the Netherlands tradition of participation in it does not make a decision of today become a fact of tomorrow. That is why planning is an important instrument for arranging commitments at the different governing levels as well as in the short and long term. Planning and subsequent decisions are based on the process concerning recognition of problems, formulation of alternative options for solving the problems, presentation of the impact of the actual situation and the alternative options as well as the selection of strategies by the competent authorities.
Although planning is applied on a voluntary basis in flood protection and water management issues, Government and parliament found that the coordination of planning between the participating authorities has to be harmonized by law. The Water Management Act (1989) formulates the framework, objectives and contents of the management plans. It also defines the updating of the plans every four to eight years.
The central Government and the provincial authorities make the strategic plans. These plans are restricted to major areas which limit the operational plans. The chosen strategies and the expected financial, economic and spatial results are shown in these plans. The water resources management plans also describe their interaction with the spatial planning and the environmental policy plans. This is important because water resources form a part of public responsibility.
Figure 8.5 represents the relationship of water resource planning with spatial and environmental policy planning. It looks like a top-down exercise, but it also works bottom-up. The plans have to be revized regularly.

The revision starts with an evaluation of the operational management plans in the framework of the current strategic policy. The results of this bottom-up exercise mainly define the issues for revising the policy.

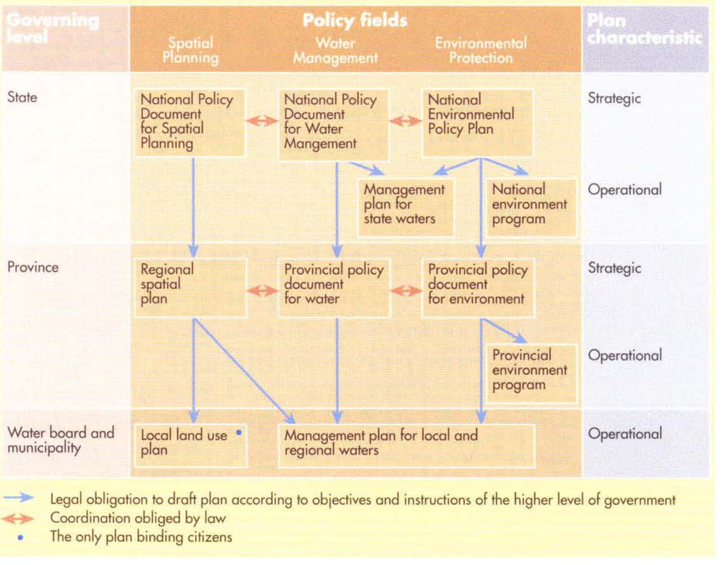


Figure 8.5 The water related planning structure in the Netherlands

8.8 System analysis, the tool in the planning process

Planning anticipates and supports the decision making of a particular strategy. In an integrated and complex water resources system it is essential to know the impacts of particular decisions and selected strategies. The state and the provinces use a system approach for water resources management. A system approach carefully identifies the important issues and alternative measures with regard to flood protection, water demand and supply. The system approach assesses and evaluates the impacts of the formulated strategies in a way that is meaningful to the decision maker. To investigate the often complicated structure of the water management problems, the many components to be considered and the complex relations between the different parts of the water management system, the analysts make extensive use of mathematical modelling and analytical techniques.
In order to carry out its planning and management task the Rijkswaterstaat commissioned Delft Hydraulics and the Rand Corporation (USA) to develop the so-called PAWN-instrument (Policy Analysis of Water Management for the Netherlands). It ranks the various user categories of the water management policies and shows the limitations and impacts of the considered solutions for all parties concerned. PAWN was used to provide information for the national Policy Documents on Water in 1985, 1989 and 1997.

8.9 Regional water resources planning and management

The structure of the strategic and operational plans by provinces and water boards enables sound water resources planning to take place at a regional level. In the regional water management and development projects, the above mentioned water system approach is generally applied. Many of the water projects are prepared and carried out within the framework of land development projects.
The Third National Policy Document on Water Management (1989) aims at an integral approach. In the past six years this policy has been implemented in provincial regulations and in plans of the water boards.
To promote the introduction of integral water management of the water boards in practice the Third National Policy Document contained regulations to stimulate

projects for improving water related interests, which also have a positive impact on other policy fields. The so called REGIWA projects aim to realize REGional Integrated WAter management in practice. Thus these projects aim to reduce the eutrophication of local and regional surface waters, reduce 'verdroging' and improve the conditions for nature-friendly river banks. These measures have positive impacts on wildlife and the environment and create new possibilities for spatial planning. The concept of integrated water management intends to find a new balance between (private) economic interests and the requirements of society for the environment and wildlife. The responsibility for the strategic decisions about the desired policy and projects lies with the national and provincial authorities. The implementation of the new policy by realization of projects is in the hands of the water boards. Before taking decisions on strategic issues the possible benefits and drawbacks of the relevant functions must be quantified. At the moment one of the difficult issues is the 'rewetting' of dried nature areas by raising water levels and introducing higher seepage rates in areas where other interests are also important. The rewetting of nature areas can particularly affect agriculture. In other cases nutrients and the application of insecticides can cause damage in nature areas. Therefore methods are being (further) developed to quantify the benefit for nature area development. Sometimes a change of land use can be a wise (but expensive) solution.

8.10 Cost and financing of flood protection and water management

Foreigners often ask about the cost of the flood protection and water management and how is it financed. This section describes the principles of financing water control activities and presents the figures for 1994.

The Netherlands government sets the following priorities in the field of financing:
- costs should be paid by those concerned or by those who are responsible for them;
- if the costs of water authorities cannot be allocated individually, they are distributed among the community of those concerned/responsible by levies;
- if both methods prove not to be feasible, financing can be provided from the general budget of the central Government (the state budget).

The first priority means that the costs of a new project undertaken to meet the licensing regulations have to be paid by the enterprise. Similarly, if a water authority implements specific requirements for an individual undertaking, the bill is presented to the enterprise.
According to the second priority, the cost of the dikes and the regional and local quantitative water management measures, exercised by the water boards, is financed by the 'user pays' principle, which is that the extent of a user's interest in a project defines the amount of their taxation and representation.

According to the third priority, the activities of the State and the provinces to prepare and harmonize the water control activities with other public interests are financed from the state budget.
Further, the costs for the main flood protection dams and storm surge barriers, as well as for operational quantitative water management activities at the central level, are financed from the central Government budget.

Table 8.1 *Costs of water control activities in the Netherlands in 1994 (in NLG million)**

Water control activity	Institutional level State[1]	Province[2]	Water board[1]	Municipality[2]	Total	NLG per capita
Flood protection	726	100	120	14	960	62
Water quantity control	290 [3]	42 [3]	690	81 [3]	1 103	72
Water quality control	548 [3]	283 [3]	1 660	1 389 [4]	3 880	252
Total	1 564	425	2 470	1 484	5 943	386

[1] Labour costs included
[2] Labour costs excluded, no figures available
[3] State and province do not distinguish between water quantity and water quality; the proportion of the water boards is applied
[4] Costs of sewerage system

Table 8.2 *Financing of water control activities in the Netherlands in 1994 (in NLG million)**

Financing principle	Institutional level State	Province	Water board	Municipality	Total	NLG per capita
National budget (general tax)	1 407	168		421	1 996	130
Interest payment-participation		74	810	5	889	58
Polluter pays to water authority	157	183	1 660	94	2 094	136
Sewerage tax				964	964	62
Total	1 564	425	2 470	1 484	5 943	386

The costs of qualitative water management activities at regional and local levels are financed by the levies raised with respect to waste discharges into regional and local surface waters.
The costs of operational management of groundwater, performed by the provincial authorities is partly financed by the levies raised with respect to the amount of groundwater extracted for industrial and drinking water purposes.
In 1994 the public authorities with water-related responsibilities spent some NLG 6 billion for flood protection, and quantitative and qualitative water management. This is 1% of the national income. The figure of NLG 6 billion does not include the cost of drinking water supply nor the costs arising from the different water-related private sectors. Table 8.1 shows the costs of the different

* These tables do not include the cost of drinking water supply

governing levels for water control tasks. The cost of public water management is financed by four sources: the state budget, the tax by the water boards based on the profit-allocation principle, the charges made by the water boards according to the 'polluter pays' principle and the sewerage tax of the municipalities. Table 8.2 shows the contributions of the financing sources of the governing levels. These data prove that the qualitative water management costs considerably exceed those of flood protection and quantitative water management.

Drinking water is supplied by 25 companies (1998). Application of groundwater or surface water as raw material for drinking water has great influence on its price. The price varied from 1.60 to 3.14 NLG per m^3 in 1996, average price 2.65 NLG. The daily consumption amounts to 130 litre per capita. This means that 126 NLG per capita is spent on drinking water.

9 Institutional and legal aspects

The legitimacy of water-related intervention was and still is an important issue in the Netherlands. This chapter summarizes the institutional structure and the present competencies of the authorities charged with water issues. It also provides brief information about the water-related laws in force.

9.1 Water administration and its background

The Netherlands is a decentralized unitary state with three main hierarchical administrative levels of water management: national, provincial and regional (Figure 9.1). At each level there are bodies with specific responsibilities: legislative and executive. A multitude of different departments or agencies is responsible for the various sectors of public policy, each deriving its authority from legislation. Water has played a dominant role in the course of Dutch history. In the 12th century local communities began to construct dikes to prevent flooding and control the water levels behind the dikes. Following the construction of dams in the tidal water courses in the 13th century, the local communities began to elect representatives to the regional meetings where the common water management affairs were discussed. These meetings formed the basis for the water boards. The election system was (and still is) based on the rule that the extent of interest defines the levy paid the costs of water control as well as participation in the administrative body. Until today the water boards still exist as specific administrative units for local and regional water management. In the 20th century the level of participation has been increased to include house owners, tenant farmers and residents because these categories were interested in flood protection and regional management too. Since the water boards take care of the water quality based on the 'polluter pays' principle, representatives of households, industries and companies participate in the administrative and executive bodies of the water boards.
In 1798 a national agency, the Rijkswaterstaat, was created in order to administer all water-related affairs at a national level. In the 19th century provincial water authorities were established and charged with the supervision of the water boards and water-related issues of the municipalities.

9.2 Institutional structure

National level

The Netherlands is a constitutional monarchy with a parliamentary system. The central Government, the executive, consists of the Monarch and the Ministers and is called the Crown. However, since the Monarch is inviolable, the ministers have full responsibility and supreme control. The ministers together form the so-called Council of Ministers (the Cabinet), chaired by the Prime Minister, which deliberates and decides on general Government policies.

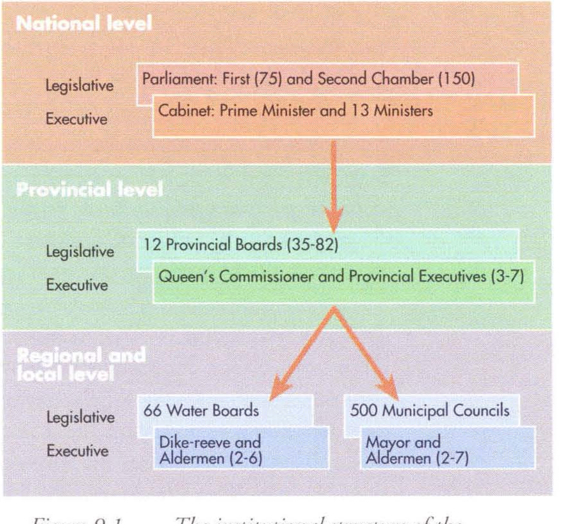


Figure 9.1 *The institutional structure of the Netherlands*

Figure 9.2 *State managed waters and infrastructure*

The Dutch parliament consists of the First Chamber and the Second Chamber of 75 and 150 members respectively. The Second Chamber, the House of Representatives, controls and approves the actual decisions of the Government. The First Chamber, the Senate, elected by provincial representatives, is the house of reflection and has the power to approve or reject a bill. The Second Chamber provides the right of amendment.
Legislative power is with the Government and Parliament together. An act may transfer the authority to issue decrees and regulations to other governing bodies, such as the Crown, Ministers, provincial authorities, municipalities, and water boards. The administrative rules given by the Crown (in practice the relevant Minister), called Orders in Council (Amvb) are quite common in the policy field of water and the environment. They prevail over provincial orders. Provincial orders prevail over orders of municipalities and water boards. The judiciary power includes the Council of State (Raad van State) and the Supreme Court (Hoge Raad). The Chamber for Administrative Justice of the Council of State is the highest judicial level responsible for administrative law. Next to this, the Council of State is the most important advisory body to the Crown with regard to judicial topics. The Supreme Court, and its subordinate courts are primarily responsible for the proper execution of the civil and criminal law.

In water management three ministries have important tasks. The Ministry of Transport, Public Works and Water Management is responsible for flood protection and water management. The water directorate of this ministry, the Rijkswaterstaat, prepares national policy on flood protection and water management. The Rijkswaterstaat supervises the implementation of the water policy by provinces and water boards. This directorate also has the operational responsibility for the state managed waters and some water retaining structures. Fig 9.2 represents the state managed infrastructure.

The Ministry of Housing, Spatial Planning and the Environment is responsible for general environmental policy; setting of water quality standards and emission standards; laws concerning air, soil and groundwater protection, waste, noise, harmful substances, radiation, Environmental Impact Statements and external safety; drinking water and sewerage; and spatial planning (land use).
The Ministry of Agriculture, Nature Management and Fisheries is responsible for general policy on agriculture, nature management, fisheries, rural areas and outdoor recreation; legislative policy concerning nature conservation with regard to species and areas.

Provincial level

The organization and tasks of the 12 provinces are ruled by the Province Act. The administrative bodies at provincial level are:

- the Provincial Council: the elected body of 45-85 members (depending on the number of inhabitants);
- the Provincial Executive: nominated by the Provincial Council from among their members;
- the Provincial Governor: chairman of the council and the executive board, nominated by the national Government.

The water management at provincial level was formerly performed by the provincial water management department. Recently these departments have merged with the provincial environmental departments.
With the exception of the state managed infrastructure, the twelve provinces define and supervise the responsibilities and activities related to flood protection and water management.
Since the Pollution of Surface Waters Act came into force in 1970, the provinces no longer have virtual autonomy in specifying the tasks and competencies in water management; the State now plays a leading role in the assignment of tasks and competencies in qualitative surface water management. The same system was continued in the Groundwater Act, the Water Management Act, the Soil Protection Act and the Flood Protection Act. The Water Board Act defines that local and regional flood protection and water management is excercised by the water boards. The provinces can make policies of their own but will also receive directives from the national Government and have to ensure implementation by the municipalities and water boards.

Moreover the provinces coordinate the policies of the different sectors of government, such as water management, environment, nature conservation, housing, physical planning and transport.

The provinces have created the Interprovincial Platform, in which organization common views and statements of the provinces are formulated.

Regional and local level

Water boards

The water boards became the competent regional water authorities in the thirteenth century. Since the fifteenth century the local embankments and polders were administered by water boards. In time thousands of water boards existed.

After the storm surge disaster in 1953 the number of water boards decreased (see Table 9.1). The scaling up process can be illustrated by the province of Groningen. The map of Figure 9.3 represents the 74 water boards in 1978 and the four interprovincial water boards in 1996. The present 66 water boards are organized according to the Water Boards Act. The water board organization comprises:
- the General Assembly, elected by specific groups such as owners of real estate, wastewater dischargers, residents;
- the Executive, nominated by the Assembly;
- the Chief Executive, chairs both bodies and is nominated by the national Government.

Table 9.1: Number of water boards

Year	1946	1969	1978	1990	1998
Number of water boards	2500	1000	400	129	66

Whereas the central Government, and the governing bodies of the provinces and municipalities are so-called 'general democracies' the water boards are 'functional' governmental bodies. The election of general democracies is based on the principle 'one man, one vote'. A functional democracy such as the water board is based on the rule 'interest-payment-say'. The distribution of seats in the water board among landowners, residents and wastewater dischargers is defined by this rule. As the situation differs in each region, the composition of the water boards varies. The provincial authorities define and supervise the tasks of the water boards under approval of the national Government. The water boards are responsible for flood protection, and water quantity and quality management in their territory, in some cases together with the management of waterways, bridges and roads. As many provincial borders do not coincide with the hydrological/hydraulic borders of the water boards, interprovincial water boards were created.
The water boards are united in the Union of Water Boards.

Municipalities
The tasks and organization of the 500 municipalities are governed by the Municipal Act. Municipal organization comprises:
- the Municipal Council: an elected body of 7-45 councillors;
- the Municipal Executive: a number of Aldermen appointed from among their members by the Municipal Council.

The Mayor is chairman of both councils, is nominated by the national Government and appointed by the Crown.
The water management task at municipal level is limited to the management of sewerage systems performed by the local public works department. The municipalities promote their common views through the Netherlands Association of Municipalities.

Drinking water companies
Drinking water supply is taken care of by some 25 drinking water supply companies. Although they have a privatized structure, the shares are owned by public authorities (provinces and municipalities). The drinking water companies are united in the Netherlands Waterworks Association (VEWIN).

9.3 Water legislation

There is a wide variety of water legislation. Apart from the fundamental statement in the Constitution, the water laws can be divided into five categories. The first one deals with the institutional framework and the organizational aspects, the second one with aspects of (integrated water) policy, the third with aspects of infrastructure. The fourth, specific, category is drinking water, and the fifth category pays attention to legislation related to water issues.

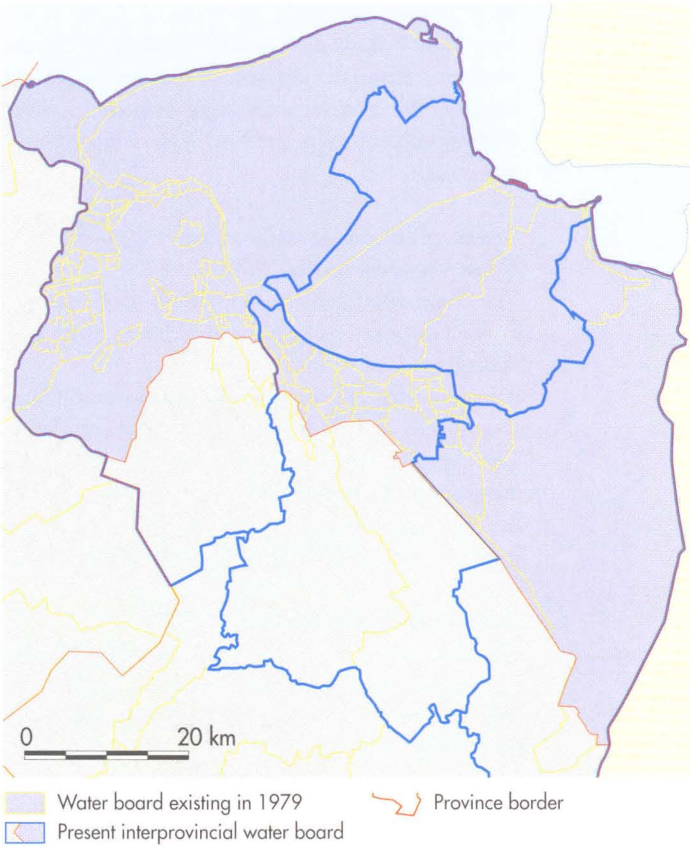


Figure 9.3 The integration of water boards in the province of Groningen: the 78 water boards existing in 1979 are incorporated in the four interprovincial water boards of 1997

Fundamental statement

Article 21 of the Constitution of 1983 states that 'the inhabitability of the country and the protection and improvement of the environment' are public tasks. Not only water management but also environmental management, nature management and physical planning are the responsibility of public administration.

Institutional and organizational aspects

Constitution
Article 133 of the Constitution defines the creation, termination and regulation of the responsibilities of the water boards. These duties are carried out by the provinces.

Water Administration Act 1900
Among various different topics, this Act includes one that deals with the organization, tasks and competencies of the Rijkswaterstaat.

Water Boards Act (1992)
The Water Boards Act contains rules about the creation of water boards by the provinces, especially regulations concerning the composition of the Water Board's Council, the competence to issue ordinances, and financing. The responsibilities and competencies of the water boards are directed towards tasks given them by the provinces.

Aspects of integrated water policy
Water Management Act (1989)
The Water Management Act defines the planning structure for water management by the Government agencies at different levels and gives rules for the quantitative management of surface waters.
It provides the following policy instruments: planning; permissions; registration of abstractions and discharges; water covenants; level decisions; and charges.
The planning structure of this Act is of major importance because it presents an integration of national and provincial plans based on the Pollution of Surface Waters Act, the Groundwater Act and the Water Management Act itself. It also includes statutory cross-references with spatial planning and environmental planning.

Pollution of Surface Waters Act (1970)
The main objective of this Act is the pollution control of all surface waters for which it provides a framework for a two-track policy: the reduction of emissions and the improvement of water quality (emission approach). The instruments of the act are: the issue of discharge permissions; the setting of standards; and the use of levies.

On the emission side it is forbidden to discharge into water unless a permission is given.

There is a levy on discharges, especially organic waste and heavy metals, which is used to recover the costs for wastewater purification and subsequent discharge. The primary permitting authorities are the national Government or the provinces, which delegate their responsibilities to the water boards.

The Pollution of Seawaters Act is a special Act which was made for the North Sea area (1975).

Groundwater Act (1981)
The Groundwater Act covers all abstractions by means of pumping works. The provincial government is responsible for the instruments provided by the Act. These are: abstraction permissions; abstraction registration; duty to report; and levies. All abstractions of more than 10 m^3/hour usually require a permission.
This Act concerns groundwater quantity only, although qualitative aspects are incorporated where the recharge of aquifers is concerned. Other quality aspects are dealt with in the Soil Protection Act.

Soil Protection Act (1987)
The act contains a general duty to prevent, and if necessary, to clean up soil and groundwater pollution. This Act provides the structural basis and the necessary

administrative instruments for the implementation of the soil and groundwater protection policy. It should be noted that, anticipating this act, a Soil Clean-up Interim Act already became operative in 1983 for the regulation of soil clean-up operations. The latter was incorporated in the Soil Protection Act in 1994.

The Soil Protection Act distinguishes two levels of protection: a general level and a specific level. Both protection levels differ from each other only in the level of acceptable risk for soil pollution caused by certain activities.

The general protection level is formed by regulatory measures set by the national Government. These rules concern the regulation of activities that may lead to pollution or impairment of soil and groundwater, and the formulation of soil quality standards.

To illustrate the system of the orders in Council, the administrative rules given by the Crown, the orders based on this law are given below:
- application and spreading of manure on soil (1987)
- discharge of liquids into soil and groundwater (1990)
- application and spreading of sewerage sludge and organic household waste (compost) on soil (1991)
- dumping of solid waste materials (1993)
- storage of petrochemical products in underground tanks (1993)
- artificial recharge of aquifers (1993)
- eaching standards for building materials produced from recycled waste (1995)

In addition to the general protection level, a specific protection level must be implemented in soil protection and in groundwater protection areas used for water supply. In these areas potentially harmful activities are either not tolerable or additional preventive measures are necessary. The acceptable risk level of pollution is lower in these areas. At present, the groundwater protection areas cover about 1 400 km^2, i.e. approximately 4% of the Netherlands.
Since 1994 the regulations concerning soil and groundwater protection areas are part of the Environmental Protection Act.

Legislation concerning sewerage collection and treatment
Sewerage management is not regulated by formal legislation, but by provincial and municipal ordinances. In the Environmental Protection Act an obligation is put on the municipalities to prepare sewerage plans.

Acts concerning (water) infrastructure
Act concerning State managed infrastructure (1996)
All activities which are not in line with the normal use of state managed infrastructure is subject to a licence: e.g. cables, wires and pipes in navigation canals, rivers and dikes.

Act on polders and embankments (1904)
This Act requires a permission to be granted by the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat) for reclaiming land from the sea, estuaries and rivers.

Rivers Act (1908)
The Rivers Act serves the 'interests of public streams and rivers'. Until recently, this rather vague formulation included mainly the protection against river flooding by safe discharge of water and ice. For all activities in the summer and winter bedding that increased the high water levels, 'hydraulic compensation' is required before a permission is granted. In 1991 the scope of the Rivers Act was expanded to include other interests such as nature, landscape and recreation.

Delta Act (1958)
This Act formulates the principles for the protection of the Netherlands against storm surges by closing estuaries and reinforcement of the dikes and dunes.

Delta Act major rivers (1995)
The 1993 and 1995 river floods gave rise to this specific act, enabling strengthening of 150 km river dikes along the major rivers in the period 1995-1996. The Act replaced the usual cumbersome time consuming procedures prescribed in 19 laws by one single decision and one possibility to appeal. Thanks to this emergency act the weak dikes were strengthened in time.

Flood Protection Act (1997)
In a sinking country threatened by rising sea and river levels, it is necessary to maintain the flood protection level achieved by the Delta Plan and by dike strengthening.
The Act contains a 'finger on the pulse' mechanism, by which each dike authority has to report about the conditions of its dikes every five years. The reports of the dike authorities are stepwise summarized by the provincial and national Governments and sent to Parliament. The Act also contains regulations about the present dike strengthening.

Legislation for drinking water
Legislation with regard to drinking water supply can be found in several acts and regulations because different aspects are concerned: source, quality and protection of the raw material as well as production and distribution. Drinking water has two main sources: groundwater and surface water. Relevant acts are: the Groundwater Act, the Soil Protection Act and the Water Management Act. These last acts create the conditions for water resources development and protection.

Drinking Water Supply Act (1958)
This act is directly concerned with the provision of water and its quality and regulates the supervision of the water producing and distributing companies in the interest of public health. It contains regulations on supply conditions, quality standards, organization and planning.

Legislation related to water issues
For the performance of the water authorities, related water legislation is also of the utmost importance. Here the legislation in the field of spatial planning and environmental and nature protection is mentioned.

Spatial Planning Act (1965)
The Netherlands has a well established system of spatial planning on three levels of administration, based on the Town and Country Planning Act of 1965, as amended in 1983. The municipalities make the most binding and country plans in which the potential uses of all areas are indicated. The provinces adopt regional plans and the national Government issues a policy document on spatial planning at a national level almost every ten years.

Environmental Protection Act (1993)
The first Dutch legislation concerning the environment was the 1875 Nuisance Act. Businesses or private individuals need licences for activities hindering the actual use of space, water and soil. The licences prescibed conditions to be respected. Since 1970, several environmental acts have been introduced dealing with water, air, soil, waste products, etc.

The basis for integrated environmental legislation was laid by the 1979 General Environmental Provisions Act which in turn formed the basis of the Environmental Protection Act which came into operation in 1993. This act provides the legal framework for the environmental plans and programmes of central government, the provinces and the municipalities and lays down the regulatory procedures for planning and permissions.
The environmental aspects of a great number of industrial activities are regulated on basis of the Environmental Protection Act.

Nature Conservation Act (1967)
This act provided extra protection to ecologically important areas by designing natural monuments. Large areas of the Wadden Sea and the Rhine-Meuse-Scheldt delta have been given this status. Presently this Act is being replaced by a new one, which will introduce nature reserve planning and in which most protective measures will be allocated to the provincial level.

10 Activities abroad: ten centuries in a nutshell

During many centuries a large number of low-lying areas all over the world have been reclaimed, drained and developed by or with the help of Dutchmen. The historical overview in this chapter on the challenges, problems, failures and successes of land reclamation shows the involvement, creativeness and perseverance of the Dutch hydraulic engineers and many other vocational emigrants.
Today's activities reflect the great experiences of former generations. However, they simultaneously show an enlargement of the scope of e.g. the development of masterplans and the introduction of environmental impact studies as part of water and lowland development.
With gratitude the publications on this subject by J. van Veen)[1] and G.P. van de Ven (ed.)[2] is referred to.

10.1 Vocational emigration and specialisms
Vocational emigration is a feature of many nations. It is defined as the emigration, temporary or permanent, of people having the same occupation with a view to practising their calling abroad. They may belong to different levels of the hierarchical organization of the vocation or profession. Emigration in the context of this publication comprises both short and long stays abroad for consulting services or construction works and permanent emigration with settlement in the new country. The reasons for emigration are varied: overpopulation, better job opportunities and living conditions in the new country, political or religious oppression, colonial expansion, longing for the unknown, and, more recently, contribution to the development cooperation or implementation of projects on a commercial basis.

As shown in previous chapters, man has transformed waterlogged and even submerged lowlands in the Netherlands into arable lands and even urban and industrial areas where surface water and groundwater levels can be controlled. This situation is not unique. Indeed, there are low-lying coastal areas all over the world which are densely populated and highly productive thanks to judicious systems of flood protection and water management. The development of some of these areas could benefit from the know-how and experience acquired in the Netherlands where reclamation started some ten centuries ago and, due to the special conditions, assumed a significance for the country as nowhere else. It is no wonder that professional emigration in the field of water and land development in the Netherlands also started early and is still continuing today.

10.2 Beginning of a large-scale emigration
It seems that the reputation of the Dutch in the field of land reclamation had established itself shortly after the beginning of works of this type in the Netherlands which was even before Norman times (9th - 10th century AD).

1 Dredge, drain, reclaim. The art of a nation. Martinus Nijhoff Publishers, The Hague, 1962

2 Man-made Lowlands. History of water management and land reclamation in the Netherlands. Matrijs Publishers, Utrecht, 1994

Ditches to drain the land were made before dike building began. The saga relates how a certain Walfridus and his son, who had been great men in draining parts of the low Wapelinga, were slain by the Normans while praying. About 950 AD the Norman invasions relented and only then could land reclamation and land drainage start properly.
Already at the beginning of the 12th century use was made of the water management knowledge of Dutchmen, especially in North Germany. It concerned the expertise to reclaim land through systematic drainage. Dutchmen had acquired this expertise with the reclamation of peat areas. The reclaimers came from the surroundings of Leiden.

The expertise did not only consist of technical knowledge, but also of the administrative organization of the free village communities. The communities with their self-rule, including water management, were not only capable of reclaiming an area by draining it, but also of maintaining the infrastructure of the water ways. In this respect the administrative instruments of issuing by-laws and carrying out inspection were of major importance.

