Water in the netherlands

Water in the Netherlands

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Water in the Netherlands

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Contents

1 Synopsis

The Netherlands ....., Holland ...., the Low Countries ...., three names for the same country? No, not exactly. The Netherlands is the correct name of this little kingdom in the north-western corner of the European continent, but many people, both abroad and in the country itself, call it also Holland. The reason is, that in the time of the Dutch Republic of the United Provinces (AD 1572-1795) Holland constituted one of the predominant and most prosperous provinces of that republic. The name of the Low Countries is sometimes used for the kingdoms of Belgium and the Netherlands together.
Since the rise of the ocean level from prehistoric times up to its present level the inhabitants of the low-lying areas in the south- western, western and north-western parts of the country, had almost permanently to fight against the water. The present country is largely the result of this struggle representing the balance of successes and failures. Dutch life is closely linked to the water and its history is full of stories about floods, dike bursts, but also of successful land reclamations and other conquests upon the sea.
A recent disaster, still in the memories of the people, happened during the tremendous storm of February 1953, when many dikes in the south-western part of the country were breached, thousands of hectares were flooded and over 1800 people drowned. In Figure 1.1 one of the many dike bursts is shown.
The danger may come not only from the sea, but also from the rivers, as during high river floods the dikes may not be able to contain all the water and are overtopped or swept away. This also happened in history in the riverine areas of the higher eastern and southern parts of the country.

Figure 1.1 One of the dike bursts during the storm of February 1953

Although many books and reports have been written on specific flood events and the Dutch experience in conquering water, there are no publications which encompass the hydrometeorological conditions, the water management system, the planning of water resources and the organization and legislation of the water industry. A booklet with this contents, written in English, was thought to be of interest not only to the hydrologist and water engineer from abroad but also to the layman.
The 40th anniversary of the TNO Committee on Hydrological Research provided an opportunity to publish such a book.

With great gratitude it is recorded that this was made possible by the voluntary contributions of a number of Dutch specialists from various institutions. Their names and affiliations are given in the list of authors.
For their great efforts in compiling the various contributions, many thanks are due to the members of the editorial committee: Messrs K.P. Blumenthal, W. Cramer, A. Volker and J. Wesseling.
The work of Mr A. Gustard (U.K.) in correcting the English language and in improving the consistency of the various chapters of the book is highly appreciated. Special thanks go to Messrs G. Santing and J.C. Hooghart and Mrs C.W.S. Posthumus for their careful reading of the manuscript and their useful suggestions.
The final shape of this booklet depended strongly on the accurate typing by Mrs G.J. Quint and colleaques under supervision of Mrs M.S. Keisrie and on the high quality of the drawings produced by Messrs M. Jansen, F. Arnoldussen and H. van Ledden.
For the final production and lay-out were responsible Messrs H.W.A.M. Frenken and J.A.F.J. Bontje.
Finally the financial support of the Hydrological Society is grateful mentioned.

H.J. Colenbrander, TNO Committee on Hydrological Research
The Hague, November 1986

For the introduction to annex 1 see page 61.

2 Geography

Situation

The Netherlands, with a land area of 34 000 square km and a population of 14.5 million (1985), are situated by the North Sea in north-west Europe in latitude 52° N and longitude 5° E (Fig. 2.1). The total territory, including inland lakes, estuaries and territorial waters, amounts to 41 160 square km.
The Netherlands comprise the delta's and former flood plains of the Rhine, Meuse and Scheldt rivers (Fig. 2.2). The western part has an elevation varying between slightly above and about 5 m below Mean Sea Level (MSL) and has little relief except for the coastal dunes. The lowest point north of Rotterdam is some 6.7 m below MSL.

Elevation

About 25% of the land area lies below MSL and in the absence of dunes and dikes 65% of the country would be flooded at high sea and river levels (Fig. 2.3).
In general the Netherlands slope from south-east to north-west. The highest point (322.5 m above MSL) is found in the hilly region in the south-east where the national boundaries of the Netherlands, Belgium and the Federal Republic of Germany meet. The central part of the country "the Veluwe", north of Arnhem, is slightly hilly with a maximum altitude just over 100 m above MSL.

Geology and soils

Throughout much of the country Tertiary and Mesozoic deposits are situated at great depth. They only outcrop or 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 Holocene and Pleistocene deposits. This is illustrated in Figure 4.5 where a geological profile is presented (Chapter 4).
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

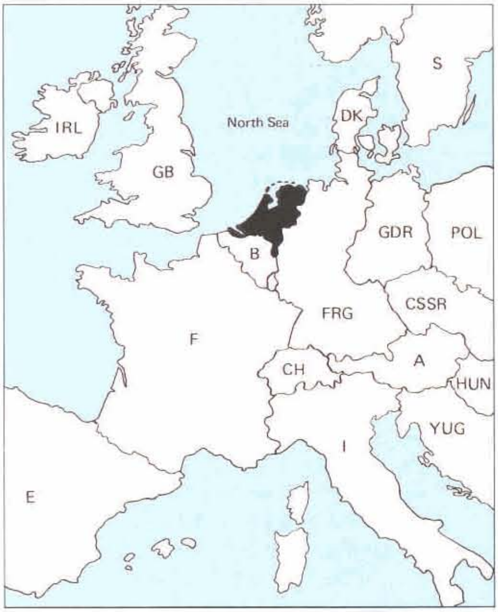


Figure 2.1 Part of Europe indicating the location of the Netherlands

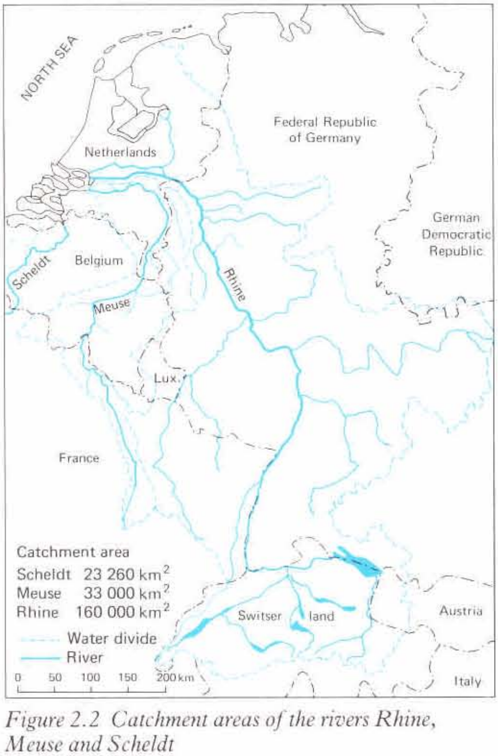


Figure 2.2 Catchment areas of the rivers Rhine, Meuse and Scheldt

fluviatile sediments) and fine sands.
Recently the drawdown of the groundwater table by drainage works has caused shrinkage and oxidation of the clay-peat soil. This has led to an additional soil subsidence of 1 to 2 m in some areas. The soils in the southern, eastern and north-eastern parts of the Netherlands consist mainly of fine loamy sand (cover sand), medium and coarse sand (often gravelly). In the south, silt and silt loam (loess) soils occur. A schematic soil map is presented in Figure 4.6 (Chapter 4).

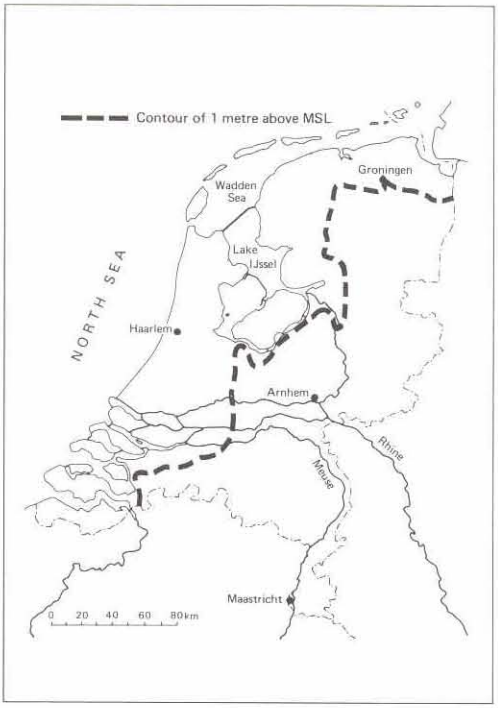


Figure 2.3 Division of the Netherlands in a "low" and "high" part

Land use

As shown in Table 2.1 about 71% of the total country's land area consists of cultivated land, of which almost two thirds is pasture, and the remainder is used for arable land and horticulture. Since 1950 the area of cultivated land has decreased considerably. Woodland and natural areas together account for no more than 13% and urban and industrial areas for 16% of the total land area.

Table 2.1 Land use in the Netherlands in 1983 (after Central Bureau of Statistics)

	land area (sq km)	%
cultivated land	24 042	70.9
woodland	2 969	8.7
nature areas (heath, dunes, etc)	1 557	4.6
built up areas (incl. roads, etc)	5 356	15.8
Total land area	33 924	100.0

Arable farming is mainly found on the fertile, well-drained marine clay soils in the north and south-western part of the country and in the newly reclaimed polders. The most important crops grown are cereals, potatoes, sugar beets and corn. Livestock farming is usually located on the less well-drained clay and peat soils where dairy farming predominates. Mixed farming is traditionally practised on the sandy soils in the eastern and southern parts of the Netherlands. Many of these farms specialise in pig and poultry farming (factory farming). Horticulture is practised in many areas. Most well-known are the bulb fields behind the dunes around Leiden and Haarlem, although bulbs are nowadays grown in many other regions. The "glass house area" with hothouses, 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-western and south- eastern parts of the country, between the large rivers and in the newly reclaimed polders.

3 Genesis of a man made environment

In the course of time the position of the Dutch shore line has varied with the rate of subsidence and the rate of sedimentation.
During the Glacial Era the coast line of the North Sea was some 200 km further north-west than its present position. In the warmer Holocene Era, however, the sea level rose and the North Sea flooded the western and southern part of the country. At present the relative sea level rise is about 10 to 20 cm per century.
Sand-ridges (called old dunes) were formed parallel to the present coast line and around 1000 AD so-called "young dunes" developed on their western side. Although the latter eventually dominated the "old dunes", the sea occasionally invaded the land and formed lakes in the eroded peat that had developed behind the dunes.
Lake Flevo in the heart of the country, which was originally a fresh water body, was transformed into an estuary after transgression by the sea. Figure 3.1 shows this large inland sea, called Zuiderzee, which reached its greatest extent around 1250 AD.
The first settlers on the "low lands", some 5000 years ago, found themselves in a poorly drained flat delta or "flood plain", intersected by a number of small and some larger natural rivers. The settlers tried, vainly at first but gradually with more success, to control the situation. Parts of the land were surrounded by dikes, initially to keep the storm tides out, then later also to maintain an optimum water level by discharging excess water.
In the south-western and northern parts of the country tidal foreland was reclaimed as early as 1200 AD. This was done by accelerating the natural deposition of silt from the sea by digging ditches orthogonal to the existing dikes and enclosing the land when it became high enough. This technique is still practised today.
In the beginning the discharge of excess water was achieved by sluices with gates which were opened at low tide. However by the end of the 16th century the windmill (Fig. 3.2) was introduced for the removal of the excess water. The windmill also offered the possibility of reclaiming small inland lakes. Many of these lakes were man-made by digging peat for heating or as source of salt. The larger and deeper lakes could not be mastered until the 19th and 20th century, when steam, diesel and electric pumps became available. The main

Figure 3.1 The shape of the Netherlands around 800, 1500 and 1900 AD respectively

Figure 3.2 Dutch windmills

reasons for the reclamation of the larger lakes were the increasing demand for arable land to produce food, the danger of flooding by the lakes (the Haarlemmermeer caused many times flooding of parts of Amsterdam and Leiden) and, last but not least, the investment of capital gained by trading and shipping in the Golden Age (17th century).

Since the beginning of the 12th century some 7 000 square km have been reclaimed. The most important land reclamation works are of more recent date. They have been carried out in the former Zuiderzee, after it was transformed into a lake (Lake IJssel) by building a 32 km long enclosing dam in 1932. Currently 1650 square km of this lake have been reclaimed. In Figure 3.3 the reclaimed areas are shown.

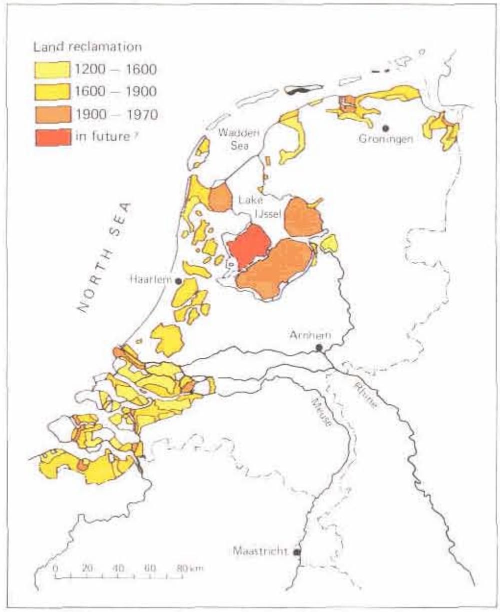


Figure 3.3 Land reclamation in the Netherlands

Another large scale project, which is about to be completed, is the so-called "Delta Project" in the south-western part of the country. This project aims at damming off the south-western estuaries of the Rhine and Meuse.

The Dutch polder system, the Lake IJssel and the Delta Project will be discussed in greater detail in Chapter 5.

4 Climate and hydrology

Climate

The climate of the Netherlands is strongly controlled by maritime influences and this results in marked climatological gradients within 30 kilometers of the coast. Table 4.1 gives mean values for a number of climatological elements for both a coastal and an inland station. Everywhere in the country mean winter temperatures are just above 0 °C and mean summer temperatures at about 16 °C. A notable fact is that coastal regions have more hours of sunshine than inland regions and a relatively small annual and diurnal temperature range. The transition from the sea to the land causes a sudden decrease in mean wind speed. At a height of 10 m above open sea mean wind speed is about 7 m/s, which is considerably higher than the value given in Table 4.1 for the coastal site De Kooy. In heavy gales mean hourly wind speeds of over 25 m/s have been recorded. Mean monthly precipitation exhibits a rather strong annual cycle; the driest months are February, March and April, the wettest are July and August (Fig. 4.2). This seasonal pattern results from the larger frequency of intense showers in summer due to surface heating and the fact that warm air can contain more moisture than cold air. Coastal sites have precipitation increased in October and November due to showers developing over a relatively warm sea surface. Only a small proportion of precipitation falls as snow and this reaches a maximum in the colder inland regions.

Table 4.1 Some climatological characteristics for De Kooy and Twente Airbase, mainly based on data for the period 1951 to 1980 (after Buishand)

	De Kooy (Coastal station)	Twente Airbase (Inland station)
Mean temperature (°C)		
January	2.6	1.4
July	16.2	16.4
Mean daily temperature amplitude (°C)		
January	4.0	5.3
July	5.4	9.9
Mean relative humidity (%)		
January	89	89
July	81	81
Mean annual duration of sunshine (hr)	1 597	1 369
Mean annual wind speed at 10 m over flat open terrain (m/s)	5.8	4.0
Mean precipitation (mm)		
annual	734	765
driest month	38	48
wettest month	88	88

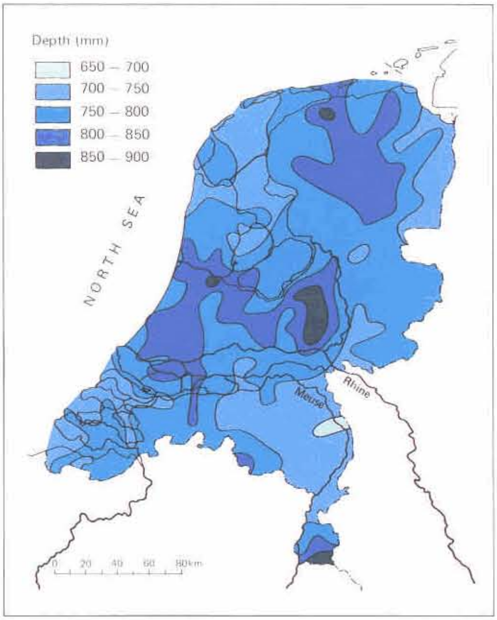


Figure 4.1 Mean annual precipitation for the period 1951 to 1980

Precipitation

In a flat country like the Netherlands local differences in mean precipitation are relatively small. Figure 4.1 illustrates the variation in mean annual precipitation which deviates by no more than 20% from the nation wide mean of 775 mm. The wettest areas are the hilly regions of the east-central and the far south of the country, where orographic enhancement of precipitation is of local importance. About 70% of the total precipitation occurs when wind directions are between south and north-west.

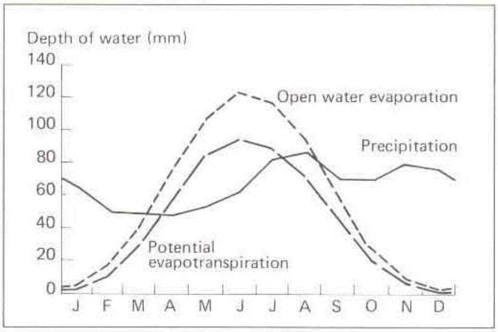


Figure 4.2 Mean monthly precipitation, open water evaporation and potentional evapotranspiration over the year (spatial averages; derived from monthly weather reports KNMI)

Precipitation is an element with a large temporal variation. For example in the 89-year record of the central meteorological station De Bilt annual precipitation ranges from 388 mm to 1189 mm. Daily and hourly precipitation totals have a much greater variability than the annual totals. The 24-hour precipitation values that are exceeded on average once a year and once every 100 years are 34 and 76 mm respectively. For 60-minute precipitation values and the same return periods these figures are 14 and 39 mm respectively. The large temporal fluctuations make efficient water management systems indispensable. The given figures are based on the data of several stations.

Evaporation

Evaporation is governed by a number of meteorological factors, such as solar radiation, temperature, humidity and wind speed. These variables depend to a certain extent upon the geographical locations. The coastal areas in the Netherlands, for example, have on average more solar radiation and higher wind speeds than inland areas and this usually leads to higher evaporation rates.
Generally a distinction is made between (E_o) the evaporation from free water surfaces (canals, lakes, but also wet paved surfaces) and the transpiration from vegetal covers (grass, arable crops, trees). The term evapotranspiration is often used for the total loss of water to the atmosphere due to both evaporation and transpiration. If sufficient water is available for plant growth evapotranspiration will be at potential rate (E_p). In case shortages of water occur, the actual evapotranspiration (E_a) will be smaller than the potential one and crop yield will be not optimal. This frequently happens in the higher lying sandy areas in the Netherlands. In general open water evaporation is higher than transpiration of a vegetal cover. The mean annual evaporation from Lake IJssel, for example, is about 700 mm whereas the mean annual evapotranspiration from grass - the most intensively studied crop in the Netherlands - varies between 400 to 525 mm. The evapotranspiration for most arable crops have been found up to 10% lower than that for grass. From water balance experiments on forest evapotranspiration in the sand dunes near the west coast, mean annual evapotranspiration depths of 700 mm were found for Austrian pines and 500 mm for oaks. Another research project showed an annual evaporation depth from paved surfaces of 110 to 180 mm.
The mean annual evapotranspiration for the whole of the Netherlands is of the order of 500 mm (including an area of 5 000 square km of water). Although the variation in annual evapotranspiration depth is small, the evaporation rate varies considerably over the year, with a maximum of 4 to 5 mm/day in mid summer to almost zero in winter. This is shown in Figure 4.2 where the monthly totals of E_o and E_p are drawn.
The open water evaporation (E_o), presented in this figure, is determined by the well-known equation of Penman. Further it is assumed that the potential evapotranspiration (E_p) amounts to 80% of the open water evaporation.

Precipitation minus evapotranspiration

The mean annual cycles of precipitation and evapotranspiration give rise to a water surplus in winter and usually a deficit in summer (Fig. 4.2).
Every winter a water surplus exists, because during that time evapotranspiration is always very low. Because of the large temporal variation in precipitation, the magnitude of the water surplus varies strongly from year to year. During summer periods water deficits will also vary in magnitude due to the temporal variation in rainfall and in very wet summers the deficit may even turn into a surplus. The difference between the totals of precipitation and potential evapotranspiration for the period 1 April to 1 September amounts to -100 mm under average

conditions and to -275 mm and +50 mm for very dry and very wet periods, respectively. These figures are the means of 6 stations. The data of these stations for the years 1911 to 1975, are analysed by De Bruin.

Hydrology

Surface water

The hydrological conditions of the Netherlands are typical for a coastal region in the temperate zone with flat lands in the lowlying part and gently undulating land in the higher part. Surface water plays an important role although in the former part of the country this role is different from that in the latter part. In the low polder areas high water levels which are controlled artificially are prevailing, whereas in the higher lying lands the water levels are lower and drainage is mostly by gravity. In these areas a part of the water courses may even become dry in summer.

Under these conditions only a small proportion of the excess winter precipitation flows directly to the channels by overland flow; the majority of it infiltrates into the soil and joins the groundwater. Part of this groundwater flows quickly to the drainage system, the remainder recharges the deeper aquifers and reaches the river system only after a period of months or years.

Due to the precipitation excess in winter and the water deficit in summer in the Netherlands, the mean river runoff is in general 2 to 3 times greater in winter than in summer. Figure 4.3 shows the variation in discharge over the period 1980 to 1984 for the river Aa in the southern part of the country. The summer lows and winter peaks are quite pronounced but they vary in magnitude from year to year due to the differences in precipitation.

The mean annual runoff varies in general

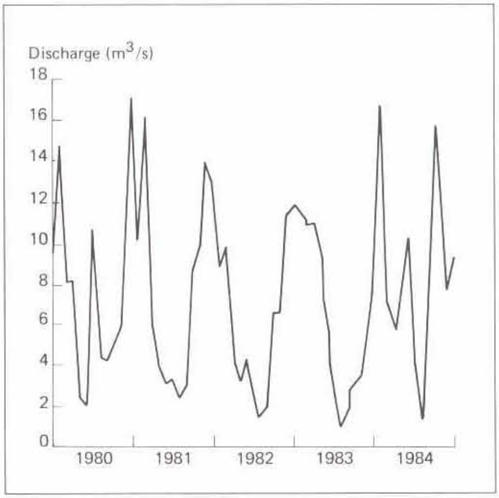


Figure 4.3 Mean monthly discharge of the river Aa

between 225 and 375 mm depending on land use in the catchment area and on the basin characteristics. These figures do not include the discharge of seepage water which occurs in many polder areas at a rate of 1 to 2 mm/day.

The Rhine and Meuse are of great importance to the hydrology of the Netherlands. The character of these two rivers is, however, quite different. The Meuse is a typical rain-fed river with peak flows in winter and generally very low flows in summer, whereas the Rhine has a mixed character being fed partly 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 summer, originating from snowmelt. The range of observed discharges of these two rivers are shown in Table 4.2.

Table 4.3 shows a water balance for the Netherlands for an average year and the very dry year of 1976 and illustrates some of the most important aspects of the hydrology of the country.

Table 4.2 The highest, mean and lowest observed discharges of the Rhine (1901 to 1975) and Meuse (1911 to 1980)

River	Upstream catchment area (km^2)	Discharges at the Dutch border (m^3/s)		
		highest	mean	lowest
Rhine	160 000	13 000	2 200	620
Meuse	33 000	3 000	230	0

	average year		dry year 1976	
	mm	$10^6 m^3$	mm	$10^6 m^3$
In				
Precipitation	775	30 100	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	2 840	110 500	1 730	67 300
Out				
Evapotranspiration	501	19 500	528	20 500
Different uses	129	5 000	154	6 000
River outflow	2 210	86 000	1 048	40 800
Total	2 840	110 500	1 730	67 300

Table 4.3 The water balance of the Netherlands for an average year and a very dry year as 1976 (in mm and in $10^6 m^3$)

The presented evapotranspiration depths refer to the real catchment evapotranspiration as referred to earlier.
Further the table shows clearly the significance of the inflows of the Rhine and Meuse, of which some 16 000 million m^3 per annum are abstracted for various purposes, such as domestic and industrial use, irrigation and abatement of salt water intrusions in the polder areas.
A high proportion of the water is returned to the river system, although rarely at the same location as the abstraction point and the quality of the water is usually modified.
Details on the water use in a normal and a very dry summer are given in Chapter 6.

Groundwater
The landscape and the subsoil of the Netherlands have the characteristics of deltaic areas.
Thick unconsolidated sediments form good aquifers and the groundwater levels are shallow.
A distinct feature of groundwater quality is the occurrence of brackish water in large parts of the coastal zones.
The problems presented to major sectors of society, including agriculture, water supply and engineering practices, are described below.

Drainage of agricultural land
More than 1 000 years ago, the inhabitants of the coastal areas tackled the problem of very high groundwater levels by cutting ditches discharging towards natural water courses. The first artificial drainage systems developed gradually into an intricate pattern of ditches, collector canals and separate polders, which sometimes obscured the natural drainage pattern and now largely influences the groundwater situation.

Drinking water supply
Private and public water supply, the latter installed during the last 100 years, were based predominantly on groundwater and this influenced the location of many settlements. Initially public water supply encountered problems only in the coastal areas where supplies of potable groundwater were limited. Fresh water lenses below the dune ridge were heavily exploited until some 40 years ago when the dunes were developed into important sites of artificial recharge with river water. Nowadays the effects of lowering the shallow groundwater table on agricultural production, natural vegetation and land subsidence, are widespread.

This has led to the need for restriction on groundwater abstraction controlled by a delicate balance between the economics of groundwater use and the environmental effects on other interested parties.

Engineering practices
Deep excavations for the construction of large buildings, sluices, docks, tunnels, etc., have necessitated the lowering of groundwater tables and the pumping of excess water. On an even larger scale this problem arises when pumping and reclaiming former lakes.

Groundwater pollution
The most recent problem concerns the pollution of soil and groundwater by a high population density, a continuously growing industrialization and intensive agriculture. The soil has become polluted by private and public waste dumps, air pollution, fertilizers and deposition of excess manure, which is easily transported by shallow groundwater to locations where it may be harmful to other interests.

Major hydrogeological features
The groundwater hydrology of the country is controlled primarily by the lithology of unconsolidated Quaternary sediments, deposited in a subsiding basin. Some geological features of the country are shown in Figure 4.4 and in the hydrogeological cross section of Figure 4.5.
The axis of the basin dips to the north-west, resulting in the largest aquifer thickness in the central and north-western part of the country. At the eastern national boundary, Tertiary and even older sediments outcrop. In the south, superficial deposits are restricted to the Lower Pleistocene age. Where the Quaternary sediments thin out, upper Tertiary layers may form exploitable aquifers. The South-Limburg region in the south of the country is the only area with hardrock sediments of Cretaceous age. The rate of sedimentation in this basin reached a maximum in the Pleistocene age. During glacial periods the deposition of thick layers of coarse sediments of fluviatile and fluvioglacial origin gave rise to the presence of extensive aquifers. At the north-western Lake IJssel transmissivities of more than 10 000 m^2/day have been determined. Aquifers are less important at the margins of the basin. Over large stretches of the eastern border no aquifer is present at all. Upper Tertiary aquifers along the southern border have transmissivities of less than 1 000 m^2/day. Values in other parts of the country are between these extremes.
The presence of ice sheets during the Pleistocene

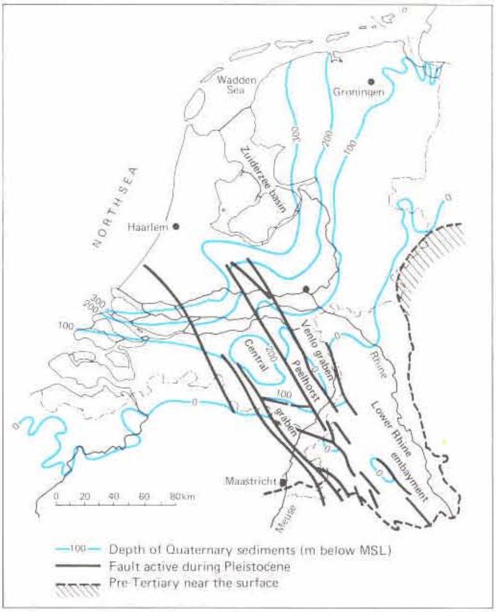


Figure 4.4 Depth of the Quaternary sediments (m below MSL), according to Zagwijn

period had a strong influence on geomorphology and, therefore, on present groundwater flow patterns. Of particular significance were the scouring of deep valleys either by melt water, or by the ice itself. These valleys have later been infilled by poorly permeable sediments partly known as potclay. The eroded coarse material formed the ice-pushed ridges, which remain as sandy hills with deep groundwater tables and high rates of natural recharge.
During the Holocene period, which began 10 000 years ago, fine sediments were deposited on the relatively low parts of the Netherlands, i.e. the coastal zones and the river valleys. The fluviatile (clay and loam), semi-marine (peat and clay) and purely marine (clay and sand) layers reach a maximum depth of 20 m near the coast, but they thin out against the higher Pleistocene ground. These layers exert a hydraulic resistance of between approximately 100 and 1 000 days against the vertical flow of groundwater. Along the coast a sandy dune ridge developed which was broken in the south-west to form an estuarine landscape and in the north to form the shallow Wadden Sea. Inland intruding sea water resulted in brackish groundwater at shallow depths.

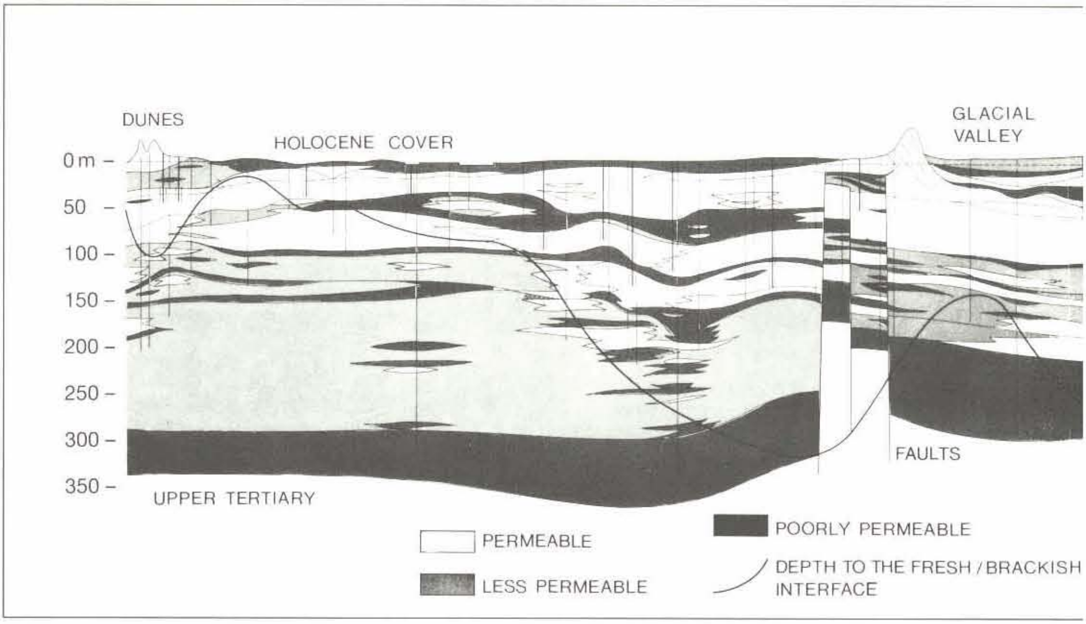


Figure 4.5 West to east hydrogeological cross section of the center of the Netherlands, according to Jelgersma

Landscape and groundwater hydrology

Groundwater levels are shallow; in 90% of the country the level is less than 1 m below land surface in winter and less than 2.5 m in summer. The only areas with a deep groundwater table are in South- Limburg, the central ice-pushed ridges and part of the dune area. Owing to the shallow groundwater table, there is a close relationship between landscape and groundwater. Three major zones exist: the higher sandy areas inland, the relatively high areas of the most recent coastal and fluviatile deposits, and a lower transition zone where extensive peat bogs developed (Fig. 4.6).

In Figure 4.7 the regional trends in groundwater flow patterns are shown.

The shallow groundwater levels in the sandy areas are largely controlled by the natural drainage system, strongly adapted to the needs of agriculture. In the coastal marine-clay areas the backbone of the drainage system is the former creek and gully system. In the peaty areas, both the landscape and groundwater flow are almost all artificial. Peat bogs were drained by long parallel ditches; large peat deposits were excavated, leaving lakes, later to be pumped and reclaimed again. All the land in these areas is below mean sea level; the non excavated areas by between one and two metres as a result of shrinkage of the peat, the reclaimed lakes to a depth of about 5 metres.

This is the land of the polders, where excess water must be pumped and groundwater flow is controlled by the variations in levels of high and low polders. The latter are the areas of groundwater discharge by a strong upward seepage of water, some of which is brackish. Present and former branches of the rivers are above the polder levels. Hence the rivers are permanently infiltrating, frequently at a high rate owing to the sandy lithology of most of the river beds.

Groundwater is recharged by rainfall in the higher sandy inland areas and at the dunes. The higher infiltrating polders and the surface water from the river branches contribute a major component of the groundwater recharge in the polder areas. In Figure 4.6 the types and rates of recharge are illustrated.

However, not all of this potential recharge reaches exploitable aquifers, for the reasons outlined below.

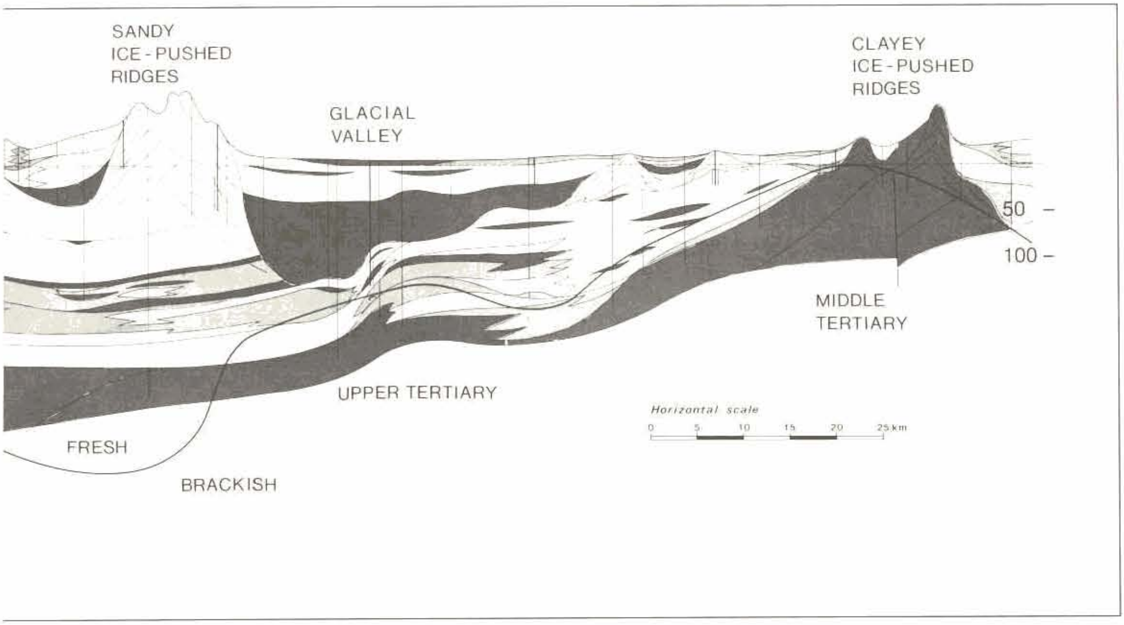


Figure 4.6 Major soil types of the Netherlands, according to Stiboka. Figures refer to mean annual runoff

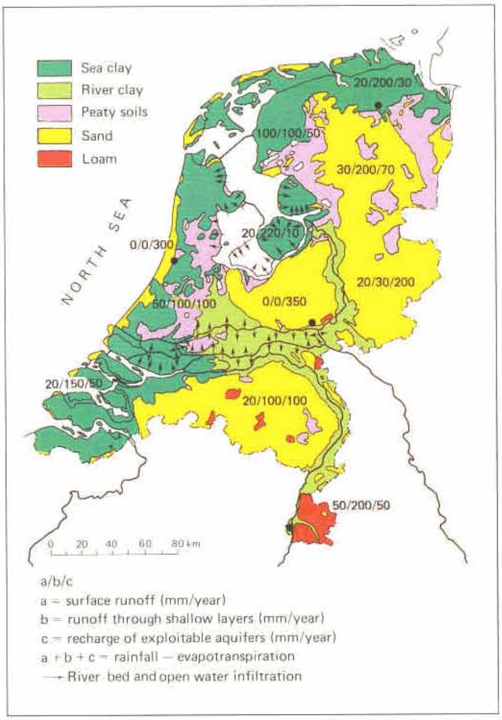
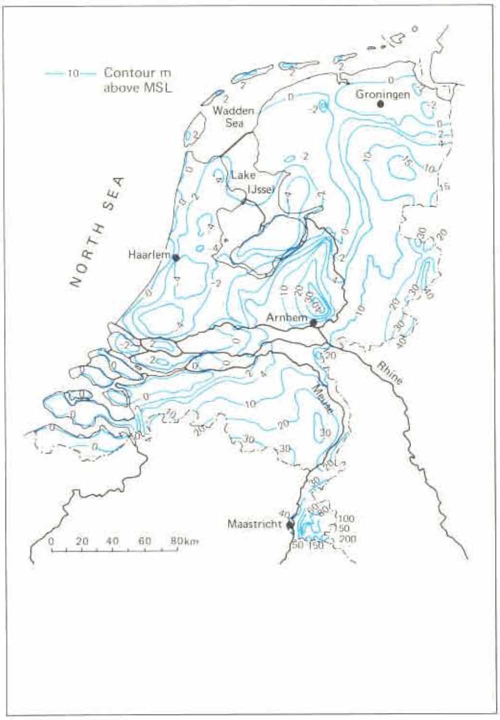


Figure 4.7 Groundwater contours (m above MSL)



The sandy areas in the northern part of the country are covered with boulder clay and brook loams. Rainfall excess is about 300 mm/year of which about 30 mm/year is directly discharged to surface water and about 200 mm/year reaches only the upper soil zones leaving approximately 70 mm/year recharging exploitable aquifers. The central sandy areas are covered in the east with a dense drainage system. From approximately 250 mm/year of rainfall excess about 50 mm/year is directly recharged to surface water or only reaches the upper soil zone, which leaves about 200 mm/year for recharge of the single aquifer. However at the ice-pushed ridges the full rainfall excess of 350 mm/year recharges the aquifer system underneath.

The areas south of the Meuse are influenced by shallow tectonic activity. From east to west a tectonic low (Valley of the Meuse), a horst area (Peel), a deep tectonic low (Central Graben) and again a tectonic high are present.
At the Peel area the unconfined aquifers are thin and have a low transmissivity. In the Central Graben the aquifer system reaches a depth of some 500 m and is covered with thick loamy layers. Of the 220 mm/year rainfall excess more than 200 mm/year recharges the Peel aquifer, but only about 100 mm/year feeds the upper aquifer of the Central Graben.

Over the low lying areas covered by Holocene sediments most of the rainfall excess of approximately 250 mm/year is discharged directly or by a short soil passage to the surface water. The exception is the dune area where the natural recharge of some 300 mm/year is locally supplemented by high rates of artificial recharged water from the Rhine, Meuse and Lake IJssel. This has a residence time of at least two months before it is abstracted and treated for drinking water.