The first mention of the involvement of the Dutch in reclamation dates from the year 1113. The ruler-bishop of Bremen then concluded a treaty with a few Dutchmen concerning the reclamation of an area in the valley of the river Weser. This treaty is virtually identical to the 'cope' agreements the count of Holland had with the reclaimers of his wilderness. The size of the homesteads and the rights and duties of the new village community were laid down. Just as in Holland the settlers enjoyed personal freedom and they were the rightful landholders.

During the 12th century the Dutch also reclaimed large areas along the river Elbe. They were in demand as settlers, because they had the technical expertise to drain areas. The settler villages are not found along the coast, but further inland. Further upstream along the Elbe, too, there have been many reclamations following the Dutch example. Here, the Dutchmen not only reclaimed the lands in the vicinity of this river, but also more inland situated areas, such as the soggy area between Salzwedel and Stendal.

There are indications that in the 12th and 13th centuries the Dutch also reclaimed land on a large scale and according to the same methods in central East England. In the vast peat areas around The Wash, some of which still have Holland in their names, a multitude of unmistakable clues point to that direction both in parcellization structures and names of fields and in historical sources.

The activities continued into the next centuries. The Dutchmen mainly moved to regions which were then in East Prussia, now the Polish territory for the greater part and Poland. Here too, they reclaimed marshy grounds by means of ditches and canals, sluices and later, windmills. The most important reclamations were in the mouth of the Nogat, a branch of the river Weichsel (Vistula). In the delta of the Nogat and further upstream the Weichsel about a dozen settlements were founded by the Dutch or the Flemish in the course of the 15th and 16th centuries. More southward - in Thuringia, Saxony and Silesia - they (also) settled on the wet grounds along the rivers.

It can be assumed that initially the reclaimers settled in these regions mainly for economic reasons. In the course of the 16th century, however, there was a change as the Dutch colonists then mainly came from Baptist circles, also called anabaptists or Mennonites, according to their leader Menno Simons. This religious group was persecuted and many fled to Prussia, Poland and later to Russia. Apart from them there were Roman Catholics who emigrated because of the changed religious climate in the Netherlands.
In the course of the 17th and 18th centuries the Dutchmen founded many more settlements, for instance in the German Pommerania (now Poland). The agricultural reclamations are characterized by a very systematic parcellization into rectangular strips of land separated by ditches, as was customary in the Dutch peat areas, too. All this shows that these reclamations did not end around 1600, but continued beyond that century.

10.3 Appearance of the individual expert

In Western Europe the 14th and 15th centuries were periods of agricultural depression. The effects differed from country to country. In the low-lying coastal areas of the Netherlands, losses of land occurred as a result of storm surges at sea.

These losses were not or could not have been immediately recovered. Since there is no evidence for a more frequent occurrence of storm surges in these two centuries than before, the only explanation of this issue is that the economic incentives for a recovery were lacking and indeed, low prices of cereals and high wages were characteristic for this period. The agricultural depression must have had a negative effect on the professional emigration in the field of land reclamation.

The situation changed completely around 1550 and favourable conditions prevailed until the last decades of the 17th century. The period 1550 to 1650 was an era with an unprecedented increase of population and an increase of currency amount. The first repercussion was a rise in prices of food stuff, in the first place of cereals. New forms of energy like aeolian power (windmills) and animal tractive power (horses) acted as technological stimuli. In a number of European countries strong central governments were established, ending feudal wars. These favourable conditions led to the reclamation of new arable lands not only in the Netherlands but also in Germany, France, England and Italy. The lands were often located in the vicinity of large cities and the reclamation works were undertaken by merchants.

Naturally, conditions were also favourable for emigration from the Netherlands but here, after 1550, a new participation came to the fore in the person of an individual expert who is called to give advice on certain matters and who, in most cases, returns to his country of origin after completing his assignment. He is the predecessor of the modern consulting engineer but he operates individually and on an ad-hoc basis. The Dutch experts who went abroad in the period 1580 to 1660 to work on lowland reclamation can be considered the first 'hydraulic engineers' of the Netherlands: Allerts, Bradley, Van Ens, Van den Houten, Leeghwater, Meijer, Van der Pellen, Rolwagen, Vermuyden, De Wit, etc.

They worked in practically the whole of Europe. Van Veen states about their performance:

> 'When we read the books about their achievements we cannot help admiring their energy and courage. Even with modern means some of the works they attempted would be outstanding. Yet, most of these intrepid men died in misery. None of them grew rich. The good they achieved was for future generations, not for themselves. They were the heralds of the new and first mechanical era'.

The most well known expert from this period is Jan Adriaensz Leeghwater (1575-1650). He was an authority on draining lakes and marshes by pumping. The water wheels, by that time mainly paddle wheels, were driven by windmills which were installed from the beginning of the 15th century. Leeghwater called himself in the first place a windmill builder. He applied them for draining large lakes to the north of Amsterdam (see Figure 4.4) like the Beemster (1612), Purmer (1622), Wormer (1625) and Schermer (1631).
Where the lift of the water was too high for a single windmill (i.e. more than 2 m), two or three windmills were installed in a series (see Figure 4.3), lifting the water step by step. Although most of his work was done in the Netherlands, he found time to do consulting work in the Baltic region, Denmark, England, France and Germany.
Dutch activities in Germany were mainly concentrated on Schleswig-Holstein. The duke of this area stimulated immigration of Dutchmen in the hope that they would contribute to the development of his country by their expertise and capital. Headed by Jan Claeszoon Rolwagen, six polders with a total area of about 2 000 ha were reclaimed. Finally it can be mentioned that the system of dry peat cutting and the subsequent rise of the peat colonies was exported to Germany.
In 1630 the first settlement, Papenburg in East-Friesland, was founded, where peat cutting was carried out 'the Dutch way', i.e. via a system of main canals and side canals. Dutch investors, engineers and surveyors played an important role in the construction. Later they were also involved in peat cutting activities, but gradually the local population took over.

The life of Humphrey Bradley, a native of Bergen op Zoom, is not well-known. His original name may have been Braat but perhaps he anglicized it after a short stay in England, where he made reclamation proposals for the Fenlands. In France King Henry IV was searching for ways to help his war-stricken country. Land reclamation was to play an important role. Humphrey Bradley was appointed 'maître des digues du royaume' by the king in 1599. Bradley's idea was to reclaim the French marshes with foreign capital. In the Netherlands such private enterprise was quite usual, albeit that it was the Dutch people themselves who supplied the venture capital. Bradley surrounded himself with fellow countrymen who had capital at their disposal. Just as in the Netherlands, the investors were granted a number of privileges, such as exemption from land taxes for a period of 20 years. In 1607 the 'Association pour le dessèchement des marais et lacs de France' was established, headed by Bradley.
In the framework of the 'Association' a great number of projects has been executed, initiated by people from the north and the south of the Netherlands.

In England, two major peat reclamation schemes were executed by Cornelis Vermuyden. He left for England in 1621. After having carried out some minor projects he was commissioned by King Charles I to make Hatfield Chase, an area of 30 000 ha situated southwest of Hull, suitable for agricultural purposes in 1626. Vermuyden improved the drainage by digging a number of canals. He made a distinction between the drainage of Hatfield Chase itself and the water coming down from the surrounding higher areas, and constructed separate drainage systems. The king was deeply impressed by the achievement and knighted Vermuyden in 1629. In 1630 Vermuyden was appointed Head of the Great Level, a peat district of well over 120 000 ha, north of Cambridge, which is the southern part of the Fen District and was to be called Bedford Level later. Until 1655 Vermuyden worked there. Just as in Hatfield Chase, Vermuyden had separate canals dug for the discharge of water from the neighbouring areas and water from its own territory. The major work was the construction of the main drainage canal, the Bedford River. Drainage of the peat caused subsidence which could amount to four metres and therefore people later switched over to drainage by windmills and pumping stations. To achieve adequate drainage, Vermuyden had proposed to dig an additional discharge canal, but for financial reasons the proposal was not realized in the 17th century, which caused a lot of waterlogging. Only between 1954 and 1964 was such a cannel dug, almost entirely along the track Vermuyden had proposed in 1638. On this occasion he was recognized as a designer of genius and one of the greatest Dutch hydraulic experts.
In Italy the Dutch engineers were less successful. Gilles van der Houten was the first to be called into the service of the Holy See in 1623 by Pope Urban VIII from whom he received the title 'Dic maestro'.
Together with his friend and successor Nicolas Cornelis de Wit, he studied the reclamation of the Pontine marshes which had been reclaimed by the Etruscans some twenty-five centuries previously. The works fell into disuse after the third century BC and were not restored during the Roman Empire. De Wit did not succeed. After him Nicolaas van der Pellen came, but he also had to give up the work in 1659.
Then Cornelis Meijer appeared on the scene. His ideas were embodied in an illuminating essay 'Del modo di seccare le Paludi Pontine', but only his son could make a modest start with the actual works. These were destroyed by the local inhabitants in 1707 and it was not before the thirties of the 20th century that the Pontine marshes were definitely reclaimed.
In the 18th century Jan Pieter van Suchtelen (1751-1836) was active in Russia. When he was 31 years old he left for Russia where he rose to the position of general and superior engineer officer. His most impressive hydraulic plan was the construction of the Catharina Canal, started in 1786 and completed in 1822.

In the 18th century the Dutch were also active in Spain, namely in the construction of the Canal Imperial from Tudela to Saragossa. In the 1870s Krayenhoff gave technical advice on how best to construct this canal. Significant was the fact that this canal was partly financed with capital via the Dutch banker Hope. The Spanish government accepted responsibility for the project. This illustrates the shift in Dutch society at that time: whereas the merchants/entrepreneurs were very active in investing in venture enterprises in the 17th century, in the 18th century they were more cautious.

It is apparent from the above that the Dutch 'hydraulic engineers' were welcome guests abroad in the 17th and 18th centuries. They had the expertise which was lacking elsewhere. That several of the projects they started failed was partly due to inadequate attention to the interests of the local population, partly because technical knowledge was still not perfect and partly because the works, once constructed, were not properly maintained. This does not alter the fact that the great interest abroad in Dutch hydraulic engineers shows that in this period the Netherlands played a leading role in this field.

The depression of the period 1650 to 1750 explains the sharp decrease of the number of Dutch experts abroad shortly after 1650. Typical symptoms were: the fall in cereal prices, relatively high real wages, little activity in the field of reclamation, conversion of arable land into grassland, extension of cattle breeding, etc. The situation changed again around 1750 when an unforeseen population growth was manifested. Whereas the large-scale emigration and the settlement of 'Hollandries' continued, the change did not increase the activities of Dutch experts abroad. This may be partly due to the fact, that in the meantime the countries in Western Europe had acquired their own expertise in the field of land reclamation and partly to a lack of initiatives and incitements. The Napoleonic era and the ensuing political issues would soon form another drawback. Actually it was not before 1850 that a real revival of the migration of experts started. By that time the world had completely changed.

10.4 Netherlands experts on the Asian scene

The decades around 1850 mark the transition of a predominantly agricultural to a predominantly industrial society in Western Europe. Hydraulic and agricultural engineering sciences expanded from land reclamation and drainage to damming rivers, constructing ports and water management on large and small scales.
Institutions for higher technical education were established. In Indonesia, the former Netherlands East Indies, the government decided to carry out large-scale irrigation projects - the so-called 'technical' irrigation. This led to a demand for a staff of qualified engineers to carry out the work. Technical education in the Netherlands had to be geared to these new needs.
For this reason an 'exotic' element was introduced in the hydraulic and agricultural education of engineers, which has remained very fruitful until today.

Thanks to the quality of the projects that were carried out in the Netherlands East Indies, the Dutch engineers acquired a good reputation in a new field.
Thus, Homan van der Heide, associated with the irrigation service in the Netherlands East Indies, was invited to come to Siam - the present Thailand - to give advice on the water management of the Central Plain. The main construction, proposed by him, a dam on the apex of the delta of the Chao Phraya river to control the division of the high waters, was built 50 years later on the same spot and according to the design he had proposed.
He also proposed the establishment of the Royal Thai Irrigation Department, of which, after having completed his mission, he became the first Director-General.

Another example of broadening the scope of activities of the Dutch engineers is the lengthy stay (4 to 10 years) from 1872 onward of a group of engineers and skilled labourers in Japan, shortly after the reinstatement of the Meiji dynasty. The engineers Van Doorn, De Rijke, Lindo, Rouwenhorst Mulder, Escher and Thissen worked in the fields of port construction, river improvement, the construction of irrigation canals and coastal land reclamation. In Japan coastal land reclamation was an age-old method to expand the acreage of cultivable land. Until the reinstatement of the Meiji dynasty, Japan had developed its own technology, independent of the developments in Western Europe. Rouwenhorst Mulder (1848-1901) studied the coastal land reclamations in the Kojima Bay near Okayama where in the 17th - 19th centuries alluvial land at the coast had been reclaimed from the sea. He proposed to complete the reclamation by making three polders. He did not propose to build an enclosing dam with a fresh water reservoir. This element was added much later, in the early 1950s (Figure 10.1).

Figure 10.1 Enclosing dam Kojima Bay, Japan

The services of the Dutch engineers have proved to be important for the development of hydraulic engineering in Japan and the Japanese were very grateful. They erected a statue for Van Doorn, who had designed the irrigation works in the prefecture of Fuhushima.

His statue looks out on Inawashiro lake, which he used for water supply by means of a tunnel. The bronze statue was saved during the Second World War, when farmers hid it in the ground. In remembrance of the works by Escher and De Rijke, to improve the discharge capacity of the river Kiso (near Nagoya), a small temple was built at the mouth of this river.

Some of the engineers mentioned earlier have also been active in China (De Rijke and Escher), especially in the field of river control. They were succeeded by engineers such as Nijhoff, Boudrez, Van der Veen and Visser, who all had to face the huge problems of the Yellow river. Another name that should be mentioned is Van den Heuvel, who set up the hydraulic laboratory in Nanjing, still the leading institute of the Peoples Republic of China.

10.5 Modern times

The drastic changes in the economic and social circumstances all over the world following the Second World War had consequences for the vocational emigration of Dutch experts in the field of water management and land reclamation. The geographical field of activities was no longer restricted to Asia, but spread to Africa, South and Central America and Southern Europe. Hundreds of senior and junior experts, including many who had worked in the former Netherlands East Indies, were given the opportunity to apply their know-how and to gain expertise. They stayed abroad for periods varying from a few weeks to several years.

The rapid development of a number of industrialized countries and the need to offer help to an even larger number of less developed countries, caused a boom of technical activities abroad. United Nations organizations, such as the FAO, UNESCO and WMO, and other international organizations, such as the World Bank and the Asian Development Bank, were looking for experts to staff their land and water projects.
In the framework of the development cooperation the Ministry of Foreign Affairs started to support many projects in countries such as Bangladesh, Colombia, Egypt, India, Indonesia, Kenya, Nigeria, Pakistan and Yemen.
Dutch consulting firms entered increasingly the international market. In competing with foreign firms, these firms had limited experience in multidisciplinary projects.

Tellegen, a consulting engineer himself, persuaded a number of Dutch consulting firms to cooperate in Nedeco - Netherlands Engineering Consultants -, which was to be a coordinating body. This organization could recruit experts, not only from the participating consulting firms, but, thanks to the support of the central government, also from the official services and universities. In this way use could be made of the entire intellectual potential of the country and experts could be selected according to the specific character of the project. This formula turned out to be a very successful one and although the participating consulting firms acquired expertise that could measure up to foreign firms, the organization still exists and has gained international reputation. Nowadays the larger consulting firms have developed various associations with local consulting firms in relevant countries. Partly they were forced to do this due to the requirements of the local governments, partly they did it for economic reasons as various tasks in the framework of a project can, of course, be implemented by local staff. For individual projects all kinds of ad hoc agreements are made during the tendering process, either with local consulting firms, or with other enterprises that are active on the international market.
As a more recent development manufacturers of all kinds of hydraulic equipment and dredging contractors entered the international market. Until the beginning of this century, there was only a limited export of such products or services. This may be partly due to the larger projects in the Netherlands, like the Zuiderzee project, the Delta Project in the south-west of the Netherlands, large-scale dredging activities in the mouth of the river Rhine, and the operation and maintenance activities in the small and large water courses and polder areas. The companies obtained special skills and developed specialized equipment, that could be exported. Partly these skills and equipment were also developed during overseas projects. Most if not all of these services have to be offered in processes of international tendering. Regarding equipment mention can be made of pumps, lifting devices and pumping stations, subsurface drainage machinery, maintenance equipment for open water courses, dredging equipment, geotextiles, canal lining and all kind of weirs and culverts. The contractors are mainly operating in the larger harbour construction and dredging projects, some of them however are also involved in the construction of land reclamation projects.
Before giving a brief review of modern land and water development projects in which Dutch experts have been, or are involved, one project in Japan will be highlighted, because of its distinct 'Dutch aspects' and the traditional relations. It is the reclamation and cultivation of a lagoon, Hachiro Gata, in the northwest of

Figure 10.2 Hachiro Gata drainage sluices

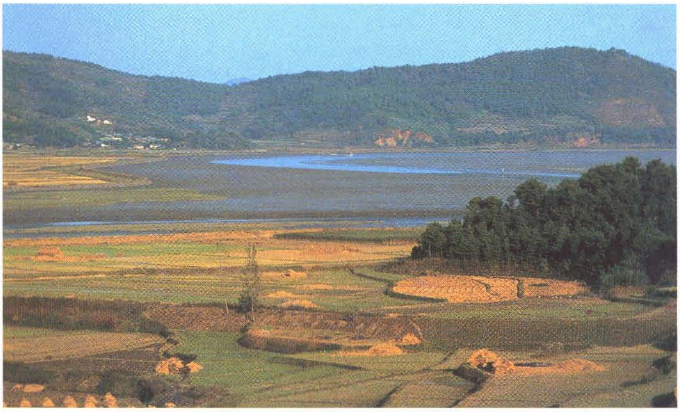


Figure 10.3 Seashore reclamation in the Republic of Korea

Honshu with a size of about 23 000 ha (Figure 10.2). The then prime minister of Japan, H.E. Shigeru Yoshida, who had visited the works in the bay of Kojima, mentioned before, and had been shown Rouwenhorst Mulder's designs, insisted on calling in Dutch experts once more (1954). Consequently, in the years 1956 and 1957 a joint project was carried out by Japanese engineers of the Ministry of Agriculture and Forestry and a group of Dutch engineers, Jansen and Volker of the Rijkswaterstaat.
Essential elements are the fresh water reservoir for additional irrigation and a wide collecting and transport canal along the east coast for the discharge of water and for the prevention of drops in the groundwater level in the neighbouring areas. The surface level in the central polder is more than 4 m below m.s.l. (Mean Sea Level) and so the area must be drained with pumping stations.
The project was completed successfully and, in keeping with Japanese tradition, a monument and a memorial stone were erected to commemorate the contribution of the Dutch engineers.

Although full responsibility for a certain overseas land and water development project is not so likely anymore, while most projects are executed under the responsibility of the local government, maybe with financial support of a bilateral, or multilateral donor, various Netherlands companies have played, or play an important role in such projects. To include all projects would result in a very long list. Therefore, only some of the more interesting ones are mentioned.

- Coastal reclamation projects:
  - seashore reclamation in the Republic of Korea
    coastal protection and reclamation of about 300 000 ha, mainly for rice production, but in the newer projects also for urban and industrial development (Figure 10.3);
  - tidal lowland development projects in Indonesia
    reclamation and development of about 1 million ha tidal lowland for small-scale agriculture;

Figure 10.4 Oil production and subsidence in Venezuela

- coastal urban or industrial reclamation projects in Indonesia, Malaysia and Thailand;
- landfill for the new airport of Hong Kong.

- Development of masterplans
For river catchments, or certain urban or rural areas, masterplans on the integrated development of water management have been made.
Some examples are:
  - the Deltas of various rivers, like the Danube in Romania, the Mekong river in Thailand, the Yangtze river in China;
  - regions, mainly focusing on irrigation development, such as water resources development planning per district in Kenya, and per catchment in the Republic of Yemen;
  - polder areas, like the Bolivar Coast polders in Venezuela. Coastal protection and polder development in an area 120 000 ha along the east coast of lake of Maracaibo, where the major part of Venezuela's oil production comes from. Due to the extraction of oil the total subsidence in the area may be up to 10 m (Figure 10.4);
  - cities, such as Bangkok and Jakarta.

- Drinking water supply and sanitation projects:
Various drinking water supply and sanitation projects in both rural and urban areas. Also in the framework of these projects, studies are executed related to water resources development, social and environmental implications.

- Environmental impact studies:
In the framework of almost all the land reclamation projects, nowadays an environmental impact analysis is required by the bilateral or multilateral donors. Many of such studies are made by Netherlands consulting firms and institutes.

- Irrigation and drainage projects:
Involvement in these projects mainly refers to consultancy work and hydraulic studies. However, all kind of equipment is also exported that is applied in such

projects. Mention can be made of pumps and pumping stations, weirs, culverts, and all kinds of control equipment. Larger projects with Netherlands involvement are:

- large-scale subsurface drainage projects in Egypt, Iraq and Pakistan;
- large-scale irrigation projects in Egypt, India, Indonesia and Pakistan.

- Dredging projects:
  Netherlands dredging contractors are leading the international dredging market and are involved in various large-scale dredging projects in harbours, rivers, tidal inlets, canals, reservoirs, etc. In addition, Netherlands manufacturers have developed all kind of special dredging equipment, both for large-scale dredging under difficult conditions, and for small-scale specialized dredging.

As in the Netherlands, almost all over the world pollution of surface water and groundwater resources is a problem of increasing importance. Various programmes have been developed and implemented to control future pollution and to clean polluted land and water areas. These experiences add a complete new field of science to land and water development, including aspects of wastewater treatment, specialized dredging methods, design and construction of disposal sites for polluted soil or sludge, and reuse of polluted material. It may be expected that in the near future all these developments can be applied on a worldwide scale.

11 Education and research organizations

In the past the transfer of knowledge and skills in the fields of flood protection and water management took place in practice. Elder experienced engineers trained the younger generation. In 1842 the Government started the education for civil engineering in Delft, mainly concentrated on water issues.

11.1 Education

The education of professional hydrologists has existed in the Netherlands for more than 40 years. Until the 1960s the subject of hydrology was included in courses on hydraulic engineering, hydropower, land reclamation, land and water use, irrigation and drainage. At present surface water, groundwater, water management, sanitary and hydraulic engineering are being taught as individual subjects comprising general introductions and some lectures on main topics. Students can choose hydrology and related topics during the last one or two years of their education as the main fulfilment of the requirements for a master's degree. Their main programmes are civil engineering (Delft University of Technology), agriculture (University of Wageningen) and geology (Free University of Amsterdam). In all three cases most elements of hydrology are studied but there is a certain emphasis on groundwater and surface water hydrology at Delft, on agrohydrology at Wageningen and on hydrogeology at Amsterdam. Certain hydrological aspects can also be studied at other universities e.g. Utrecht and Groningen (Departments of Physical Geography) and Twente (Department of Process Dynamics and Environmental Control).

The disadvantage of this study system of hydrology as a specialization within a major branch is that the students cannot study hydrology full-time. The advantage is that hydrology and water management can be placed in the perspective of practical applications in large fields of economic development and environmental quality.

At bachelor degree level hydrology and water (resources) management is part of the lecture programme of many courses in civil engineering and agriculture.

The Dutch universities cooperate with many universities in the countries of the European Union in the framework of the Socrates programme (staff and student exchange) and the European Thematic Network of Education and Training for Water. The EU programme Phare/Tempus provides cooperation with universities of Central and Eastern Europe.

In the Netherlands various courses are being provided for foreign experts. There are international postgraduate courses lasting eleven months focusing, among others, on hydrology, hydraulic engineering and land and water development. Qualified participants may follow 'master of science' and 'PhD' programmes. The courses are organized by the International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE) in Delft. Besides these, there are several postgraduate courses at the International Institute for Aerospace Survey and Earth Sciences (ITC) in Enschede, the Agricultural University Wageningen and the International Institute for Land Reclamation and Improvement (ILRI) in Wageningen.

As a contribution to capacity building programmes of multilateral and bilateral donors, more and more projects are implemented, where institutes or universities in developing countries are supported with the development of curricula of courses at various levels and with the set up of research programmes.
Also in the framework of research and implementation projects, training components become more and more an integrated part of the projects.

Recently the inter-institutional Netherlands School for Advanced Studies in Hydraulic and Geotechnical Engineering (SHGE) was started. The increasing population on this globe concentrates in river and coastal zone areas. More interests than ever before pose specific requirements on water resources. Technological developments can provide tools to measure, calculate and manage the water systems. Today mathematical models can assess the various impacts on the supply possibilities of the water systems concerned. Transfer of knowledge and experience was and is an important issue in this country.
To bring together expertise, research and training efforts, the universities of Delft, Twente and Utrecht, the International Institute for Hydraulic and Environmental Engineering (IHE), Delft Hydraulics, Delft Geotechnics and scientific institutes resorting under the Ministry of Transport, Public Works and Water Management decided to create the SHGE. The main objective of the school is the promotion and support of mono- and multidisciplinary research contributing to sustainable development around water issues. The school has to create optimal conditions for the generation of young, talented researchers who will transfer the results to colleagues, designers, contractors and water system managers. The school will concentrate on three specialities: fundamentals of water and soil physics; design, construction and management of hydraulic structures; and comprehensive policy preparation for flood protection and water management issues.

11.2 Research organizations

In the Netherlands a great number of institutes, university departments, services and other organizations are active in the field of hydrology and water management research. Due to the great diversity of organizations, co-ordination of the research activities is considered essential.

Initially the TNO Committee on Hydrological Research (CHO-TNO) brought together the main research organizations and water management authorities at national, provincial and regional levels. In the period 1946-1993 CHO-TNO fostered co-ordination and co-operation in the field of hydrology and water management considerably and facilitated the transfer of research results and exchange of information. Many reports containing results of hydrological research were published in the series 'Proceedings and Information' of the CHO-TNO.
CHO-TNO's role of promoting co-ordination and co-operation has been gradually taken over by research institutions involved in the same research programmes and projects. Further, exchange of information occurs incidentally and is mostly focused on timely items from the viewpoint of science, management and/or policy. In this respect a number of scientific and technical associations with an individual membership, such as the Netherlands Hydrological Society, play an increasing role. In Annex 1 a selection of the institutions and associations is presented.

Since some decades two national Research Councils have been dealing with the demands and opportunities of research in the medium and long terms, concerning, among other things, rural areas and the environment, thus including water issues. At present, the National Council for Agricultural Research (NRLO) is carrying out foresight studies to explore social, scientific and technological changes over the next fifteen to twenty years which may affect developments in agribusiness, rural areas and fisheries. Possible new dilemmas, challenges and opportunities are explored. The Advisory Council for Research on Nature and Environment (RMNO) is focusing on matters concerning the environment, nature research, and sustainable development once every four years leading to a Long Term Perspective on strategic research.

During more than twenty years water boards, provinces and the Ministry of Transport, Public Works and Water Management have channelled research of joint interest through the Foundation for Applied Water Research (acronym in Dutch STOWA). The general objective of STOWA is to carry out applied research for the benefit of all water management authorities in the Netherlands. It tries to achieve this goal by investigations in the fields of groundwater and surface water, collection, transport and treatment of wastewater, and flood defence. STOWA offers central services, collects and distributes information and knowledge in these fields.

12 Trends in research

During the last ten years there has been an evident shift in Netherlands hydrological and water-related research. This chapter describes the important trends over a longer period and pays special attention to the recent changes. Reference is made to the selection of research topics in Chapter 13.

12.1 Netherlands situation

In the Netherlands the topographical situation and the intensive use of land and water are major factors determining the nature and extent of Dutch hydrological research. Naturally most important has been the continuous struggle against the sea and rivers, the reclamation of land, the drainage of areas with high groundwater levels and the demands for adequate water supply. These challenges have resulted in developing a comprehensive expertise of Netherlands engineers in the fields of hydraulic engineering and hydrology. As in some other countries, the systematic study of hydrology in the Netherlands started in the second half of the nineteenth century. Earlier, only occasional studies of specific aspects of the hydrological cycle had been undertaken. The flat Netherlands countryside with its very high groundwater tables and extensive aquifers has stimulated research in groundwater problems. In contrast, the study of our surface waters has been concentrated mainly in the hydraulics of water and sediment movement in open channels. Much research has been associated with large-scale engineering works like the canalization of the Rhine, the reclamation of the former Zuiderzee (now Lake IJssel) and the Delta Works. Dutch engineers gained an international reputation for their high standard of hydraulic engineering and also the physical and mathematical modelling of tidal and inland waterway systems. This expertise has been exported successfully to many countries and this will continue for years to come.

It can be stated that up to the mid-1980s, most hydrological research fell into one of three main categories: water supply, agriculture and environmental quality. Now and in the years to come, many questions within these categories have still to be solved and are subject to research.
The same applies to urban hydrology, a rather new branch of hydrological sciences. These four categories will be briefly discussed in this chapter and, if relevant, reference is made to the research topics presented in Chapter 13.

Various recent developments, national as well as international, affect the scope of the hydrological research in the Netherlands. The following paragraphs will therefore touch on these items and also link them -when relevant- to the research topics of Chapter 13.

Hydrology faces new and challenging problems. Due to the increase of the world population and strong industrial expansion, the need for water will grow. The relation between hydrology and environmental quality, will be stronger in the future. It will be increasingly difficult to fulfil the demands for water of good quality and at the same time the problems of sanitation and disposal of (solid) waste will demand continual attention. With respect to this, studies on sustainable development of water and environment and the relation between environment and

physical planning are of utmost interest: hydrologists have important contributions to make to these studies. See also research topics 13.1, 13.2 and 13.8.
The hydrologists will face new challenges in their field of expertise. They will have to contribute to studies concerning new subjects like the recycling of wastewater and new water saving techniques. The ongoing studies on the hydrological consequences of climate changes will be increasingly important. The effects of the hydrological cycle on regional and global scales will be subjects of research. Special reference is made to Chapter 13, research topics 13.9 and 13.10.