Between the upper reaches of river branches an interesting situation occurs. At high river levels and low groundwater levels (in summer) the river branches are infiltrating and the neighbouring area will show upward seepage. In the reverse situation with high groundwater levels and low river levels the present and former river channels become recharge areas for the rainfall excess.

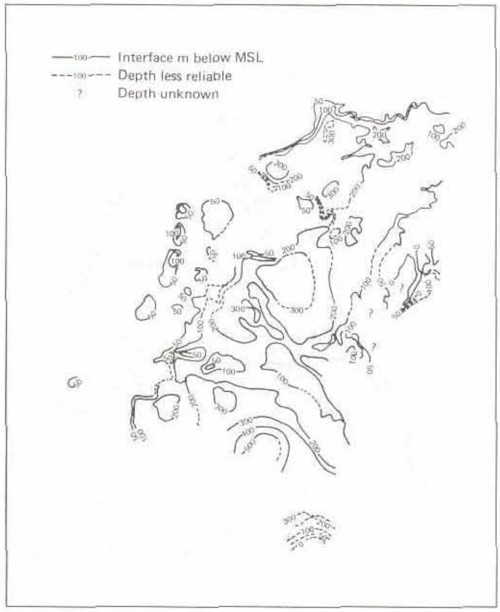


Figure 4.8 Depth of the fresh/brackish interface of the groundwater (m below MSL), according to TNO-DGV

The presence of saline and brackish groundwater
As mentioned before, most of the shallow groundwater in a broad coastal belt is brackish (Fig. 4.8). This is due to the activity of the marine transgressions before and during the deposition of the Pleistocene aquifers. Throughout the country a transition towards brackish groundwater at greater depth can be found; this is determined by geology and geohydrological processes.

5 Management of water quantity and quality

Water quantity management

Introduction

The hydrological situation of the Netherlands is largely governed by the fact that almost the entire country lies in the estuarine area of three rivers, the Rhine, Meuse and Scheldt. Figure 2.2 illustrates this and Figure 2.3 shows how the country can be divided into a "low" region below high tide level and a "high" one situated above this level. The low part of the country and the river areas of the higher parts are made entirely of polders. A polder is a typical Dutch landscape and means a low lying level area, isolated from the surrounding hydrological regime. In a polder the water levels are controlled by pumping excess water into the storage canals ("boezems"). Figure 5.1 illustrates the principle of a polder and Figure 5.2 shows a modern pumping station. In some cases the excess water can be (partly) discharged by gravity through sluices. In dry periods it may be necessary to reverse the direction of water movement and transfer water from the "boezem" canals into the polder waters. Precise water level control is essential in the low areas because a fall in water level could be followed by irreversible subsidence of the soil surface and by the disintegration of building foundations and canal linings. Moreover, the interests of navigation, recreation and nature preservation must also be met. In the "high" parts of the country the channel system to transport surface water is limited. In contrast to the low polderlands groundwater in this area is in general of good quality.

Reclamation of the Zuiderzee

Figure 3.1 shows the Netherlands at the beginning of the 20th century. The central embayment was called the "Zuiderzee", where inundation from the sea caused major flood disasters like in 1916. This triggered the decision to carry out a long-cherished plan to close off and partly reclaim the Zuiderzee. The enclosing dam with large discharge sluices was completed in 1932 to impound "Lake IJssel", named after the river IJssel, a branch of the Rhine which carries about 10% of the Rhine flow into the lake. The lake was gradually transformed into a fresh water basin by receiving this fresh water flow and evacuating the surplus through sluices. By constructing four polders on a scale not previously envisaged, part of the Lake IJssel was reclaimed and turned into rich farming land at one of the lowest levels in the Netherlands (Fig. 5.3). In the most recent polder land-use development is in progress, while the decision on the reclamation of a fifth polder ("the Markerwaard") has been recently postponed. The remaining lake is large enough to constitute a major fresh water reservoir (at present 500 million m^3) by water level control within a range of 20 cm. The northern and north-western parts of the country are supplied with fresh water from the lake which also receives excess water from this area.

The Delta Project

The south-western estuarine area of the country consists of islands, surrounded by deep and tempestuous estuaries. Into these estuaries the Scheldt and the Meuse discharge, as well as 90% of the Rhine flow. All this fresh river water mixes with the salty water of the North Sea. Following the disastrous flood of 1953, the so-called "Delta Project" is being implemented

Figure 5.1 Scheme of a Dutch polder

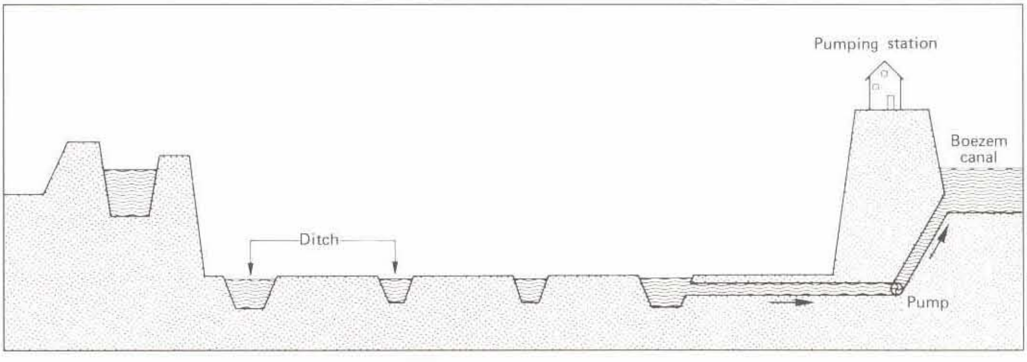


Figure 5.2 Modern pumping station

with the aim of damming the south-western estuaries (Fig. 5.4). The Rotterdam Waterway and the Wester Scheldt were excluded from the scheme because of their importance as entrances to the harbours of Rotterdam and Antwerp. Safety around these waters is being achieved by a substantial reinforcement and heightening of the dikes.

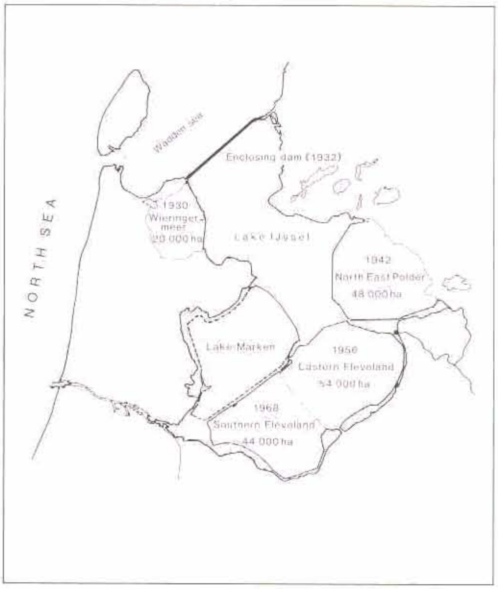


Figure 5.3 Reclaimed polders in the Lake IJssel

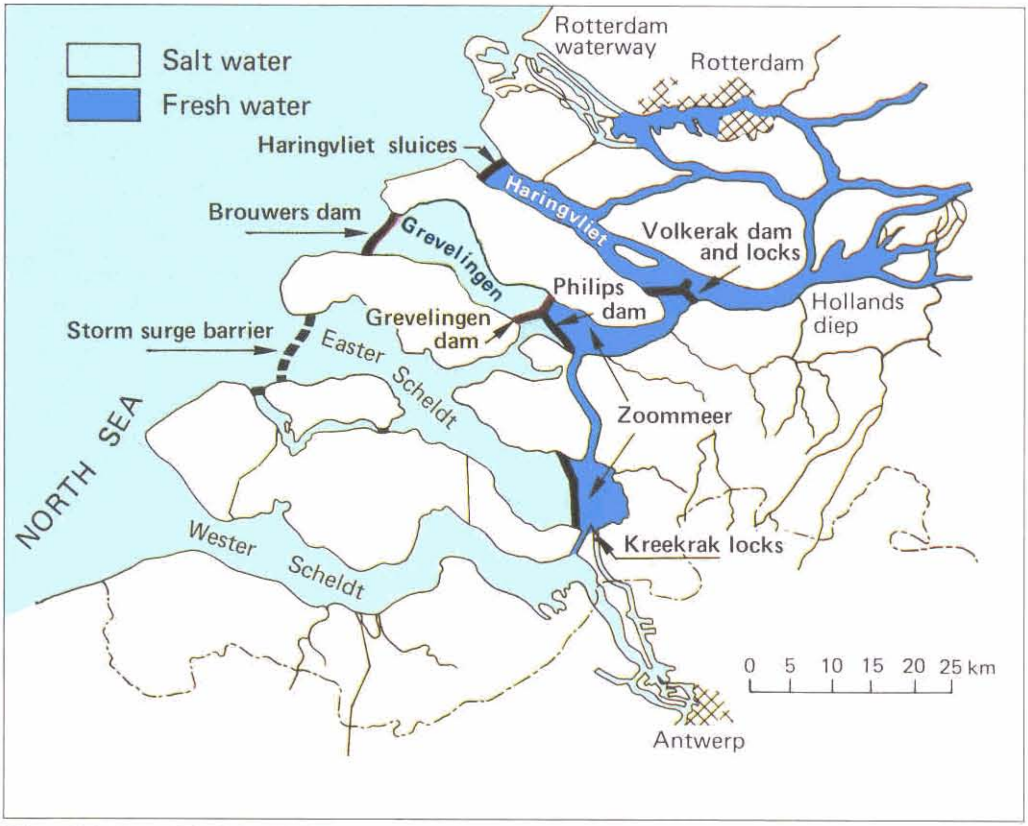


Figure 5.4 Map of the Delta Project

The main features of the project are as follows. There are three primary dams: the Haringvlietdam (Fig. 5.5), the Brouwersdam and the Easter Scheldt Barrier Dam (Fig. 5.6).
The Volkerakdam divides the northern and the southern Delta basins; the former is important for national water management.
According to the plan the Easter Scheldt was to be closed by one of the largest dams ever built in the Netherlands. Environmental considerations finally led to the decision to build a "storm surge barrier dam", that leaves tidal movement largely unmodified, but can be closed during storm surges. The dam is operational since October 1986 at a cost of almost 8 000 million guilders (some 3 500 million US dollars).
Secondary dams in the southern basin are the Grevelingendam, built primarily for the temporary function of moderating tidal currents during the project's construction phase and the Philipsdam, that together with the Oyster-dam helps to create a fresh water basin ("Zoommeer") in the otherwise salty southern system. The latter two dams will increase the safety of shipping on the Antwerp-Rhine shipping connection. As required by the interests of navigation or water management the dams have been provided with locks and sluices.

Figure 5.5 Haringvlietdam with sluices

Figure 5.6 Easter Scheldt storm surge barrier

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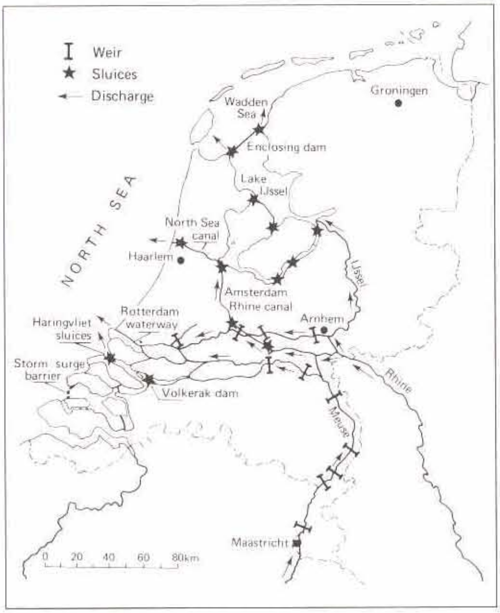


Figure 5.7 Infra-structure of the Dutch water system

Figure 5.8 One of the three weirs (double "visor" gate) in the Rhine

The fresh water of the northern Delta basin is supplied by the discharge of the Rhine and Meuse. The primary Haringvlietdam is equipped with enormous drainage sluices that keep salt water out at high tide and discharge surplus flows 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, but the required outflow to the sea imposes a heavy demand on the national water balance, especially in periods of drought.

Major intakes of river water and navigation
The main rivers with weirs and outlets can be seen in Figure 5.7. They are the country's main system for transportation of fresh water and their control is important for water management purposes. The Meuse and the Lower Rhine have been canalised for navigation. The three weirs of the Lower Rhine also provided a means for controlling water flow. Figure 5.8 illustrates the novel weir design of one of them which incorporated two "visor" gates. The uppermost weir is one of the major "taps" of the system. At low flows it is partly or entirely closed, enabling more water to flow down the river IJssel to improve the depth for navigation and to augment the supply to Lake IJssel. The manipulation of the remaining two weirs is then tuned so as to maintain an adequate water depth for shipping. Amsterdam harbour lies at the eastern end of the North Sea Canal and is separated from the sea in the west by locks for seagoing ships. Operating these (and other) sea-locks leads to salt water intrusion in the rivers. Amsterdam is connected to the Rhine by the Amsterdam-Rhine Canal, for which plans were made to improve the flexibility of the supply system by permitting substantial transfers of water in either direction. An alternative scheme of canalising the river IJssel was also proposed but both projects were rejected on the grounds of not being cost-effective. This decision was based on the results of a study (Policy Analysis of Water management for the Netherlands, or "PAWN"), that is described in more detail in Chapter 8.

Artificial recharge and storage reservoirs
Although potable groundwater is restricted in the west to a narrow belt of coastal dunes they do form an important resource.
However, this supply would long since have been depleted without artificial recharge of river water made possible after Second World War by the construction of pipes for conveying Rhine-water to the dunes. A later extension of the pipe network enabled the superior quality of the Meuse to be exploited for artificial recharge.

The advantage of this artificial recharge is that infiltration can be restricted to periods of relatively good water quality and that, although soluble substances are not removed, underground storage generally leads to an improvement of river water quality.
Some of these advantages are also obtained by reservoir storage which is practised in the south-western part of the country.

Table 5.1 The quantity of various compounds and elements imported into the Netherlands by the Rhine and the Meuse in tonnes per year in three different years

Compound or elements	1975		1980		1984	
	Rhine	Meuse	Rhine	Meuse	Rhine	Meuse
Polycyclic aromatic hydrocarbons	not known	1.8	32	9	12.5	9.4
Phenols	1 062	68	710	70	587	103
Mineral oils	18 655	1 845	14 800	4 180	7 285	4 095
Chromium	2 210	90	1 617	103	713	367
Copper	1 290	110	1 165	115	679	191
Lead	1 385	105	1 262	258	548	322
Nickel	634	26	728	72	373	87
Zinc	8 696	1 534	8 348	2 782	4 478	2 012
Mercury	21.9	1.1	15.6	3.4	5.5	2.5
Cadmium	132	19	117	37	17	24

Water quality management

Owing to their geographical position many water bodies in the Netherlands are eutrophic even under natural conditions. The increased population, together with the industrial and agricultural developments in Western Europe, has resulted in the increasing pollution and eutrophication of many lakes and canals. This has led to severe problems with low oxygen content of many waters and an excessive bloom of blue-green algae. Additional problems associated with the contamination of the bottom of the lakes and river beds with heavy metals and organic micro-pollutants have also come to the fore.

Combating water pollution has become a major goal of government policy, both at national and international level. The Rhine is much more polluted than the Meuse and is often referred to as the biggest sewer of Europe. As a result of international negotiations a number of pollutants in the Rhine has been reduced during the last decades (Table 5.1). The concentration of other pollutants has not decreased as is shown in Figure 5.9; the chloride load has even increased over the last decades (Fig. 5.10). The unfavourable consequences of these trends are described in more detail in the section on eutrophication.

Water pollution control

The legal framework for combating water pollution in the Netherlands is provided by the Pollution of Surface Waters Act of December 1970. The national policy for sanitation and water quality improvement is formulated in the "Water Action Programme" that has been drawn up every five years since 1975. For harmful substances, like DDT, PCB's, mercury and cadmium, a direct emission control is applied (emission objective approach). For some substances limiting values for discharges have been agreed upon internationally (European Community, International Commission for the Protection of the Rhine against Pollution). The reduction of pollution by less harmful substances is dependent on the water quality of the receiving waters and the application of a "best practicable means" approach using water quality objectives.

Water pollution is caused by emissions of very different composition, originating from various

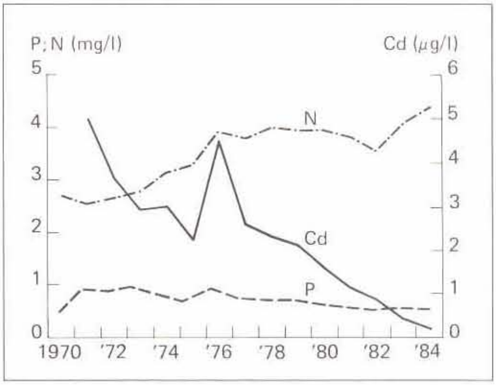


Figure 5.9 Concentration of phosphate, nitrate and cadmium in the Rhine water over the period 1970 to 1984

Table 5.2 The production and removal of oxygen consuming load of waste water in the Netherlands over the period 1969 to 1990 (in million of population equivalents)*

Source	1969	1975	1980	1985	1990
Domestic	12.5	13.3	14.2	14.6	14.8
Industrial	33.0	19.7	13.7	11.3	8.8
Total	45.5	33.0	28.0	25.8	22.8
Removal in public treatment works	5.5	8.7	12.6	14.4	17.4
Load of surface waters	40.0	4.3	15.4	11.4	6.2

* A population equivalent unit is the oxygen consuming load of waste water produced by one person over a day; an average household produces 3.5 units

Element	House hold	Traffic	Wet and dry fall out	Total	Industry
Chromium	24	0.2	3	27.2	134
Copper	103	0.4	30	133.4	65
Lead	14	397	51	462	128
Nickel	7	0.2	5	12.2	52
Zinc	114	19	181	314	656
Mercury	0.7	–	0.5	1.2	0.7
Cadmium	1.4	–	1.2	2.6	19

Table 5.3 The discharge of heavy metals into surface waters by non-point sources and industry in the Netherlands in 1980 (tonnes per year)

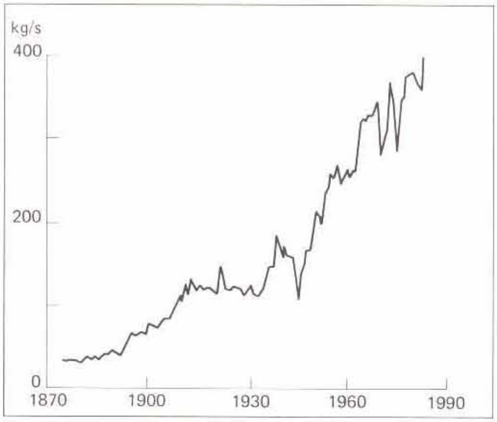


Figure 5.10 Chloride load of the Rhine over the period 1885 to 1984

sources. The sources can be divided into two major groups: point sources and non-point or diffuse sources. The most important point sources are relatively easy to identify and to treat. They include industrial discharges and effluents from sewage treatment plants. Non-point sources are difficult to trace and the emissions follow different pathways. Examples of non-point sources are wet and dry atmospheric fall out, urban and agricultural runoff.

In the seventies the efforts to improve surface water quality were aimed not only at increasing the oxygen content, but also at decreasing the discharges to surface waters of other pollutants, such as heavy metals and synthetic organic substances. The construction of biological treatment plants by public authorities and industry have together with other pollution control measures produced a marked improvement in water quality. In the period 1971 to 1984 public treatment capacity in the Netherlands increased from about 5 to nearly 15 million population equivalents* (Table 5.2). Table 5.3 illustrates the importance of further research on the quantity and origin of heavy metals and other micropollutants from non-point sources and industry. Information in the Netherlands on the levels of organic pollutants continues to be limited to a number of groups of compounds discharged into water courses of national importance.