Due to the expansion of modern society the living conditions will change. However, the people of the Netherlands have been convinced more and more that it is crucial to maintain the natural environment as much as possible. Therefore water management tools also have to be focused on minimizing the environmental effects. See further research topics 13.5 to 13.8 and 13.11 to 13.15.

The accurate description and analysis of the hydrological system and processes and the development of new models will remain important tools for recognizing new problems in time and contributing to their solution. With respect to this there is the need for continuing attention to monitor the hydrological cycle. The ongoing improvement of measuring devices and measuring methods is necessary and the use of Geographical Information Systems is essential. The scope of interest in this paragraph is linked with decision supporting tools presented in Chapter 13.

In 1985 the Ministry of Transport, Public Works and Water Management published a memorandum, named 'Living with Water', which can be considered as presenting a fundamental change in the ideas on water policy and water management. The memorandum introduces a new approach to the role and functions of the national water systems as part of the physical environment, and to the need to integrate water management measures depending on various interests. In 1989 the strategy for integral water management, based on the water system approach was presented in the Third Policy Document on Water. In order to make this strategy operational, new outlines for water-related research were formulated, with a broader scope than before, in the field of hydrology and hydraulics as well as ecology, soil science, economics, technology and legislation.

From the ecological point of view, there is a need to deepen the knowledge on ecological relations in (regional) surface fresh waters, for the use of integrated water management, nature development and nature management. In this respect the following trends for the Netherlands fresh water research should be mentioned: ecological description of the actual and target situation of the surface waters, development of methods to monitor and evaluate changes in water quantity and quality, development of methods and models that relate management measures to ecological changes.

It looks strange that in a wet land such as the Netherlands, its population is facing the problematic situation that in the long run, the availability of sufficient water of good quality may not be ensured according to the demands of drinking water supply, nature reserves, agriculture and horticulture. A further harmonization of

national and regional water management is needed. This situation has led to various scenarios with options for different conflicting (spatial) interests and their hydrological consequences. Such research is still in progress, as well as studies to enlarge the knowledge on soil moisture processes, desired groundwater levels and quality, and water demands on agriculture, nature reserves and forests. Reference is also made to current development of modelling tools for sustainable water management. Furthermore supporting studies on regional water management plans are necessary. Policy makers and managers of water resources show increasing interest in using these results. Such activities may reflect on agriculture, which may benefit from the groundwater levels in nature reserves.
Another trend which needs attention is the increasing importance of the international dimension in hydrological and water-related research. This development is the result of various activities, such as river basin hydrology (Commission for Hydrology in the Rhine-basin, CHR), international programmes on global or regional hydrological problems (International Hydrological Programme - IHP of UNESCO, Operational Hydrology Programme - OHP of WMO, International Geosphere-Biosphere Programme of ICSU, Environment Programme of EU); international strageties in physical planning, water policy, environmental or nature policy (European Ecological Network- EECONET), a coherent network of sustainable ecosystems, e.g. the wetlands, that are of international importance; and bilateral cooperation between universities and institutes.
For the coming years the following items will have high priority: sustainable water systems, water quantity and quality at river basin level, flood protection, water policy and management of cities, groundwater at risk, water scarcity, climate change and its hydrological consequences, ecohydrology, hydraulic engineering projects.

12.2 Hydrological research and water supply

The first Netherlands public water supply company was set up in Amsterdam in 1853. It derived its water from the North Sea dunes by extraction of groundwater. Little was known at that time about groundwater hydrology and it was in the early 1850s that the first systematic investigation of groundwater flow in the Netherlands was performed. From that date geohydrological research and investigations kept pace with the development of groundwater resources. Throughout the years the potential for groundwater withdrawal has been studied extensively at a local and regional scale. For many decades the classical approach was followed: geohydrological mapping, water balance studies and pumping tests. In later years simulation models were introduced and proved to be very useful extensions of the scientific tools available for the hydrologist. The development of these models began in 1940 with the introduction of physical analogue models, followed in 1970 by more powerful mathematical models. Special interest continues in the salt water intrusion from the sea and the swelling of brackish groundwater bodies. From the investigations in the 1850s to the present day research has been carried out in the dune areas, not only into the salt-fresh water transient zone, but especially into the movements of this zone due to natural circumstances and human activities. Research in this field has been focused on improving the mathematical modelling of groundwater flow which incorporates changes in the density of water. The salt water intrusion caused by groundwater abstraction has been the first limiting factor in the exploitation of fresh groundwater bodies in the

Netherlands. In the 1930s it was concluded that mining of the fresh groundwater in the dunes took place. This led in 1940 to the introduction of artificial recharge with surface water. In the following years this method proved to be successful from the point of view of water supply. From about 1970, however, it became evident from field observations that large scale artificial recharge operations could lead to a serious impact on the natural vegetation and fauna of the dunes due to changes in the groundwater regime and the groundwater quality. This has led to a comprehensive research programme to evaluate the feasibility of artificial recharge by means of wells instead of canals or lakes. It is expected that such a method, if properly implemented, will have less environmental impact. Although over most of the Netherlands the geohydrological situation is favourable for groundwater extraction on a large scale, in practice there are substantial limitations caused by the undesirable environmental impacts. In particular the negative effects on agriculture and natural values became evident in several areas. Therefore the hydrological research was intensified on the relation between groundwater, soil moisture and evapotranspiration.
This has resulted in a set of methods to calculate the effect on crop yield, ranging from simple graphical relations to very complex and sophisticated numerical models. Progress has been made with respect to determining the impact on the natural environment at the level of species or ecosystems.
Another research topic is the relation between groundwater withdrawal and surface water. This is important when dealing with the exploitation of groundwater near the banks of the large polluted rivers, like the Rhine. In these situations the configuration of wells is critical in providing adequate travel times of water particles between surface water recharge locations and groundwater abstraction points. A second point of interest is in the impact of groundwater withdrawal on the surface water regime, where in the case of small water courses it is important to study the impact on the ecosystem and landscape.

In a densely populated and highly industrialized country like the Netherlands there are many human activities which hold a (potential) threat for soil and groundwater pollution. Hydrologists are becoming more and more involved in the search for solutions of this environmental problem. Specific research topics, directly related to water supply, include identifying of protection zones around the well field based on flow pattern and the vulnerability of the groundwater system in these zones.
About one third of the yearly amount of drinking water distributed by the Netherlands water supply companies is withdrawn from surface water, especially from branches of the rivers Rhine and Meuse. The need for related hydrological research, however, is small. Both river discharges and water quality are comprehensively monitored and evaluated in the framework of the Dutch water management system.

12.3 Hydrological research and agriculture

Before 1950, from a scientific point of view, there was only little progress in hydrological research related to agriculture, although there was always a keen, practically orientated interest in drainage problems of agricultural land. From 1950 agricultural research has developed rapidly. The necessary impulse came from the need for large scale improvements and intensification in agriculture to achieve higher crop yields. Research in this area covers a broad scientific spectrum, in which hydrology and soil physics plays an important role. For many years the study of evapotranspiration or, more generally, the study of water flow in the soil-plant-atmosphere system has been a major subject in agricultural research. As a starting point one may consider the water balance study of the Rottegatspolder (1947 to 1952). This was the first experimental hydrological basin in the Netherlands, although it was a typical Netherlands polder area and not a natural river basin. After a period of lysimeter studies in the 1950s, theoretically based physical mathematical concepts for water transport in the soil-plant- atmosphere system showed a new dimension to evapotranspiration research from 1960 onwards. These concepts were based partly on research abroad and partly on original work of Dutch hydrologists and meteorologists. The introduction of the computer in the early 1970s was a major improvement in the operational value of theoretical concepts. Extensive monitoring of experimental basins also supplied data for calibration and verification of numerical models simulating soil moisture flow, evapotranspiration and crop growth, and for calculation of the water demand of crops.

This has led to the development of a wide range of techniques and a high level of expertise. As a result of the socio-economic aspects of agriculture one may anticipate further research in this field in the near future. Reference must also be made to the use of remote sensing techniques in establishing the variation in soil physical and hydrological field conditions. Based on airborne reconnaissance it has proved to be possible to draw an areal map of actual evapotranspiration, thus providing a new potential water management tool.
In the greater part of the Netherlands the groundwater level is near the surface and consequently influences the soil moisture conditions in the root zone. This explains the continuous research effort in the field of agricultural water management. Initially research was carried out almost exclusively for the improvement of land drainage to improve soil structure and allow heavy farm machinery in the field. From the late 1960s attention has focused on the conservation of water in dry periods by the control of surface water levels and on additional supplies of surface water. In the extreme dry year of 1976 it became clear that in some areas a substantial deficit could occur between the water demand of the crop and the actual available water in the root zone. Current research in this field is carried out within a framework of a system approach to water management problems at a regional scale.

These problems arise from the conflicting interests of agriculture, drinking water supply and environmental protection (including natural conservation) and also from the economic feasibility of technical solutions. Specific problems include the impact of groundwater resources development on crop yield, the environmental impact of the (excessive) use of fertilizers and manure on water quality and the large-scale use of groundwater for irrigation of farmland. The solution to these problems will undoubtedly influence the research of Netherlands hydrologists for some time to come.

12.4 Hydrological research and environmental quality

Several environmental problems, identified in the 1960s and 1970s, are determining the hydrological research in the 1980s and 1990s. Some of these problems originated from changes in the hydrological regime as a result of human activities and have been described earlier. Another group of problems is related to the pollution of soil and water by waste disposal and some forms of land use. Large-scale drainage and groundwater exploitation have led to substantial changes in the groundwater regime in some areas and in the soil moisture conditions. This has consequences not only for the crop yield, but also for the natural environment. However, in contrast with the estimation of agricultural impact, research has not led to the development of operational methods for the quantitative assessment of the effects on natural vegetation, fauna and ecosystems. Much research will be needed in this complex area particularly in the development of quantitative relationships between changes in the hydrological regime and the effects on the environment. Another important research topic for Dutch hydrologists in the coming years will probably be the impact on hydrology and water management of an increasing carbon dioxide concentration in the atmosphere. This may lead to a change of climate but also to rapid rise of the sea level, a factor which causes much concern to the people living 'behind the dikes'. The climate change may also have repercussions for the precipitation patterns, with consequences for flood protection along the rivers and basic level water management. The pollution of the surface water is another environmental issue, which has contributed to a new dimension in hydrological research in the Netherlands. In the 1960s the unwanted environmental effects of the growing population and the industrial expansion in the basins of the Rhine and Meuse became evident. A major concern for the future of the public water supply and the aquatic ecosystems led to a comprehensive monitoring and research programme. Much effort was put into the development of water quality models, thereby building on the extensive knowledge of the hydraulics of Netherlands rivers, lakes and estuaries.

This research has resulted in a wide range of operational models and other methods used in water quality management. During the 1970s it became clear that groundwater quality was gradually deteriorating, not only as a result of local point sources, but also at a more regional scale from various diffuse sources. Groundwater in the Netherlands appeared to be more vulnerable than was previously thought. This awareness gave a strong impulse to hydrological research, and soil and groundwater quality problems will continue to direct research programmes in the coming years. At first research focused especially on pollution by point sources such as waste disposal and oil spillage. After the discovery of some severe cases of soil pollution in urban areas, hydrologists, together with soil scientists and chemists, became involved in clean-up operations developing a new field of expertise.
Nowadays there is also a special interest in more diffuse sources of pollution, including the use of fertilizers, manure and pesticides in agriculture, and the effects of acidification. In this field the Dutch hydrologists have to work together with fellow scientists and engineers from other disciplines. Their particular contribution deals with the transport of nutrients and (toxic) pollutants in the saturated and unsaturated zone. In this respect new methods for field investigations have been developed, along with groundwater quality models. Furthermore continuous attention is given to spatial and temporal variability, and to the extrapolation of point-values into area-values. This concerns various

pollutants, soil characteristics and hydrological conditions. The research topics 10 and 12 of Chapter 13 illustrate questions of current interest.
This research is not only related to the assessment of the nature and extent of pollution in the field, but is also connected with the prevention of pollution, including the development of methods for the safe disposal of hazardous waste.
Recently - in 1993 and 1995 - the Netherlands was facing the problem of high floods in our main rivers, the Rhine and Meuse. This led to the evacuation in 1995 of 250 000 people in the endangered areas. A research challenge will be the determination and prediction of the discharges in the main rivers on a more physical base. It is a common challenge for the Rhine and Meuse countries.

12.5 Urban hydrology

Netherlands hydrologists as well as hydraulic experts have been involved for many decades in the water management of urban areas. The acquired knowledge and experience were successfully applied in the development of new towns, especially in the reclaimed polders in the former Zuiderzee. Nevertheless urban hydrology in the Netherlands has been recognized only recently as a branch of hydrological sciences in its own right. Today's research topics include the relation between precipitation and drainage, the environmental aspects of sewerage systems, the functions of open waters in urban areas and the control of surface water and groundwater levels. Most sewers in the Netherlands are of the combined type, although the number of separate sewerage systems is steadily increasing. Since water quality became an important issue, the acceptability of an overflow structure in a combined sewerage system has been assessed on the basis of its overflow frequency. If the frequency exceeds the standard, generally in-pipe storage is increased. For flat areas, typical for most parts of the Netherlands, this approach indeed reduces the overflow frequency. However, no attention has been paid to the receiving water. Large eutrophic water bodies can stand more polluted discharge than small oligotrophic water. In practice most overflow structures discharge into small, semi-stagnant and stagnant waters, which are highly vulnerable. Considerable progress has been made to assess the effects of overflows, both in physical-chemical and ecological ways, to provide the basis for new standards. Research in rainfall-runoff modelling is necessary to optimize sewer design by including surface and sewer routing terms and precipitation losses due to infiltration in paved surfaces. Furthermore, research is in progress on sewer quality processes to establish a better understanding of the accumulation, mineralization and re-suspension of the sewer sludge, which take place due to the small gradients of the sewer pipes.

Besides the above mentioned items dealing mostly with a technological approach to urban hydrological problems, two recent developments deserve our attention.
Firstly, integral water management is being introduced within urban areas, with the aim to relate quantitative and qualitative aspects of surface water and groundwater to each other (internal coherence). Moreover, urban water policy and management are being related to questions concerning physical planning and the environment of adjacent rural areas (external coherence). See Chapter 13, research topic 13.4).
Secondly, strategies are being developed for ecologically sound urban development ('Ecopolis-strategy'). Water is only one of the 'flows', besides energy, waste and

traffic. Water also fulfils a crucial role within the urban landscape and the spatial policy of cities (built-up and open areas). Furthermore, citizens' involvement is needed in the management of their daily environment, including various aspects of water. In the coming years research efforts will be directed to the operational side of these strategies by means of interdisciplinary studies.

13 Research topics

The number of research topics presented in this chapter, reflects some aspects of the wide scope of Netherlands hydrological research and water-related activities, which are being carried out by universities, research institutes and consulting firms. The contents do not cover all subjects of the research efforts up to 1996. For example, no cooperating projects with research institutions abroad are presented.
The 15 research topics form four groups:
- *management related research (1-5),*
- *ecosystem related research (6-9),*
- *specific research (10-11),*
- *decision supporting tools (12-15).*

The trends in research are described in Chapter 12.

13.1 Pollution prevention and Sediment pollution

P.B.M. Stortelder[1]

Measures to prevent the input of contaminants have been effective for the improvement of water and sediment quality in the last decades. However, the present day quality criteria are not yet fully met and research is continuing on the further reduction of discharges into water. Besides the discharges from industrial point sources, diffuse sources are often responsible for exceeding quality standards. Therefore research concerning diffuse sources has increased remarkably.

Clean technology, preventive action and wastewater treatment
An extensive research programme is being undertaken for the development and implementation of sustainable techniques for pollution abatement in the next three to twenty years. The programme, named SPA (Dutch acronym for clean technology, preventive action and waste water treatment), is co-ordinated by the Institute for Inland Water Management and Waste Water Treatment (RIZA).

The sub-programmes are:
- CLEANTECH: research into clean technology emphasizes the development of new or improved processes and products that are less damaging to the environment; major lines of research include replacement of wet processes with dry ones, closed cycles;
- PREVENT: prevention is aimed at current processes within companies, including not only technical measures but also logistics, organization and production;
- INDUS: research into industrial wastewater treatment in the final stage of the processes and at subflows; major fields of attention include oxidation techniques for wastewater treatment and closed cycles by useful application of removed substances;

[1] Rijkswaterstaat, Institute for Inland Water Management and Waste Water Treatment, RIZA, Lelystad

- COMMUNAL: the main goals of investigation are focused on the following problems: the discharge of micropollutants by sewage treatment plans, the treatment of sewage sludge and the problems concerning storm overflow; with respect to current treatment systems, the emphasis is on effluent polishing and innovative techniques;additionally, new communal wastewater treatment system concepts are considered.

Diffuse sources

Important diffuse sources are:

- agriculture (nutrients and pesticides);
- shipping (polycyclic aromatic hydrocarbons (PAHs), copper and tributyltin anti-fouling paint);
- building materials (corrosion of galvanized steel, plain zinc, sheet lead and copper water tubing; leaching of creosote-impregnated embankment materials);
- runoff from roads (mineral oil and heavy metals);
- consumer products (pollutant compounds in products);
- atmospheric deposition.

Solutions to deal with the problem of diffuse sources are in many cases to be found by tackling the source, often product, itself. This approach can be successful only if all environmental consequences are taken into account.Research on the complete life cycle of the product alternatives is therefore necessary. Research is focused on topics such as the behaviour of coaltar paints for ships without PAHs, and life cycle studies on alternatives for zinc roof gutters, copper water tubing and creosote-impregnated embankment materials. Beside dealing with prevention by introducing product alternatives, research looks at the reduction of emissions to surface waters. Examples of such studies are investigations for improvements in the currently used spraying techniques for pesticides, and research on measures to reduce nutrient leaching and purification techniques for runoff from roads.

Another topic concerning diffuse sources is the research of the transport of pollutants, especially in the field of agriculture (nutrients, pesticides). This research is focused on quantification of the loads of pollutants to surface water and groundwater using mathematical models and taking into account among others biodegradation and sorption processes.

Sediment pollution

The waters in the Netherlands act as a sink for the pollutants discharged by the rivers Rhine, Meuse and Scheldt and by local sources. From 1930 up to now, a large amount of pollutants has accumulated in the Netherlands. More than 300 heavily polluted sites have been identified. The total amount of heavily polluted sediment is about 100 million m^3 and may cause serious environmental risks. Remediation of these sites is planned.Moreover, ten million m^3 of moderately polluted sediments have to be dredged yearly for nautical and hydrological reasons. Maintenance dredging of rivers, canals, estuaries and harbours is needed to safeguard land use and to facilitate economic activities, e.g. transport of goods and agriculture.Research concerning sediment pollution has been increased remarkably over the last ten years. The topics are: inventory of sediment pollution, behaviour of pollutants in sediment, ecological risk assessment, treatment and re-use of polluted sediment and design of disposal sites.

Identification of sediment pollution and dredging
A national monitoring programme has been carried out since the late 1980s. Research focuses on the optimization of the monitoring strategy, introducing geographic information systems, and classification systems for the characterization of polluted sediments. Much attention has been given to in-depth site investigations to quantify and locate the polluted sediment as accurately as possible. Environmental dredging methods, allowing accurate dredging and limiting/preventing the dispersal of pollutants are studied.

Physical and chemical behaviour of sediment
Knowledge in this field is relevant for risk analyses of polluted sites, methods for remediation, decisions concerning the free disposal of sediment and disposal in special sites.

Topics in this field are:
- modelling of the accumulation of pollutants in sediment;
- biodegradation of pollutants under anaerobic conditions;
- adsorption and desorption processes in sediments, including the analysis of pore water concentrations and the decreasing rate of desorption processes as a function of time ('aging' of sediment);
- transport of pollutants accumulated in the sediment to surface water and groundwater;
- changes in bio-availability of sediment pollutants due to a change from anaerobic to aerobic conditions, e.g. when sediment is disposed on land.

Ecological risk assessment
The use of ecological risk assessment is strongly promoted in the field of sediment management. There is a growing awareness of advantages in addition to generic sediment quality criteria. Topics in research on ecological risk assessment are:
- derivation of generic sediment quality criteria;
- development of bioassays for sediment toxicity testing;
- integrated chemical, ecological and ecotoxicological assessment of sediments (TRIAD-approach);
- remediation of highly contaminated sites;
- disposal of slightly to moderately contaminated dredged material;
- habitat rehabilitation of slightly polluted sites.

Treatment and re-use
A nationwide Development Programme for Treatment Processes for Polluted Sediment (in abbreviation POSW) is in a final stage. The Institute for Inland Water Management and Waste Water Treatment (RIZA) is the leading partner. Research institutes, private companies and governmental agencies are working together in developing remediation techniques that are both environmentally effective and cost-effective. The techniques which seem to be promising and on which further research is focused are:

- physical treatment methods, emphasizing separation techniques which can decrease the volume of sludge to be treated or deposited; the methods are also aimed at supplying a clean product suitable for re-use; especially particle separation by settling and using hydrocyclones, and flotation techniques are studied;
- chemical and thermal treatment methods, which can reduce the quantity of pollutants, or convert them into non-hazardous substances; techniques which are studied are wet oxidation at high temperature and pressure, dry thermal treatment and chemical extraction with acids, complexing agents or organic solvents;
- biological treatment methods, where micro-organisms are used to degrade toxic compounds to harmless or less toxic substances, e.g land farming and aeration of suspensions; these methods are relevant to mineral oil and PAHs;
- immobilization methods, aimed at physical-chemical bonding of the pollutants in such a way that the risk of dispersal into the environment becomes a negligible factor, e.g. sintering or melting of sediment resulting in ceramic products ranging from gravellike to glassy products and artificial basalt.

Design of disposal sites

In the Netherlands the government aims at cleaning and re-utilization of polluted sediment. However the large-scale techniques for separation and cleaning will not become available in time. Therefore large disposal sites for the storage of polluted sediment are being, and will be, built. Much research effort is concentrated on the design of environmentally safe disposal sites. Topics are:
- mathematical description of the consolidation process;
- quantification of fluxes to surface water and groundwater using mathematical models;
- isolating measures;
- selection of locations in order to minimize environmental risks;
- construction methods for disposal sites.

13.2 Artificial recharge for public water supply

J.H. Peters[2]

This contribution deals with a general description of recharge systems that are used in water supply in the Netherlands. It also reports about the side-effects. The trends for the near future are: well recharge as an alternative for surface spreading (open recharge); ecological engineering and (re)design of open recharge systems to improve biotopes or to reduce the effect on nature; and recharge as an alternative for groundwater withdrawal to prevent any further loss of wetlands and to sustain shallow groundwater systems.

Reasons for artificial recharge (AR)

In the Netherlands AR is carried out for several reasons. One of the reasons is to expand the capacity of groundwater abstraction, to overcome a problem of brackish water or of a declining groundwater table when natural replenishment by rainfall is

[2] KIWA, Research and Consultancy, Nieuwegein

insufficient. Another important reason is that with AR surface water can be used without chlorine or ozone to get hygienic safety. In fact purification of pretreated water during soil passage (also indicated as 'aquifer treatment of pretreated river water') is predominantly disinfection. Constant quality by mixing (including temperature) is also accomplished. Using AR water supply companies can overcome problems concerning short interruptions of intake or purification and problems related to transport of the water. It reduces the required treatment and transportation capacity because infiltration is more or less constant and continuous whereas abstraction varies to meet daily peak demands. Seasonal storage is achieved. AR also forms a filter for enigmatic constituents that might be present in the purified water but that are unknown mainly because analysis methods fail.
From the experiences gained it can be concluded that with AR the use of surface water is possible in a simple, safe, solid and sustainable way.

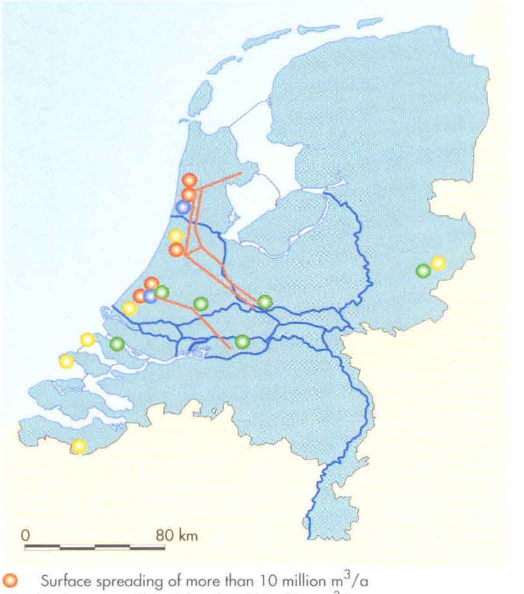


Figure 13.2.1 Artificial recharge sites and well recharge systems

For two decades the possibilities of recharging deeper aquifers have been contemplated. Since 1990 two well recharge systems have been in operation, each infiltrating and abstracting approximately 4 million m^3 annually. Figure 13.2.1 shows the 11 AR-sites with surface infiltration and the two sites with well recharge systems that started in 1990. Red/yellow dots are systems with surface spreading of more/less than 10 million m^3/year; blue dots mark locations of the two well recharge systems both operating at about 4 million m^3/year; and green dots indicate locations of pretreatment.

Table 13.2.1 Sources for pretreatments of infiltration water (1990)

	million m^3	%
Rhine	62	35
Lake IJssel	29	17
Meuse	69	39
other	16	9
total	176	100

In 1990 a total of 180 million m^3 was infiltrated. Of this amount 176 million m^3 was pretreated. The most important sources are the two major rivers Meuse and Rhine and Lake IJssel (Table 13.2.1). The River IJssel, a branch of the river Rhine,

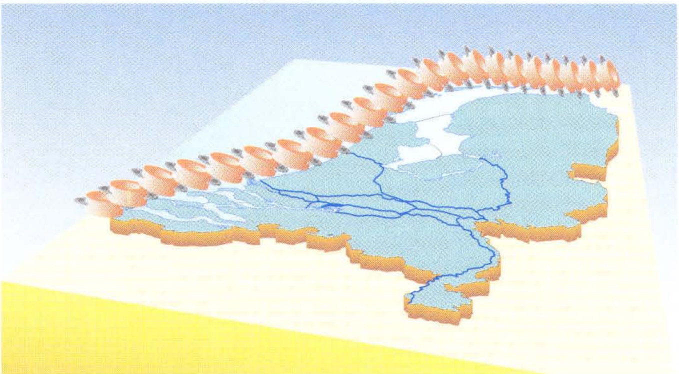


Figure 13.2.2 The dune area as nature's backbone

flows into Lake IJssel: thus 52% stems from the river Rhine and 39% from the river Meuse.

In 1995 97% was pretreated with coagulation and flocculation, flotation or sedimentation and rapid sand filtration. This has had a tremendous effect on the operational problems related with clogging of the infiltration ponds. Since coagulation was included in most pretreatments in the mid 1970s, cleaning the ponds is not required. Since early 1996 the remaining 3% is also pretreated with at least filtration. Additional treatment, for instance active carbon filtration, required to meet conditions dictated by government and province, is subject to discussion. The standards with respect to micropollutants in the infiltration water are under study.

Until 1990 all recharge took place in ponds, basins, canals and pits with so-called open recharge predominantly along the North Sea coast (Figure 13.2.2). The water is abstracted primarily with wells and drains and also with some horizontal radial collector wells and open abstraction canals. The quantity infiltrated with surface spreading was 179 million m^3 in 1990. The open water (the area of all means of infiltration) was 307 ha and the territory used by all AR-systems (the amount of space of infiltration and abstraction and the region in between) was 2405 ha. So the specific area used by open AR-systems is 13 ha/(million m^3/year) on average.

The area ranges between 4 and 25 ha/(million m^3/year). The average entry rate or flux is 0.6 million m^3/year/ha (ranging from 0.2-2.0) or 0.16 m/day (in the range 0.05-0.50). Travel times are in the range of 20 to 200 days. Open recharge has proved to be a valuable technique with which unreliable surface water can be turned into a safe source for drinking water. However, only the phreatic aquifers are used. Moreover, there has been substantial opposition because of the effects on landscape, nature and the environment as described in the next paragraph.

Side-effects of surface recharge

The flora and fauna of 40 000 ha of coastal dunes (less than 1% of the surface of the Netherlands) are very rich. Approximately 70% of plant species that are found in the Netherlands are present in this area, especially in dune slacks. Almost 10% of species occur exclusively in the dunes. The abundance of plant and animal species is prominent compared to other areas of comparable size. This is caused by the relative absence of human activity, the huge diversity in gradients and process conditions caused by wind, water and soil. The dune area as a whole is the essential backbone (Figure 13.2.2) of the 'Ecological Structure', a concept of government policy concerning nature.

In 30% of this dune area the water table is affected by abstraction of fresh water. Artificial recharge counteracts this.

In 6% of the area the landscape and vegetation are altered due to the excavation and operation of recharge basins. The disadvantages of artificial recharge are the introduction of water that, however pretreated, is eutrophic; unnatural fluctuations of the water level, infrastructure and human activity for maintenance, monitoring and operation.

Excavation for basins and ponds causes a disturbance of the subsoil. Major plant nutrients promote growth of plants in and along the basins. Recharge and abstraction cause the groundwater level to rise and fall in an unnatural way. Thus matters have changed and enlarged basin-type-recharge and recharge at other dune locations are no longer accepted.

Future trends

Related to artificial recharge a number of trends occur. First of all, both the quantity that is infiltrated and the number of sites are expected to expand. However, it is government policy to guard the 'Ecological Structure' against further ecological impacts. So well recharge is contemplated as an alternative for open recharge. The most extensive AR-systems are in the province of South Holland. The terrain compared to the amount of water production is large. There are plans to reduce the open recharge in the most valuable and vulnerable parts and to redesign and intensify other parts in order to accomplish interesting conditions and biological diversity. Also there is ecological engineering and (re)design of open recharge systems to improve biotopes or to reduce the effect on natural values. Furthermore there is a tendency to recharge aquifers with pretreated surface water near groundwater abstractions as an alternative for groundwater withdrawal to prevent any further loss of wetlands.

In the 1950s the waterworks started research on the use of deeper aquifers for 'aquifer treatment' of surface water. At larger depth the layers are thicker. Sometimes however, these are saline or brackish. Recharge experiments with test wells have been carried out in the 1960s, 1970s and 1980s.

The great difficulty of using recharge wells has always been their rapid clogging. That is why a lot of research has been carried out to discover the causes. It was found that main causes are suspended matter in the water, organic matter (growth of bacteria), gas bubbles ('air binding') and mixing of dissimilar waters before injection. To have an indicator of the main causes of clogging two parameters have been developed. One is MFI. It is considered as an indicator for clogging by suspended matter. AOC is a parameter that indicates whether clogging due to growth of bacteria is to be expected. The problems that occur when oxic and anoxic (containing iron) groundwater is mixed just before injection are very well known. Filter slots will get clogged very rapidly by iron-rich biomass.

It was concluded that problems with clogging can be overcome or largely avoided by proper exploration, good design, construction and operation and adequate pretreatment. In 1996 two well recharge systems were in operation, another two are under construction. As yet 95% of recharge is carried out by surface spreading. There are plans to stop open recharge in the most valuable and vulnerable sites and to redesign and intensify other ones in order to achieve interesting conditions and biological diversity. Also there is ecological engineering and (re)design of open recharge systems to improve biotopes or to reduce the effect on natural values. In optimization according to the concept of 'Open Infiltration New Style' the recharge system:

- is quasi natural instead of artificial;
- fits the landscape;
- has adequate pretreatment to reduce nutrients;
- is intensified to reduce the area occupied by the system;
- is (re)designed to create natural geographic gradients;
- is in natural and constant operation to reduce unnatural changes of the water table;
- is one in which regular activities for cleaning, monitoring and operation are minimized or absent.

The Netherlands is a flat country with shallow groundwater tables. It is observed that these water tables decline partly due to groundwater pumping. In the last three decades the average water table has dropped 30 cm and calcium-rich seepage has been reduced, influencing natural conditions. It is judged that the amounts that can be abstracted are limited. Maximum amounts are imposed by the provinces. This is the reason that waterworks choose to inject pretreated surface water near well fields already in use for pumping. In this way the net abstractions do not increase, or are reduced, and so are the effects on the environment. Thus on the one hand any further loss of wetlands is prevented, and on the other hand waterworks can continue to operate the existing systems of pumping, treatment and distribution. The trend is for new recharge systems to be planned because new or enlarged groundwater pumpings are no longer permitted.

13.3 Coastal zone management

H.J. de Kruik[3]

The Dutch Coast

The Dutch coast is made up of dunes, dikes and other water barriers. Together they protect the low areas of the Netherlands against the North Sea. The dunes represent about three-quarters of this line of defence, varying in width from less than one hundred metres to several kilometres. In order to obtain a good impression of coastal processes, it is important to consider the first line of dunes (the foredune), the beach and part of the shallow sea floor (going down to approximately 8 m; the shallow shoreface Figure 13.3.1). The foredune, the beach and the shallow shoreface together form the coastal system, offering a natural,

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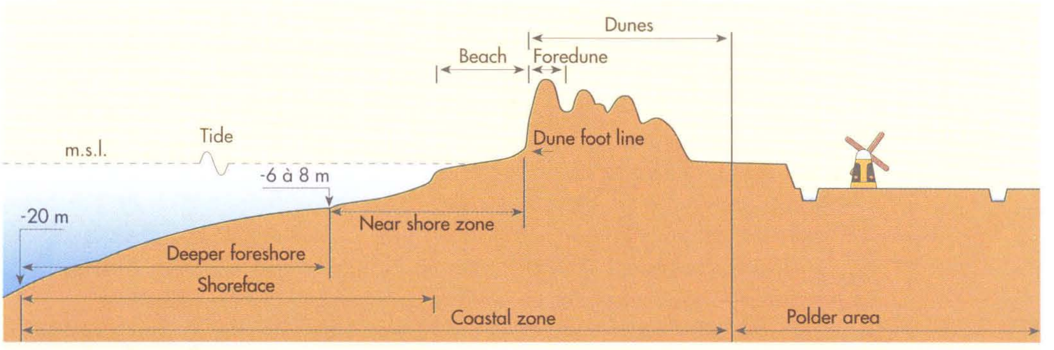

Figure 13.3.1 Cross section of the coastal zone

sandy defence to the sea. This system is also subject to the exchange and relocation of sand. As long as the sand is not lost from the coastal system, it plays a role in coastal protection.
The dune coast and the beach flats (occurring at the extremes of the Wadden Islands) are dynamic in character. Under the influence of the forces of nature, this barrier is constantly moving. At some locations there is sand accretion, at other locations erosion prevails. Erosion and accretion patterns may vary in time, but they are now well known. Comparable sand balance studies have been performed on different time and space scales.
Based on that information, shoreline predictions are made, indicating locations where accretion and erosion can be expected in the coming decades.
There are two forms of coastal recession: relentless, day to day erosion and the incidental damage resulting from storms. Walking on the beach after a storm, it may be noticed that part of the dune front has been washed away. This often looks quite alarming. In fact, such storm damage is less serious than continual 'creeping' erosion.

If the dunes are damaged as a result of a storm, this is a different issue to the perpetual erosion of the coastline. One of the characteristics of a natural dune coast is that a fresh-cut dune face forms a natural part of the landscape from time to time.

Furthermore, storm damage to the dunes is not permanent. During a storm, sand from the dunes is transported to the beach and the shallow shoreface. During periods when the weather is calm, the waves return the sand to the coast. The policy of coastline management is primarily intended to compensate for this ongoing erosion. Structural damage to the beach and dunes can be prevented by adding sand to the coastal system (nourishment).
Current policy with regard to coastal protection (dynamic preservation) utilises the natural processes along the coast wherever possible. This allows our coast to maintain its characteristic appearance, with special natural qualities for northwest Europe.

Coastal defence policy

Public discussion on a new national policy for coastal defence started in the 1980s. Until 1991 an ad-hoc policy was followed: measures were only taken when the

safety of the polderland was at stake or specific values were threatened. In 1989, the Discussion Document, including four policy alternatives was launched. Out of the four policy alternatives the preservation alternative was almost unanimously preferred by all parties. In November 1990, the national Parliament ratified the Preservation alternative.
This policy choice is primarily aimed at enduring safety against flooding and sustainable preservation of the values and interests in the dunes and on the beaches. To emphasize the wish for the preservation of the natural dynamics and character of the dune coast, the chosen alternative was specified and called 'Dynamic Preservation'. Important aspects of the policy choice include a yearly budget for coastline maintenance (NLG 60 million, 1990 price level), administrative measures and the choice for sand nourishment as the main method to combat erosion.
The policy choice in 1990 marked a new era in coastal defence policy in the Netherlands. The most important aspect of this choice is that for the first time in history the coastline is to be maintained at a fixed position: all structural erosion is to be counteracted.
For the dikes, dynamic preservation of the coastline means that the dike remains strong and in place. For beach flats, this offers maximum freedom for natural processes, while for the dunes a standard of reference will be agreed on which cannot be compromized any further. This reference standard is known as the basal coastline. The basis for this basal coastline is the position of the active volume of sand. By calculating this position, local fluctuations will be filtered out. If the actual coastline trend threatens to pass the basal coastline due to continual coastal erosion, timely preventative measures will be taken. In practice, this implies the execution of sand nourishment. Every year, the position of the coastline is measured and compared to the reference standard: the basal coastline.

The results are presented in Coastal Charts. These charts are used as a basis for the annual sand nourishment programme. The Department for Public Works and Water Management draws up an indicative work programme for nourishment projects. The indicative work programme is discussed in the Provincial Consultative Bodies for the Coast (the so-called POKs), where all parties involved in coastline management can express their opinions. The POKs report to the Minister, who then determines the programme of nourishment works for the following year.

The work is then contracted out to dredging companies, who carry out the sand nourishment required. The sequence of activities as described above is repeated every year. There is a two-year interval between coastal monitoring and coastal nourishment. For example: the coastal measurements carried out in 1996 will eventually lead to the nourishment works carried out in 1998, and so on.

Institutional and legal framework
Coastal defence in the Netherlands is not only a State affair. Provincial authorities and local water boards have specific tasks, as outlined in the Flood Protection Act (1995).

The tasks are divided according to the following system:
- water boards manage dikes and dunes: they maintain them in the technical sense and they strengthen the dikes and dunes if necessary; they protect them from

damage by acts of man. No one is allowed to do anything in, on, or near a dike or dune without a licence from the water board;
- provincial governments supervise the water boards in the execution of their technical duties, but also in their administrative and financial powers. Provincial governments have the power to give the water boards instructions;
- the central Government in particular the Minister of Transport, Public Works and Water Management supervises the provincial governments. The minister has the power to give the provincial government instructions, if province and water board do not execute these instructions, the minister can execute measures at the expenses of the water board.

Preservation experiences
In the last six years important steps implemented the coastal defence policy: Definition of the basal coastline, monitoring and evaluation of sand nourishment works (totalling 6 million m^3 sand per year).
Nature conservation organizations and ecologists fully support the policy choice of preservation of the coastline and the choice for 'soft' coastal defence methods (sand nourishment).
From the viewpoint of coastal defence, there are possibilities for natural development of coastal areas, although not everywhere and not unconditionally.

At some locations, the added sand is rapidly carried away via deep tidal gullies; this occurs, for example, near large tidal inlets in between the barrier islands in the north of the country. To carry out sand nourishment more frequently and in larger volumes could become a very expensive solution here. In such situations, 'hard' coastal protection measures (seaward solutions) in combination with sand nourishment can lead to cheaper solutions. For two locations along the Dutch coast feasibility studies are worked out for several alternative defence measures.
Innovative sand nourishment techniques are considered. In 1993 a shoreface nourishment project was carried out on the island of Terschelling at a water depth of 5 to 7 meters. A desk study has indicated that foreshore nourishment, under certain conditions, will be less expensive than beach nourishment.
Moreover, during the execution of a foreshore nourishment project, recreational activities on the beach are not interrupted.

The sand used for sand nourishment is taken from offshore in the North Sea. In order to ensure that the coast is not undermined and to minimize disruption of life on the sea floor, the sand is extracted at depths greater than 20 metres.
So-called trailing suction hopper dredgers are used to carry out sand nourishment. Since 1990, every year some 5 to 7 million m^3 of sand have been added to the Dutch beaches.

From the experience gained to date, it appears that sand nourishment holds a number of important advantages over other methods of coastal protection. The principal advantages are as follows:
- repeating sand nourishment is economical in comparison to the construction and maintenance of 'hard' coastal protection measures;

- sand nourishment fits in with the natural character of the Dutch coast. The natural processes along the coast are hardly disturbed and there are no negative consequences for neighbouring coastal sectors. The latter often does apply to dikes and groynes;
- sand nourishment is a very flexible approach towards combating coastal recession: it can be utilized virtually everywhere, is easy to adapt with regard to sand volumes applied and it allows spreading coastal protection.

Future developments

An increase in sea level rise is, in combination with the subsidence of land, widely considered to be one of the most serious threats for low-lying countries such as the Netherlands. Future coastal zone management plans have to take into account the effects of global warming. The main questions are: what kind of effects will global warning have, and what will be the impact of (increasing) sea level rise? The Dutch coastal policy reviews three scenarios of future sea level rise; the rates are respectively 25 cm (present sea level rise without acceleration), 60 cm (expected sea level rise) and 85 cm (extreme scenario including 10% more wind and waves) in the next 100 years. For the preservation of the coastline, the additional costs (expected sea level rise) would be NLG 15 million per year, i.e. an increase of the present nourishment budget by 25%. Both in terms of finances and know-how the Netherlands can cope with the consequences of an increased sea level.

The situation in the Netherlands is less vulnerable than in many of the low-lying developing countries and several small island states, because sand resources are available from the bottom of the North Sea and the existing beach-dune system still has resistive capacities through its dynamic processes.

13.4 Urban water management

G.D. Geldof[4] and F.H.M. van de Ven[5]

Introduction

In former days urban surface water had mainly a storage function. Combined sewer overflows and stormwater out of the sewerage system had to be stored temporarily and had to be discharged to the sea or rivers as quickly as possible. The assumption was made that the quality of urban surface water could never be as good as the quality of surface water in rural areas. As a result, activities in the field of ecology never reached the city.

Nowadays urban water is approached differently (Figure 13.4.1). In urban areas, in contrast to rural areas, the surface water is used in a much wider, multi-functional way: recreational, hydrological and ecological functions are paired with the aesthetics of a pleasant urban landscape. Compared to rural areas, urban areas are subject to fewer restrictions in the dynamics of the system.

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Figure 13.4.1 Surface water in a Dutch residential area

From a hydrological point of view there are some specific differences between urban and rural water systems. Because of the large number of impervious surfaces in urban areas, there is less evaporation and part of the stormwater is discharged very rapidly. This can be judged as a drawback. However, there are also some benefits. Urban areas, for example, offer good opportunities for the collecting of stormwater to be utilized elsewhere.
There are now some more data available about the surface water quality in Dutch cities. These figures show that in areas where the old combined sewerage systems have been improved or replaced, the surface water quality is better than in an 'average' rural area. There is also greater ecological potential than expected. As a result, water managers in the Netherlands increasingly focus on revitalizing urban water systems. Research programmes are being undertaken to investigate the potential of urban water and to find solutions for the problems which still remain, such as the combined sewer overflows and the problems caused by groundwater levels which are too high or too low.

It is characteristic of the research into urban water management that a lot of attention is given to the relationship between sewerage systems, surface water and groundwater. This is an important step in giving form and content to integrated water management.

Sewerage systems

Traditionally two kinds of sewerage systems are applied in the Netherlands: the combined sewerage system and the separate. With the combined sewerage system the domestic or industrial wastewater and the stormwater are collected in one pipe and pumped to the sewage treatment plant. The problem with this sewerage system is that, in periods of heavy rain, the water cannot be adequately stored. Combined sewer overflows (CSOs) occur in which the stormwater mixed with wastewater flows into the surface water. This is unfavourable to the surface water quality. With separate sewerage systems, wastewater and stormwater are collected and transported separately. The system contains two pipes. The wastewater is pumped to the sewage treatment plant. The stormwater is discharged to the surface water. When considering the surface water quality, the separate sewerage system is also not optimal. In practice, there are many houses with wrong connections. As a result, some domestic wastewater is still discharged to the surface water directly. Also, stormwater from roofs, roads, paved areas and other impervious surfaces can be unacceptably polluted.

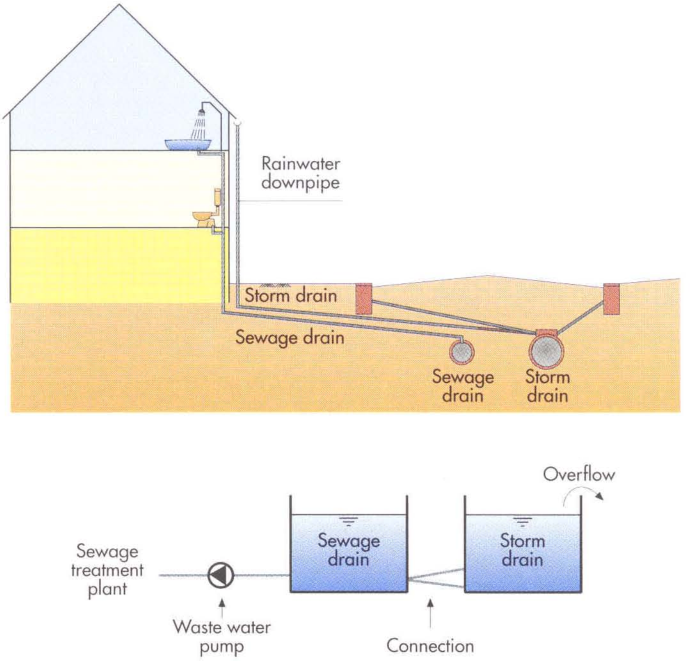

Figure 13.4.2 Schematic diagram of the improved separate sewerage system

Nowadays, in new residential areas the improved separate sewerage system is applied (Figure 13.4.2). This system is unique to the Netherlands. With this system the wastewater and stormwater are collected separately. The difference from the normal separate system is that the two pipes are connected to each other. The water from the stormwater sewer can flow to the wastewater sewer, but not the other way round. As a result, all the waste water is pumped to the sewage treatment plant, together with the most polluted part of the stormwater (the socalled first flush). The rest of the stormwater flows directly into the surface water.
Figure 13.4.3 shows an example of the connection structure between the two pipes. Because of this structure, the system is not susceptible to incorrect house connections. The improved separate system has many variations.

Over the last years a lot of research has been carried out into the relationship between sewerage systems and surface water quality. Thus, in 1989 the study of the National Working Group into the relationship between sewer systems and water quality (NWRW) was completed. The study resulted in a profound increase in knowledge about processes in sewer pipes and other sewerage facilities.
Many measurements have been carried out and many alternatives for quality improvements have been weighed up against each other.

As a result, it is not only possible to implement 'clean' sewerage systems in new residential areas, but is also possible to apply new techniques to improve the sewerage systems in existing areas. Many measures have been carried out to reduce the number of combined sewer overflows (CSOs).
These measures have been evaluated and the results published. A learning process is thus emerging.
Now a combination of organizations has put together the so-called 'Leidraad Riolering', the national guideline for sewerage systems.
A remarkable development of recent years concerns real-time control for combined sewerage system structures. Nearly all the sewage in the Netherlands is pumped, because the country is flat. By adding a central control unit to a sewerage system, the storage in the system can be utilized optimally. In hilly areas the potential for real-time control in combined sewerage systems is also good.

Groundwater

The Netherlands are located in a flat delta and the permeability of the subsoil is often very low. As a consequence, the groundwater levels in many areas are high, less than one metre below surface level. In urban areas this can give rise to serious problems. When there is groundwater in the crawl space or in the basement, moisture and fungus problems may arise in the house. This can affect public health. On the other hand, when groundwater levels are too low, problems may occur with the wooden pile foundations, which might rot.

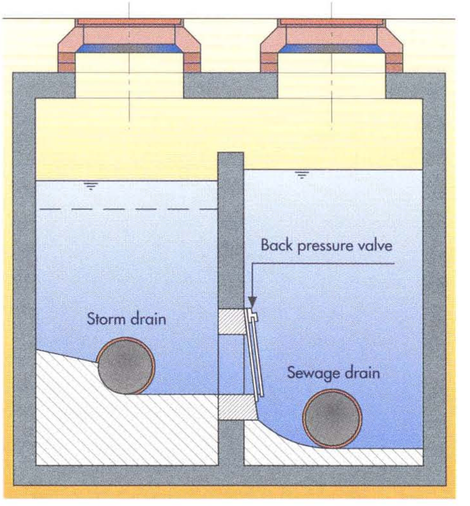

Figure 13.4.3 The connection structure of the improved separate system

At the end of the 1980s, research projects were initiated for looking into the possibilities for tackling the problems with groundwater levels. At first, attention was given mainly to the technical aspects of both the drainage and house construction. Nowadays, there is an increasing interest in the policy aspects of urban groundwater management. A good start has been made in solving the problems.

Source control

From the experience gained in looking at groundwater problems in urban areas, the insights into the urban water system have significantly increased. There is an increasing awareness that surface water, sewerage systems and groundwater have to be looked at in relation to each other. The urban water balance as a whole should be the starting point for taking measures to solve problems or for utilizing potential in urban areas. The more processes in urban water management are considered in an integrated way, the more attractive source control management becomes. Source control is the alternative to the end-of-pipe approach. With the end-of-pipe approach, as much as possible (polluted) urban runoff is collected and pumped to a treatment plant, so it can be treated centrally and under controlled conditions. For a long time this has been the basic philosophy. With source control, pollutants are tackled at or near the source as much as possible in order to prevent pollution of the runoff. Illustrations of source control are: the application of durable materials, the utilization of rainwater for washing and toilet flushing, the surface and subsurface infiltration of stormwater, purification of stormwater in reed beds or alder bushes, etc. Much of the research during recent years has focused on these techniques.

The infiltration of stormwater is one of the techniques with a great deal of potential. By infiltrating stormwater into the subsoil, instead of putting it to the sewerage system, combined sewer overflows and peak flows can be reduced and a contribution can also be made to improving the groundwater flow. Many nature reserves in the vicinity of urbanized areas are deteriorating due to problems with 'verdroging' of the soil, leading to a systematic decrease of the groundwater levels. As a consequence, nature reserves are deteriorating. Stormwater infiltration can be considered as a measure to restore the water balance. However, there is often a problem with the high groundwater table in the urban area.

Figure 13.4.4 Subsurface infiltration facility in Zwolle

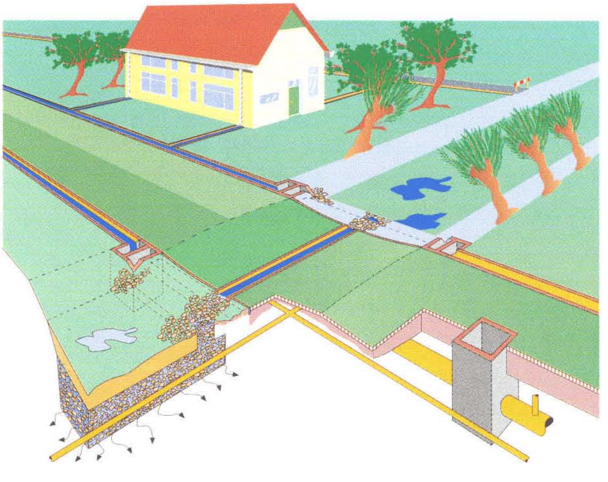

Figure 13.4.5 The 'wadi' as a structure for drainage and infiltration

One of the solutions to these problems is presented in Figure 13.4.4. It concerns the subsurface infiltration facility in Zwolle. Here, an infiltration trench has been constructed under the roads. To increase their stability, all roads in the Netherlands are founded on a bed of coarse sand. This sand is at least one metre thick.

By constructing the infiltration facility in this sand bed, instead of constructing it in the clay or peat soil, the infiltration capacity can be increased significantly. This makes it economically feasible to apply stormwater infiltration in areas with low permeability of the subsoil.

Figure 13.4.5 shows another construction. It concerns the 'wadi', based on the German 'Mulden Rigolen System'. The drain pipe running at the bottom of this facility acts simultaneously as groundwater level control and for draining the infiltrated water. Nowadays, both for new urban areas and existing ones, it is common practice to look for the BMP (Best Management Practice). For urban drainage based on the characteristics of an area, the best combination of measures is determined.

Solutions are explored in the spectrum of possible outcomes between source control and end-of-pipe techniques on one side and constructive and nonconstructive measures on the other.

Integrated water management

Within integrated water management two kinds of coherence are distinguished. The first one is internal coherence. This is designed to relate water quantity, water quality, groundwater and surface water to one another. A great deal of attention has been given to this kind of coherence. The efforts referred to in research into sewerage systems, groundwater and source control make this abundantly clear.

The second kind of coherence within integrated water management is the external coherence. This means that water policy has to be related to policies of physical planning, environment, nature, etc. For urban areas substantial progress has been made over the past decade. Recent research results show that a good external coherence is important for the multi-functional demands that are made on urban surface water. Giving form and content to the external coherence is essential for the shift from the end-of-pipe approach towards source control. To implement measures for source control, there must be a great deal of consultation with the parties involved.
Experience has been gained in involving citizens in the process of problem solving. It became increasingly clear that, to achieve a sustainable, multi-functional use of the urban water, efforts could not be restricted to a 'technical fix' only. On the other hand, technical analysis can provide the insight and support to install an urban drainage system as an integral part of the urban living environment.

13.5 The Aquatic Outlook, options for water policies in the long term

J.P.A. Luiten[6] and P. Huisman[7]

Sustained development is the target of almost every modern water management policy. The sustainability is focused on human life and the ecological quality of the environment. Both aspects are essential for life on earth. This means that well balanced relations have to be set between human activities and ecological aspects. Policy analysis may help to approach sustainability. Therefore it is necessary to acquire information on both ecological and economical aspects of water systems.

The essence of the exploration of the water systems is to obtain quantitative information on the physical, chemical and biological components as well as on the uses of waters within the catchment area, related to quantitative objectives and natural background values, and expressed in a minimum number of variables. It concerns state managed and regional waters, surface waters and groundwater, salt and fresh water and the influence of transboundary waters.

The project 'The Aquatic Outlook' of the Ministry of Transport, Public Works and Water Management aimed to provide the scientific base and policy analysis from which future water management plans could be derived. As a first step an inventory of the current water quality and actual users levels has been made and analysed.

The analysis will be supplemented by the prognosis for future quality and use. It requires an up-to-date information flow. The intention is to set up data banks. One of the conditions to realise the Aquatic Outlook is an adequate set of model instruments. These instruments support the 'prediction' of the future under influence of the actual policy in integrated water management. Further, these

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instruments make it possible to set up and to implement possible modifications in the policy. It provides the base for a policy analysis. The models aim to quantify the measures and impacts on the water and the socio-economic systems. For an objective assessment measurable criteria are necessary.

The Aquatic Outlook finally resulted in the report 'Future for water' 1996. The report concludes that many improvements of the aquatic ecosystem have taken place since 1985. However, the aimed improvements could not be realized everywhere.

The report also presents the perspectives of four possible water policies:
1 continuation of the current policy,
2 priority for human use,
3 maximal improvement of the water system by available and feasible technical means (system improvement),
4 realization of all target issues by available means and radical change in public behaviour (radical change in behaviour).

For details of the policies see Table 13.5.2.

The perspectives are based on the conditions of 1995. The time horizons for the policies are 2015 and 2045. The financial impact of the policies 1, 2 and 3 are quantified for the year 2015 in Dutch guilders (see Table 13.5.1). Policy 4 of 2015 and the policies for the year 2045 are described only qualitatively.

Table 13.5.1 Total costs of the three policies for the Netherlands society (in 10^9 NLG)

Alternatives	1995	2015
Current policy (1)	8.3	10.4
Priority for human use (2)		10.6
System improvement (3)		34.4

The findings of this study are (see also Table 13.5.2):
- the present policy shows many discrepancies with the 1989 formulated target situations. The discrepancies are caused by incomplete implementation of measures and growth of population, urbanization and economics. The evaluation shows that the implementation of the policy has to be continued to avoid bottle-necks in future;
- policy 2 oriented to solve bottle-necks for user functions and to promote the potentials of the water systems, shows almost the same results as policy 1. The reason of this outcome lies in the applied pro-criterion: the benefits of proposed measures must exceed the costs. Many measures taken to promote user functions did not meet this criterion;
- policy 3, maximally removing bottle-necks and serving the ecological potentials of the water systems, shows a considerable improvement compared with the present policy. Important measures taken to achieve these results are sharpening the policy concerning discharge of substances and rehabilitation measures;
- policy 4 shows that all target situations can be achieved but it requires considerable

Table 13.5.2 Summary of measures in the different policy options

category	current policy (1)	priority for human use (2)	system improvement (3)	radical change in behaviour (4)
local authorities	- sewerage plans - 75% P and N removal - connections for isolated buildings	- N removal at 1995 level - isolated buildings at 1995 level	- extra treatment phase - connections for isolated buildings disconnection of some rainwater	- same as system improvement - re-use of rainwater
industry	- discharge permission - agreements with target groups	- extra measures for chemical, base metal, paper industry and waste treatment	- extra measures for all sectors	- esp. clean technology, closed water cycles
agriculture	- integrated memorandum on fertilizer policy - Multi-Year Crop Protection Plan - legislation on surface water pollution by glasshouse horticulture	- largely identical to current policy - improved fertilizer distributors - stockshed measures	- more stringent policy on fertilizers - more stringent pesticides policy - wildlife-oriented management of ditches	- crop reallocation based on hydrology - extensification of rural areas - intensive 'industrial' agroparks
materials	- PAH measures for inland navigation	- gradual substitution in construction and renovation	- active replacement of materials - corrosion inhibitor in drinking-water	- use of non-objectionable materials only
road traffic	- policy on vehicle use	- same as current policy	- collection and infitration of highway runoff	-same as system improvement
maritime shipping	- tackling accidental and routine discharges of oil	- observance of international conventions on reducing oil discharges	- improved organization of port collection facilities encouragement of alternatives to Tributylin	- alternative energy sources - ecotax and special harbour dues - physical measures against anti-fouling coatings

social changes. It assumes a radical change in the economic conditions, all environmental costs are being passed on to consumers also on a global scale.

The costs of the present policy and priority for human use will increase by 1% per year, while the alternative system improvement requires 7% increase in cost per year. Two thirds of the increase in cost of systems improvement are caused by the application of hyperfiltration to all wastewater treatment stations. The Government will use this study to formulate the long term water policy and will decide in 1998 about the measures for the period 1998-2002 and future years.

13.6 Preservation of the Wadden Sea ecosystem

N.M.J.A. Dankers[8]

Introduction

An estuary can be defined as a coastal sea with a recognizable tide and a salinity gradient. The only remaining complete estuaries in the Netherlands are the Western Scheldt and the Ems-Dollard. In many aspects the Wadden Sea can still be considered an estuary. Since the construction of the 'Afsluitdijk' closure dam a natural connection with the river IJssel is no longer existent, but the sluices in the dike discharge fresh water and maintain a salinity gradient within the Wadden Sea.

The Wadden Sea (Figure 13.6.1) fulfils a number of functions which may be in conflict with one another. Because of long term human interventions a number of natural functions has been lost or decreased in value. Islands eroding on the North Sea side and accreting at the Wadden Sea and thus travelling inland with the rising sea level are now stabilized by coastal defence works. Gradients between fresh-, brackish and saline marshes have disappeared, and no rivers are freely flowing to the sea. The closure of the inland Zuyderzee caused the disappearance of an estuarine herring species which, in turn, caused the decline of the dolphin. Migrating fish such as houting and sturgeon have disappeared. Most salt marshes have been diked and slowly reproducing organisms such as whelks and rays have not survived the fisheries pressure. Biogenic structures such as oyster reefs, sabellaria reefs and mature mussel beds have disappeared or decreased in abundance or complexity.