Table 5.4 The influx of phosphorus to Dutch inland waters in tonnes per year from Rhine, Meuse and inland sources

Source	Rhine	Meuse	Inland
P.influx (tonnes/year)	50 000	5 000	23 000

Eutrophication

The phosphate content of many Dutch water courses is high and as a result it is a key element in the eutrophication of shallow fresh surface waters. The phosphate content of the Rhine is also relatively high (Fig. 5.9) and when this water feeds Lake IJssel and Lake Marken algal blooms readily develop. This figure also shows that the phosphate content of the Rhine have slightly improved over the last decade but that the nitrate/nitrite content has increased.

The relative importance of the influx of phosphorus to Dutch inland waters by the Rhine is also illustrated in Table 5.4.

Reduction in phosphate levels will not always lead to a reduction in the growth of algae, unless the level is reduced below a certain threshold value. This reduction will be impossible for waters that receive a high phosphorus load from groundwater. For waters directly influenced by the Rhine international co-operation is essential to attain satisfactory levels of phosphate. Removing phosphates from the water discharged to the Rhine would require additional investments by neighbouring countries at up to 500 million guilders.

However, this is a relatively small amount when compared to the total investment made in sewerage and waste-water purification plants in the whole of the Rhine basin. Industry is also reluctant to reduce levels of poly-phosphates in detergents because of the costs involved, although 40% of poly-phosphates in detergents have now been replaced by other chemicals. Until progress is made with the lowering of phosphorus loads in neighbouring countries it is unlikely that eutrophication can be reduced for the Netherlands as a whole. Phosphorus control measures including the removal in sewage treatment plants must be implemented before any effect can be expected. The close relationship between water quantity and water quality management also offers some scope for improving water quality by using alternative , careful manipulation of open water levels and the diversion of water rich in nutrients.

Sediments
The Rhine, Meuse and Scheldt transport not only water to the Netherlands but also sand and silt, while in the estuarine regions sand and silt are deposited by the sea and dredging is necessary to keep harbours and navigation routes open. Some 65 million cubic metres per year are removed from Dutch harbours and it has become apparant that these sediments are seriously polluted by oil, heavy metals, PCA and halogenated organic compounds like PCB, drins and HCB. The polluted material threatens the aquatic ecosystem and poses environmental problems when the dredged material is disposed or in water or on land. The impact on flora, fauna, surface water and groundwater curtail the number of suitable disposal sites.
Existing sites are now being evaluated to determine the geochemical and ecological processes associated with the deposition of dredged material and the dredging techniques are also being rapidly improved to prevent water pollution during dredging. Public resistance to dumping polluted sludge in water and on land has led to a policy aiming at centralising the disposal. An Environmental Impact Assessment is being carried out to examine the effects of dumping of 10 million cubic metres of sludge per annum in the North Sea near Rotterdam for a period of 15 years commencing in 1987.
Also in international fora (e.g. the Rhine Commission) attention has been paid to the effect of contaminated river sediments and this may call for renewed efforts to reduce discharges of harmful substances.

Overview of the Dutch water management problems

The main objectives of the Dutch water resource system are to transfer the correct quantities of water of the desired quality at the right times to the places where it is needed. This presents some problems in normal periods but severe difficulties in droughts as the following brief observations will show.
The oldest water resource problem is the intrusion of sea water which occurs directly through the open estuaries. As mentioned before a number of estuaries has been closed halting the direct intrusion of sea water. However, in the interest of navigation, locks have been installed in the dams where appreciable amounts of saline water are still admitted to the fresh water system.
In the low-lying polder areas, there is a constant upward flow of brackish or saline groundwater, affecting the water quality in soils, ditches and canals. The salt water intrusion increases as the mean sea level is rising. But also increased shipping traffic, larger locks, bigger harbours and deeper entrance channels have entailed a further increase of the salt intrusion. This is particularly noteworthy in the Rotterdam Waterway, where the intake of fresh water supply (Rhine water) for agricultural and drinking water purposes into the western part of the country had gradually to be moved 20 km further upstream. The Delta Works have improved the situation, but the present inlet is by no means safe under all conditions, since almost all the minimum observed Rhine discharge at the Dutch border is required to prevent salt-water intrusion beyond the inlet point.
Other substances that pollute surface waters in the Netherlands are typical of a densely populated, heavily industrialized country. The problems of micropollutants, heavy metals and eutrophication are the most difficult to tackle, neither have waste heat problems and the problem of contaminated river sediments any quick and easy solution.
Thus surface waters in the Netherlands are often of unsuitable quality and, apart from the

usual method of purification at the source, a system to remove salt and other pollutants is to "flush" the polder waters by introducing fresh water at one end and pumping out poor quality water at the other. In the majority of the cases this "cleaning" has to be done with water of the Rhine. This river supplies approximately two thirds of the total fresh water supply of the Netherlands (Chapter 6). The ironic fact is that this water is heavily polluted during periods of low flows when cleaning is most urgently required. As a result the flushing of polders in dry periods is either useless or would require exceptional quantities of water which are unavailable.

By damming estuaries, to provide protection from storms and from salt, the Netherlands are able to store and utilize much of the imported surface water from the Rhine which occurs in varying proportions in the majority of the waters of the Netherlands.

Fresh groundwater (the much preferred source for many uses) is available only in the south and east, and in the dune area along the coast. In many regions the groundwater resources are already fully exploited.

In September 1985 a Water Management Policy Report based on the previously mentioned PAWN study, was published. This gives the government's long term view on this policy area. It is one step in the long process of engineering, management, quality and quantity planning and legislation, that is intended to give the country a set of water systems, where human needs and ecological equilibrium will be in harmony. Water resources management in the Netherlands is described in detail in Chapter 8.

6 Water use and water supply

In society water is used in many ways, for example in the household, in industry (for processing and cooling) and by power stations (cooling only). Furthermore in the Netherlands huge quantities of water are used for irrigation and the repulsion of salt intrusion.
Water is also important for many other interests, such as for navigation, fishery, recreation, nature conservation and landscape.
Furthermore surface water is used for the transportation of pollutants.

Domestic and industrial use

Over the past decades the domestic and industrial uses have developed quite differently. Figure 6.1 illustrates that both have shown a steady growth after the Second World War until the early seventies when domestic consumption increased much more slowly and industrial water use went even into decline. It is worthwhile noting that in the Netherlands the domestic water consumption of 120 l per capita per day is still low compared with other developed countries, although a direct comparison is difficult.
The reduction in industrial use was due to the oil crisis in 1973 which led to an economic recession. A second reason was that in 1970 a Pollution of Surface Waters Act restricted the discharge of polluted water by means of a licence and a levy system. As a consequence industry economized its water use by recycling and by other conservation measures and specific water use (the water use per gross added value) dropped remarkably (Fig. 6.1). The industrial production has tripled in the period 1957 to 1982.
Table 6.1 shows that of the total water abstracted for domestic use 67% is from groundwater and 33% is from surface water. The preference for groundwater reflects the difficulty of using surface water with its inherent fluctuations in discharge, temperature and chemical composition.
In contrast to domestic use only 14% of the water used by industry and services is from groundwater and 86% is from surface water sources. The use of water for cooling by power stations is the dominant surface water use; this water is returned at a higher temperature to the surface water system.

Irrigation and abatement of salt intrusion

Although the Netherlands is known as a "wet" country and water seems to be abundantly available in many areas, shortages of water occur particularly in dry periods. Under these conditions grassland and agricultural crops suffer from drought damage. Figure 6.2 illustrates the crop damage for a very dry year as 1976. In that year for surface irrigation and sprinkling around 475 million m^3 of surface water and 300 million m^3 of groundwater were used.
For flushing and rinsing of the canal systems of

Table 6.1 Water abstractions in million m^3 ($10^6 m^3$) in 1981 (excluding surface irrigation and sprinkling)

Use	Groundwater		Surface water		Total	
Domestic		410 (67%)		200 (33%)		610 (100%)
Industry, services						
– cooling	180		3 205		3 385	
– other purposes	390		300		690	
		570 (14%)		3 505 (86%)		4 075 (100%)
Sub-total		980		3 705		4 685
Power stations		–		10 100		10 100
Total		980		13 805		14 785

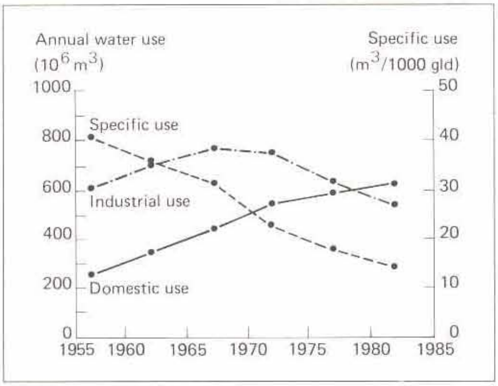
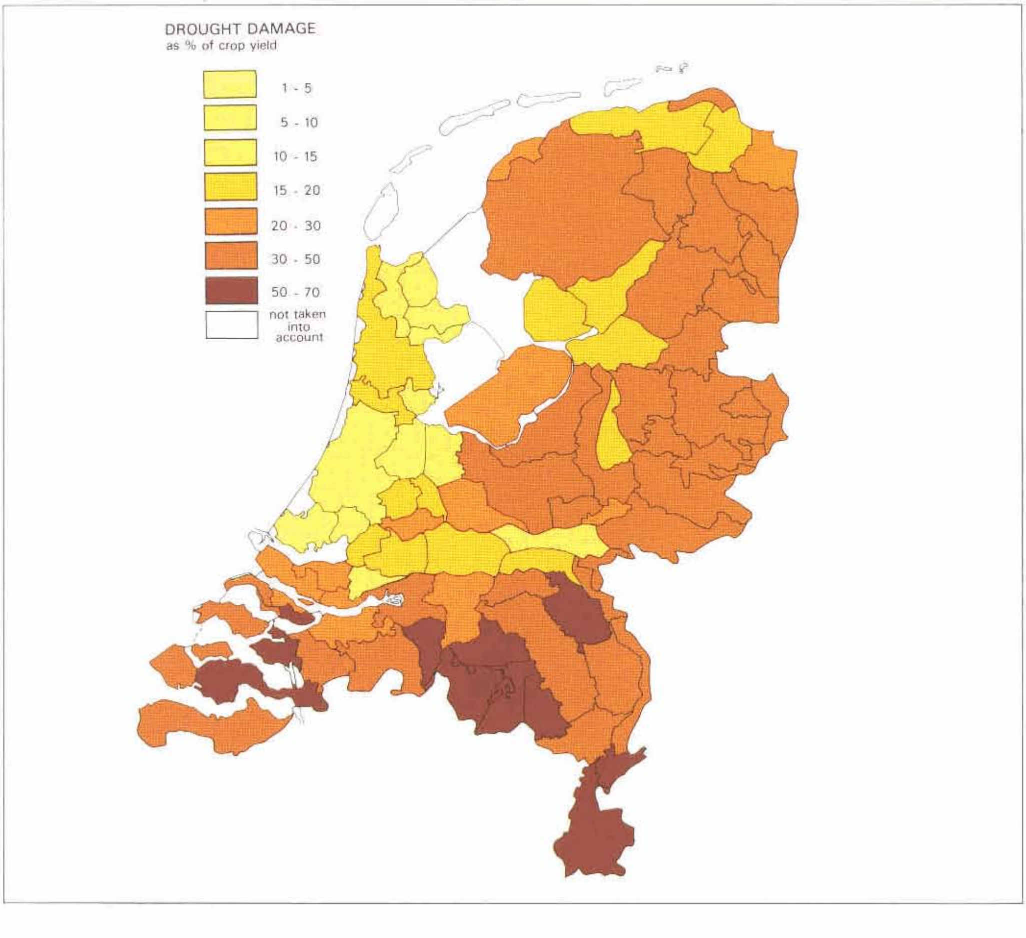


Figure 6.1 Domestic and industrial water use over the period 1957 to 1982

Figure 6.2 Reduction in crop yield in various regions during a very dry year (situation 1976)



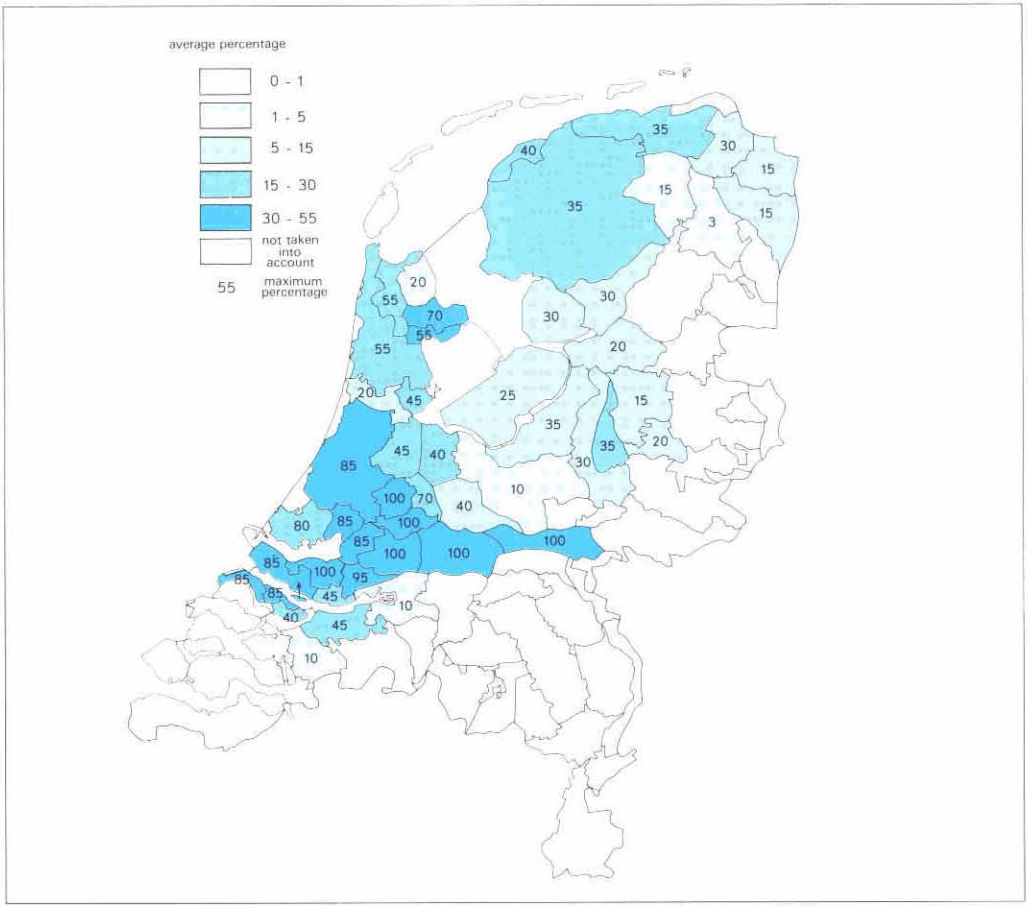
the polder areas, in order to control the salinity of the surface water in dry periods, some 35 m^3/s of river water must be available. As mentioned before to limit the saline intrusion at the Rotterdam Waterway huge amounts of water are needed (approximately 650 m^3/s).

Other water interests

Examples of a more indirect use of water include navigation, fisheries and recreational purposes, such as swimming, sailing and surfing. The conditions that must be met for this category of users are usually not so complex.
A sufficient water depth in the rivers and canals is necessary for navigation. For fisheries and recreation the emphasis is on the quality of the water and the requirements of a constant water level. Adequate water level control and flushing of water courses and lakes to maintain an

acceptable water quality are therefore essential. Water also has an important role in nature conservation and general amenity. For example any changes to the natural hydrological regime will effect the terrestrial and/or aquatic environment. In this respect can be mentioned the threat to wetlands by a lowering of the water table due to the drainage of arable land and the artificial abstraction of groundwater. Although it is often criticized, water is used as a vehicle to transport pollutants or even as a recipient basin for waste. Sensitive resources management is required because this type of use is often a serious threat to the aquatic environment.

Figure 6.3 Percentages of Rhine water in the water system in various regions during a very dry year (situation 1976)



Water balances

In the foregoing the various water needs are mentioned and in Chapter 4 the main sources of fresh water are described.
It is necessary to find out if all the needs can be met by the available sources. The "supply" and "demand" items must therefore be balanced. In Table 6.2 water balances are given for summer periods (April to September) since these periods are the most critical with respect to water supply. The balances are prepared for the total country for an average summer and the very dry summer of 1976 respectively.

Supplies

Table 6.2 shows that the water volumes imported by the Rhine and Meuse are more than twice as much as the amount of local precipitation. In an average year the water in

	Average summer		Summer 1976	
Supply	mm	$10^6 m^3$	mm	$10^6 m^3$
Precipitation	382	14 900	208	8 100
River inflow (Rhine, Meuse)	893	34 700	460	17 900
Surface storage (o.a. Lake IJssel)	13	500	13	500
Subsurface storage	123	4 800	98	3 800
Recycled water	31	1 200	31	1 200
	1 442	56 100	810	31 500
Demand				
Evapotranspiration	423	16 500	436	17 000
Domestic and industrial water use	60	2 300	60	2 300
Flushing	15	600	30	1 200
River outflow	944	36 700	284	11 000
	1 442	56 100	810	31 500

Table 6.2 Water balances of an average summer period (April to September) and the very dry summer of 1976. The water volumes are expressed in mm water depth and in million m^3 (10^6 m^3) (total area 38.9 x 10^3 square km)

storage at the onset of the summer period can be estimated to 5 300 million m^3; in a dry year this storage is some 1 000 million m^3 less. The subsurface storage is made up by soil moisture and extracted groundwater.
Much of the water used by households, industries and services is returned to the river system after treatment.
Occasionally the quality of the water is still not too good and it is assumed that only half of it is re-usable (see the water balance term: recycled water).
The drained off cooling water of the power stations is not taken into account (neither the abstraction of it).
In this case it is a question of internal water circulation since all the abstracted water is recharged and only the temperature of the water is increased.
The discharge of the polders, due to the flushing of the canals, is also not taken into account since the quality of the water is too poor for re-use.

Demands

The greatest water consumer is evidently the vegetation since evapotranspiration amounts to some 425 mm. This figure does not represent potential evapotranspiration since not everywhere is sufficient water available for optimal crop growth.
Reductions of evapotranspiration occur which are assumed to be in the order of 5 to 10% in an average year and at least 25% in a very dry year such as 1976.
These reductions occur, notwithstanding for example 1 500 million m^3 of water being supplied to the cultivated land by irrigation and infiltration in 1976.
The water uses for households, industries and services is small in comparison to crop use.
Table 6.2 shows that in an average summer river outflow amounts to almost 37 000 million m^3. This outflow is sufficient to meet the volume of fresh water needed to repulse the previously discussed saline water intrusion at the Rotterdam Waterway. For this purpose in a summer period 10 000 million m^3 is needed.
In a very dry summer, however, the situation is much more critical as river outflow is of the same order of magnitude as the volume needed for the abatement of saline intrusion. This is particular true because river flow is not equally distributed in time and a considerable proportion of flow occurs in the beginning of the summer period when it is less effective.

Water distribution

To supply areas, where is not readily available, water must be transferred over long distances by open water courses or sometimes closed conduits. In this respect the main river system, as discussed in Chapter 5, is very important. The water of the Rhine is distributed over a great part of the country (Fig. 6.3). This is only possible by the existing dense secundary and tertiary network of water courses. However, to adequately supply areas with pronounced water shortages the infrastructure for the distribution of surface water must be improved. The drought areas are for example the southern, eastern and north-eastern sandy areas of the country. However, economically it will not be feasible to improve the water infrastructure in such away that all shortage can be met. Another example of water transfer is the 160 million m^3 of river water per year extracted in the central part of the country and transported by closed conduits to the western and north-western dune areas. In these areas the river water is infiltrated as discussed in Chapters 4 and 5.