Figure 13.6.1 The Wadden Sea: mussel-banks, gullies and flats at the Ballumerbocht near Ameland

[8] DLO Institute for Forestry and Nature Research, Wageningen

The grey seal disappeared in the Middle Ages, but is returning now. Some species such as common seal, eiderduck, tern and brent goose are abundant again after hunting stopped or breeding sites were protected.

However, natural causes have also had a great impact on biological parameters. The low stock of the herring was partly caused by a shift in currents in the North Sea. The subtidal eelgrass beds in the Wadden Sea disappeared because of a disease and the strong erosion of salt marshes is caused by an increase in mean high-tide levels by more westerly winds.

Research in the Wadden Sea is directed among other things at the quantification of dose-effect relationships of human impacts, the study of the relation of physical or biological processes and the ecotopes that are shaped and maintained by these processes.
When these processes are understood, and the habitat requirements of species or ecotopes are known, it is possible to maintain or create ecotopes which are considered worth conserving. Further studies are also needed to quantify the outcome of management practices.

Physical processes as 'critical capital'
From a nature management point of view the more important ecotopes are those which are formed and maintained by an interplay of physical and biological processes. If only physical processes are important, the regeneration ability will in general be good, unless the physical processes are prevented from acting. It is important to identify which processes are essential. These should therefore be considered 'critical capital'.
In the North Sea, the Wadden Sea and the estuaries, tides and waves cause the mixing of the water column, transport of sediment, nutrients and organisms. Light and temperature are responsible for the primary production. In the estuarine and coastal regions the tidal amplitude determines the large-scale morphology of the coastal area. Sandy coasts with a small tidal amplitude develop into a system of barrier-islands with intertidal flats between the islands and the mainland. Areas with a large tidal amplitude form an open coast with intertidal sand banks. The tidal currents together with wind and waves are responsible for the maintenance of gullies and tidal flats. Wind, and the availability of sand are the primary factors in dune and island formation.

Physical processes which have taken place since the last ice ages have determined the large-scale morphology of the North Sea. The southern part is characterized by a coarse sandy sediment in a shallow sea. The sediment is continuously moving because of tidal currents and waves. This sediment may be transported to the coast or into the Wadden Sea.
In the tidal areas along the coast several characteristic structures have developed. The Wadden Sea system is characterized by complete gully structures. That means, a tidal inlet, ebb and flood systems and main channels, which branch into small gullies and creeks in sandy or silty areas or salt marshes. Within the Wadden Sea system there is a diversity of tidal flats with sediment of different silt content and different exposure times.

In an interplay of physical and biological processes, salt marshes and dunes are formed. Some structures have a biogenic origin such as oyster and mussel beds, reefs of tube building polychaetes or eelgrass fields.

The Wadden Sea is a relatively young system. It has developed because of a sea level rise during the last 6 000 years. It is uncertain whether present changes in sand banks and coast line are due to the fact that the system has not reached a balanced climax situation or whether changes are due to changing natural conditions which may occur in long-term cycles (more than 100 years). Some geomorphological developments can be observed on even shorter time scales.

The western Wadden Sea developed after inundation of fresh and brackish marshes in the 12th century. The eastern part is older, but was also influenced by large inundations. Because of sedimentation and reclamations the area has been reduced considerably since then.

The area near the tidal inlets is very dynamic. Sand banks in the tidal inlet migrate in a clockwise direction and cross over to the next island. The sand moves along the island as a wave. The tip of the island shows a cycle of growth and erosion, depending on the availability of sand. On some high sand flats vegetated dunes may develop. Occasionally these islands move in the direction of the sand transport, and may eventually disappear.

In quiet places under favourable conditions a salt tolerant pioneer vegetation may develop on tidal flats. When the pioneer vegetation is succeeded by a vegetation of the next successional stage, the young, low-lying salt marsh will maintain itself by enhancing sedimentation. In a period with sea-level rise, the marsh will grow higher but if the tidal flat lags behind, a cliff will be formed along the marsh. Subsequently the marsh will erode until a new vegetation develops on the bare, gently sloping tidal flat.
Although the system as a whole will contain the major elements of a marine or estuarine system, any specific part of the area may not contain all elements every year.

Dynamic elements of the 'critical capital'
It is essential to determine which elements of the ecosystem must be regarded as 'critical capital'. Critical capital are elements which are essential for the maintenance of the system and cannot be replaced when destroyed. It can be processes, geomorphological or biogenic structures, species, or elements like scenic beauty.

The critical physical actors are tide (both amplitude and horizontal tidal flows), river runoff, wind and waves. These can be influenced by coastal engineering works.

Critical biological parameters are: primary production, secondary production, predation and breakdown of organic matter. Large-scale influences on these parameters can occur through increase in turbidity, pollution, regularly occurring anaerobic conditions or large-scale impacts on population parameters such as birth or mortality. These last mentioned impacts can be caused by disturbance, collecting, hunting or fisheries.

For complex biogenic structures the critical factor is time for development. Chronic impacts, for example fishery on mussel beds, will hinder development.

Research and management practices

Present investigations are aiming at understanding the most important processes and their function in the formation and maintenance of ecotopes. Another direction of research is studying the impact of earlier mentioned human activities. Based on the results of these investigations, activities are now being undertaken to improve the present system and restore lost ecotopes. In the man-made salt marshes the function of gullies and creeks for import and export of water, sediment and organic matter is now sufficiently known, and on the basis of this knowledge new designs for gully systems are being tested. These designs resemble natural creeks, and it is expected that they will maintain themselves. New management practices of the discharge sluices are being tested, based on the knowledge of the requirements of migrating fish. The result is a strong decrease in skin diseases in flounder, and a better stock of flounder in Lake IJssel. Management plans in the fishery sector, based on the knowledge of regeneration capacity, seem to be leading to a re-establishment of mature mussel beds and maintaining or improving the carrying capacity for birds.

Research in future will have to be directed more at quantifying the results of management practices. For a sensible quantification it will be essential to compare the results with a goal. Setting the goals will be a great challenge, and for a quantification of this goal it will be essential to carry out investigations in reference areas.

13.7 Improvement of fish stocks in inland waters

W.G. Cazemier[9]

As the quality of the river Rhine is of great importance for water quality in a major part of the Dutch wetlands, the objectives of the Rhine Action Programme (RAP), as formulated in 1986, are of great interest to the Netherlands as a whole.

One of the most daring objectives is the rehabilitation of the aquatic ecosystem of the Rhine in a way, that presently extinct species such as the Atlantic salmon (Salmo salar) could again be part of the fish fauna in the year 2000. In that case, it is assumed, the Rhine will most probably be suitable for other vulnerable species as well.

A wide variety of fish species, including a significant proportion of anadromous and vulnerable freshwater species, is considered as an indicator of good water quality in the main river. Anadromous populations, because of their biology, require specific hydro-morphological conditions. These conditions were lost due to weir and dam construction.

[9] Netherlands Institute for Fisheries Research, RIVO-DLO, IJmuiden

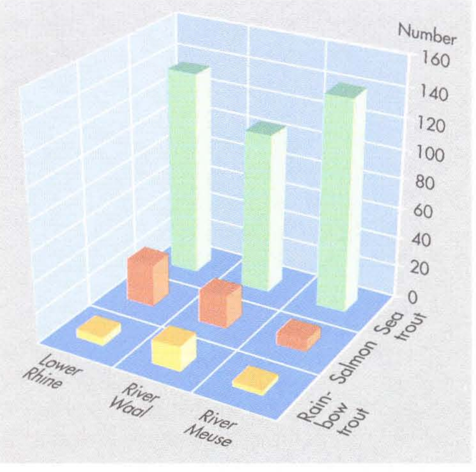


Figure13.7.1 Presence of migratory fish in 1995

In addition, following sudden toxic emissions into the water, fish mortality, especially of the most sensitive species, is mostly the first indicator of pollution and its source.
The international RAP programme has initiated many activities in the watershed: the status of spawning places was studied, nursery areas and possible obstructions for migrating fish have been assessed, water pollution has been monitored and reduced, fish passes have been constructed, and migration of fish through these facilities has been studied.

Young as well as adult salmon and sea-trout (Salmo trutta) have been released, marked and tagged, in order to follow their migration patterns. Changes in the quantity and quality of the fish fauna have been monitored on a permanent basis.
The Netherlands contributed substantially to these programmes. The Netherlands Institute for Fisheries Research (RIVO-DLO) is closely involved in the above mentioned programmes as well as in the planning of activities, and acts as an advisor to authorities.
The activities have been rather successful. Water pollution has decreased substantially. Adult salmon and sea-trout have again returned to the rivers Rhine and Meuse and accomplish their upward migration in these rivers (Figure 13.7.1). Spawning activities of these salmonids have been detected in a German tributary of the Rhine and there is substantial evidence that this resulted in healthy offspring. Young salmon and sea trout, descending the river on their way to the North Sea, have been regularly observed. River and sea lamprey (Lampetra fluviatilis, Petromyzon marinus) and river fishes such as barbel (Barbus barbus), chub (Leucscus cephalus), bleak (Alburnus alburnus) and bullheia (Cottus gobio), are regularly being caught again.

The present programme should be followed up by a variety of measures, as the objective of a stable, self sustaining population, especially of the anadromous salmonids has not yet been reached. This challenge will be taken up by the national organizations involved. More fish passes have been planned in tributaries and even at huge weirs in the Upper Rhine to offer the salmonids the possibility to reach more of the former spawning places. In the Netherlands the number of fish passes planned in the river Meuse and Lower Rhine will be completed and other measures will be taken to make the river morphology more suitable as a biotope of the wanted species.

13.8 Groundwater flow systems and the distribution of hydrochemical types of water in the west of the province North Brabant

R.J. Stuurman[10]

Introduction

Since TNO has mapped the hydrogeology of the Netherlands at a scale of 1:50 000, attention has been shifted to processes of groundwater flow. This involves applying hydrological systems analysis in an attempt to elucidate spatial relationships. The mapping of the groundwater recharge areas and the seepage or exfiltration areas linked to them by groundwater flow is an important item. Furthermore, during hydrological systems analysis special emphasis is given to determining the processes between the various components of the water system: surface water, groundwater, soil and sediment. The quantitative, qualitative and ecological interactions between these components and the connected water-dependent ecological features need to be understood.

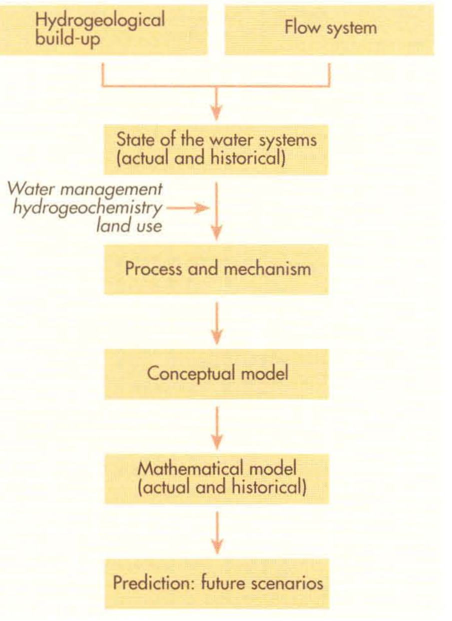


Figure 13.8.1 System approach of geo-hydrological problems

The first phase generally involves creating a conceptual model of the present and historical states of the water system. This information is used in a subsequent phase, for quantification by means of a numerical model study. Ultimately it is possible to predict the impacts of planned interventions or changes (Figure 13.8.1).

Some of the results obtained during studies commissioned by the water managers in the province of North Brabant are outlined further on. Most of these studies were conducted as part of attempts to restore nature conservation areas suffering with 'verdroging'. 'Verdroging' is a serious threat to ecological features in the Netherlands. The 'verdroging' processes have often brought drastic lowering in the water levels and changes in water quality of many nature conservation areas.

The development of groundwater composition

In general, water quality is under grave threat. Clean water is essential for drinking water supplies and for ecological features, and therefore the systems analysis pays much attention to the chemical state of the groundwater and surface water. To complement this information, the age of the groundwater is often ascertained from isotopes (carbon 14, tritium), so that the transport or travel time can be determined.

The mapping makes use of a classification of water types, land use maps, the geochemical properties of subsurface formations and all existing water analyses. It is often necessary to sample additional groundwater filters, too. The costs can be slashed by using the groundwater filters already installed for watering livestock,

[10] Netherlands Institute of Applied Geoscience TNO - National Geological Survey, Delft

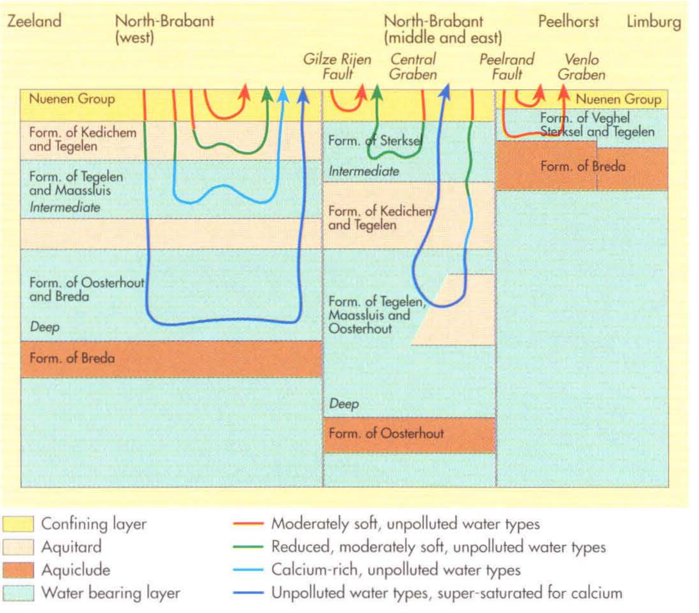


Figure 13.8.2 The changing water quality of percolating water under areas of natural vegetation in the Province of North Brabant

irrigation or industry. In addition, inexpensive chemical field kits can often be used to determine the water type.

The composition (geochemical properties) of the medium through which the groundwater flows is crucial for an understanding of the distribution of chemical water types. Yet little is known about this, and systematic research has only recently begun. Fig 13.8.2 shows the development of the groundwater composition in the west of North Brabant, in relation to the geochemistry and flow pattern. The surface formation is a thin layer of non-calcareous aeolian material (some of it eroded), largely comprized of quartz grains. This overlies a fluviatile formation of intercalated extremely fine sand and clay, which is also non-calcareous but has a relatively high organic matter content and contains many pyrite/marcasite crystals. Under this formation there is an aquifer, marine in origin and consisting of coarse sands. It is separated from the deeper aquifer by a thin layer of clay (Kallo clay). The hydro-geological base is composed of very poorly permeable Tertiary sands and clays.

The geochemical structure described above has the following consequences for the groundwater composition. Acid rain that infiltrates no further than the top layer will become more acid as a result of evapotranspiration and processes of denitrification. Locally, where aluminium hydroxides occur, it becomes extremely acidic and contains high concentrations of heavy metals. When this type of water then flows through the shallow poorly permeable formation it deoxidizes rapidly, loses its nitrate, and any iron it contains goes into solution. This is accompanied by a decrease in acidity. When it reaches the first aquifer this groundwater becomes basic as a result of dissolving fragments of sea shell. The calcium concentration here (c. 40 mg/l) is in equilibrium with the carbon dioxide supplied from the soil. If it infiltrates deeper, through the Kallo clay, and reaches the deeper aquifer, this water becomes supersaturated with calcite (calcium concentrations of about 100 mg/l).

This indicates that there is a source of carbon dioxide in or immediately below the Kallo clay possibly as a result of methane genesis a process which produces carbon dioxide in addition to methane.

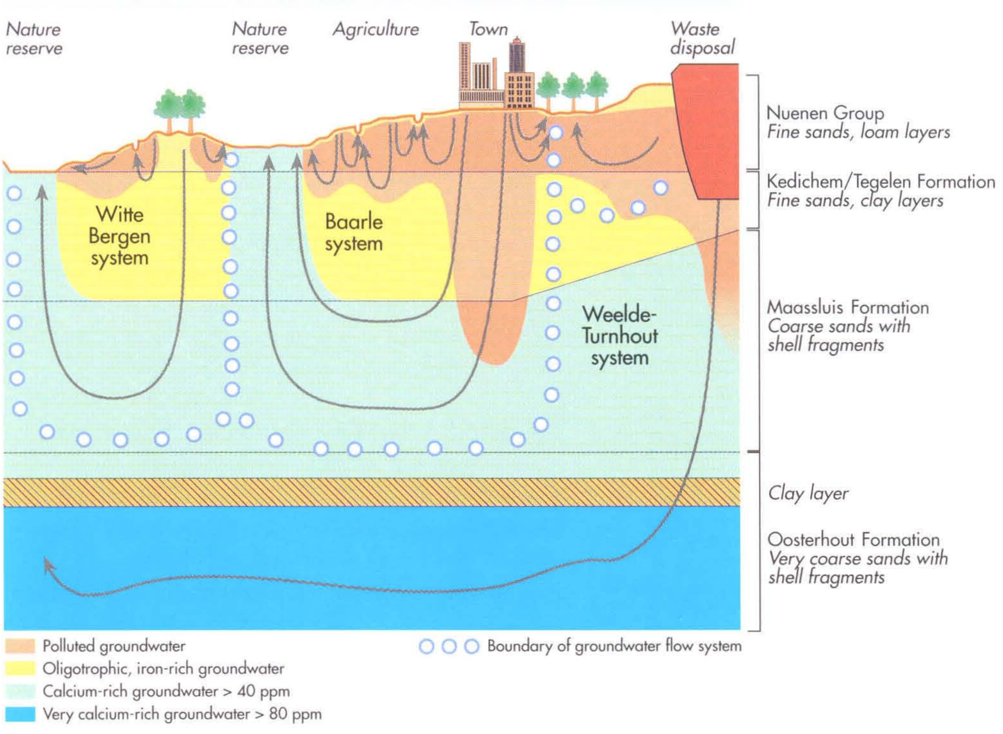


Figure 13.8.3 Nature depending on groundwater discharge is vulnerable to the type of land use. Especially land use in the infiltration area strongly influences the future quality of groundwater discharge

It is clear that this knowledge can be used to ascertain the depth from which shallow groundwater in exfiltration areas originates. If the water is iron-rich and calcium-poor, it has only flowed through the sandy parts of the shallow, poorly permeable formation. If it is strongly mineralized and has a calcium content of around 100 mg/l, then it originates from the deepest aquifer (c.100-150 m).
The regional distribution of hydrochemical types of water Figure 13.8.3 shows an example of a map of water types. It can be seen clearly that the shallow water under farmland and built-up areas is polluted.
The shallow water under naturally vegetated areas is strongly acidified.

How deeply the water penetrates depends on the location within the groundwater system and the travel time. Only in the groundwater recharge areas does the polluted water reach the deeper aquifer. Within the intensely drained area between the infiltration and exfiltration areas, the polluted water generally penetrates no deeper than 10-15 metres. This is because the drainage network removes this shallow groundwater quickly and effectively (short flow paths). The result is that the quality of the surface water is largely determined by the quality of the contaminated, nutrient-rich shallow groundwater. In the groundwater recharge areas, pristine calcium-rich water rises up from great depths. From Figure 13.8.3 it is clear that at some time in the future the Manke Goren exfiltration area will be affected by polluted water flowing in from the farming area around Baarle Nassau and that the Kromme Hoek exfiltration area is under threat from agriculture

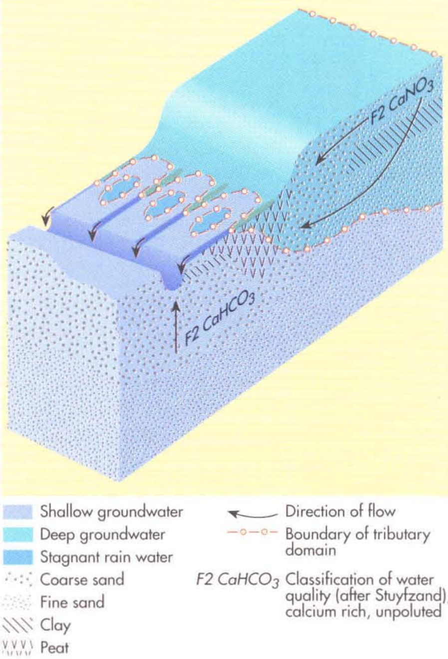


Figure 13.8.4 Groundwater in brook valley

encroaching on the Witte Bergen groundwater recharge area, which at present is still largely under woodland.

The local distribution of water types in a brook valley

The distribution of water types within an exfiltration zone is very important for water-dependent wildlife. In Figure 13.8.3 it can be seen that two flow components meet in the brook valley: a calcium-rich, pristine deep component, and a severely polluted, nitrate-rich shallow component. A third component is also important: the flow from local rainfall.

Figure 13.8.4 shows the distribution of these water types in a typical brook valley in Brabant. Most of the root zone here is still basic, because of the strong upward flow in winter and the presence of drainage ditches which remove the polluted shallow groundwater. Lenses of rainwater occur locally, where the water table has fallen and therefore rainwater is no longer removed with the overland flow of exfiltrating water but it is able to infiltrate.

Ultimately this rainwater zone will acidify after the buffer complex has been exhausted.

In many areas this natural distribution of water types no longer exists. As a result of the decline in the intensity of upward seepage and the fall in the level of water in the brook, clean deep water is now only found under the watercourse.

The relation between surface water and groundwater

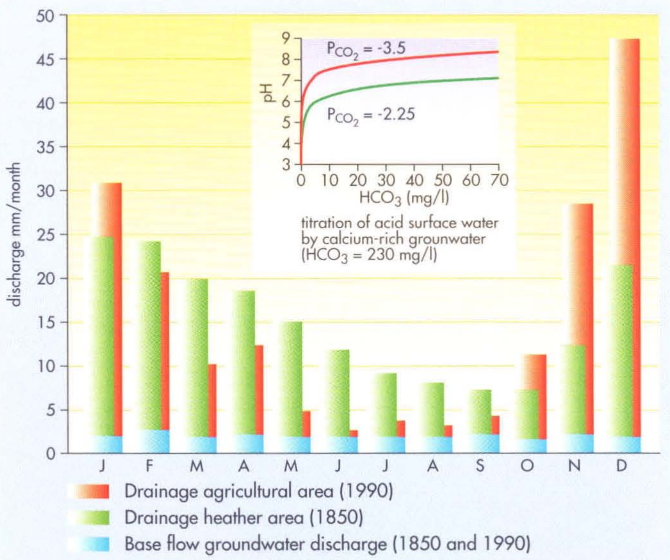
Surface water has an important influence on the ecological features in the brook valley in many ways. In the summer, the level of water in the brook plays a role in the genesis of the local water table. Surface water can also influence the root zone qualitatively, via flooding. Figure 13.8.3 shows that the brook discharges shallow drainage water from the farming area and also seepage from the brook valley. Formerly, an important part of the agricultural area was heathland, and the drainage was much less intense.

Nowadays the quality of the brook water is very poor because the shallow groundwater under the farmland is drained off, and in the summer the brook almost dries up. What was the 'natural' situation? A reservoir discharge analysis and geochemical computational models were used to reconstruct this situation. The result (Figure 13.8.5) indicates that the level of water in the brook used to be much higher in the summer. Strikingly, although 90% of the natural discharge used to be shallow, acid heathland water, the pH of the surface water was neutral. The calculations showed that the mixing of this water with a relatively small volume of basic upwelling water was sufficient to buffer it. This insight has important implications for the restoration of water systems, such as those where it is assumed that ecological features are related to flooding.

An integral analysis

The examples presented have demonstrated how the present state of the water system and the interactions and processes between its components can be studied.

This information is often necessary in order to be able to restore nature areas that have been severely degraded as a result of 'verdroging' and eutrophication. It has led to a widening of the hydrological researcher's field of work. Now, during the research greater emphasis is laid on understanding the relationships between the quantitative and qualitative processes. In addition, more attention is being paid to investigating the processes that play a role at the interfaces between the various hydrological subsystems (i.e. groundwater/surface water, aquatic ecology).



Many nature reserves at the Pleistocene sandy region are situated in the brook valleys. The actual water quality of the brook water is very poor due to drainage of shallow polluted groundwater on the agricultural areas. Due to canalization also discharge is more rapid than under natural conditions.
Using reservoir analysis combined with hydrogeochemical systems analysis the historical discharge distribution and water quality can be determined.
Under natural conditions the brook was discharging a large amount of shallow, former acid, groundwater out of the heather areas. In the brook valley this water was mixed with local calcium-rich groundwater discharge. Even with a small amount of groundwater discharge acid water changed into a neutral water type.

Figure 13.8.5 Reconstruction of the historical qualitative and quantitative aspects of the brook valley discharge

13.9 Integrated plan for the river Meuse

J. Nijhof[11]

The Meuse is very much a rain-fed river. The rate of discharge at Eijsden varies from less than 10 m^3/s in a dry summer to 3000 m^3/s under extreme conditions when there is heavy precipitation in the upper reaches see Figure 13.9.1. In the provinces of North Brabant and Gelderland, the river has been enclosed by dikes (Figure 13.9.2) since the Middle Ages.

During the first half of this century, to assist shipping, seven weirs were built, various bends were straightened and the river's summer bed widened.

[11] Grontmij Consulting Engineers, De Bilt

Figure 13.9.1 The catchment area of the Meuse

The river flows naturally, only where it forms the border between Belgium and the Netherlands and along its tidal section, though even these stretches have been dredged and straightened. Towards the end of the 1980s national discussions about sustainability started, which resulted in new objectives for the water scene in the early 1990s. The new national objectives concern an integrated approach to the protection against flooding, the stimulation of environment-friendly navigation and the development of large-scale wet nature habitats. In this framework the national and provincial Meuse authorities formulated the following objective for a Meuse Management Plan (vision and programme):
To maintain and effect the sustainable development of a healthy, safe and prosperous Meuse economy while protecting the ecology, beauty and recreational value of the river.

The river Meuse has many functions. Some, such as its use as a commercial fishing water, have declined, while others, such as its role as a source of hydroelectric power, have only recently emerged. The common prerequisites for most of these functions are: the need of water, the necessity for protection against high water, the demand for clean water and nature development.

One important aspect of the water management strategy is the integrated approach which is based upon the interrelationships between the relevant issues.
Possible developments involving the identified functions are assessed in relation to all the quantitative and qualitative considerations pertinent to the water system (Figure 13.9.3).

The study and assessment of the various functions has a number of stages (Figure 13.9.4).

- The development in question is examined to determine whether it is within the capacity of the water system (by reference to water quality objectives, etc.);
- Functional interrelationships are examined (is the development in question positive, negative or neutral in terms of its effect on other functions);
- A functional study is performed to determine the technical feasibility of the development in question (reconstruction, zoning, etc.);
- The development in question is assessed to determine whether it complies with all active and proposed policies;
- A judgement is made, which may be in favour of or against the development, or may take on the form of a recommendation that further research has to be carried out;
- To maintain and effect the sustainable development of a healthy, safe and prosperous Meuse economy while protecting the ecology, beauty and recreational value of the river.

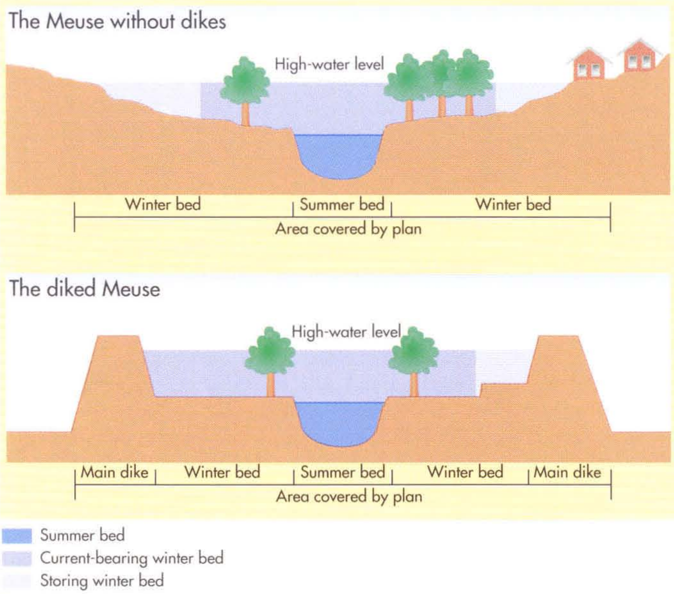


Figure 13.9.2 Cross-section of the Meuse

The management plan covers about 200 km of the river, including its winter bed and the quarry ponds lying within its winter bed, plus the three major canals connected to the river (the Julianakanaal, Lateraalkanaal and Maaswaalkanaal).
Much of the river's basin is in France, Belgium and Germany (with the basin of the Rur and Niers). In addition, the Meuse forms the Netherlands' 60 km long border, making water distribution and pollution control international issues.

The Meuse Management Plan emphasises:

- Safe discharge of water, ice and sediment;
- Careful water distribution in dry periods;
- Trying to make the Meuse a source of clean water;
- Optimizing the river's role as a commercial thoroughfare with recreational potential;
- Developing the river as an ecological artery with a characteristic identity.