7 Hydro-environmental features

A large part of the Netherlands consists of wetlands; the Dutch created land from water but created also water in reclaimed land. This activity became clearly visible in the polder landscape with its numerous canals, ditches and shallow lakes. Rivers were regulated and also most of the brooks on the higher sandy soils. Estuaries were cut off from the sea by dams which prevent normal tidal effects and sea water intrusion. The original flora and fauna was and is affected by these works so that natural hydro-environments are rare in the country. The Wadden Sea is the largest natural area left; the Oostvaarders plassen - a marshy area created in one of the reclaimed IJsselmeerpolders - may be seen as a newly created semi-natural environment famous for its birdlife. Still existing "natural" hydro-environments survive by the gratitude of special planning and managing water and land, but everywhere water quality is influenced by man, even the quality of groundwater.
In this chapter a short view will be given of recently developed guidelines for hydro-environmental management of water in the Netherlands in the context of the abatement of water pollution.

Classification of surface waters

In every surface water living organisms are present which organize biocommunities in relation to the morphologic, hydrologic, physico-chemical and soil properties. This totality is an hydro- environment. In each hydro-environment various communities can be distinguished. There are communities in open water, such as fishes, communities of bottom living plants and animals, communities from litoral zones and others. Hydro-environmental management is focussed on the water related processes and structures. Interactions of organisms, such as competition, predation, chains of food, is another aspect of the ecosystem-total which will not be considered here as it is the special care of nature management.
It will be clear that there are numerous hydro-environments in the Netherlands, like canals, ditches, pools and low land lakes, which need

Figure 7.1 Oostvaardersplassen, a marshy area in the newly reclaimed Flevo-polder

management as a result of unceasable human interference of these waters.
Therefore a hydro-environmental description is needed in order to know the constrictions of measures to be taken in relation to the demands of living of the communities.
The demands and the managing measures for the different water-bodies are different and so the hydro-environments are grouped in classes, which for the Netherlands runs as follows:

1 Flowing waters
Springs, rivulets, brooks and streams in river basins
2 Man-made stagnant waters
Ditches, canals, urban waters, delta reservoirs, gravel, sand and peat-pits, drinking pools
3 Stagnant waters, mainly of other origin
Coastal dune lakes, moorland and low land lakes
4 Brackish waters
Tidal waters such as estuaries and creeks.

The classes show differences in hydrology, morphology, origin, age, chemical composition, salinity and the structure and dynamics of the biocommunity. The type is strongly dependent on the hydrological regime as the soils of large parts of the Netherlands are permeable and surface water and groundwater are interacting.
As such the idea of distinguishing hydro-environmental types fits well with the work of hydrologists who also distinguish regional hydrological units. Surface waters in the Netherlands must always be considered in relation to groundwater and possibly be connected with other surface waters.
The same is true for terrestrial environments with agriculture, forests or wetlands. In fact these environments could be also taken as hydro-environments.
The study of water in forest, nature and landscape is the special subject of several institutions where ecologists, botanists and foresters work together.
The surface waters are the special interest of hydrobiologists, be it practising in water management problems or not; the classification of surface waters presented here is the result of recent work.

Figure 7.2 Small moorland lake in the high part of the country

Evaluation, quality and standards

The surface waters in the Netherlands are different in quality. From outside the country rivers like Rhine and Meuse are carrying minerals, organics and silt to the low lands. The natural quality is therefore characterized by high concentrations of nutrients like phosphate and nitrogen. As a result growth of algae and aquatic vegetation is luxurious. The waters are eutrophic; oligotrophic waters occur only on the higher sandy soils in the eastern and southern parts of the Netherlands. Most of the waters are also turbid, not only as a result of high plankton densities, but also by resuspension of silt and organics. In the brackish tidal zones this turbidity is mainly due to inorganics while growth of plankton is hampered by the low light penetration. The intrusion of salt water from the North Sea causes gradients in salinity of surface water and groundwater, which is also reflected in the present biocommunities.

Today this general picture is drastically influenced by technical works as dams and dikes, creation of polders, regulation of rivers and not in the least by pollution. The hydro-environments are all affected in one or more of its components. All surface waters in connection with water of the Rhine are now dominated by blue-green algae. The fresh and brackish tidal zones are reduced to a few localities. It is the task of water managers to define standards for the water quality and the hydro-environmental quality in this situation.

From an ecological point of view standards can not be set around one digit and one environmental factor, as the value of the environmental factors are fluctuating daily, yearly and even in longer periods. Ecological factors are manifest in ranges and this should be incorporated in the standards. For the characterization of the environment the combination of factors (and ranges) is essential. The hydro-environmental standards therefore are more elaborated than others given in the "Pollution of Surface Waters Act". For example this act sets a standard for the chloride content of 150 mg/l for the use of water for drinking water at the water intake point. For brackish environments, however, the figures are higher than 150; for oligotrophic hydro-environments the standard is up to 40 mg/l and for oligohalinic environments 100 to 1 000 mg/l if we consider hydro-environmental standards. It will be clear that controversial interests are involved for the realization of optimal functioning of the surface waters. It is certain that the ecological objective for an adequate management of hydro-environments can not be achieved by fixing a general valid digit on national level which is applicable to all types of surface waters. The demands for the different hydro-environments are different and this is the (ecological) reason to set up a classification of waters as mentioned before.

For the Dutch surface waters descriptions are made in routine examinations of the existing types. This resulted in assessing the ranges of the relevant environmental factors of the hydro-environment type. As most of the waters are disturbed it is often difficult to derive the Normal Operational Range (NOR) of the system. This could be estimated by comparing with undisturbed objects of one and the same type, if present, or on the basis of historical data which are seldom present. Only the relevant components of the type are considered, divided in general and specific factors. The latter are specific for the region or locality; the general ones are factors which must be considered in every surface water. Some components are involved in ecological processes but also influenced by the physical properties of the environment. For example calcium is an ecological factor, but it also plays a role in chemical processes related to soil and water chemistry. As to the ecological parameters it must be mentioned that in surface water the total biomass is the sum of fish, plankton, bottom and litoral flora and fauna. For practical reasons the estimation of biomass is restricted to some of the components collected in routine samples. For example kg fish per ha, chlorophyl-a or number of bottom living animals per m^2. Indicator species indicate the hydro-environment in its bioquality. If the diversity of species is low and the number of individuals of the few species is high the periodicity is disturbed and ditto the NOR. This for example is the case for blue-green algae in many of the Dutch surface waters, which show permanent blooming of the algae through the year.

With respect to the water management of terrestrial-ecological systems a special study pertaining to forests and natural vegetations must be mentioned. Three functions of water in the ecosystem are distinguished:

a the operational function, i.e. the quantity of water available in the hydrological regime for plant and animal;

b direct conditional function, which includes factors like soil temperature, oxygen content, available nutrients, etc.;

c other conditional functions like humification, food cycles and leaching.

Implications with respect to water management are the quality and quantity of groundwater, the extraction and suppletion thereoff, long distance effects of slowly moving groundwater and possibilities of suppletion of groundwater by surface water.

Since groundwater and surface water clearly interact a further elaboration of several aspects of this phenomenon is necessary before application in operational water management will be possible.

8 Water administration and water resources management

Water administration

The first settlers in the Low Countries had to protect their lives and cattle against flooding from the sea and this led to the creation of the "polders". In the Middle Ages single or groups of polders were combined to form "Water Boards", one of the earliest forms of government administration in the Netherlands, in which landowners had the right to elect their governing board. These have been followed by dike boards, storage-basin boards and purification boards. All organisations, both old and new, continue to carry out an important function in the administrative structure of the country.
In the sixteenth century the Netherlands were no more than a set of autonomous counties and duchies and only at the end of that century did the country emerge as a united political state. The political power now carried by Provinces is reflecting this historical background.
Municipalities and water boards operate with a high degree of independence, under the supervision of the provincial authorities. The central government, of course, has the supervision and final decision in many matters, and particularly in matters regarding the safety, distribution and quality of water.
The central government and the governing bodies of provinces and municipalities are so-called "general democracies". The governing boards of the water boards are elected by landowners and other functional groups.
In a country like the Netherlands it is not surprising that all levels of government have responsibilities in water management. Some 10 to 20 years ago the approximate division was that responsibility for safety and navigation was resting with the central government and the provinces and that the responsibility for water levels and internal distribution was resting with the water boards. The responsibilities of municipalities were incidental.
The government has transferred overall responsibility for water resources management to the Public Works Department (Rijkswaterstaat). Likewise, the provinces have Public Works Departments with comparable responsibilities. More recent administrative developments include the amalgamation of water boards and creation of boards with specialized responsibilities, such as: dike management and water purification (after the Pollution of Surface Waters Act came into force). The general picture, however, has always been of a very decentralized form of government with separate responsibilities, maintained by traditional codes of conduct. This system has been functioning well for many centuries.
However, the modern developments of population growth, industrialization, pollution etc., call for integrated water management policies. These developments identified deficiencies in the decision making process regarding legislation and a need for a more coherent approach to planning and policy making. For example the Ministry of Environment, though not responsible for water management, is developing environmental policies which include the soil, groundwater and aquatic environment and shares with Rijkswaterstaat the responsibility to develop water quality standards. Furthermore, physical planning, environmental and water resources management are no longer separate fields of policy. This illustrates the fact that the developments of modern society have made it increasingly difficult to develop a cohesive and consistent water policy. Such a policy must balance the conflicting interests of the various sectors and regions and should be able to enhance the efficiency of water utilization.

Legislation, planning, finance.
Although there was a clear need for an integrated Water Management Act, in practice the Pollution of Surface Waters Act was considered most urgent and has been operational since 1970, followed by the Groundwater Act of 1982.
A Soil Protection Act (which includes the protection of groundwater) is now actually being promoted in response to the recent discoveries of pollution from various sources.
The act will be operative by the end of 1986.
A Water Management Bill with several integrating characteristics is being discussed in Parliament, but it is not fully comprehensive covering all facets of the interdisciplinary issues of planning development and management of surface and groundwater resources.
The policy instruments of these laws are generally licences and charges, but comprise also prohibitive and restrictive measures. The responsibilities are structured differently. The Pollution of Surface Waters Act divides responsibilities (dependent on the "ownership"

of the water) between government and provinces; the latter may (and in most cases do) delegate these tasks to water boards. The Groundwater Act and the Soil Protection Act delegate the major responsibility to the provinces, with a supervision at national level. The Water Management Bill divides responsibilities between the different levels of administration and apart from licences (administration to private entities) has the new concept of "water agreements" (between authorities). Like most modern acts, those mentioned have extensive procedural securities built in with possibilities for appeal.
Planning procedures had developed into an unmanageable multitude of planning obligations. For this reason the Water Management Bill is now being reformulated to simplify the entire planning system.
The latest tendency is towards an integrated approach to water sytems (local, regional or national), meaning that all relevant aspects are taken into account. System, in this context, is not only water, but also river beds and banks, shores, and all forms of aquatic life.
Finally it should be mentioned that the method of financing water policy is subject to reconsideration. The usual financial sources are the government's general budget, the charges and levies ensuing from the various laws and the obligatory contributions to water boards. On the one hand a policy to improve the quality of life (and water!) against the odds of modern industrial society tends to become increasingly expensive. On the other hand, in managing a complicated system, it may become unclear who has responsibility for payment for a quantitative measure, exclusively aimed at qualitative improvement. For the time being these problems are unsolved in the Netherlands. They have, however, been identified and there are positive efforts to arrive at solutions. In the remainder of this chapter the topic of the water resources planning process, as a part of water resources management, will be discussed. This will include a general outline of water resources management in the Netherlands and a summary of the planning process, structure and analysis.

Water resources management

Why manage?
Water resources management is based on an understanding of the nature of the water resources system and of the role of public authorities.
The water resources system - as we have seen in the previous chapters - includes all elements required to produce water and water-related goods and services and consists of the following components:
1 the totality of water and its physical, chemical and biological components in and above the soil in an area considered;
2 natural elements, such as rivers and lakes;
3 the man-made physical elements, such as weirs, pipelines and canals;
4 the administrative elements, such as the existing regulations and organizational structures.
Management of this water resources system is essential in order to produce the required outputs in the most efficient way.
Water resources management can be conceived

Table 8.1 Broad scheme of the management of groundwater and surface water by public authorities, on strategic and operational level

object of management / management level	surface water		groundwater
	national waters	regional and local waters	
strategic level	central government	provinces	provinces
operational level	central government	water boards (some provinces)	provinces

as a production function which transforms the quantity, quality, time and location characteristics of surface water and groundwater into the quantity, quality, time and location characteristics of the desired outputs: irrigation water, water-based recreational opportunities, flood damage reduction, municipal water, industrial water, navigation opportunities, bearer of aquatic ecosystems, conditions of the soil for agricultural or building purposes.
The role of public authorities in water resources management stems from the basic objective that water resources - as a public good - should be exploited in such a way that they produce maximum net social benefit. The demands of the various users are often competitive and/or conflicting. To meet all the demands is usually impossible and therefore choices have to be made. It is the task of management to make the choices and then execute them.

Who is managing what?
In the Netherlands water resources management is a task of public authorities and not of private persons or institutions. This can be historically explained, but is also a conscious political choice. Public involvement in water resources management is found to be essential, for example in:
1 provision of collective goods, such as flood damage reduction;
2 regulating conflicts between various use categories when they apply for the same amount of water at the same time and the same location;
3 controlling the use of water from a viewpoint of general interest, such as regional development and public health.
The public authorities which are involved in water resources management are numerous. The central government is responsible for the state-managed waters (the waters of national importance, the great lakes and the territorial sea). Within the guidelines of the central government the provinces are responsible for the non statemanaged waters and the groundwater. The provinces have delegated tasks and responsibilities with respect to surface water to approximately 200 water boards. Most of them control only the quantitative aspect. Three provinces did not delegate the qualitative aspect of the surface water management. The others delegated it to some 20 to 30 water boards. The majority of the water boards control either quantitative or qualitative aspects. For the simple observer it looks like a patchwork quilt but it works! However, complications arise with other water resources management tasks, such as coastal and dike management, waterway management and the management of the underwater beds and river banks. Water resources management is closely interwoven with different areas of public responsibility, such as environmental policy and physical planning and as a result co-ordination is of utmost importance.

How is water managed?
Instruments for water resources management have been described in the previous sections. This section deals with the planning instrument, the outstanding instrument of the next decade. Planning in this chapter is considered as the formulation, evaluation and selection of strategies, that consists of a combination of the following components:
1 physical measures;
2 implementation incentives;
3 institutional arrangements.
Implementation incentives in relation to water demand encourage users to a socially desired level of water use and discharge pattern through charges, levies, permits, zoning, subsidies and regulations. A plan is the written reflection of the chosen strategy.

Planning process
Why planning?
Although the water resources system in the Netherlands is very complicated it has developed into a coherent and well ordered system. Water-related human activities and natural processes act upon each other; they are each others limiting conditions but each water system has its own individual characteristics. In order to harmonize their functions, characteristics and processes, it is necessary to manage them as a unit. This requires a continuous weighing of (human) interests and the potential of a water system. Water resources management is multi-objective. The objectives are partly complementary and partly conflicting and the trade-offs between each of them are not always clear. This demands for a careful selection of management objectives and allocation of resources in time.
Policy making and the Dutch tradition of

participation in policy making does not make a decision of today a fact tomorrow. This time-factor is another reason for planning. Planning and subsequent decision making are based on a planning process; i.e. the process of formulation, evaluation and selection of strategies, resulting in management inputs. The outcome of a planning process is sometimes an independent plan.
Although planning is not a new phenomenon, it is quite recent that the legislator has prescribed by law different kinds of plans to ensure an overall planning process for water resources management from general objectives and national policies to detailed local plans.

Planning structure
The central government, the provinces and the water boards make their own water resources management plans. At the strategic level it is a masterplan and at the operational level the plans are more detailed. In Table 8.2 the groundwater and surface water management scheme of Table 8.1 is re-presented, but completed with the plans the public authorities have to make. In the present state of the Dutch water resources management the planning unit is both interacting and interrelated. Planning options and management strategies are increasingly developed on an interdisciplinary basis. With increasing complexities in the planning process, water resources planning is no longer the domain of engineers and economists.
Participation by others, especially in analysis, is essential and this must involve the disciplines of mathematics, law, biology, chemistry, ecology and public administration.

The frequency of plans
The present planning frequency, as laid down in acts and proposed in bills, is ten years. However in 1985 the Minister of Transport and Public Works and the Minister of Housing, Physical Planning and Environment presented to Parliament a proposal to modify the Water Management Bill so that the frequency of all the water resources management plans would be reduced to once in four years. This is very frequent considering that this kind of planning is new although ideally planning should be an iterative process and not an ad-hoc action once in four years. Major planning every ten years can be inflexible and unsuitable, for both detailed planning and for master plans. With a more frequent planning there is the possibility of extending the term by another four years.

Contents of a water resources management plan
The strategic water resources management plans are restricted to major areas which limit the operational plans. The chosen strategies and the expected financial, economic and spatial results are given in the strategic plans.

Relationship with environmental policy plans
The water resources management plans also describe their interaction with the environmental policy plan. This is important because water resources form a part of different

Table 8.2 Broad scheme of the water resources management plans to be made by public authorities, on strategic and operational level

object of management / management level	surface water		groundwater
	national waters	regional and local waters	
strategic level	policy document on water management	provincial water management plan	
operational level	management plan	management plan	

areas of public responsibility with no hierarchy. These areas are water management, environmental policy and physical planning. The structure of the environmental plans will be the same as the WRM-plans. The structure is given in Table 8.3.

Analysis in the planning process

Systems approach to water resources management
Planning anticipates and supports decision making on a particular strategy. In an integrated and complex water resources system it is essential to know the effects of particular decisions and chosen strategies. Dutch public authorities, especially at state and provincial level, have increasingly chosen a systems approach to water resources management. A systems approach carefully identifies the important issues and alternative measures related to supply, demand and institutional organizations and assesses and evaluates the impacts of formulated strategies in a way that is meaningful to the decision maker. The initial

Table 8.3 Proposed structure for the water resources planning (public water supply is excluded)

management level \ policy area		water management	environmental policy	physical planning
central government	strategic	national policy document on water management	national environmental policy plan	structure plan(s) etc.
	operational	national management plan	environmental policy implementation programme	
province	strategic	provincial water management plan	provincial environmental policy plan	regional study plan(s)
	operational		environmental policy implementation programme	
water board	operational	quantity/ quality management plan		

task is to identify the questions which must be answered. Too often research is executed where it is not clear what questions are being addressed. It is therefore imperative that analysis for water resources management is management-oriented.
The planning of public water supply will not be dealt with explicitely. This sector is governed by the Water Supply Act, which forms the legal basis for e.g. drinking water standards, planning, governmental and provincial supervision. Nowadays some 100 public water supply companies are servicing about ninety-nine percent of all houses and a substantial part of the Dutch industries. Almost all public water supply companies are either a municipal service or a limited company, which shares are beïng held by the municipalities and the provinces concerned.

Modelling the Dutch water resources system: PAWN
The growing complexity of water resources management: i.e. the complicated structure of the problems, the many components to be considered, the aspects of space and time and the often complex relations existing between the components of the water management system, forced the Dutch analists to seek methods to help them in their tasks. More and more they were forced to make extensive use of mathematical modelling and analytical techniques.
In order to carry out its planning and management task the Rijkswaterstaat must be aware of the consequences of any chosen operation. In order to meet these objectives the Rijkswaterstaat initiated the so-called PAWN (Policy Analysis of Water Management for the Netherlands). The assignment was given to the Rand Corporation (USA) and Delft Hydraulics (the Netherlands).
The objectives of PAWN were:
1 to indicate the coherence and the ranking between the various use categories related to the Dutch water management system;
2 to show the limitations of the existing water management system and suggest solutions to these problems;
3 to indicate the consequences of these solutions for all parties concerned in as many aspects as possible. Specifically PAWN was meant to provide information for the document 'De waterhuishouding van Nederland' (National Policy Document on Water Management).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FOR ITS USE OF INNOVATIVE MANAGEMENT SCIENCE

THE NETHERLANDS RIJKSWATERSTAAT IMPLEMENTED A NATIONAL WATER MANAGEMENT POLICY BASED ON AN INTEGRATED SYSTEM OF OVER 40 MODELS, AFFECTING FACILITIES, OPERATING RULES, PRICES AND REGULATIONS, AND SAVING HUNDREDS OF MILLIONS OF DOLLARS IN INVESTMENT AND AN ESTIMATED $10 MILLION DOLLARS IN ANNUAL OPERATING EXPENSES

H. NEWTON GARBER
President

San Francisco
May 15, 1984

JOHN LASTAVICA
Chairman of Awards Committee

Figure 8.1 Management Science Achievement Award 1984 for the PAWN-project

Given the fact that water management is an active process, the provision of a useful tool to be used in subsequent studies is essential. In the PAWN study approximately 40 models were built at the heart of which is the Water Distribution Model. The Institute of Management Sciences awarded the Management Science Achievement Award for 1984 to the PAWN project for its use of innovative management science (Fig. 8.1).

Regional water resources planning
Following recent legislation, analysis and planning are also taken seriously at provincial level where a surface water quality plan has been completed and a groundwater plan is being developed. Although the Water Management Bill has not been passed by Parliament, most provinces are already anticipating the strategic provincial water management plan which includes quantity and quality aspects of groundwater and surface water. There are differences between the provinces; not only in

their approach, but also in identifying priorities and in implementation. To compare the results and to influence the policy of other public authorities involved in the Dutch water resources management, it is important to use the same scenarios, criteria etc., and instruments, such as compatible computer models. The Rijkswaterstaat encourages the provincial use of PAWN instruments.

In conclusion

An important step in the modernization of the Dutch water resources management is the introduction by law of the planning instrument. The coherence that characterizes the water resources systems makes the integrated approach essential.
The opportunities to support water resources management have multiplied through the development and introduction of a systems approach in water resources management.
The coming years will prove:
- whether planning will be able to live up to expectations;
- to what extent the definition of a water resources system can be broadened to make an integrated approach possible and
- whether a systems approach, the use of computer models and ongoing automation will become general practice for the public authorities involved in the Dutch water resources management.

9 Trends in Dutch hydrological research

The situation in the Netherlands and the intensive use of land and water are major factors determining the nature and extent of Dutch hydrological research. Most naturally 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 the Dutch engineer in the fields of water engineering and hydrology.
In common with some other countries the systematic study of hydrology in the Netherlands started in the second half of the nineteenth century. Before this date only occasional studies of specific aspects of the hydrological cycle had been undertaken.
The flat Dutch country side with 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 on 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 water engineering and also for 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.
Apart from the hydraulic research most research falls into one of three main categories: water supply, agriculture and environmental protection. These categories will be briefly discussed and in addition some attention will be paid to urban hydrology. Related research carried out in the field of ecology, soil science, geology, soil mechanics and fluid mechanics will not be dealt with.
Before discussing the research trends some general observations will be made on the use of computers.
The computer now plays a dominant role in the field of mathematical modelling of hydrological processes and in the collection and processing of data from monitoring networks and other sources. Radical changes in the methodological aspects of hydrological research have taken place and these will continue. After the introduction of the computer in Dutch hydrological research about 1970, there has been a rapid development in numerical mathematical models becoming more complex and being used for more challenging problems. During this time, however, less attention was paid to thorough model validation and to the data requirements of many models.
In common with his fellow hydrologists in other countries the Dutch hydrologist is responding to these problems by focusing attention on the reliability of model results and high standards of collection, processing and quality control of data.
This includes the study of spatial and temporal variability of hydrological characteristics and the optimizing of monitoring networks and mapping programs.

Hydrological research and water supply

The first Dutch 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 1850's 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 in the Netherlands.
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 extentions of the scientific tools available for the hydrologist. The development of these models began in 1940 with the introduction of physical analog models, followed in 1970 by more powerful numerical mathematical models.
Special interest continues to be taken in the salt water intrusion from the sea and the upwelling of brackish groundwater bodies. From the investigations in the 1850's to the present day research has been carried out in the dune area, not only into the salt-fresh water transient zone, but especially into the movements of this zone

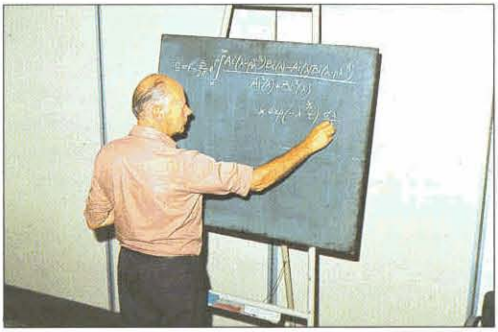

Figure 9.1 Although the computer leaves its mark upon today's hydrological research, it is fortunately still the hydrologist who has the leading part, sometimes using the old fashioned blackboard

Figure 9.2 Infiltration of surface water for groundwater recharge in a dune area

Figure 9.3 Exploration of the nation's aquifers has always been a key issue in the systematic hydrological studies related to water supply

due to natural circumstances and to human activities. Current research in this field focuses 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 1930's it was concluded that mining took place of the fresh groundwater in the dunes. 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 program 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 effects on agriculture became evident in several areas. Therefore 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. This stage has not yet been reached with respect to the estimation of the impact on the natural environment at the level of species or ecosystems. However, it is hoped that the current stimulating co-operation between hydrologists and ecologists will lead to useful results in the near future.

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 for this environmental problem. Specific research topics, directly related to water supply, include identifying 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 Dutch 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.

Hydrological research and agriculture

Before 1950 there was from a scientific point of view 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 yield. Research in this area covers a broad scientific spectrum, in which hydrology and soil physics are playing 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

Figure 9.4 Various human activities, e.g. the excessive use of manure in agriculture, have led to serious environmental problems. The understanding of these problems and the search for solutions have necessitated new directions in hydrological research

it was a typical Dutch polder area and not a natural river basin.
After a period of lysimeter studies in the 1950's theoretically based physical mathematical concepts for water transport in the soil-plant-atmosphere system gave 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 seventies caused 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 possible to draw an areal map of actual evapotranspiration, thus providing for 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 into the improvement of land drainage to improve soil structure and allow heavy farm machinery on the field. From the late sixties attention has focussed 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 analytical 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 Dutch hydrologists for some time to come.

Hydrological research and environmental protection

Several environmental problems, identified in the sixties and seventies, are determining the hydrological research in the eighties and nineties. 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 in some areas to substantial changes in the groundwater regime and 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 impacts, 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 the Dutch hydrologists in the coming years will probably be the impacts 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 pollution of the surface water is another environmental issue, which has contributed to a new dimension in the hydrological research in the Netherlands. In the sixties 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 in the Netherlands led to a comprehensive monitoring and research program. Much effort was put into the development of water quality models, thereby building on the extensive knowledge of the hydraulics of Dutch rivers, lakes and estuaries. This research has resulted in a wide range of operational models and other methods of use in water quality management.
During the seventies 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 thought before. This awareness gave a strong impulse to hydrological research and soil and groundwater quality problems will continue to direct research programs well into the nineties.
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 residential areas hydrologists, together with soil scientists and chemists, became involved in clean-up operations developing a new field of expertise in the Netherlands.
Nowadays there is also a special interest in more diffuse sources of pollution, including acid rain and the use of fertilizers, manure and pesticides

in agriculture. In this field the Dutch hydrologists have to work together with fellow scientists and engineers from other disciplines. His particular contribution is dealing with the transport of pollutants in the saturated and unsaturated zone.
In this respect new methods for field investigations have been developed in recent years, along with the development of groundwater quality models. This research is not only related to the assessment of the nature and extent of the pollution in the field, but is also connected with the prevention of pollution, including the development of methods for safe disposal of hazardous waste.

Urban hydrology

Dutch hydrologists as well as hydraulic experts have been involved for many decades in the water management of urban areas. The acquired knowledge and experience have been succesfully 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 quite recently as a branch of hydrological sciences in its own right.
Todays 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 sewer systems is steadily increasing. Since water quality became an important issue in the Netherlands, the acceptability of an overflow structure in a combined sewer system is 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 of the Netherlands, this approach indeed reduces the overflow frequency.
However, no attention was paid to the receiving water. Large eutrophic water bodies can stand more polluted discharge than small oligotrophic water. In practice most overflow structures discharge on small, semi-stagnant and stagnant water, which are highly vulnerable. Research is in progress to assess the effect of overflows, both in a physical-chemical and in an ecological way, 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 resuspension of the sewer sludge, which take place due to the small gradients of the sewer-pipes.

Postscriptum at the reprint of 1989

Since this book was published in 1986 the changes in Dutch hydrological research have focussed on the development of new initiatives particularly relating to special topics, such as the effects of water management on the natural environment. As an illustration of present Dutch research annex 1 brings together nine case-studies on various subjects. The cases show the versatility and wide range of expertise in the institutions responsible for research. Moreover annex 1 underlines the increased need for basic research and makes clear that many problems have to be solved by means of integrated research programmes which consider both the requirements for agriculture, water supply and the maintanance of natural ecosystems.
Furthermore the case-studies illustrate the application of research projects at different scales and the rapid growth of computer-applications in this field.
Table 11.1 summarises information on the research institutions in the Netherlands.

10 Activities abroad of Dutch experts in the field of water and lowland development

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 practice their calling abroad. They may belong to different levels of the hierarchic organization of the vocation or profession. An obvious example is the emigration of skilled European farmers and agricultural experts and labourers to North America and Australia where, a century ago, arable land was still plentiful and where they could settle and apply their knowledge.
The common occupation may be a speciality which because of the specific natural or socio-economic conditions of a country has attained a high degree of development and has received high appreciation elsewhere. Typical examples are the emigration of French wine-growers to California (USA) during the past four decades and the emigration of German beer brewers to other thirsty countries!
The emigration may also be related to technical innovations like the activities of British engineers in many countries in the period of the first railways, some 100 years ago.
Emigration in the context of this paper comprises both short stays abroad for consulting services and permanent emigration with settlement in the new country and naturalization. The reasons of the emigration are varied: over population of the country of origin, better job opportunities and living conditions in the new country, political or religious oppression in the country of origin, colonial expansion, longing for the unknown, and, more, recently, contribution to development aid.
As shown in previous chapters of this booklet, man has transformed waterlogged and even submerged lowlands in the Netherlands into arable lands where surface 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 a judicious system 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 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 in the present times.

Beginning of a large scale emigration

The first Dutch settlement known in history in a marshy area abroad is located in Germany near Hamburg, in the Wilster Marsh on the Eastern banks of the Elbe-estuary. It was the Bishop of Bremen, Frederic, who as early as 1103 had invited settlers from the "Low Countries", as the Netherlands were called in those days, to reclaim marshes in the neighbourhood of that city. Possibly there had been similar earlier migrations.
The Wilster Marsh was reclaimed by Dutch settlers in 1130. It is but one of the many "Hollandries" in Western Europe.
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 (8-9th century AD). Ditches to drain the country 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 (they have always been pictured with spades in their hands) were slain by the Normans while praying.
About 950 AD the Norman invasions relented and only then land reclamation, land drainage and dike building could start properly.
Chroniclers relate in laudatory terms about the drainage work undertaken by the Dutch crusaders in the Nile delta in Egypt.
Dante, in one of his poems pays a tribute to the "Flemish dike and drainage people", another tribe of the Low Countries.
The emigration towards the East which started in 1130 lasted until quite recently. It extended to low-lying parts of Germany, Poland and Russia which formed the "Eastland" of joyful songs of that time.
The Kings of those far-away countries invited Dutch immigrants to settle in low marshes, where no other people would or could live, offering them the land and privileges. An early

settlement was a town in the delta of the Vistula river in Poland, named Prussian Holland and founded in 1297.

One wonders what motivated the farmers of the Low Countries to emigrate to Eastland and to build up a new living at the cost of hard work turning bad land into good land. It is known that the period 1150 to 1300 witnessed a great prosperity not only in the economy, initially in agriculture, but also in the fields of art and literature.

The population increased rapidly and so did the prices of cereals! Hence it became attractive to reclaim land, including peatlands, tidal forelands and lands in lower river valleys not only in the Low Countries but also in other parts of Europe. These factors were favourable for migration of people from this region but do not explain fully the spectacular "trek" to Eastland. Was it overpopulation in the framework of those days or an innate longing for the unknown?

There is more certainty about the motivation of the Mennonites to leave their country towards the end of the 16th century when religious persecutions started. These persecutions of Mennonites and others also explain why emigration to Eastland continued even when the prospects of reclamation of waterlogged lands had become less attractive than they were in the 12th and 13th century. The trek of the Mennonites can be followed until 1860. Before and after the First World War many Mennonites left Russia where they had migrated from the Vistula delta by way of Poland. Some 10 000 people made their way to the United States (Kansas) and to the Gran Chaco and Belize in South and Central America where they reclaimed land once more.

Appearance of the individual expert

In Western Europe the 14th and 15th century 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 be 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 missing 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. Bethemont in his book has given an analysis of the factors that are important for the implementation of works in the fields of irrigation, drainage and flood control. He classifies these factors into three main groups, viz.: the incitements for a change, the existence of favourable "vectors" and a society which is favourable and receptive to changes.

The incitements comprise factors such as: population increase, economic perspectives, cultural aspirations and challenges by environmental disasters. Under the "vectors" appear the technological stimuli like innovations and also changes in staple crops. The social group comprises the requirements of a minimum of stratification and coherence for the establishment of social structure capable to impose collective management of hydraulic systems.

The period 1550 to 1650 was an era with an unprecedented increase in population and an increase of (gold)currency. The first repercussion was a rise in prices of food stuff, in the first place of cereals.

New forms of energy like aeolian power (wind mills) 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 works were undertaken by merchants. In some cases Dutch business houses participated in the financing of projects in France.

Naturally conditions were also favourable for emigration from the Netherlands but here a new participation came to the fore in the person of the individual expert. Before the 16th century vocational emigration was formed by large groups of people consisting mainly of farmers and agricultural labourers. Undoubtedly there must have been leaders among them who conducted the works but they did not go alone and settled permanently with the groups on the new lands. After 1550 one sees on the scene the single 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. This appearance of the individual expert is related to the general increase of population. In many cases the commissioner was not so much looking at people to settle in the newly reclaimed areas as at technologists to design the works. The list of Dutch experts who went abroad in the period 1580 to 1660 to work on low land reclamation comprises the first hydraulic engineers of the Netherlands: De Wit, Van der Pellen, Meijer, Van den Houten, Rollwagen, Van Ens etc. They worked in practically the whole of Europe, from Sweden to Italy and from England to the Wolga. Van Veen in his book states about their performance: "When we read the books about their achievements we can not 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'. It is of some interest to have a closer look at the activities of three typical representatives of this group: Leeghwater, Vermuijden and Bradley.

Most of the work of Jan Adriaensz Leeghwater (1575 to 1650) was done in the Netherlands but he found time to do consulting work in the Baltic region, Denmark, England, France and Germany. His name is well-known in the Netherlands as an authority on draining lakes and marshes by pumping. The pumps (water-wheels) were driven by windmills which had begun to replace the wheels driven by horses from the beginning of the fifteenth century. Leeghwater called himself in the first place a windmill builder and he applied them for draining large lakes to the north of Amsterdam 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 series lifting the water step by step.

Sir Cornelius Vermuijden (1590 to 1685) is not so well-known in the Netherlands as he did most of his work abroad, in England. He was born at Sint Maartensdijk in Tholen, where his family was connected with the Roosevelts. He found some of his countrymen already in England like Janszoon, Frieston and Van Croppenburg. He associated himself with some of them, such as Van Valkenburg and Van Buren and thus he is perhaps the founder of the first Dutch consulting firm in the field of land reclamation abroad. He had the good fortune to be backed by three successive Stuart sovereigns. Already naturalized in 1624, Vermuijden was knighted later and received estates from the king. His main achievements were the Yorkshire marshes and the Fens of the Wash. The Yorkshire marshes had been the site of a few failed reclamations before the 17th century. No one in England thought that Vermuijden would succeed, but he succesfully drained the whole area with the aid of Flemish and Dutch workers, who afterwards became settlers.

Clearly, Vermuijden was succesful but this does not mean that he did not meet any opposition, especially in the realization of his great plan, the drainage of the Fens. Opposition came from merchants of the cities in the areas who contended that reclamation would damage navigation. Other people lost the profits of hunting and fishing and the rights of rough pasture in the marshes. At Cambridge the voice of the University was raised against the drainage of the Fens. In 1632 there were riots at Ely and anti-Dutch pamphlets were circulated. More than once sluices were broken by the rabble and Vermuijden himself narrowly escaped death several times. But time and again the Kings took him under their wing.

One of the difficulties of the reclamation of marshes or lakes which lead to opposition of the inhabitants of the surrounding areas is the drainage of these areas after reclamation. The solution commonly applied by the Dutch engineers consisted of dredging a catch canal along the ridge of the adjacent areas to cut off the drainage water from the new lands. This diversion may worsen the drainage because of the decrease of the flow gradient. Vermuijden's idea consisted of increasing the general gradient of the drainage by means of one short-cutting channel running towards the Wash, namely the

present Old Bedford River.
By 1655 the planned works were finished and soon the benefits of the works became apparent. There was general jubilation expressed in a verse epic in 1685 by a Samuel Fostrey:
"I sing no battles fought nor armies foil'd
"Nor cities raz'd .....
"I sing floods muzled and the ocean tam'd
"Luxurious river govern'd and reclam'd ...
Later serious difficulties were experienced with the shrinkage of the peat resulting in hampered drainage. Vermuijden applied windmills for pumplift but in his time no prediction of the subsidence was possible. It is interesting to note that another Dutchman, Jan Barents Westerdijke, advocated another solution which was to gain many adherents in subsequent centuries.
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 his name after a short stay in England where he had also proposals for the Fenlands. It was King Henk IV of France who wanted to reclaim a number of marshes in connection with agriculture, navigation and floods. Being unable to find subjects willing to take on of the task which he considered essential, he called in Bradley in 1599 and created the special post of "Master of Dykes of France" and which died with him in 1639. Bradley surrounded himself with fellow-countrymen who had capital at their disposal. Some, like Herwast, Van Gangelt, Comans and Hoeufft, were Calvinists; others, like the brothers Van Ens were Catholics. Many privileges were granted to the drainage engineers by the royal edicts of 1599, 1607 and 1639. Bradley succesfully reclaimed many marshes in many regions of France. His general design principle was the same of that of Leeghwater and Vermuijden including the peripheral canal to the sea to divert water from the surrounding catchment areas away from the reclaimed low-lying areas ("Ceinture des Hollandais" in the Petit Poitou). This, however, was only completed after his death because of hostility of the local population.
Bradley did not hesitate to propose a total enclosure of the Bay Mount St. Michel, a project which one day would certainly meet serious technical and environmental objections.
In Italy the Dutch engineers were less successful. Gilles van der Houten was the first Dutchman called into the service of the Holy See in 1623 by Pope Urban VIII from whom he received the title of "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 before present. The works fell into disuse after the third century BC and were not restored during the Roman Empire. De Wit did not succeed because, as it was said, "he wanted to do too much at the same time". After him Nicolaas van der Pellen came, but he also had to give up the work in 1659. Then Cornelis Meijer, a Catholic from Amsterdam, 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 actual works. These were destroyed by the local inhabitants in 1707 and it was not before the thirties of the twentieth century that the Pontine marshes were definitely reclaimed.
Meijer was more successful with more limited enterprises like those in the middle part of the Tiber valley and in the outskirts of Rome between 1675 and 1678.
It is significant to note that the emigration of Dutch farmers and individual reclamation experts to Prussia and Poland was accompanied by activities of Dutch architects in cities like Gdansk (Dantzig), Bremen and Copenhagen (Anthonis van Obbergen and Lieven de Key). The most striking example is Gdansk which was almost entirely built in the style of Renaissance of the Northern and the Baroque of the Southern Netherlands (1600).
This acceptance of this architecture is not surprising considering that in Poland alone there were ultimately (1836) 2000 villages inhabited by the descendants of the Dutch emigrants and 830 villages in Posen.
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: fall of the cereal prices, relatively high real wages, little activity in the field of reclamation, conversion of arable land into grassland, extension of cattle breeding etc. There are reports about abandoned fields and deserted villages. The depression was felt not only in Western Europe but, to some extent, also in Central and Eastern Europe.