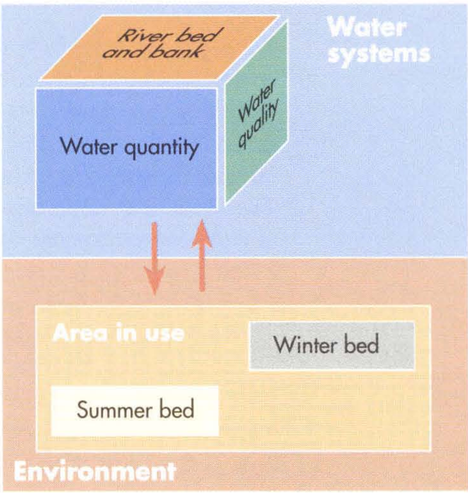


Figure 13.9.3 Interactions between water

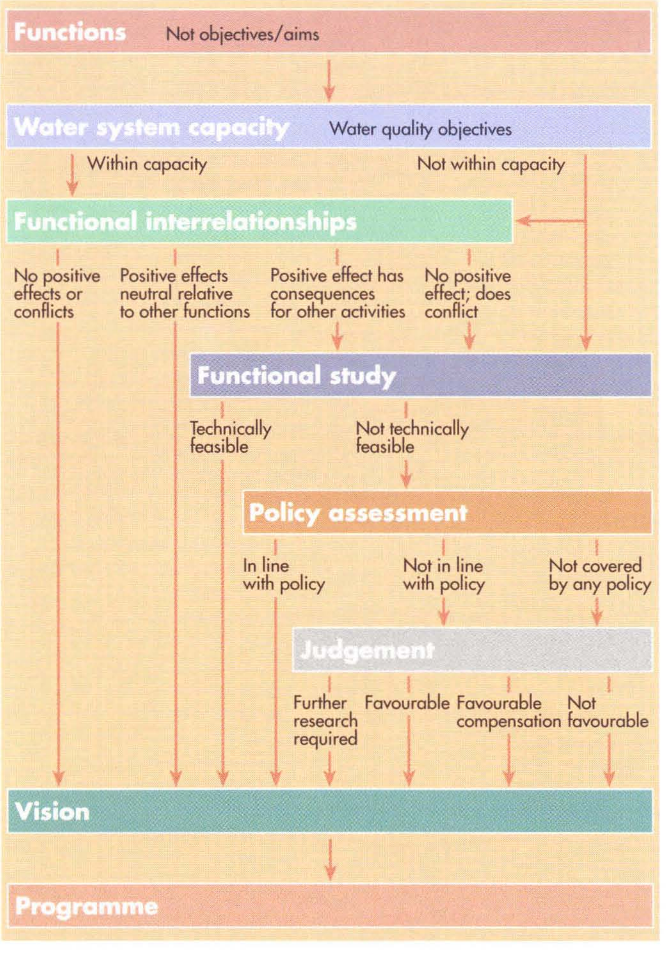


Figure 13.9.4 Problem approach of the Meuse study

It is important that the development and management of the Meuse is effected with the support and participation of the relevant governmental bodies and regional water authorities. From the initial formulation of the plan, the views and participation of those concerned have been invited. The aim is to bring about the integrated functions development of the Meuse through initiatives which have a broad impact and contribute to the realization of the primary objective.

Examples of such initiatives include:

- The proposed development of the Meuse along the Belgian-Dutch border as a river valley with secondary channel and riverine woodlands, through carefully judged mining schemes, bringing ecological, visual and recreational benefits, while also contributing to the safe discharge of water, ice and sediment. Similar initiatives are also possible at other points along the Meuse (Figure 13.9.5);
- Raising the water level in the weir-controlled stretch of the river, so that commercial barge operators could use deeper-draught vessels. This would inevitably mean raising the groundwater level, which would help groundwater-dependent flora and fauna in the affected areas, be of benefit to farmers and increase the scope for hydroelectric power generation;
- The Meuse is an important source of drinking water and its importance is increasing as groundwater extraction is reduced to combat the 'dry up' of the land, which is harmful to nature and the landscape, as well as to agriculture. Bank infiltration schemes along the river can be useful not only from the point of view of providing drinking water, but also by offering ecological and recreational perspectives;
- Not all functions fit easily within the plans for the future of the Meuse. Given the ever present danger of flooding, restrictions will be imposed on potentially vulnerable new residential and commercial developments within the river's winter bed. The amount of agricultural land within the winter bed will be further reduced over the next few years, allowing the development of natural habitats, landscape features and recreational facilities.

From the examples listed above, it will be apparent that the involvement and support of various governmental bodies and other parties will be required if the river is to be developed as planned.

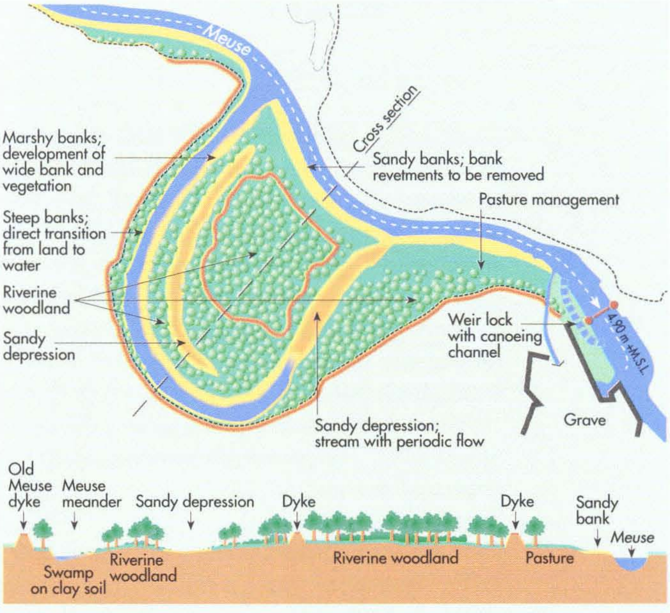


Figure 13.9.5 Rehabilitation plan of the Meuse near grave

The Meuse Management Plan outlines the framework within which the Limburg Directorate of Transport, Public Works and Water Management wishes to cooperate with other parties. Furthermore it presents the long-term vision and a list of projects to be carried out during the coming five-year period. Regular management and maintenance of the banks, river beds and hydraulic engineering works will take account of the ascribed river functions. Fish ladders will be fitted in the weirs, and access for walkers, cyclists and canoeists improved. The processes of granting and renewing licences under the Rivers Act and the Pollution of Surface Waters Act will be adapted where necessary. The International Commission for the protection the Meuse has the task to develop a joint approach to fight against the pollution of the river. Further, mechanisms for detecting and warning of sudden pollution incidents and high volumes of water will be developed or improved at the international level.

To help bring about the ecological recovery of the Meuse, the intention is that at least twenty-five metres of land on either bank of the river should be purchased or its freehold acquired.

The scope for developing riparian woods along the river banks or in its winter bed, possibly while also achieving relief reduction, will be increased.

In the next few years, environmental impact studies will be carried out to determine the scope for developing natural habitats on the border of the Meuse in combination with gravel extraction, and to establish what the consequences of deepening and increasing the water level would be in the weir-controlled stretch of the river.

13.10 Climate scenarios

A.M.G. Klein Tank[12]

General Circulation Models (GCMs) are the natural tools for studying the response of environmental systems to future climate change. They synthesize existing knowledge of the physical and dynamic processes of the climate system, allowing many of the complex interactions between the various climate components and the exchange of energy and water vapour at the surface. Nevertheless, hydrological impact studies generally need more detailed information about the possible future climate conditions for the site or region of interest than can be derived from GCM simulations. Due to their coarse resolution and simplified representation of atmospheric processes, GCMs lack a realistic description of climate variability (and extremes) at the small spatial scale and the short time scale the hydrologist is interested in. This mismatch between climate models and hydrological models is illustrated in Figure 13.10.1.

Over the last decades several methods have been developed to supplement the GCM simulations with a range of climate change scenarios at the appropriate resolution for hydrological studies. Four approaches can be distinguished:

1. transformation of a base-line climate series conforming with GCM predictions of large-scale changes in the seasonal means;
2. stochastic generation of local climate time series by adjusting the parameters in a time series model according to predicted changes in long-term means and variances;
3. stochastic generation of local climate series conditional on large-scale atmospheric circulation patterns (= statistical downscaling);
4. deterministic simulation of regional climates using a high resolution limited area model nested in a GCM (= deterministic downscaling).

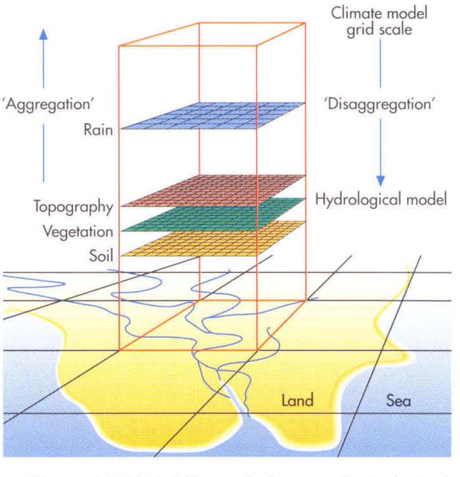


Figure 13.10.1 Mismatch between hydrological and climate models (after WMO, 1992)

The first method is most widely used. The advantage of transformation compared to stochastic generation and deterministic simulation is its simplicity and the fact that it automatically provides a realistic variability on daily as well as on longer time scales. But transformation is less appropriate for precipitation than for temperature as a result of the high spatial variability of precipitation and the deficiencies in the GCM representation of precipitation.

Recently scientists abroad have developed a statistical downscaling method and applied it to derive Iberian precipitation changes in winter, based on experiments with the GCM of the Max Planck Institute in Hamburg (Germany). The results show large

[12] Royal Netherlands Meteorological Institute, De Bilt

differences between model predicted rainfall rates and those derived using the model predicted circulation patterns. At the Royal Netherlands Meteorological Institute (KNMI) local precipitation series were transformed using the observed relation between mean precipitation and temperature.
The only GCM information required for such a precipitation scenario is the large-scale temperature change over the area of interest. Direct GCM predictions about changes in the seasonal means of precipitation are not used. The KNMI method is described briefly below and an example is given.

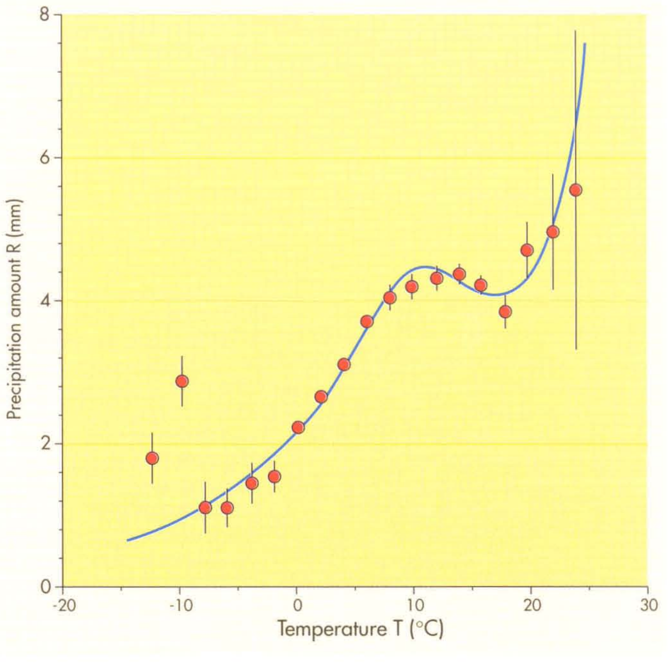


Figure 13.10.2 Mean precipitation mounts R (dots) at surface air temperature T class intervals of 2° C for wet days at De Bilt (1906 - 1981). The smooth curve represents the fitted regression relation, the error bars the standard deviations of the means (after Buishand and Klein Tank, 1996)

The increase of the maximum concentration of water vapour with temperature (Clausius Clapeyron relation) causes fronts and other weather systems to produce more rain at higher temperatures. This effect explains part of the relation between mean precipitation amount and surface air temperature for wet days (threshold 0.1 mm) at De Bilt in Figure 13.10.2. A notable exception is the behaviour in the intermediate temperature regime, where the mean precipitation amount decreases with temperature. This is caused by a decreasing activity of large-scale precipitating systems at temperatures > 15°C. These systems become rare at temperatures > 18°C, but then convective showers become increasingly active and the mean amounts rise again. The precipitation scenario is obtained by transforming the precipitation amounts on wet days using Figure 13.10.2.

The procedure is as follows:
1. apply a GCM-predicted change in seasonal mean temperature to all observed daily temperatures;
2. determine for each wet day the resulting relative change in the mean precipitation amount from Figure 13.10.2;
3. multiply the observed daily amounts by the calculated relative changes (multiplying factors).

In this scenario only the effect of a prescribed atmospheric warming is taken into account. The relative changes in steps 2 and 3 assume implicitly that the atmospheric

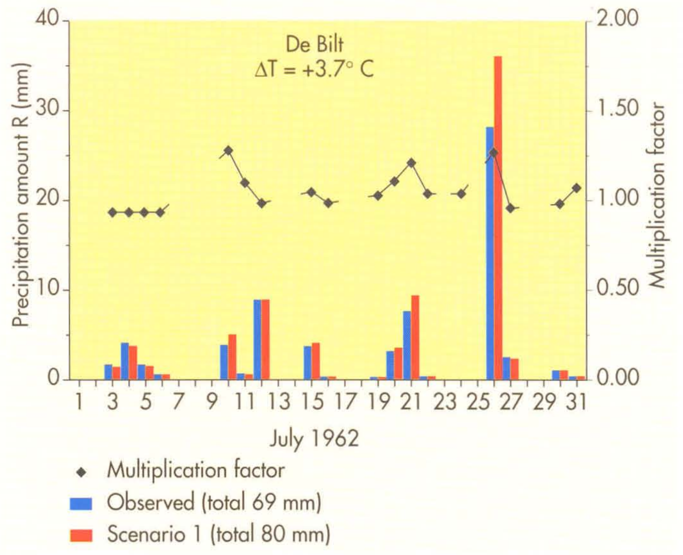


Figure 13.10.3 Precipitation amounts in the observed and transformed July 1962 month at De Bilt for scenario 1. The solid black squares represent the multiplying factors

circulation changes according to its present-day dependence on temperature. More flexible scenarios can be obtained by prescribing also a change in the atmospheric circulation.

The daily precipitation amounts in the 1961-1990 record of De Bilt were transformed by the above method. The prescribed changes in temperature (+3.0, +2.3, +3.7 and +3.4°C for winter, spring, summer and autumn, respectively) were taken from the Canadian Climate Centre GCM predictions of large-scale changes in the seasonal means ($2xCO_2$ $1xCO_2$ experiment). Figure 13.10.3 illustrates the effect of the transformation on the July 1962 precipitation data. The multiplication factors are also shown.

At De Bilt, the largest precipitation change (+20%) occurs in winter and the smallest (+5%) in autumn. The annual mean amount increases by 10%. These values differ considerably from the precipitation changes as predicted directly by the GCM for the nearest grid point (+28% in winter and no change on average over the year). An attractive feature of the transformation method is that the scenarios and their updates can easily be implemented in impact studies. The transformed daily series have a realistic variability at daily as well as at longer time scales and extreme cases for sensitivity studies can be constructed from past (extreme) episodes. Scenarios in the form of monthly, seasonal or annual time series can be obtained directly from the transformed daily series.

13.11. Soil-water-vegetation-atmosphere interactions and their role in studies on land use and water management

J. Schouwenaars[13]

Introduction

In agriculture, forestry, nature management and a wide range of environmental issues, the interactions between soil, vegetation and atmosphere play an important role. Studies in this field focus on the exchange of momentum, heat and water. During the last decade several research groups formed by soil scientists,

[13] University of Groningen, Faculty of Biology, Groningen

meteorologists, hydrologists, agronomists and ecologists have made important progress in understanding soil-water-vegetation-atmosphere interactions for the assessment of effects of alternative management options.

As a result there is now a wide range of physically-based models available for the description of water and heat transfer.

Water transport in the root zone
Over the years and in a number of different research projects in the Netherlands, measurements have resulted in the establishment of a data base, containing 620 measured soil hydraulic characteristics (water retention curves and unsaturated conductivity). All soil horizons measured were classified according to soil texture and type of horizon. In this classification procedure 18 different texture classes are distinguished for both top and subsoils. After grouping the measurements in the appropriate texture class, geometrically averaged hydraulic characteristics are calculated for each one. Linking this 'Staring Series' with the soil map gives an areal description of the soil physical composition of the unsaturated zone. This procedure is currently being used in a wide variety of regional studies on land use and water management.
Soil water balance measurements could profit from improved techniques like time domain and frequency domain reflectrometry. After pilot experiments with an osmotic tensiometer, showing high accuracy up to -16 Bar pressure head, more detailed studies have started on its applicability in field studies.
In studies on groundwater recharge in the sandy region of the Veluwe, ground radar equipment was used to measure changes in soil water content at different depths. Further improvements are necessary.

Several problems related to water transport in the unsaturated zone remain and are subject to ongoing studies, such as those related to preferential flow.

Preferential flow
In soils, transport of water is often heterogeneous with part of the infiltrating water travelling faster than the average wetting front. This has important consequences for simulating the soil water balance and therefore on the calculation of crop water use, crop yield, solute transport and pollution of groundwater and subsoil. In sandy soils unstable wetting fronts and hydrophobic properties are responsible for preferential pathways.

A large part of the Netherlands is covered with clays and peat. The continuous swelling and shrinking of these soils result in much attention being given to preferential flow related to cracking and subsidence. The properties of these macropores are related to the soil water content. Using field observations combined with simulation modelling, the researchers have tried to develop improved concepts to describe soil water movement in these soils.

Predictive models for vegetation development
In the last decade Dutch agronomists and soil scientists have contributed significantly to the development of our understanding of crop growth in response

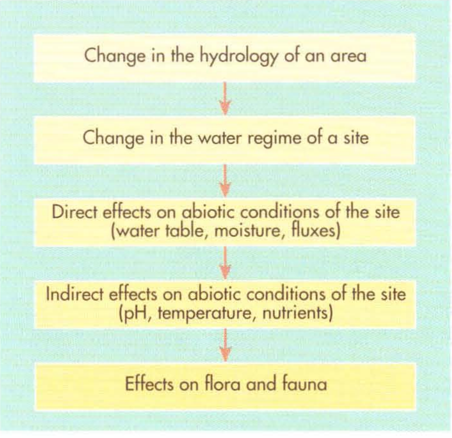


Figure 13.11.1 Schematic diagram of the relation between changes in the water regime of an area and the effect on ecosystems

to environmental conditions. In several international agronomical projects, crop growth models are implemented for scenario studies. These studies vary in scale from individual management problems (e.g. sowing date, use of fertilizers) to regional problems (crop forecasting, early warning) and international policy studies (e.g. scenario studies for the European Union).
In most models, developed in the beginning of the 1980s, crop growth and production was considered only for crops well supplied with nutrients. Currently, the growth under nutrient limited conditions is receiving more attention leading to improved simulation models for nutrient dynamics in the soil-water-plant system. Field experiments and laboratory studies are set up to describe the carbon, nitrogen and phosphorus cycle and their interrelations.
Plant physiological research has revealed that stomatal aperture of many plant species is reduced by CO_2. The changes in transpiration to be expected as a consequence of atmospheric CO_2 concentrations are studied for different types of vegetation such as agricultural crops and forests.

Ecohydrology
Ecohydrology is an interdisciplinary field in which hydrologists work together with soil scientists and ecologists. Changes in vegetation are often caused by changes in abiotic site factors, such as pH, nitrogen availability and soil moisture.
Thus ecohydrological research has revealed new insights into ecosystem functioning in relation to water management (Figure 13.11.1). In this new interdisciplinary field, ecologists, soil scientists and hydrologists cooperated closely in the period 1981-1989 (Committee on the Water Management of Nature, Forest and Landscape; supported by Government grants) to model and link up regional groundwater and surface water systems to local groundwater regimes and these ultimately to moisture conditions, soil base status and nutrient supply. Coherent series of operational simulation models for hydrochemistry, which deal with non-conservative components and include complicated chemical equilibria and nutrient dynamics have been generated and linked to regional hydrological models. In the meantime much empirical information, including relative optimum values, has been gathered for a number of operational site factors in relation to the appearance of plant species.

In this way existing knowledge-based-indication systems of plant species could be calibrated to site factors and incorporated in models evaluating plant species responses to changed site conditions, simulated by the abiotic models.

Nevertheless ecohydrologists have to cope with fundamental and practical problems. The difference between scales in which hydrological processes can be modelled and in which water management measures are taken, as compared with the relevant water dependent abiotic processes at the plant site which occur at the micro level, could not yet be bridged satisfactorily. The need of data for the coherent series of simulation models frequently results in a data crisis or unacceptable high costs for data collection in applied regional or local studies.

This stimulated the development of simple tools. Sample cards have been developed which consist of dose-effect relations derived from applications of the complex simulation models to reference land units displaying ecological land qualities.

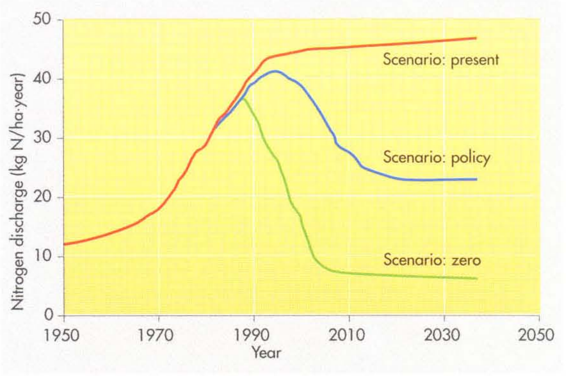


Figure 13.11.2 N-leaching from rural areas towards surface waters

Leaching of nutrients and pesticides

Given the high livestock density in some regions of the country and the intensive use of fertilizers, one of the main concerns in Dutch research projects is to predict accurately nitrate and phosphate leaching to ground and surface waters (Figure 13.11.2 and Figure 13.11.3). Nitrate leaching from agricultural soils has frequently led to concentrations above the EU drinking water standards. Most data originate from sandy soils.

In grassland on heavy clay soil, nitrate transport occurs mainly via preferential flow through mesopores and macropores, resulting in small mobile-water volumes and high nitrate leaching rates. Current research focuses on a more adequate prediction of nitrate leaching in heavy clay soils.

Since 1989 a pesticide registration procedure exists for assessment of the potential of pesticides to leach to groundwater and to persist in the top soil layer. Current research projects involve soil scientists and microbiologists working on improved understanding and modelling of pesticide behaviour in soils.

Acidification

To investigate the effects of acid atmospheric deposition on trees and soil at the forest stand level, intensive monitoring programmes and integrated simulation models have been developed. They are used to simulate the reponse to the Dutch (policy-)target deposition scenario.

In the Netherlands, various acidification scenarios are being analysed for the next century using a combination of an integrated soil water transport and quality model with a multiple stress model for vegetation.

Evaporation of forests and wetlands

In the past Dutch research on evaporation has largely been focused on homogeneous agricultural crops. However, most natural vegetation types are characterized by an heterogeneous structure. Progress has been made in developing physically-based models for multiple-layer canopies. In the National Research

Programme on 'verdroging' it is recognized that too little information is available about evaporation from forests and (semi-)natural vegetation. A new research initiative on evaporation of forests has been started recently. Wetlands and other types of nature reserves are expected to be studied in more detail in the next years. In recent years some of the work on forest hydrology has been carried out in support of the acidification research coordinated by the Dutch Priority Programme on Acidification. Much attention has been paid to canopy wetness, water transport in the unsaturated soil layers and transpiration. Interception and canopy wetness were studied because dry deposition resistances are related to canopy wetness. These studies revealed that predicted evaporation rates and canopy wetness duration depend primarily on the way in which turbulent exchange is described. Here, an extra research input from meteorologists is required.

Regionalization

Regionalization of local-scale modelling concepts is important to improve regional hydrological models. A basic aim is to develop physically-based techniques for aggregation of local-scale information to the regional scale. A series of experiments has been initiated to test and develop parameterizations of spatial heterogeneity.

Inverse modelling techniques are used to estimate regional or effective parameters, e.g. soil hydraulic properties, rainfall-runoff relations and groundwater recharge. These land surface experiments provide a methodology and data set to develop and test regionalization algorithms.
For instance, for soil acidification, three dynamic models have been developed for application at local, national and continental (European) scales.
Studies on the influence of advection on the energy budget of a forest edge have resulted in an improved theory of surface layer integration in a heterogeneous landscape. The peculiarities of the structure of the landscape at the scale of ca. 10 km have led to studies on soil-vegetation-atmosphere exchange of momentum, sensible and latent heat and carbon dioxide at that scale.

The average exchange cannot simply be a summing up of the elements. The newly developed theory will be used to scale up local observations to areal averages for General Circulation Models.
For predictions at the regional scale, the interactions between the planetary boundary layer and the vegetation have to be taken into account.

During recent years, important progress has been made in registration and elaboration techniques for estimating transpiration rates. Hardware and software facilities have improved the use of eddy correlation techniques to estimate latent heat fluxes above canopies. Sap flow measuring techniques have been improved.

Dutch meteorologists, hydrologists and soil scientists are involved in a series of experiments initiated by the World Climate Research Programme and the International Geosphere-Biosphere Programme. These experiments have concentrated on key biomas in the world such as temperate agricultural land/forest (HAPEX-MOBILHY), desertification threatened areas (EFEDA), tropical savannah (HAPEX-Sahel) and plans exist for experiments in the tropical rainforest (LBE) and tundra.

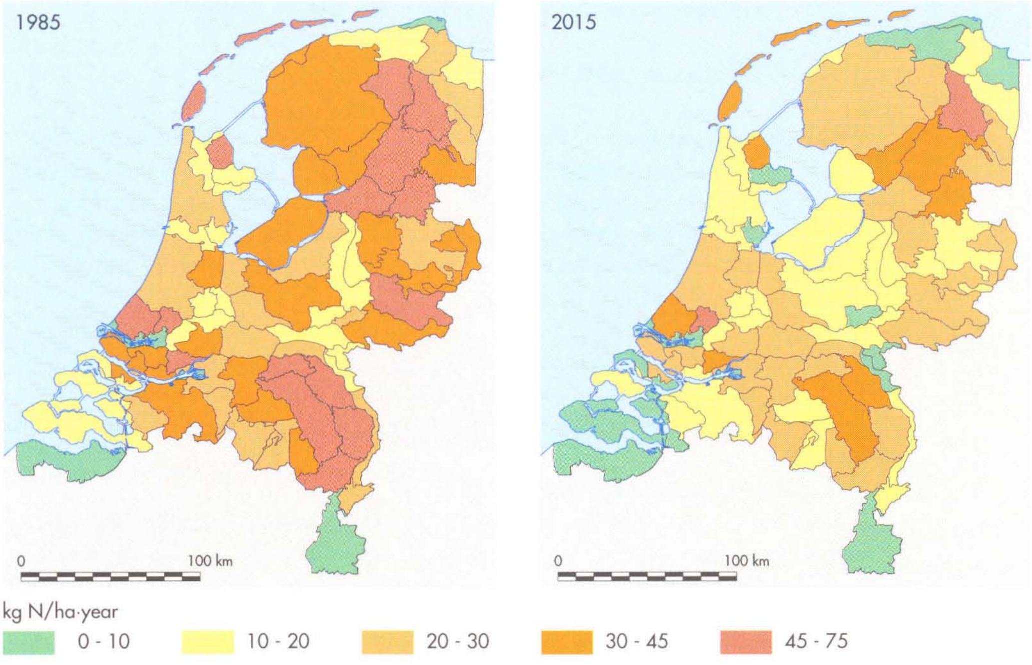


Figure 13.11.3 N-leaching from rural areas towards surface waters in 1985 and 2015

Remote sensing

Remote sensing measurements of land surface radiative properties offer a means to indirectly measure land surface conditions at a range of scales. An estimation of evaporation from radiative properties of the land surface is hampered by the fact that only very few parameters of flux-profile relations can be derived from remote sensing measurements. Recently a surface energy balance algorithm for land was developed in a way that only a limited number of site measurements is needed on soil temperature and near-surface vertical air temperature difference. An empirical relationship between these profile characteristics offers a method to estimate sensible heat flux density.

The methodology followed in these experiments is to combine small-scale measurements of energy partitioning at a few relevant typical vegetation types with larger scale measurements obtained by aircraft and remote sensing and compare these with modelling results. These data are used to include subgrid variability in large-scale hydrological and atmospheric models. This methodology reduces the uncertainty of evaporation estimates in regional water balances with remote sensing measurements.

13.12 Prediction and evaluation tools for water quality models

P.I. Adriaanse and R.F.A. Hendriks[14]

In the Netherlands many of the relatively small agricultural fields are surrounded by surface water. As a consequence, the use of pesticides and fertilizers on the fields results in emission of these substances into the surface water. This is one of the main reasons why the quality of large parts of these waters does not meet the water quality standards. To evaluate surface water quality, the DLO Winand Staring Centre has developed a set of simulation tools.

This research topic describes the results of two types of model simulation:
- prediction of the exposure of pesticides to aquatic organisms;
- evaluation of measures to reduce nutrient concentrations in surface waters.

a. Exposure of aquatic organisms to pesticides

The TOXSWA model has been developed to predict acute and chronic exposure of aquatic organisms to pesticides. The present version describes the fate of pesticides in a single field ditch including the underlying sediment.

In TOXSWA, pesticides can enter the surface water by spray-drift, atmospheric deposition and the soil routes runoff and drainage (Figure 13.12.1). The concentration is calculated as a result of advection and diffusion, volatilization, transformation in water and sediment and sorption to suspended solids, macrophytes and bottom material.

Experiments

To validate TOXSWA, model results have been compared with measured concentrations from two experiments:

I *chlorpyrifos in microcosm without macrophytes.*
Experiment I and II were carried out simultaneously in indoor microcosms, which each consisted of a glass aquarium in which a 0.1 m sediment layer and a 0.5 m column of overlying water were introduced. The fate of chlorpyrifos was studied in two microcosms devoid of macrophytes. A single dose of chlorpyrifos was applied to the systems simulating spray-drift deposition. The microcosms were kept under constant climatic conditions.

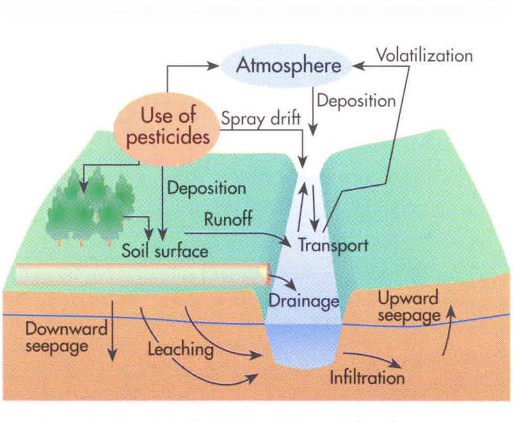


Figure 13.12.1 The TOXSWA model: relation between pesticides and aquatic ecosystem

II *chlorpyrifos in mesocosm with macrophytes.*
In this experiment the fate of chlorpyrifos was studied in two outdoor stagnant ditches.