The situation changed again around 1750 when an unforeseen population growth occurred. 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 due partly 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 trek of experts occurred. By that time the world had completely changed.

Dutch experts on the Asian scene

The decades around 1850 mark the transition in Western Europe from a predominantly agrarian to a predominantly industrial society. Hydraulic and agricultural engineering extended from reclamation and drainage to river engineering, harbour construction, as well as large and small scale water management. Institutions for higher technical education were established. In Indonesia, which was then ruled by the Dutch, the Government decided to embark on large scale irrigation works (the so-called "technical" irrigation) and there was a need for a staff of qualified engineers to do the job. The technical education in the Netherlands had to be geared to meet the new needs.

Thus in Dutch hydraulic and agricultural engineering an "exotic" element was introduced which has proved to be very fruitful up to the present times.

Thanks to the good quality of the works carried out in the "East Indies" the Dutch engineers acquired a favourable reputation in a new field. Engineer Homan van der Heide, who was a civil servant in the government, was invited in 1905 to proceed to Siam (now Thailand) to advise on the water management of the Central Plain. He realized that the rice growing in Thailand was quite different from that in the East Indies. The main structure he proposed, a headwork at the apex of the delta to control and distribute the flood waters, was built 50 years later at the same spot and with the same design as he had proposed. He also proposed the establishment of a Royal Thai Irrigation Department of which he became the first Director General after completion of his mission.

Another example of the broadening of the field of activities of the Dutch engineers is provided by the prolonged stay (4 to 10 years) of a group of Dutch engineers and skilled labourers in Japan starting in 1872, soon after the Meiji restoration. It is also an example of the international transfer of technological know-how.

The engineers Van Doorn, De Rijke, Lindo, Rouwenhorst Mulder, Escher and Thissen worked in the fields of harbour construction, river improvement, irrigation canal construction and tidal land reclamation.

The last mentioned field was a centuries old practice in Japan to increase the arable land area and up to the Meiji restoration Japan had developed its own technology, independently of the developments in Western Europe. Engineer A.T.L. Rouwenhorst Mulder (1848-1901) studied tidal land reclamation in Kojima Bay near Okayama where in the 17th-19th century land was gained from the sea by progressive reclamation of the silted up foreshore. Mulder made the bold proposal to round off the reclamation of the bay by enclosure and partial reclamation of the remaining water area (Fig. 10.1). His ideas must have been inspired by the studies in the Netherlands which were carried out in the same period and finally led to the formation of the "IJsselmeer" and the Zuiderzee works as described elswhere in this publication. The plans and drawings of Mulder have been carefully preserved showing among others how he proposed to close the main dam, namely by sinking fascine mattresses one upon other. In this way a horizontal sill is obtained which grows gradually in height. The project however was not carried out before the 1950's. The services of the Dutch engineers proved to be of great value for the development of hydraulic engineering in Japan and the Japanese showed a striking gratitude. A statue was erected for engineer Van Doorn who designed irrigation works in Fuhushima Prefecture. His statue is overlooking Lake Inawashiro which he used as source of water by tunneling. The bronze statue was saved during the Second World War by local farmers who concealed it in the ground. In commemoration of the works of Escher and De Rijke to improve the flood capacity of the Kiso river (near Nagoya) a small

temple was erected near the mouth of that river. Some of the engineers mentioned before were also active in China (De Rijke and Escher), mainly in the field of river engineering. They were succeeded by engineers like Nijhoff, Bourdrez, Van der Veen and Visser, who all got confronted with the enormous problems of the Yellow river.
Mention should also be made of Van den Heuvel who founded the hydraulic laboratory at Nanking which is still the leading institute in China.

Modern times

The profound changes in the economic and social conditions of the world after the Second World War naturally had their repercussions on the professional emigration of Dutch experts in the field of water and lowland development. The emigration of farmers looking for new land to settle which had virtually come to an end around 1900 was resumed after 1945 because of the poor post war economic conditions of the Netherlands and the scarcity of new land in the densely populated country. It was no longer Eastland which attracted the people but rather three overseas countries: Canada, New Zealand and Australia. With the economic recovery of the country after 1960 and the increasing prosperity in the sixties, this emigration decreased sharply.
The rapid development of a number of industrialized countries and the need to assist a much larger number of less fortunate countries brought about an explosion of the technical activities abroad.
United Nations organizations like FAO, Unesco and WMO and other international organizations like the World Bank and the Asian Development Bank were looking for experts in the field of water and land development to staff their projects. In the frame work of development co-operation the Ministry of Foreign Affairs started to support many projects in a large number of countries such as Indonesia, India, Pakistan, Nigeria and Colombia.
The geographical field of activities was no longer limited to Asia but extended to Africa, South and Central America and Southern Europe.
Hundreds of senior and junior experts, including many who had been working in the

Figure 10.1 Enclosing dam of Kojima Bay. Two sets of sluices have been built on either end of the dam to drain off excess water from the fresh water reservoir to the sea

Figure 10.2 Hachiro Gata drainage sluices. These sluices and the dam seperate the water of the Japan Sea (to the right) from the fresh water of the reservoir

Figure 10.3 Hachiro Gata. One of the two pumping stations of the Central Polder (15 300 hectares). The total drainage capacity is 43 mm per day

former East Indies, got an opportunity to apply their knowledge and to acquire practical experience. They stayed abroad for periods varying between a few weeks and several years. Naturally the Dutch consulting firms did not remain idle. However in the competition with foreign companies the Dutch firms experienced the drawback of not having all the expertise required in multidisciplinary projects. Engineer Tellegen, himself an individual consulting engineer, convinced a number of Dutch consulting firms to co-operate in "NEDECO", 'Netherlands Engineering Consultants' which would act as a coordinating body. NEDECO can draft experts not only from the participating consulting firms but, thanks to the enthousiastic support of the government, also from governmental agencies and universities. These include experts in the fields of economy, sociology, geology etc. In this way use can be made of the total intellectual potential of the country and experts can be selected according to the specific nature of the project. The formula proved to be quite successful and although the participating consulting firms acquired in the course of time an expertise commensurable with that of foreign firms, NEDECO is still operating having gained a good international reputation of its own.

It is not possible to give an outline of all projects in the field of water and lowland development outside the Netherlands in which Dutch experts became involved. An exception will be made for one project in Japan because of the pronounced "Dutch aspects" and the traditional relations. It is the reclamation of a lagoon, Hachiro Gata, in the northern part of Honshu (Fig. 10.2) with a size of some 23 000 hectares. The then Prime Minister of Japan, H.E. Shigeru Yoshida, who had visited the works at Kojima Bay mentioned earlier and where he was shown the drawings left by Rouwenhorst Mulder, insisted to call again experts from the Netherlands (1954). As a result a project was drawn up in the years 1956 to 1957 jointly by the Japanese engineers of the Ministry of Forestry and a group of Dutch engineers headed by Professor Jansen, the first director of the Delta-works in the Netherlands. Essential elements are the fresh water reservoir for supplemental irrigation and along the eastern shore a wide belt canal in the interest of the drainage and the ground water in the adjacent areas. Land evaluation in the central polder is more than 4 metres below Mean Sea Level and for this reason the area has to be drained by pumping (Fig. 10.3). The project was successfully completed and in keeping with the Japanese tradition a monument and a memorial stone testify to the participation of the Dutch engineers.

11 Education and research organizations

Education

Education of professional hydrologists in the Netherlands has taken place relatively recently. Until the sixties the subject of hydrology was included in the courses on river engineering, hydropower, landreclamation, irrigation and drainage.
At present surface water, groundwater and water management 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 main fulfilment of the requirements for a master's degree. Their main programme is either civil engineering (Delft Technical University), agronomy (Wageningen Agricultural University) or geology (Amsterdam Free University). In all three cases most elements of hydrology are studied but there is a certain emphasis on river hydrology at Delft, on agrohydrology at Wageningen and on hydrogeology at Amsterdam. Certain hydrological aspects can also be studied at other Universities e.g. at Utrecht and Groningen (Departments of Physical Geography) and Twente (Department of Process Dynamics and Environmental Control).
The disadvantage of this system of hydrology as a specialization within a major branch is that the students can not 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.
There is a post-graduate course in the Netherlands with a duration of eleven months which is entirely devoted to hydrology. It is the International Course for Hydrologists which has been organized in the International Institute for Hydraulic and Environmental Engineering at Delft. There is also the International Postgraduate Course in Irrigation and Drainage (Wageningen) and the courses at the International Institute for Aerospace Survey and Earth Sciences (Enschede) which include hydrology.

Research organizations

In the Netherlands a great number of different institutes, departments, services and other organizations are active in the field of hydrology and water management research. It can be seen from Table 11.1 that the overall picture of water research organizations is quite scattered and that a central institute of hydrology does not exist. Because it is hardly possible to mention all the different institutions, in Table 11.1 (pages 57, 58, 59) a selection is presented. Many of these organizations are active in a broad field of research. In the table only the principal research topics are indicated.
Due to the considerable number and great diversity of organizations co-ordination of the research activities is essential. Since 1946 the TNO Committee on Hydrological Research (CHO-TNO) is active in this field and brings together the main research organizations and water management authorities at national, provincial and regional level. The goals of the CHO-TNO are:
- to foster and promote co-ordination and co-operation in the field of hydrology and water management;
- to encourage and facilitate the transfer of research results and technical know-how;
- exchange of information;
- the organization of technical meetings and the setting up of working-parties.

Recently a new bureau was started up, closely linked to CHO-TNO and meant to be the operational branch of a co-operative association comprising all water administration authorities and water research institutes. The objective is to enhance the efficiency of research efforts for the planning required by modern water legislation. The name of the association is SAMWAT.
Another co-ordinating body is the Netherlands Council for Agricultural Research (NRLO). This is an umbrella organization advising on and mediating in the whole of Dutch agricultural research. One of the sections of this council is dealing with land use planning and management of nature and environment. These last research fields belong also to the domain of the Advisory Council for Research on Nature and Environment (RMNO).
Also a number of scientific and technical associations with an individual membership are substantially contributing to a better understanding and co-operation of the specialists in the various disciplines. The addresses of some of these associations are given at the back of this booklet.

Participation in international organizations

Besides their different scientific/technical orientation the international organizations involved in hydrological research show a basically different origin: governmental and non-governmental. The most important governmental organizations running hydrological research programmes are Unesco with the International Hydrological Programme (IHP) and the WMO with the Operational Hydrological Programme (OHP). The Netherlands are contributing to both programmes rather substantially. To stimulate and co-ordinate the Dutch activities a National IHP-Committee has been set up. This committee is formed by representatives of several institutes and services (Fig. 11.1). Dutch experts also contribute to projects of many other governmental organizations such as the FAO, WHO, EC, OECD and the Council of Europe. Apart from the Dutch activities in the framework of various governmental organizations fruitful contacts and contributions to the work of the non-governmental organizations are also made. The addresses of the national secretariats of a number of these international organizations are mentioned at the back.

Figure 11.1 Structure of the Dutch National Committee for the IHP

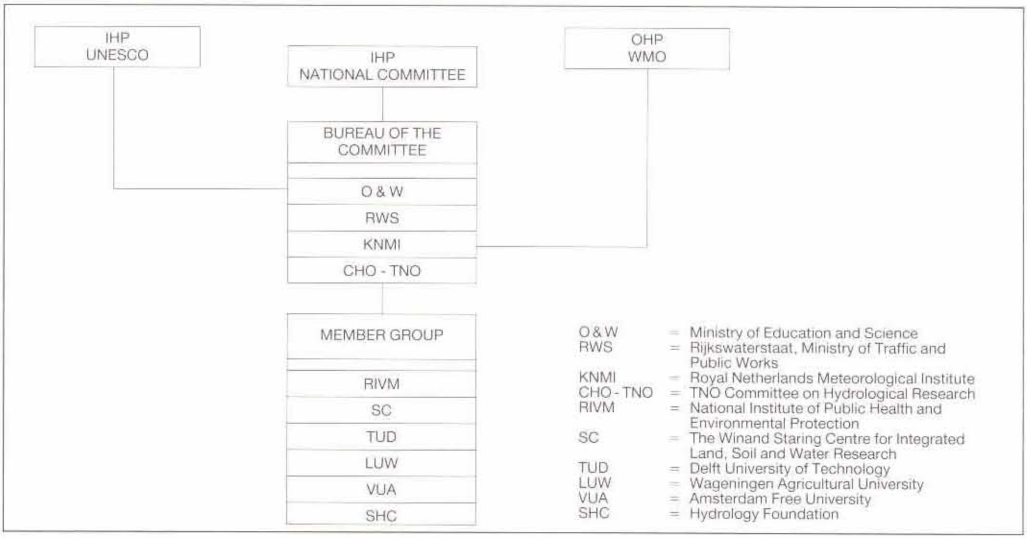

Table 11.1 Selection of institutions based upon the CHO-membership list; the principal research topics are indicated*

Institution	surface water	groundwater	water quantity	water quality	soil physics	soil protection	hydro-meteorology	ecology	hydrogeology	forestry
	Principal research topics									
Water management										
Rijkswaterstaat, Institute for Inland Water Management and Waste Water Treatment	x	x	x	x						
Rijkswaterstaat, Tidal Waters Division	x		x				x			
Association of Province Councils**										
Regional Water Boards**										
Public health/environmental protection										
National Institute of Public Health and Environmental Protection	x	x	x	x	x	x		x	x	
Drinking water supply										
The Netherlands Waterworks Testing and Research Institute, KIWA	x	x	x	x		x		x	x	
Water Supply Companies	x	x	x	x						
Agriculture/landscape management										
National Forest Service								x		x
The Winand Staring Centre for Integrated Land, Soil and Water Research	x	x	x	x	x	x	x	x	x	

* *Addresses are given on the pages 89 to 92* ** *Research topics are not indicated*

Institution	surface water	groundwater	water quantity	water quality	soil physics	soil protection	hydro-meteorology	ecology	hydrogeology	forestry
	Principal research topics									
Dorschkamp Research Institute for Forestry and Urban Ecology								x		x
Research Institute for Nature Management	x	x			x			x		
International Institute for Land Reclamation and Improvement	x	x	x						x	
Universities										
Wageningen Agricultural University, Department of Soil Science and Plant Nutrition		x			x	x				
Wageningen Agricultural University, Department of Land and Water Use	x	x	x	x						
Wageningen Agricultural University, Department of Hydraulics and Catchment-Hydrology	x		x				x			
Wageningen Agricultural University, Department of Nature Conservation	x			x				x		
Delft University of Technology, Sanitary Engineering and Water Management Group	x	x	x	x					x	
Twente University of Technology, Department of Process Dynamics and Environmental Control	x			x				x		
Free University - Amsterdam, Department of Hydrogeology and Geographical Hydrology	x	x	x	x					x	
University of Utrecht, Department of Physical Geography	x	x		x		x		x		
University of Groningen, Department of Physical Geography and Soil Science						x				

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Institution	Principal research topics: surface water	groundwater	water quantity	water quality	soil physics	soil protection	hydro-meteorology	ecology	hydro-geology	forestry
Consultants **										
Various Dutch Consulting firms* are active in the field of hydrological, water management and environmental research										
Other institutes										
TNO-DGV Institute of Applied Geoscience		x	x	x					x	
TNO Division of Technology for Society	x	x		x		x				
Delft Geotechnics		x			x					
Limnological Institute of the Royal Netherlands Academy of Arts and Sciences	x			x				x		
Netherlands Geological Survey		x							x	
Delft Hydraulics	x	x	x	x		x		x	x	
Royal Netherlands Meteorological Institute							x			
International Institute for Hydraulic and Environmental Engineering	x	x	x	x				x		

* *Addresses are given on page 90* ** *Research topics are not indicated.*

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(some suggestions for further reading)

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Annex 1

Selection of current research topics

Introduction

The trends in Dutch hydrological research described in Chapter 9 cover a wide range of subjects. However there are three common research themes in this small, low lying and densely populated country. First, conflicting demands in land and water use leading to an integrated approach to problem solving; second, a wide range in the scale of hydrological problems leading to practical solutions in planning and management and third, continuous interactions between salt and fresh water, ground and surface water and quantity and quality leading to custom made solutions.
The nine studies presented in this annex illustrate the wide variety of hydrological issues, the main research themes, the problems which are being addressed and their solutions.
The first study "*Decision support system for water management in regions with intensive agriculture*" describes how (regional) water management policies for efficient control of water quantity and quality are being aided by the development of a scenario generating system and a policy analysis system. Complicated relationships within the hydrological system and its interactions with the water users have been modelled. In addition to these relationships the support system will be of help in analyzing alternative solutions, incorporating social, economic and environmental factors.
The amount of animal waste, one of the factors of the decrease in water quality, forms the basis of the next case "*Nutrient losses to groundwater and surface waters*". The nutrient imbalance in agriculture has led to intensive studies for estimating nutrient losses to groundwater and surface waters. Two types of studies can be distinguished: First, studies of nutrient processes and second, regional studies in watersheds for policy analysis.
An adequate long term provision of drinking and industrial water requires a continuous care for the quality and - if needed - the development of a protection policy. The contribution "*Some trends in the quality and protection of groundwater for public water supply*" shows by hydrochemical monitoring the steady deterioration of raw water quality through manure, fertilizers and pesticides and describes protection instruments at national and regional level. In the struggle to maintain sufficient drinking water of good quality in a region characterised by a gradual decrease of water quality inventiveness is required.
The specific use since 1940 of the Dutch dune-area to store surface water in phreatic aquifers for public water supply is an example of national inventiveness in response to resource and spatial limitations. In "*Artificial recharge and drinking water supply*" research on clogging and hydrological aspects of well recharge is described together with the impact of a hydrological regime on the natural vegetation in the recharge areas.
Developments in society and environmental consequences were taken into account when the government took a decision on the management of the watersystem in Lake Grevelingen in the south-western part of the country. The choice of fresh or salt water was dependent on the relation to surrounding water systems and to demands from agriculture, nature conservation and water recreation. The case "*Lake Grevelingen, fresh or salt?*" proposes that, after the 1986-decision that the lake will remain saline, the next step - optimizing water management - requires a new type of research programme. This should include both fundamental and applied research in existing institutions and a new multidisciplinary approach to implement the knowledge for environmental impact studies and for political decision making.
"*Biomanipulation: a useful tool in water management*" is the title of the next case study. This describes the wide scope of instruments in Dutch eutrophication policy to recover ecosystems of small lakes (e.g. reduction of phosphorus load). The importance of using detailed knowledge of biological feedback mechanisms and hydrochemical processes is essential to take the right measures to improve water quality. Hydrological expertise is also applied in this area in a multidisciplinary framework.
The care for the natural environment in relation to water is no longer restricted to the dunes. Recently, this field of research, named ecohydrology has gained increased attention. Government bodies at all levels and nature conservation services must decide how to manage the natural environment on a regional basis particularly with respect to soil, ground- and surface water. The contribution "*Ecohydrological research and nature conservation*" analyses the research needs of water-dependent

plantlife. The role of hydrology is also described in order to model regional water systems to link them with local groundwater regimes and moisture conditions and to model hydrochemical processes.
Due to interactions between surface and subsurface hydrology and hydrochemistry the mapping of subsoil is an important issue in the Netherlands. The contribution "*Mapping groundwater*" describes the state of the art and new developments, such as the classification of flow systems and the impact of geo-information systems on the production and use of maps. If these maps present integrated knowledge for example of groundwater quality, soil characteristics and flow patterns, then they can be used by geo-scientists, including hydrologists, to solve practical problems.
The last illustration of research concerns the "*Application of remote sensing in hydrology*". Point information resulting from traditional field investigations may be interpolated to regional information by applying remote sensing techniques. Completely new possibilities of monitoring the environmental changes in time are the direct benefit of remote sensing. Examples are given of monitoring surface water (to detect illegal discharges), monitoring agricultural crops (regional distribution of evapotranspiration; testing agrohydrological simulation models) and delivering input to (geo-)information systems (e.g. at the service of watershed management). In principle the expertise can be applied in the Netherlands and in other countries.