[14] DLO Winand Staring Centre, Wageningen

In the ditches (length 40 m, width of the water surface approximately 3.4 m) a sediment layer of 0.25 m and a 0.5 m column of overlying water were introduced. The ditches were dominated by submerged macrophytes (e.g. Elodea nuttallii, Chara spp. and Ranunculus circinatus). A single dose of chlorpyrifos was applied to the ditches simulating spray-drift.

The properties of the insecticide chlorpyrifos and the herbicide linuron were used as input parameters for the two models (Table 13.12.1).

Simulation results

Simulations were carried out with the TOXSWA model for the described experiments. In Figure 13.12.2a the simulation results of the chlorpyrifos experiment in the microcosm with no macrophytes and the measured concentrations are shown.

TOXSWA gave an overestimation of the measured concentration. All input parameters of the models were determined with great accuracy, except the concentration of suspended solids in the water layer. Because of the high sorption capacity of chlorpyrifos, the amount of sorbing material is a sensitive parameter.

In Figure 13.12.2b the simulation results of the chlorpyrifos experiment in the outdoor mesocosm and the measured concentrations are shown. The simulation results appear to start at a concentration of about 40% of the dose applied. This is due to the fact that TOXSWA assumes instantaneous adsorption equilibria. Therefore immediately after application, a large part of the chlorpyrifos is adsorbed to macrophytes.

Table 13.12.1 Characteristics of chlorpyrifos

Chlorpyrifos	
Solubility (mg/l)	0.7
Vapour pressure (Pa)	0.002
Sorption coefficient to sediment based at organic matter content (dm^3/kg)	234
Sorption coefficient to macrophytes based at dry weight of macrophytes (dm^3/kg)	2 000
Transformation coefficient in water as DT50 (day)	75
Transformation coefficient in sediment as DT50(day)	115

Conclusions

Results of model simulations show that TOXSWA gives good predictions of the chlorpyrifos concentration in water. For pesticides with high sorption capacity, sorption to macrophytes appears to be the major process which influences pesticide concentrations in stagnant waters.

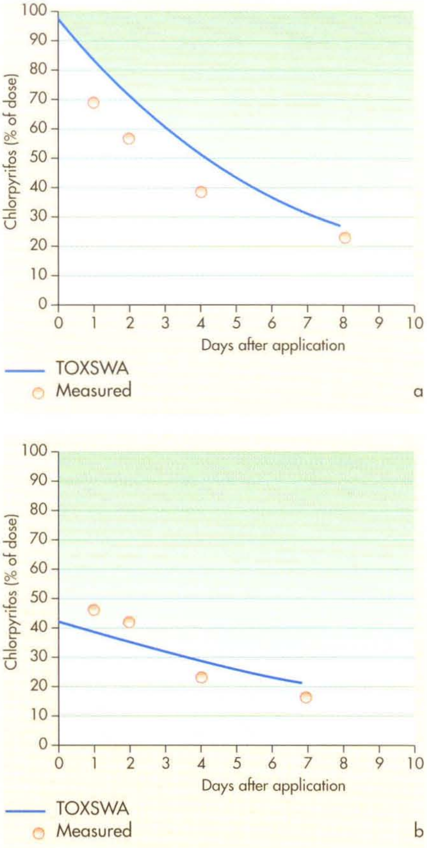


Figure 13.12.2 Simulations with the TOXSWA model: calculated and measured results

b. Models to evaluate measures to reduce eutrophication

In the Netherlands large parts of the surface water systems in rural areas are highly eutrophic. In order to lower current eutrophication levels, remedial measures are required. The effectiveness of these measures can be evaluated by using a combination of simulation models. A case study was carried out in the Bergambacht polder in the western part of the Netherlands. The Bergambacht polder can be characterized as a peat pasture area. Owing to the high eutrophication level, duckweed grows there abundantly.

The eutrophication is caused by high nutrient emissions from the soil, from sewage treatment plants, and from phospate-enriched sediments, and by inlet of nutrient-rich water. Several remedial measures were evaluated. In this case study, measures to reduce fertilization did not lead to a significant reduction of nutrient concentrations in surface waters, and therefore they are not discussed here.

Simulation tool

The effectiveness of measures to reduce eutrophication was evaluated using a simulation tool that combines leaching models and surface water quality models. Different models were used for water quantity and water quality. Figure 13.12.3 gives an overview of the models that are used in this study.

To predict the emission of nutrients from the soil system, the dynamic ANIMO simulation model was used (Agricultural NItrogen MOdel). Originally, ANIMO was developed for simulating nitrogen leaching to groundwater and surface water. The present version of the model simulates phosphorus leaching as well.
The ANIMO calculations are based on hydrological information provided by a separate hydrological model, namely FLOCR. The NUSWA model (NUtrients in Surface WAter) calculates the concentration of organic and inorganic nitrogen and phosphorus compounds in both water and sediment on a regional scale. Transport of nutrients between nodes is calculated on the basis of discharges simulated by an external hydraulic model, namely SIMWATS. The emission of nutrients from the soil system is obtained from the ANIMO leaching model.

Scenarios

Different scenarios were formulated based on three remedial measures. These scenarios are:

i autonomous scenario: present legislation for fertilizer use, dredging natural accretion of sediment, improving the water purification plants according to the latest regulations;

ii duckweed removal: autonomous, plus removal of duckweed each time the surface water system was 80% covered with duckweeds;
iii dredging: autonomous, plus dredging the sediment layer to a thickness in 1994, so that emission of phosphate to the overlying water layer would be reduced;
iv improving water purification plants: autonomous, but further purification of urban loads according to best technical means;
v total scenario; autonomous, plus the three measures described in (ii), (iii) and (iv).

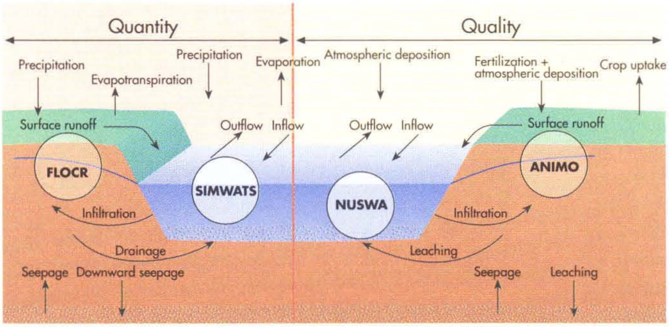


Figure 13.12.3 Overview of models used

The simulation period started in 1990. The concentrations calculated in that year were considered to be the reference concentrations. The simulation was carried out for a period of 35 years. The measures were assumed to start in 1994.

Calculated concentrations

For the years 1995, 2000 and 2025 a model output was analysed and the concentrations of total phosphorus and total nitrogen were calculated as the weighed average for the study area during summer.

The results of the scenario calculations are represented relative to the average concentration during summer in the reference year 1990 (Figure 13.12.4).

Conclusions

For evaluating alternative measures to reduce nutrient concentrations in the surface water in the Bergambacht polder, a combination of leaching and surface water models was used. In the autonomous scenario, concentrations of both nitrogen and phosphorus decreased in time due to a reduction of the use of fertilizer and emissions from water purification plants.
The reduction in the phosphorus concentration was more substantial, because the release of phosphate from the sediment decreased as well. Removing duckweed caused a reduction of both nitrogen and phosphorus. Dredging the total sediment layer caused a significant decrease in phosphorus concentrations just after this measure was carried out.

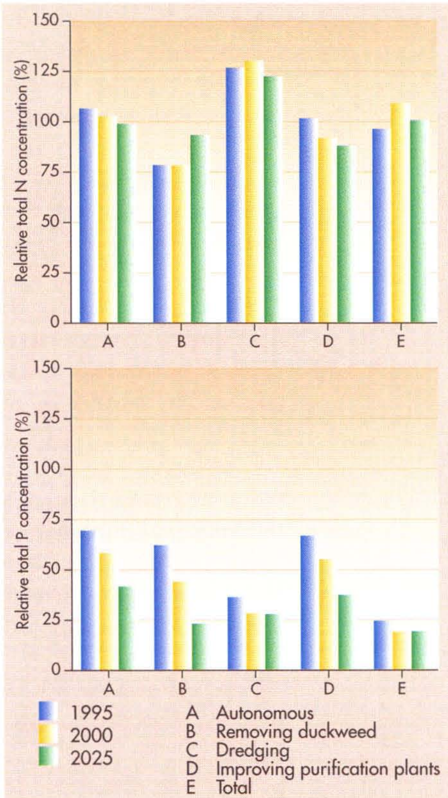


Figure 13.12.4 Calculated concentrations of N and P for the yers 1995, 2000 and 2025

The phosphorus concentration stabilized a few years after the dredging. Nitrogen concentrations increased, but this phenomenon was probably caused by the model assumption that with the sediment layer the total denitrification capacity is removed. Further purification of urban loads resulted in a small decrease of nutrient concentrations.
Only in the vicinity of the water purification plants, was this effect significant. Implementing all three measures together, resulted in a reduction in the phosphorus concentration by 80% in 2025 compared with the concentration calculated in 1990, but had hardly any effect on the nitrogen concentration.

13.13 Modelling for integrated water management

E. van Beek[15]

Current developments in modelling
Computer modelling has become an important tool for the Dutch water managers, supporting them in their planning and operational tasks. Consequently the water research institutes invest heavily in the development of appropriate technologies and tools. This includes the development of complex state-of-the-art 1-, 2 and 3-dimensional hydrodynamic and water quality models to be used on a high, specialist level, but also the development of simple, very user-friendly models and database systems oriented for lower managerial and operational levels.

At the same time, research is being carried out on new modelling techniques such as neural networks and the application of generic algorithms for water management.

A major development is the increasing use of the Internet to make information from distribution systems available. The Ministry of Transport, Public Works and Water Management facilitates the use of this medium by providing a major information entrance through Nederland Digitaal Waterland (Netherlands Digital Waterland).

From the viewpoint of integrated water management, the most important developments are related to the emergence of integrated information and model systems. To develop such integrated systems it is required that new techniques are applied and that consensus is reached in the water industry on the informatics architecture supporting such systems.

Informatics architecture for the water industry
In recent years, several initiatives have been taken to achieve a common informatics architecture for water management. The government stimulates these developments by providing subsidies. The main program is LWI (Land-Water-Environment Information Technology) in which the government, engineering consultants, information technology companies, research institutes and universities join forces

[15] WL/Delft Hydraulics, Delft

to develop, at a pre-competitive level, instruments and systems that will enable the Dutch water organizations to perform faster and more cheaply. The program runs from 1994 till 2003. During the first five years it is supported by the government. After that period LWI must show the first commercial spin-off and be able to support itself.

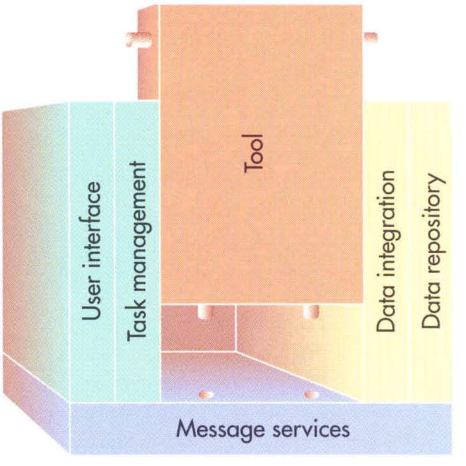


Figure 13.13.1 Basic structure of Toaster Model

Another important initiative has been taken by the water managers themselves. Their joint research bureau STOWA (Foundation of applied research in water management) runs projects that aim to define a common data exchange format between computer models and Geographical Information Systems (GIS). Other projects aim at getting agreement on the selection of a line of 'consensus models' to be used by all water managers at the various government levels.

Developments take place in an evolutionary way. Step by step the information and model systems migrate towards an architecture in which integration of the various components can take place with a minimal effort and maintenance can be guaranteed at reasonable costs. These developments include:
- the use of Object Modelling Techniques (OMT) makes the link between the modules explicit, enables the use of interchangeable modules with a common data structure, supports the evolutionary development of the system, guarantees consistency of the data of objects addressed in separate modules;
- the definition of a common data exchange format and a common 'plugbox' for models and data systems facilitates the coupling of models and data systems;
- the use of the 'Toaster Model' as reference base for system development (Figure 13.13.1) enables the integration of existing and new software components (tools) that are basically incompatible by providing application of neural techniques and software components.

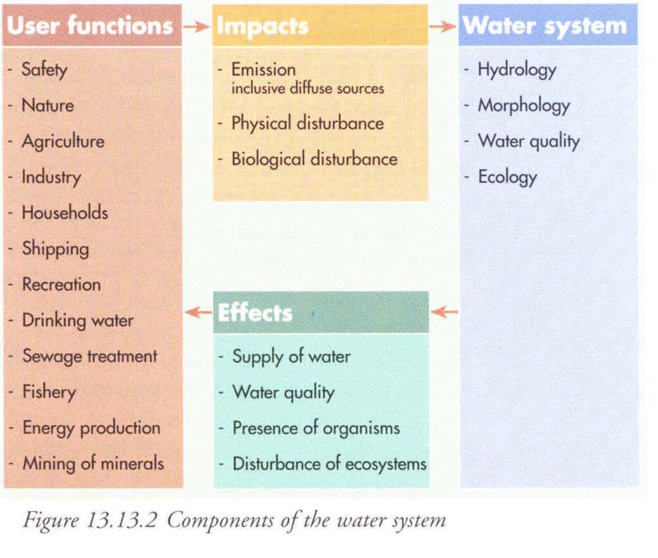


Figure 13.13.2 Components of the water system

Integration of models

The concept of integrated water management requires that the various models needed to analyse water resources systems are integrated.

Such integration is not only required for the various components of the natural system (surface water and groundwater, quantity and quality) but also for

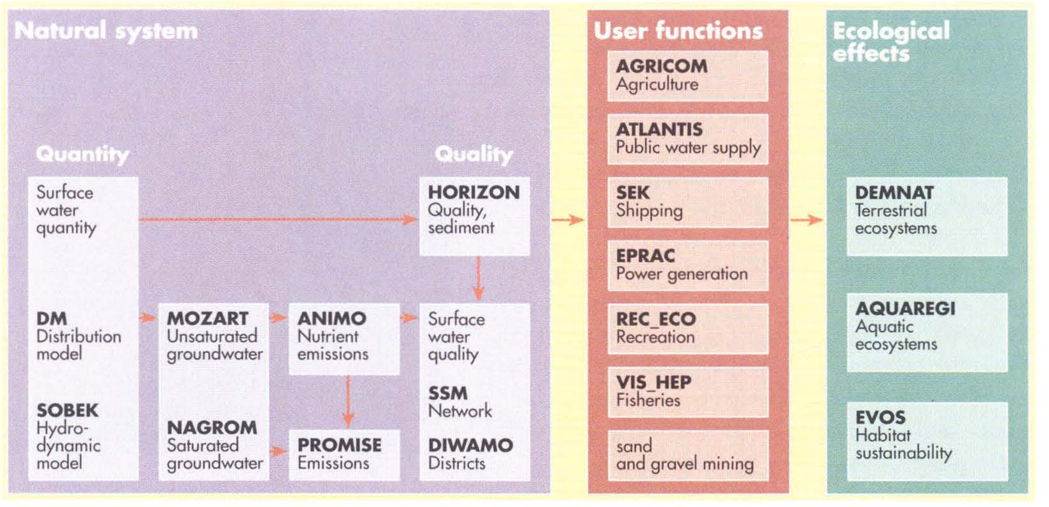


Figure 13.13.3 Model system, PAWN (fresh water part)

the user functions involved and the impacts and effects that result from the interaction between the user functions and the water system (Figure 13.13.2).

At the national level such integration has taken place in the so-called PAWN modelling system (Policy Analysis of Water Management for the Netherlands). An overview of the fresh water part of PAWN is given in Figure 13.13.3. A similar system exists for the salty part of the Dutch water system. The main feature of this integrated model system is that an explicit link has been made by various models describing the natural system and the socio-economic system (the use functions). This enables the simultaneous evaluation of measures and strategies of both systems. Given the objective of sustainable use much emphasis is given to the effects that those measures have on the aquatic and terrestrial ecology.

Development of a generic Decision Support System
The next step in modelling is to embed the integrated models into a Decision Support System (DSS). The purpose of a DSS is to assist the decision maker in finding adequate solutions to real world problems. Given the iterative character of problem solving, a DSS needs to have strong interactive capabilities with good pre-processing facilities that support the generation of alternative solutions and good post-processing facilities that allow the user to draw the conclusions more easily, faster and better. Figure 13.13.4 illustrates the basic components of the genetic DSS that is now under development.

User interface
Supports the managerial tasks and problem-solving process of the user; enables manipulation of data and steers the performance of the various modules within the DSS.

Data interface
Takes care of the link between the various components of the DSS; will be more and more structured according to an OMT approach.

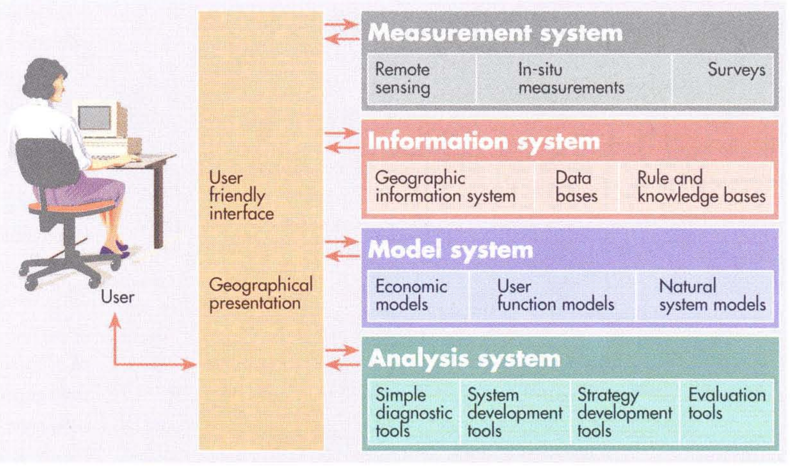


Figure 13.13.4 Set-up of generic Decision Support System for water management

Measuring system
Contains the raw data of remote sensing, in-situ measurements and data from socio-economic surveys.

Information system
Is the core of the DSS and contains a database system with all the relevant data on the natural and socio-economic systems of the specific application; a GIS supports the input, manipulation and presentation of the geographical data. The model system contains the integrated models that describe the natural and socio-economic systems.

Analysis system
Provides the tools to analyse available information, supports the development of the particular application of the DSS (links required models to the system, helps to design the schematization, etc), and supports the definition, analysis, evaluation and comparison of alternative measures and strategies.

The LWI organization mentioned before has accepted the above architecture as the base for the development of a generic DSS for the Dutch water organizations.

Several components of the user interface and the analysis system are already developed by Delft Hydraulics and, in combination with available modules from the information and model system layers, are being applied for various rivers, estuaries and coastal seas in the Netherlands and abroad.

Harmonization of data
The most challenging part of the quest for consensus on integrated information and modelling systems might well be the harmonization of the data that are used at the various planning and operational levels. Figure 13.13.5 illustrates the relation between the regional, national and international levels for salt and fresh water systems in which analyses need to be carried out at each level for the whole system as well as for the various (local) components.

At present most water managers use their own data which only in exceptional cases are consistent with the data on other levels. The integration of models requires that the underlying data and schematization are consistent.
This can be obtained by reaching consensus on the sources that contain the master-information. In general these will be external databases that are continuously

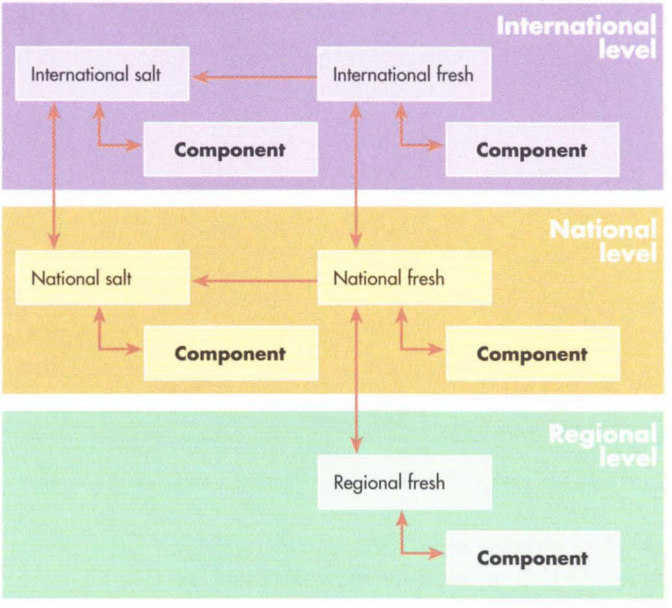


Figure 13.13.5 The relation between the regional, national and international levels for salt and fresh water systems

maintained and updated such as central statistical databases and GIS-systems containing information on land use, socio-economic activities, natural resources, etc. The manipulation of this master-information, possibly combined with specific information of own databases, will result in the schematization and related data of the base level of the water resources system. The schematization of the other levels will be obtained by prescribed aggregation and disaggregation procedures. This approach guarantees that, although the level of detail may differ, the basic data and schematization of the various applications will stay mutually consistent.

Moreover, it will enable the use of different levels of schematization within one application if this is required for specific problem areas that need to be analysed (e.g. transport of heavy metals at a national scale combined with eutrophication issues at a regional level).

AQUEST

The most recent initiative is the start of the AQUEST 'project' by the Ministry of Transport, Public Works and Water Management. Based on the above mentioned developments with respect to increased information availability, generally accepted models and Decision Support Systems, AQUEST aims to improve the supply and communication of information between the water managers themselves and between the water managers and society, being the ultimate stake holders of integrated water management. The final goal of AQUEST is to enhance preparedness for changes in water management and to improve effective support of decision making. It is anticipated that AQUEST will seek cooperation with other European countries to reach consensus on a common approach, needed to enable integrated water management on a (transboundary) river basin scale.

13.14 Groundwater monitoring networks

G. Jousma[16] and J. Willems[17]

Introduction
Monitoring networks play an important role in unravelling the secrets of the groundwater regime. They provide the data on groundwater levels and groundwater quality used to analyse the groundwater flow and transport processes in an area.

In turn, this information about the geohydrology of the area is indispensable for planning and control of groundwater exploitation and for the protection of the environment. Groundwater reserves are not only an important resource for life, they also have considerable economic value. Monitoring networks are used to find a balance between optimum use of groundwater and minimum risks for the economy and the environment.

Groundwater monitoring networks
A groundwater monitoring network basically consists of a number of observation wells that usually have been installed with a common goal. The observation wells consist of a screen at a certain depth in the earth and a standpipe that allows the state of the groundwater (water level or water quality) to be monitored from the surface. A monitoring well may be a single observation well or may consist of several observation wells with screens at different depths. The objectives of monitoring differ largely. For the so-called 'primary networks' the main objectives are to control the groundwater regime at a regional scale, to detect long-term trends and to offer reference values for local networks. These primary groundwater monitoring networks serve to support water management at a national and provincial level. The objectives of 'local networks' are very diverse. Local groundwater level networks may serve to control the impact of water abstraction or intensive drainage, the efficiency of operation of well fields, the fluctuation of the water table in natural reserves, the depth to the water table in urban areas, etc. Local groundwater quality networks may be used to control the impact of land use, to control the situation at potential pollution sources or to serve as early warning systems around pumping stations. The local networks may be nested in the primary networks: the primary networks are then used to provide the unaffected reference values for local monitoring.

The frequencies of monitoring are different for groundwater level and groundwater quality. Whereas groundwater levels are monitored twice a month (for the majority of monitoring wells in the Netherlands), four times a year or occasionally with other frequencies, the groundwater quality is usually monitored once a year or once in several years, depending on the magnitude of quality changes.

[16] Netherlands Institute of Applied Geoscience TNO - National Geological Survey, Delft
[17] National Institute of Public Health and Environmental Protection, Bilthoven

Organizations involved in monitoring

The responsibility for groundwater level and groundwater quality monitoring lies with various organizations.

Groundwater level monitoring on the national and provincial level is a joint responsibility of the provincial governments and the Ministry of Transport, Public Works and Water Management. The 'primary' networks for groundwater level monitoring contain more than 5000 monitoring wells. Network design, operation and maintenance as well as data storage and data dissemination has been delegated largely to the Netherlands Institute of Applied Geoscience TNO - National Geological Survey. At a local level several organizations are involved in operating groundwater monitoring networks; these include municipal authorities, water boards, water supply companies and trust organizations. A large part of the data of these local networks is also stored in the national data base.

With respect to groundwater quality, three levels of monitoring can be distinguished. The National Institute of Public Health and Environmental Protection (RIVM), commisioned by the Ministry of Housing, Physical Planning and Environment, has the responsibility for the national network. On a regional level provincial groundwater quality networks exist. The data from both the national and provincial networks are stored at RIVM and together with the groundwater level data in the central data base at TNO.

The National Groundwater Archive

Since 1948 the Netherlands Institute of Applied Geoscience TNO-National Geological Survey has been in charge of the National Archive on Groundwater Level Data, collecting groundwater level data from various wells for analyses at national and regional scales. The present On-Line Groundwater Archive (OLGA) provides electronic access to the databases of more than 500 customers each year.
The database contains over 15.5 million groundwater level data from about 24 000 observation wells and 77 000 groundwater quality analyses. The data were brought together during the past decades by hundreds of organizations and thousands of volunteer observers. For proper control of the data-inflow, quality assurance procedures have been developed for observation and maintenance of wells, data input, data storage and data dissemination. Experts of the Institute are frequently consulted for installation or restoration of wells, for installation of automatic monitoring equipment, and for maintenance of observations wells. Besides groundwater level data the groundwater quality data from both the national and provincial groundwater quality monitoring networks are also stored in this national database.

In recent years, a major development has been the linkage of the groundwater database to the nationwide Regional Geohydrologic Information System (REGIS), an advanced GIS system developed by TNO for regional water management. The system provides its users with all data for analysis of the groundwater system. It combines borehole data, geophysical data and data from pumping tests with topographical data and data on surface water runoff systems.

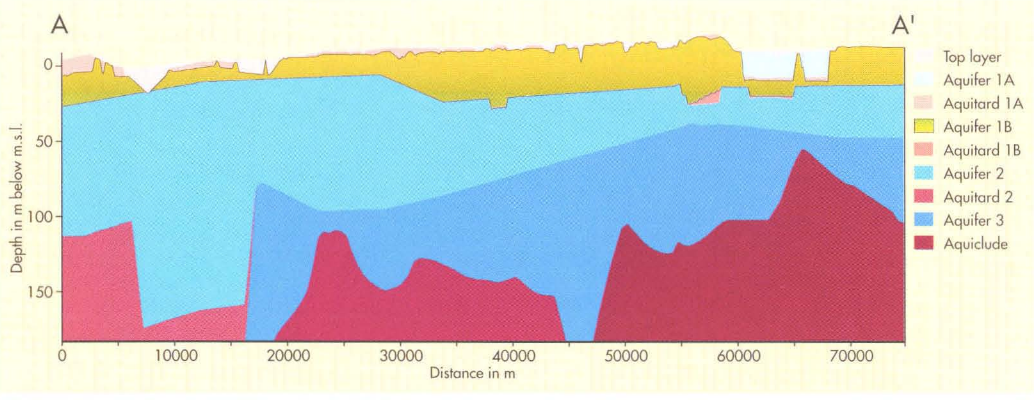


Figure 13.14.1 Hydrogeological model of the subsoil with the REGIS system

The system assists in making two-dimensional images of the hydrogeological setup of the subsoil (its aquifers, aquicludes, fault and fold zones, etc.), both horizontal and cross-sectional. It also generates the data for groundwater modelling. All provinces and the national government participate in the REGIS project.

Mapping groundwater levels an example of using national databases

The example shows how a groundwater level contour map, which is basic information for any groundwater study, can be obtained by the combined use of REGIS and OLGA. The example concerns groundwater levels in the province of Drenthe in the eastern part of the Netherlands. The procedure consists of two steps:

- With the help of the REGIS system the hydrogeological model of the subsoil is examined and defined on a regional scale. This results in a layer model of the aquifers (permeable layers) and aquitards (less permeable layers), as shown in Figure 13.14.1. Because of the capacity of the system to store and reproduce three-dimensional information, cross-sectional images can be produced for any location-line selected.
- A selection of the monitoring wells with screens in the upper aquifer is made from the OLGA database. At the user's request the database produces the water levels for the aquifer (the upper one in this case) and period of time selected. The result can be presented in a contour map of pre-selected intervals (Figure 13.14.2).

Results from the National Groundwater Quality Monitoring Network

The National Groundwater Quality Monitoring Network has been in full operation since 1984. It consists of about 380 especially devised monitoring wells with screens of 2 m length at 2 m depth intervals, e.g. 5-15 m and 15-30 m below surface level. The density of the network is about 1 well per 100 km^2.

The network was designed in order to:

a. assess the actual quality situation, especially in relation to human influence on groundwater quality (notably diffuse sources of pollution);
b. assess long-term changes in groundwater quality as a result of natural and/or man-made causes and;
c. allow the use of quality data for research purposes.

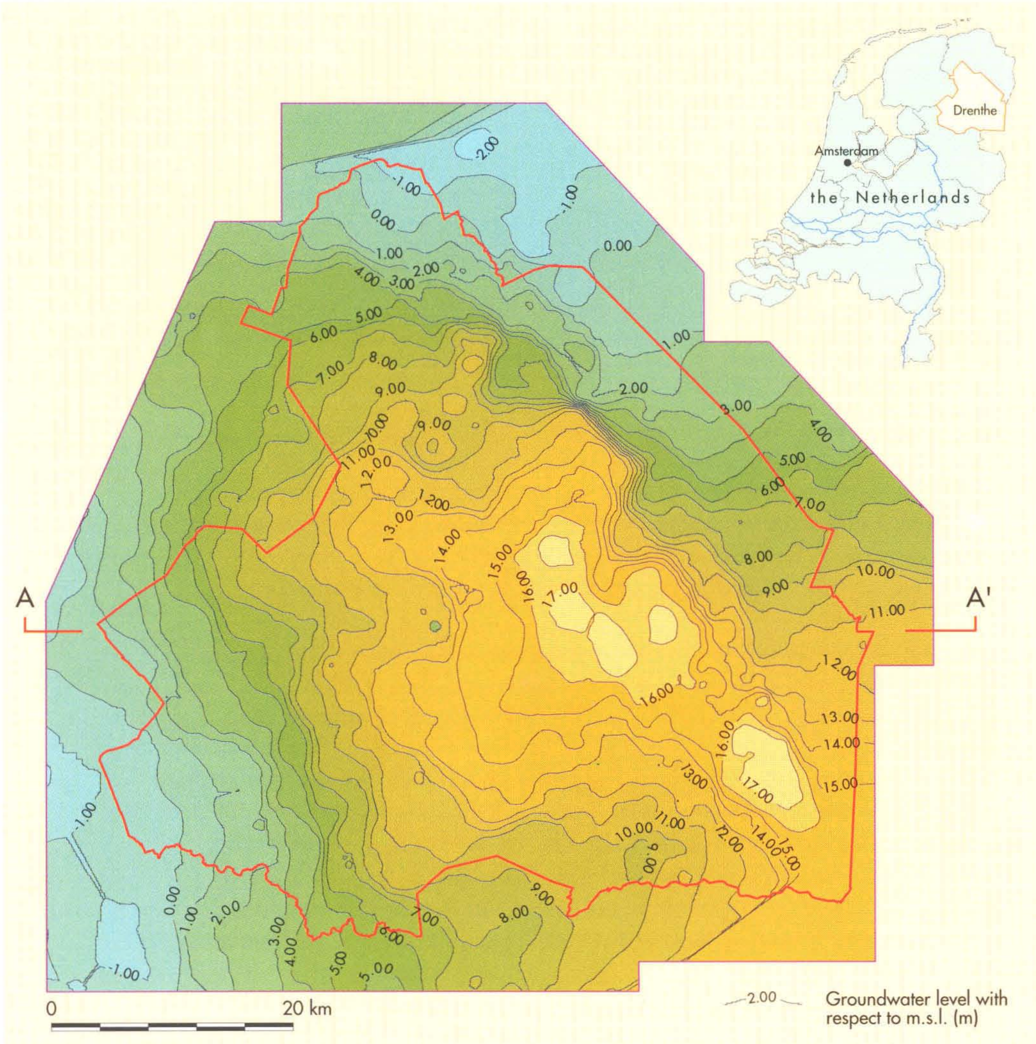


Figure 13.14.2 Groundwater levels in aquifer 1B

Important design criteria were that all major combinations of land use and soil type should be covered and that the wells should, as much as possible, be evenly distributed over the country. The wells are sampled yearly and the program of analysis covers 27 parameters.

Since the 1990s much attention has been given to statistical analyses of the groundwater quality data. Two approaches have been used: a classical statistical approach and a geostatistical approach. Some results for nitrate, based on the data from both the national network and six provincial networks, are presented on page 171. The examples demonstrate that it is possible to use the statistical techniques successfully in providing spatial information on groundwater quality. This information can be used to optimize the network.

A. A classical statistical approach

Figure 13.14.3 compares the mean nitrate concentration in 1992 for 13 combinations of land use and soil type with the target value (TV) of 5.6 mg/l. The vertical bars represent 95% confidence intervals of mean nitrate concentration per land use combination for both the upper and the lower screen. The number of wells has been indicated on top of the bars.

Results show that in the sandy areas nitrate levels exceed the TV for pasture (i), silage maize (j) and arable land (k); only for silage maize the 95% confidence interval is completely above the TV. The results illustrate the effect of the use of manure and fertilizer in agriculture, which is the highest in the sandy areas, and the vulnerability of groundwater to pollution in these areas. Notably in silage maize, the amount of manure applied to the soil was very high during the 1980s. Also it can be seen that the nitrate levels in the upper (wells) screens are higher than those in the deeper ones, owing to a combined effect of denitrification and slow downward movement of groundwater.

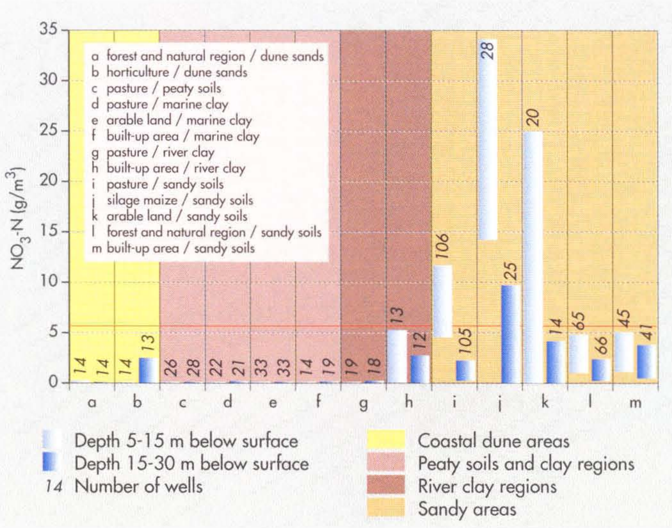


Figure 13.14.3 Nitrate levels in groundwater (95% confidence intervals)

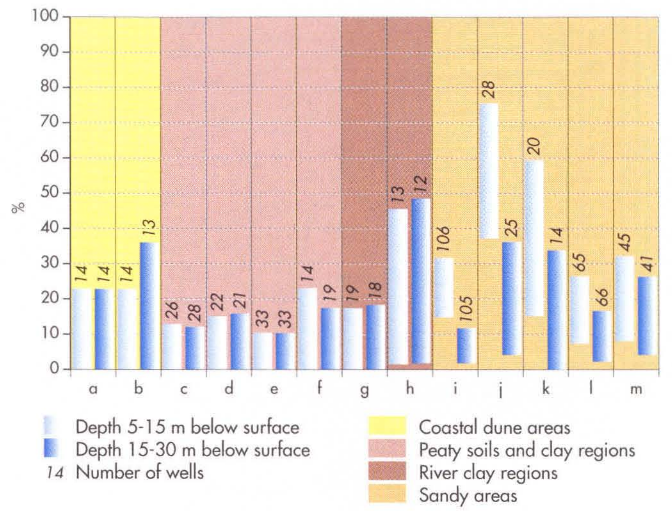


Figure 13.14.4 Area soils (% of total area with nitrate levels in groundwater above target value, 5.6 g/m^3 nitrate-N) expressed in 95% confidence intervals

Figure 13.14.4 presents the percentage of the area exceeding the TV for nitrate for combinations of land use and soil type. In general the confidence intervals are wide and the areal percentage above the TV is not distinguishable: see for example uncultivated sand in the coastal dune area (a). In agreement with Figure 13.14.3, the most important exceedance of the nitrate TV occurs in the sandy areas: more than 10% of the area in the case of pasture (i), silage maize (j) and arable land (k). It follows that the groundwater in more than 30% of the area maize on sand (j) has nitrate concentrations above the TV.

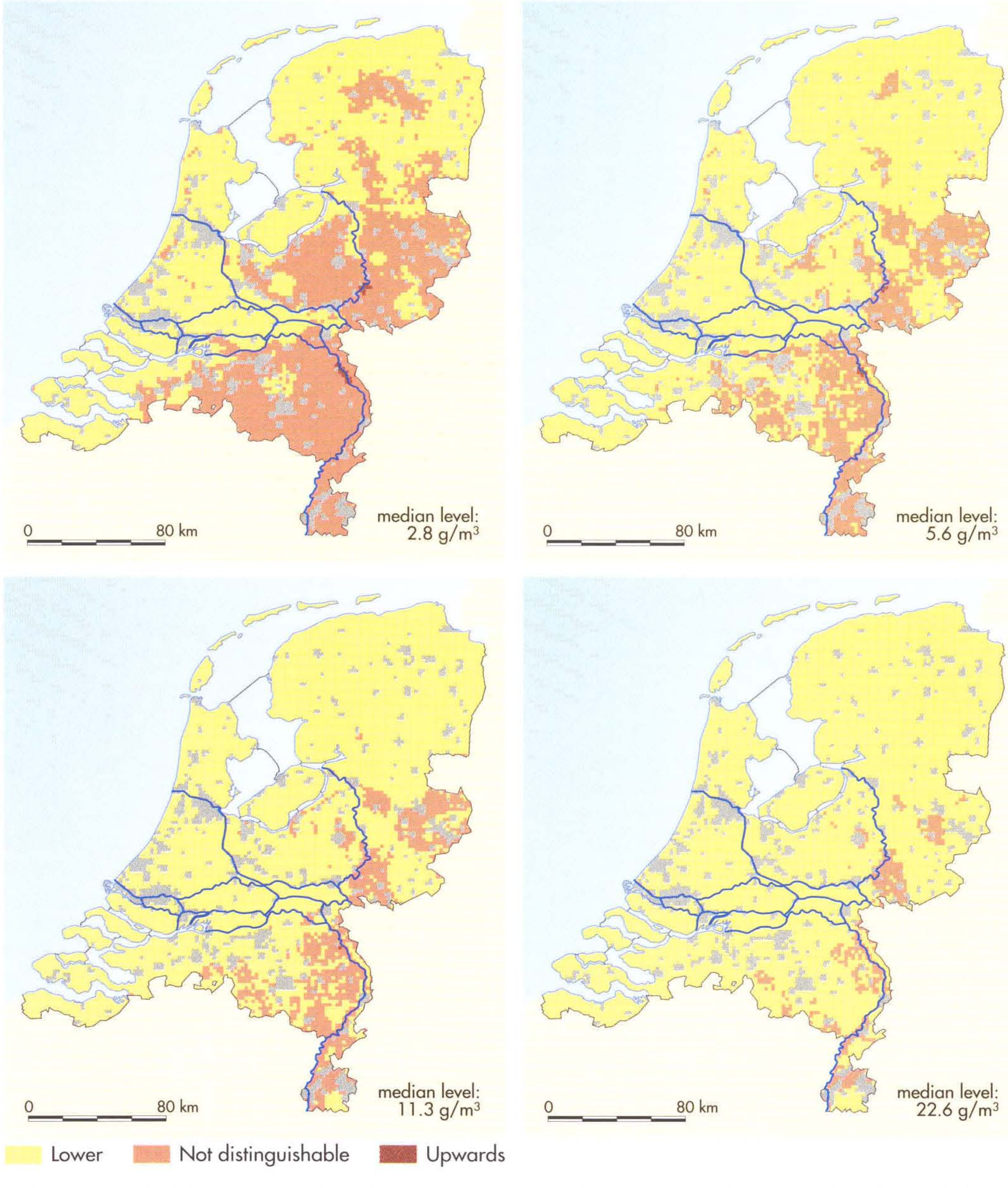


Figure 13.14.5 Maps of nitrate-N in the groundwater (depth 5-15 m below surface); confidence intervals for 4x4 km block, median values related to 4 concentration levels

B. A geostatistical approach

Since 1994, maps of 25 quality parameters have been prepared by estimating the concentrations in 4 x 4 km blocks with the help of the kriging technique. The maps are based on stratification by soil type and land use, applying 1991 data. The quality estimates at unsampled locations (4 x 4 km blocks) are presented as 95% confidence intervals of median concentrations; they are compared to target values and drinking water standards.

Figure 13.14.5 shows the results for nitrate as related to four concentration levels, viz. 0.5 x TV (2.8 mg/l), TV (5.6 mg/l), 2 x TV (11.3 mg/l) and 4 x TV (22.6 mg/l).
Only a few blocks show median concentration levels significantly higher than the TV. In the eastern and southern parts of the country (sandy soils) large areas cannot be distinguished from the TV in a statistically significant way.
However, it must be kept in mind that the information represents median values which implies that a number of individual samples may exceed the TV.

The information of Figure 13.14.5 offers the maximum of detail given the present network density, which is high in the Netherlands compared with other European countries. It also shows that confidence intervals are rather wide, which is mainly a result of the limited number of wells per soil type/land-use combination.
Also other factors may contribute to these wide intervals, such as the hydrogeological and the hydrogeochemical characteristics of the area, which are not taken into account due to a lack of geographical information. From additional analysis it was concluded that leaving out the provincial networks resulted in a considerable loss of information.

13.15 Information systems

J. de Sonneville[18]

Trends in data handling
The complexity of integrated water resources management poses a continuous challenge to the hydrological profession of today. On the one hand, deepening of hydrological knowledge is required to provide a better insight in the occurrence, flow, nourishment and interaction of water within its environs; on the other hand the profession needs to be broadened, integrating hydrological know-how and other disciplines in a comprehensive management framework of environmental management, physical planning and (socio)-economic development.

Information systems play an increasingly important role in the support of integrated water management, where a systems approach is required in the application of the geosciences. Properly designed information management systems can provide the framework of analysis to support water resources management decisions. The successful integration of geosciences and other disciplines and the application of numerous models, such as flow models, decision support models and uncertainty models depends on the availability of detailed and accurate data. Vast volumes of data are being generated through dedicated networks which monitor quantitative and qualitative aspects of the hydrological environment. Data management capability is a cardinal part of an information management system.

Advances in information technology have greatly facilitated the management of water resources data. Table 13.15.1 presents the trends in data management which

[18] Netherlands Institute of Applied Geoscience TNO - National Geological Survey, Delft

are the direct result of the developments in information technology. These trends are being accelerated because the quality of hydrological research is increasingly determined by the degree in which know-how in the various hydrological disciplines can be utilized in conjunction and be integrated with knowhow in other disciplines.

Table 13.15.1. Information-technological trends with respect to data

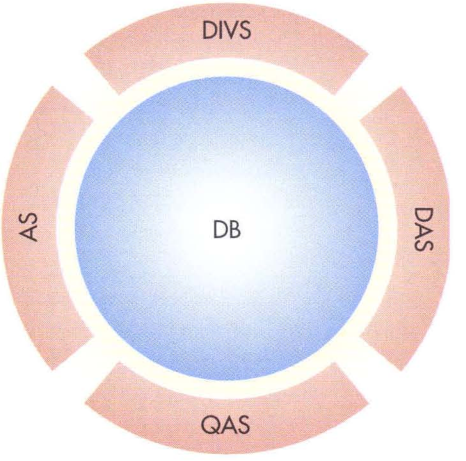
Item	Past	Present/Future
1	storage of data files in paper archives	all data files in digital format
2	all data present at one location, to improve access through electronic data transmission	data can be stored in a distributed environment, access
3	separate storage of discipline-oriented data types	integrated storage of all data types
4	limited availability of basic data	very many basic data
5	reliability and accuracy of data is 'static' (e.g. through re-processing)	reliability and accuracy of data is 'dynamic'
6	non-harmonized acquisition, quality control, storage, reduction, analysis, interpretation, presentation and dissemination of data	total integration of all aspects and processes of data utilization
7	creation of standard products on the basis of data files	instantaneous generation of customized information
8	research mostly based on synthetic data files	research mostly based on real-type data files, in particular with regard to the optimization of networks, data acquisition andmodelling
9	low-level technology for requesting or disseminating information	availability of interactive geo-scientific visualization systems
10	low-level technology for storing and accessing all data files	availability of interactive geo-scientific information systems

With regard to the items mentioned in Table 13.15.1, most progress has been made in items 1-6. Notable has been the commercial development of relational database management systems and geographic information systems, which are examples of generic information technology, as well as computer networks and communication (telematics) systems.

Status of information management systems

The development of integrated information management systems, resulting from further developing item 10 of Table 13.15.1, is still in its infancy. Although abundant application software exists nowadays, this software environment often consists of a patchwork of application packages featuring incompatible interfaces to either database management systems or spatial analysis (GIS) systems.
As a result of this fragmentation, the full potential of data and software cannot be

realized. The large volume of data makes the development of a conceptual model from basic data still a formidable challenge. Another challenge remains the accurate translation of the modelling results through combination with other thematic data which truly supports the decision-making and policy development in water resources management.



DB Data Base
DAS Data Acquisition System
DIVS Data Interpretation and Visualization System

Figure 13.15.1 Schematic representation of a Generic Geohydrological Information Management

A major constraint in the development of information management systems is the very high amount of development costs. When completed, the system may be too large and too complex to be used efficiently. Moreover, complex systems may only work well, if the right data are available. The efficient use of a powerful information system puts exacting requirements on the collection and the quality control of data.
High development costs stimulate the incorporation of commercially available software, such as database management systems and geographical information systems, statistical libraries, model codes, knowledge systems, etc. However, the integration of such components has in the past mostly led to information systems which are rigid in their design because of the particular requirements of the individual user and data-interfaces for the integrated components.

Central groundwater information

The systematic collection and storage of groundwater data to assist groundwater management started in 1948 with the setting up of a groundwater archive within the Netherlands Institute of Applied Geoscience TNO-National Geological Survey. The institute is now responsible for the collection, processing and evaluation of groundwater data and for making the information available to the water management authorities, interested public, and private institutions or enterprises. The paper files of the groundwater archive were automated in 1970, thereby providing computer support for activities related to the operation of the groundwater observation network and offering new possibilities in the field of data processing and presentation.

Requirements for a Generic Geohydrologic Information Management System (GIMS)

Current research is being carried out on the development of a Generic Geohydrologic Information Management System (GIMS), which combines the storage and processing of data with the analysis and application of simulation models and decision supporting models in one integrated water management framework. The development of GIMS started from a conceptual functional model, five of the most important elements of which are shown in Figure 13.15.1.

The central element in the schematic presentation is the database (DB). This DB holds all the necessary data and information to carry out water management:

hydrological, socio-economic, administrative, geographical, non-geographical, source and interpreted data. The Data Acquisition System (DAS)enables the entry of data and all other information into the database through electronic transfer, digitising, etc. The Data Interpretation and Visualization System (DIVS) provides the interpretationand visualization of the source data and interpreted information. Examples are graphical and numerical presentation of information, modules for the treatment of geographical information and statistical modules for data reduction and determination of accuracy and uncertainty.

The Analysis System (AS) includes the application of analysis tools such as simulation models (surface water, groundwater and ecological models, etc.), decision support and uncertainty models. An integral part of a GIMS is a Quality Assurance System (QAS) which controls the internal quality of the GIMS, such as database management, spatial analysis and modelling environment. It presents information about the origin, measuring method of data, the error margin on derived parameter values and information on the uncertainty of various methods of analysis applied. A number of IT developments have been instrumental in the development of GIMS: such as database management, spatial analysis and modelling environment.

GIMS applied to geoscience
An example of development on the basis of GIMS is a advanced development of the geohydrological information system REGIS. The approachfocuses on the intelligent integration of a generic commercial database and spatial analysis technology to arrive at a comprehensive, state-of-the-art, modular information management system around a common geoscientific data model.
The system is designed to provide the necessary support for those activities that take place during a water resources study or water resources management project.

In support of the activities outlined above, REGIS provides:
a. facilities to store and maintain all geohydrological data collected in the area;
b. functionality to derive and maintain a geohydrological model of the area under study (Figure 13.15.2);
c. functionality to use this model in the management phase, e.g. to support simulation of the effect of management scenarios and provide answers to questions of the type 'what if ?'

The system has three major design features:
d. integration;
e. flexibility; and
f. support for many different users.

The need for integration exists on three levels; integration of data, integration of functionality and integration of user's interface. Flexibility includes both scalability and adaptability. The system is scalable to support local scale projects, but also regional and nationwide studies. Moreover it is possible to tune the system in such a manner that all the topics that are really of interest to a certain problem can be covered but irrelevant topics are left out. The system is adaptable so that it can be customized in order to adjust it to the specific needs of a particular project. Because geohydrological studies are usually carried out by a team, the REGIS can be configured as a multi-user system.

Figure 13.15.2 Example of a groundwater quality study with REGIS

Concerning (a), (b) and (c) mentioned before, the following information on the basic functionality of REGIS is relevant:

- The data store is managed by a commercial SQL based RDBMS. The RDBMS system offers powerful functionality for the maintenance of data. The data store has been loaded with a geohydrological data model, allowing storage and maintenance of the entire range of information that can be of interest in the field of geohydrological engineering such as reservoir characteristics, groundwater data (quality and quantity), groundwater production and use, etc.
- The geohydrological model which will be set up for a certain area of interest consists basically of a model describing the groundwater reservoir and a number of models (stochastic or deterministic) describing the temporal behaviour of the groundwater.
- In order to predict the effects of management measures on the groundwater system, prediction tools are used. Because the (geo)hydrological problems encountered in groundwater management vary significantly from region to region, an information system should be able to accommodate various numerical models, which are often very specifically oriented towards one type of a problem.

DINO, Central Geo Databank and Information Dissemination Facility

All the geo-information systems have access to the central geo databank implemented at the Netherlands Institute of Applied Geoscience TNO-National Geological Survey.

From 1998, all the non-spatial data of the on-line groundwater databank OLGA and all the spatial data generated with REGIS will be integrated into one corporate datasystem, DINO.

All basic geohydrological and geological data, interpreted geological and geohydrological data such as permeability and porosity, spatial data such as the nationwide geohydrological layer model, thematic and time-dependent data such as groundwater levels and quality, will thereby become available on-line. The institute is collaborating with the Survey Department, Rijkswaterstaat, for the incorporation of hydraulic and surface water (course) data.

Appendix

Some useful addresses

Ministries

Ministry of Transport, Public Works and Water Management
Rijkswaterstaat
PO Box 20906
2500 EX The Hague - NL
Phone +31 70 351 80 80
Fax +31 70 351 83 35

Ministry of Agriculture, Nature Management and Fisheries
PO Box 20401
2500 EK The Hague - NL
Phone +31 70 379 39 11
Fax +31 70 381 51 53

Ministry of Economic Affairs
PO Box 20101
2500 EC The Hague - NL
Phone +31 70 379 89 11
Fax +31 70 347 40 81

Ministry of Housing, Spatial Planning and the Environment
PO Box 30945
2500 GX The Hague - NL
Phone +31 70 339 42 30
Fax +31 70 339 12 88

Ministry of Foreign Affairs
PO Box 20061
2500 EB The Hague -NL
Phone +31 70 348 64 86
Fax +31 70 348 48 48

Ministry of Education, Culture and Science
PO Box 25000
2700 LZ Zoetermeer -NL
Phone +31 79 323 23 23
Fax +31 79 323 23 20

Provinces

Association of Province Councils (IPO)
PO Box 97728
2509 GC The Hague - NL
Phone +31 70 314 34 14
Fax +31 70 324 31 34

Water Boards

Union of Water Boards
PO Box 80200
2508 GE The Hague - NL
Phone +31 70 351 97 51
Fax +31 70 354 46 42

Municipalities

Association of Netherlands Municipalities (VNG)
PO Box 30425
2500 GK The Hague - NL
Phone +31 70 373 83 93
Fax +31 70 363 56 82

Water related institutions

Rijkswaterstaat, Institute for Inland Water Management and
Waste Water Treatment (RIZA)
PO Box 17
8200 AA Lelystad - NL
Phone +31 320 298 411
Fax +31 320 249 218

Rijkswaterstaat, National Institute for Coastal and Marine Management (RIKZ)
PO Box 20907
2500 EX The Hague - NL
Phone +31 70 311 43 11
Fax +31 70 311 43 21

Royal Netherlands Meteorological Institute (KNMI)
PO Box 201
3730 AE De Bilt - NL
Phone +31 30 220 69 11
Fax +31 30 221 04 07

Foundation for Applied Water Research (STOWA)
PO Box 8090
3503 RB Utrecht - NL
Phone +31 30 232 11 99
Fax +31 30 232 17 66

Netherlands Water Partnership
c/o Ministry of Housing, Spatial Planning and the Environment
Directorate DWL/IPC 630
PO Box 30945
2500 GX The Hague - NL
Phone +31 70 339 42 53
Fax +31 70 339 12 88

National Institute of Public Health and Environmental Protection (RIVM)
PO Box 1
3720 BA Bilthoven - NL
Phone +31 30 274 91 11
Fax +31 30 274 29 71

The Winand Staring Centre for Integrated Land, Soil and Water Research
PO Box 125
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Fax +31 317 424 812

Netherlands Institute of Applied Geoscience TNO
- National Geological Survey

PO Box 6012
2600 JA Delft - NL
Phone +31 15 269 69 00
Fax +31 15 256 48 00

PO Box 157
2000 AD Haarlem - NL
Phone +31 23 530 03 00
Fax +31 23 535 16 14

Delft Geotechnics
PO Box 69
2600 AB Delft - NL
Phone +31 15 269 35 00
Fax +31 15 261 08 21

WL/Delft Hydraulics
PO Box 177
2600 MH Delft - NL
Phone +31 15 285 85 85
Fax +31 15 285 85 82

Netherlands Waterworks Association (VEWIN)
PO Box 70
2280 AB Rijswijk - NL
Phone +31 70 395 3535
Fax +31 70 395 3420

KIWA Research and Consultancy
PO Box 1072
3430 BB Nieuwegein - NL
Phone +31 30 606 95 11
Fax +31 30 606 11 65

Government Service for Land and Water Management
PO Box 20021
3502 LA Utrecht - NL
Phone +31 30 285 85 90 / +31 30 285 85 75
Fax +31 30 285 89 99

Universities/International Courses

Delft University of Technology
Faculty of Civil Engineering and Geosciences
PO Box 5048
2600 GA Delft - NL
Phone +31 15 278 91 11
Fax +31 15 278 65 22

Wageningen Agricultural University
Water Resources Department
PO Box 9101
6700 HB Wageningen - NL
Phone +31 317 482 778 / +31 317 482 293
Fax +31 317 484 885

Free University of Amsterdam
Faculty of Earth Sciences
De Boelelaan 1107
1081 HV Amsterdam - NL
Phone +31 20 444 56 66
Fax +31 20 444 56 55

University of Utrecht
Department of Physical Geography
PO Box 80115
3508 TC Utrecht - NL
Phone +31 30 253 27 49
Fax +31 30 254 06 04

IRC International Water and Sanitation Centre
PO Box 3015
2601 DA Delft - NL
Phone +31 15 215 17 15
Fax +31 15 212 29 21

International Institute for Infrastructural,
Hydraulic and Environmental Engineering (IHE)
PO Box 3015
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Fax +31 15 212 29 21

International Institute for Aerospace Survey and Earth Sciences (ITC)
PO Box 6
7500 AA Enschede - NL
Phone +31 53 487 42 89
Fax +31 53 487 43 36

International Institute for Land Reclamation and and Improvement (ILRI)
PO Box 45
6700 AA Wageningen - NL
Phone +31 317 490 144
Fax +31 317 417 187

Consultants

Netherlands Engineering Consultants (NEDECO)
PO Box 90413
2509 LK The Hague - NL
Phone +31 70 382 15 45
Fax +31 70 347 70 53

Secretariats of Dutch Associations

Netherlands Hydrological Society (NHV)
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International Hydrological Programme (IHP) of UNESCO and Operational Hydrological Programme (OHP) of WMO
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International Commission on Irrigation and Drainage (ICID)
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Literature

Books and reports about applied water research are available in the HYDROTHEEK in Wageningen (e-mail: BLUW.HAAFF@PD.BIB.WAU.NL). Information about ongoing research can be obtained by consulting the STOWABASE in Delft (e-mail: STOWABASE@Library.TUDelft.nl).

Source of figures

Ministry of Transport, Public Works and Water Management, Directorate-General Rijkswaterstaat: *1.1, 2.1, 2.2, 2.3, 4.1, 4.2, 4.3, 4.4, 4.5, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 8.3, 8.5, 9.1, 9.2, 9.3, 13.3.1, 13.4.1, 13.9.1 and 13.9.2.*

Royal Netherlands Meteorological Institute: *3.1, 3.2, 13.10.1, 13.10.2 and 13.10.3.*

Ministry of Agriculture, Nature Management and Fisheries: *6.3.*

DLO Institute for Forestry and Nature Research: *13.6.1.*

Netherlands Institute for Fisheries Research: *13.7.1.*

DLO Winand Staring Centre for Integrated Land, Soil and Water Research: *13.11.2, 13.11.3, 13.12.1, 13.12.2, 13.12.3 and 13.12.4.*

Ministry of Housing, Spatial Planning and the Environment: *8.2.*

National Institute of Public Health and Environmental Protection: *3.3, 3.5, 3.6, 3.7, 3.8, 3.9, 13.14.3, 13.14.4 and 13.14.5.*

Water Board De Aa: *3.4.*

Union of Water Boards: *8.1.*

Commission for the Hydrology of the Rhine basin: *7.1.*

International Commission for the protection of the Rhine: *8.4.*

Netherlands Institute of Applied Geoscience TNO - National Geological Survey: *3.5, 3.6, 3.9, 3.10, 13.8.1, 13.8.2, 13.8.3, 13.8.4, 13.8.5, 13.14.1, 13.14.2, 13.15.1 and 13.15.2.*

KIWA Research and Consultancy: *13.2.1 and 13.2.2.*

WL/Delft Hydraulics: *13.13.1, 13.13.2, 13.13.3, 13.13.4 and 13.13.5.*

GRONTMIJ Consulting Engineers: *13.9.3, 13.9.4 and 13.9.5.*

TAUW Water: *13.4.2, 13.4.3, 13.4.4 and 13.4.5.*

G.P. van de Ven: *4.6.*

A. Volker: *10.1 and 10.2.*

E. Schultz: *10.3 and 10.4.*

J. Schouwenaars: *13.11.1.*

Amsterdam	Capital	Aa	Water course of major importance for this publication
Friesland	Province		Province border
Middelburg	Province capital	Veluwe	Nature area of major importance for this publication
De Bilt	City or town of major importance for this publication		