Decision support system for water management in regions with intensive agriculture

Need for measures

An increasing water demand combined with the pollution of groundwater and surface water has put a heavy burden on the environment in the Netherlands, especially in regions with a sandy soil and with a tradition of factory farming. The amount of animal wastes cannot be disposed of by fertilization at the optimum level. Over-fertilization of maize fields and dumping of slurry on fallow land is currently common practice. Most soils in sand regions have poor retention capacities for the slurry minerals which result for example in the excess nitrate being easily leached, which increases the nitrogen load on groundwater.
In dry periods water is supplemented by sprinkling and by subsurface irrigation. The lowering of groundwater levels that results from drainage and from abstraction by farmers for sprinkling and by public water supply companies deteriorate conditions in wet nature conservation areas. Supply of surface water of a "foreign" quality is often detrimental to sensitive hydrobiological ecotopes in the surface water system and infiltration to the subsoil and groundwater flow can be a further hazard. A schematic diagram of the interactions of water users is given in Figure A.1.

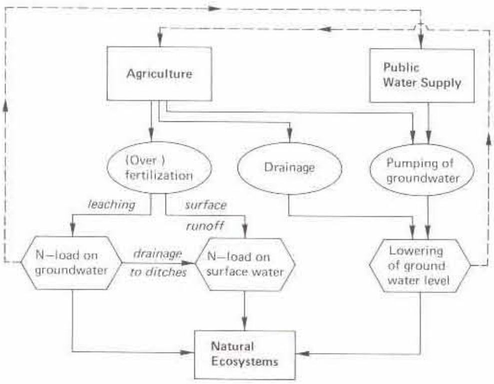


Figure A.1 Some interactions of agriculture, public water supply and natural ecosystems through water resources

Central government and regional authorities realize that measures are needed for attaining a satisfactory balance between economic developments and long-term environmental conditions. The complexity of the relations between water users and water subsystems, as well as the large number of possible water management alternatives, make it hard to design policies for the efficient control of quantity and quality of water. The matter is even further complicated by the difficulty in predicting the behavioural response of the different water users. Therefore a decision support system is being developed for aiding the design and evaluation of regional water management policies.

Decision support system

The design of a future state of a region consists of two separate stages with corresponding elements in the decision support system (Fig. A.2). With the scenario generating system the regional authority can generate scenarios that meet certain requirements with respect to the well-being of the different water users. This well-being is quantified in terms of indicator values, for instance income from agriculture, employment, nitrate concentrations in groundwater, etc. The scenario generating system generates, in a sense, a reference state of future regional development that could be reached if all the water users would behave in the way the authority wants.

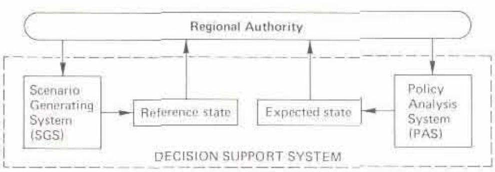


Figure A.2 Overview of the Decision Support System. For simplicity it is assumed that regional water management is in the hands of one (fictitious) regional authority. The SGS is for the identification of future possibilities; with the PAS the regional authority can evaluate the effects of potential water management measures

With the policy analysis system the authority can evaluate the effects of certain policy measures. If it turns out that the reference state is not reached, the authority has to either lower his ambitions or try another policy. The behavioural responses of farmers (and other water users) are hard to predict using mathematical models. Though initial attempts have been made at constructing a formalized mathematical model of farmers' behaviour, this model is not operational yet. That leaves common sense for predicting the reactions of water users to various measures. Additional constraints can be added to the scenario generating system in order to ensure that the obtained scenarios have an increased practical value.

Scenario generating system

The scenario generating system concerns relatively well understood processes that allow the use of mathematical modelling. For the simulation of the regional hydrological system and its interactions with the water users, four coupled models have been developed: a groundwater model, a crop production model, a regional nitrogen model and an ecological impact model. These models are of the comprehensive type: they provide the most detailed possible description of certain processes. They are however not suitable for a quick generation of scenarios that are to be analysed by the authority. For this, linear models are more suitable. However the simplicity of the linear models results in the use of a relatively crude approximation to reality. The comprehensive models will therefore always be needed for verification and more accurate estimation of scenarios that seem promising.

The scenario generating system can give the authority answers to different types of questions with respect to possible future developments of a region. These questions are of the type "maximize (or where appropriate minimize) a certain indicator of well-being, under the following constraints for the remaining indicators...". Apart from physical constraints derived from the environmental system, there can also be constraints derived from estimates concerning farmers' attitudes towards changing their economic activities. These estimates derive from the policy analysis system, as explained above.

Preferably the answers of questions put to the scenario generating system should be forthcoming after some on-line computing. However, it was found that certainly for the type of problems addressed in this context it is not possible to simplify the models to such an extent that the computation time becomes acceptable for interactive running and at the same time maintain credibility of the system. But for easy user access and interpretation of results an interactive system with colour graphics has indeed been developed.

The interactive system used for creating Figure A.3 makes possible a visual comparative analysis of scenario data by means of colourings of subunits on a topographic map or by colour graphics in the form of pie and bar charts. Twin maps and charts are used for this purpose. The duplication can either be used for comparing results of two different scenarios or for comparing two different aspects of the same

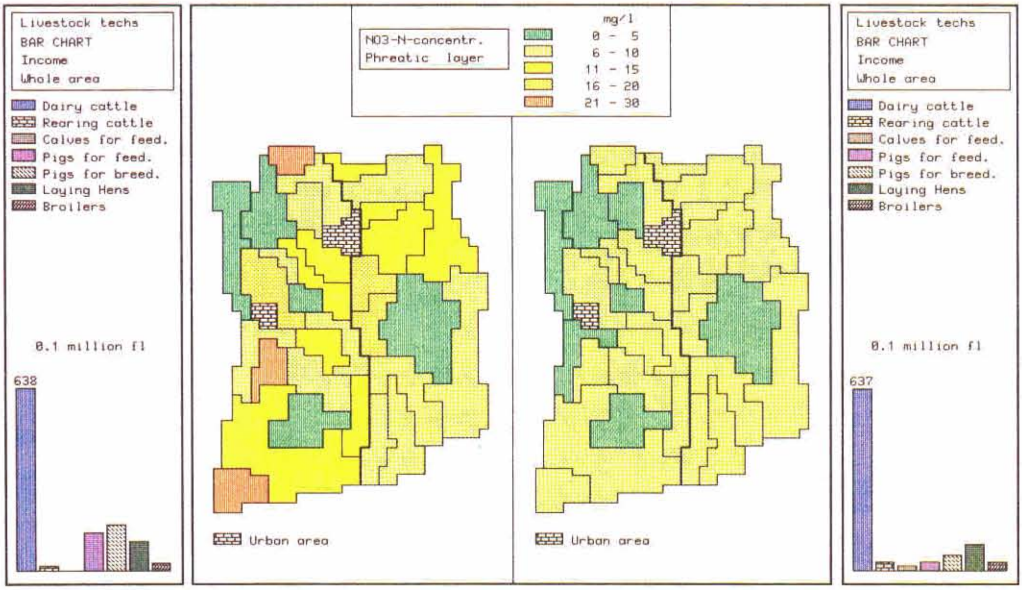


Figure A.3 Example of results generated with the scenario generating system. The left- and right-hand sides of the figure show results of two different scenarios. Both scenarios were generated by means of maximizing income from agriculture: the left-hand scenario with no constraint on the concentration of nitrogen in groundwater, the right-hand scenario with a constraint on the maximum NO_3-N concentration of 10 mg/l. The consequence of the imposed N-constraint is a reduction of the annual income from agriculture by 10%. This reduction is mainly due to a reduction of the intensities of the "livestock technologies", as illustrated by the bar charts.
Used abbreviations: "techs" - technologies
"feed." - feeding
"breed." - breeding
fl - Dutch florin

scenario. The use of a menu-hierarchy allows implementation of the system with very many different types of data in the database. This is especially advantageous when showing results of integrated environmental modelling, because inherently many different aspects are involved. By using the interactive display system the authority can analyse generated scenarios and can evaluate them in terms of his own preferences and judgements. No doubt he will require additional scenarios to be generated on the basis of his analysis of the ones that are initially presented to him. He may also want to revise his estimates concerning the behavioural responses of the regional water users.

Nutrient losses to groundwater and surface waters

Nutrient imbalance in agriculture

Before the 1950's livestock was mainly fed with farm grown crops. There was a cycling of nutrients at farm level and the rather small losses of nutrients were balanced by inputs of mineral fertilizers and concentrates. After 1950 great changes took place in agriculture. Livestock densities and the use of concentrates and mineral fertilizers increased. These developments resulted in much higher nutrient inputs than outputs via crop, meat and milk. Figures on nutrient production in manures and mineral fertilizers applied are given in Table A.1 for the Netherlands as well as for the Peel region. This region of about 50 000 ha of agricultural land has one of the highest livestock densities per ha in the Netherlands. In areas with very high livestock densities like the Peel region most of the manure produced by pigs, poultry, veal calves and steers goes to forage maize land. If the total available amount was applied on forage maize land, this land would receive 1109 kg N and 253 kg P per ha per year. These amounts are much higher than uptake by the maize crop which are approximately 200 kg N and 35 kg P per ha per year. The utilisation of total nutrients input on

Land-use	Production of manure (t)		Nutrients in fertilizers (kg/ha) N*		P	
	Neth.	Peel	Neth.	Peel	Neth.	Peel
Grassland						
– manure of cattle except veal calves and steers	64	93	369	537	50	72
– mineral fertilizers			257	286	7	2
Arable land						
– manure of veal calves, steers, pigs and poultry	32	155	215	1109	55	253
– mineral fertilizers			140	44	28	10

* Exclusive of losses in stable and from storage

Table A.1 Nutrients in manure produced in 1984 and in mineral fertilizers applied in 1980, given for the Netherlands (Neth.) and for the Peel region (Peel) for different types of land-use

forage maize land is therefore very low and amounts to approximately 15% for N and P, which is the same as that found for dairy farms in the Netherlands for N and 34% for P.
The imbalance between input and output of nitrogen has led to agricultural practices which were accompanied by high environmental losses via leaching and surface runoff. Losses of nitrogen (N) and phosphorus (P) have contributed to the present environmental problems like eutrophication of surface waters and deterioration of soil and groundwater quality.

Nitrogen losses

The quantification of nitrogen losses to groundwater and surface waters is carried out in two types of experiments which are quite complementary to each other with respect to scale and data collection intensity. The first one is carried out on experimental fields and is characterised by an intensive data collection for studying processes in which nutrients are involved. The second one is carried out at a regional level in watersheds for policy analysis.
The fate of applied N is very much influenced by site-specific factors, for example, soil characteristics, hydrological conditions and climate and by factors which depend on agricultural practices, for example, amount of manure and mineral fertilizer applied, time and technique of application and land-use.
Therefore no fixed figures can be given for the losses of N from the rooting zone to groundwater and surface water. The influence of some of these factors on N-losses has been quantified on experimental fields.
Soil type and water management appeared to be important factors for nitrate leaching. Sandy soils give nitrate leaching losses which can be a factor two to three times higher than those found for clay soils at the same level of N-fertilization. Sandy soils normally have a lower water content in the unsaturated zone than other soil types resulting in a greater leaching depth for a certain amount of precipitation.
Moreover the lower water content improves aeration which leads to a reduced denitrification potential in the unsaturated zone.
Sound water management favours N-uptake by the crops and helps to reduce nitrate leaching. This can be realised by the management of the groundwater table depth and supplemental irrigation in dry periods. Experiments were carried out in grassland on two sandy soils which differed in depth to groundwater. The sandy soil with a deep groundwater table partially received supplementary irrigation. The effect of different supply rates of mineral N on nitrate leaching losses was measured at one meter depth below the soil surface. The mineral N-supply is the sum of N in mineral fertilizers and the mineral N coming from slurry. The higher the mineral N-input the stronger the increase in nitrate concentration (Fig. A.4).
At higher inputs of mineral N a smaller part is consumed by grass resulting in increased nitrate leaching. The lower nitrate concentration at the high groundwater table can be explained by higher N-uptake in the grass due to a higher capillary rise and better conditions for denitrification in the upper metre of the soil. Irrigation in dry periods was responsible for an extra N-uptake in the grass and resulted in lower N-concentrations especially at higher fertilization levels. At the optimum N-fertilization level for the Netherlands of 400

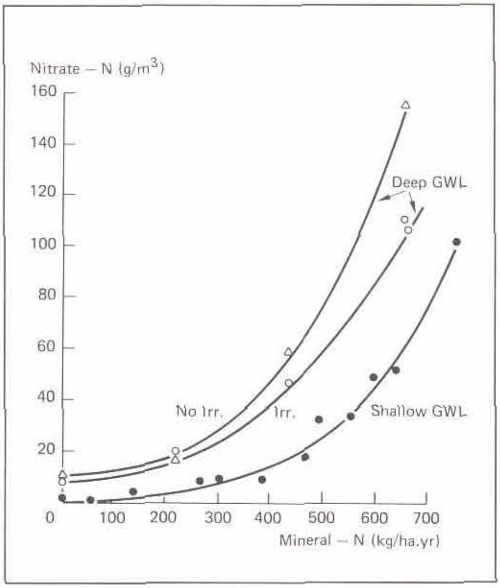


Figure A.4 Nitrate concentration in the leachate in the leaching period of 1982/1983 at about 1 m below soil surface at different supply rates of mineral-N for mowed grassland on sandy soils with shallow groundwater level (GWL: 0.4 m below soil surface in winter and 1.4 m in growing season) and deep groundwater level (GWL: more than 2.5 m below soil surface). The field with the deep water table was with irrigation (Irr.) and without irrigation (No Irr.) in dry periods. The amount of leachate is roughly 300 mm per year

kg/ha irrigation caused a decrease in the nitrate concentration by nearly 20% in the leaching period between autumn 1982 and spring 1983. At lower N-input the N-supply tends to be the limiting growth factor resulting in smaller reductions for the nitrate concentration in the leachate.

The excessive application rates of animal manures on silage maize land and of mineral fertilizers especially on grassland in sandy soil regions has led to situations that the nitrate concentrations in the upper groundwater are far above the maximum acceptable concentration for drinking water (11.3 g/m^3 N). Discharge of these groundwaters on surface waters will result in an increase of the nitrate load. Nitrate concentrations can be reduced during transport to deeper soil layers by dilution and denitrification processes. The significance of denitrification depends on the bioavailability of organic matter and pyrite (FeS_2) in the

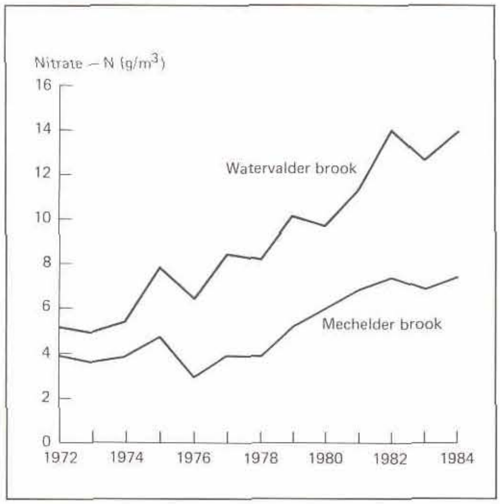


Figure A.5 Concentration of nitrate-N in the surface waters of two brooks in the region Zuid-Limburg in the period 1972-1984

geological formations. Long term measurements of nitrate concentrations in two brooks clearly reflect the increased N-inputs from mineral fertilizers and animal manures in the past decades (Fig. A.5). Differences in nitrate concentration between surface waters are due to differences in soil factors, agricultural practices and geohydrological circumstances. A reduction in nitrate leaching can be reached by applying mineral fertilizers and manures during the growing season and in amounts which do not exceed crop needs.

Surface runoff and interflow can be responsible for transport of NH_4^+ and organic N over the soil surface and through the top layers of the soil to surface waters. These processes are important in periods with high precipitation rates on soils with a reduced permeability for water due to soil physical characteristics or a high groundwater table. A significant contribution to N-loads on surface waters in the Netherlands can be expected outside the growing season when animal manure is put on agricultural land. The consequences of manure application for N-concentrations in surface runoff depend in the first place on the amount of manure applied. In the second place the time elapsed between manure application and the surface runoff event influences the impact of a certain manure dose. The longer this time interval the lower the

N-concentration due to a decrease in the available N on the soil caused by volatilization, biochemical turnover and infiltration. The threat of water pollution is especially high when surface runoff occurs within a few days after spreading.
The concentration of NH_4^+ and organic N found in surface waters of regions with a sandy soil and a high animal manure production is roughly 4 to 6 g/m^3 N. Leaching from naturally occurring organic N-reserves in the soil is responsible for 1 to 3 g/m^3 N, the remaining part is coming from surface runoff and interflow processes. To prevent or reduce pollution by surface runoff and interflow, manures should be applied during the growing season and they should be injected into the soil or quickly incorporated after surface application.

Phosphate losses
The mobility of phosphates in nearly all of the soils is very restricted as a result of chemical reactions with clay minerals and especially certain metal ions. The concentration of ortho-phosphates in soil solution is regulated by adsorption and precipitation processes in which Fe, Al and Ca play an important role. These processes contribute to the situation that the 'natural' total-phosphate (P) concentration in groundwater under mineral soils is normally in the range of 0.01-0.3 g/m^3.
The maximum amount of P which can be stored in the soil depends very much on soil type and is calculated from the oxalate-extractable Fe and Al content in soil. The storage capacity for the upper metre of the soil ranges from a thousand to ten thousand kg P per ha. Transport of P to deeper soil layers takes place if the P-input by mineral fertilizers and animal manures exceeds the remaining capacity in the overlying layers to store P. The excessive production of animal manures in some regions in the Netherlands has led to a longterm over-application of manures on part of the agricultural land resulting in soils which are naturated with P up to some tens of cm depth. In those situations total-P concentrations in the upper groundwater have been measured of some grams per cubic metre, which is far above the 'natural' value. Discharge of these groundwaters on surface waters will result in an increase of the P-load.
Interflow is an other pathway for nutrients from soil to surface water, it can be expected in wet periods in soils with a reduced permeability resulting from natural soil composition and soil compaction. The role of interflow for P-transport to surface waters has been studied on a sandy soil where frequent manure applications resulted in soil compaction for the layers between 10 and 30 cm depth and in a P-saturated top soil of 20 cm depth. A bromide solution was applied as a tracer to assess the transport route through the soil. A zone of 8 m width on both sides of the ditch till a depth of roughly 30 cm appeared to contribute to the P-load of surface waters by interflow. The total-P concentration of the interflow water was on average 7 g/m^3, which is very high compared to the concentration in precipitation (0.1 g/m^3).
The importance of surface runoff for surface water quality has already been discussed in the chapter dealing with nitrogen. In the surface runoff waters total-P concentrations were measured up to 15 g/m^3 when a runoff event occurred shortly after the application of 3 tons dry matter of manure.
The total-P concentration in waters, running from agricultural lands, recorded in watershed studies range from 0.5 tot 5.0 g/m^3. This resulted in discharge rates varying from 0.6 to 10 kg P per ha agricultural land corresponding with losses of respectively 0.3 and 5.7% of P produced in animal manures. The most important explaining variables are: amount of precipitation, groundwater table depth and P-saturation of the soil.

Some trends in quality and protection of groundwater for public water supply

Actual situation
Groundwater is the main source for public water supply in the Netherlands. About one third of the withdrawn quantity of groundwater originates from rather vulnerable sites, with phreatic water. At these sites, problems with the groundwater quality are growing. The main problems arise through manure and pesticides. The 1987 Soil Protection Act provides the structural basis and the necessary administrative instruments for the soil protection policy in the Netherlands. This policy is primarily directed towards the achievement of a general (basic)

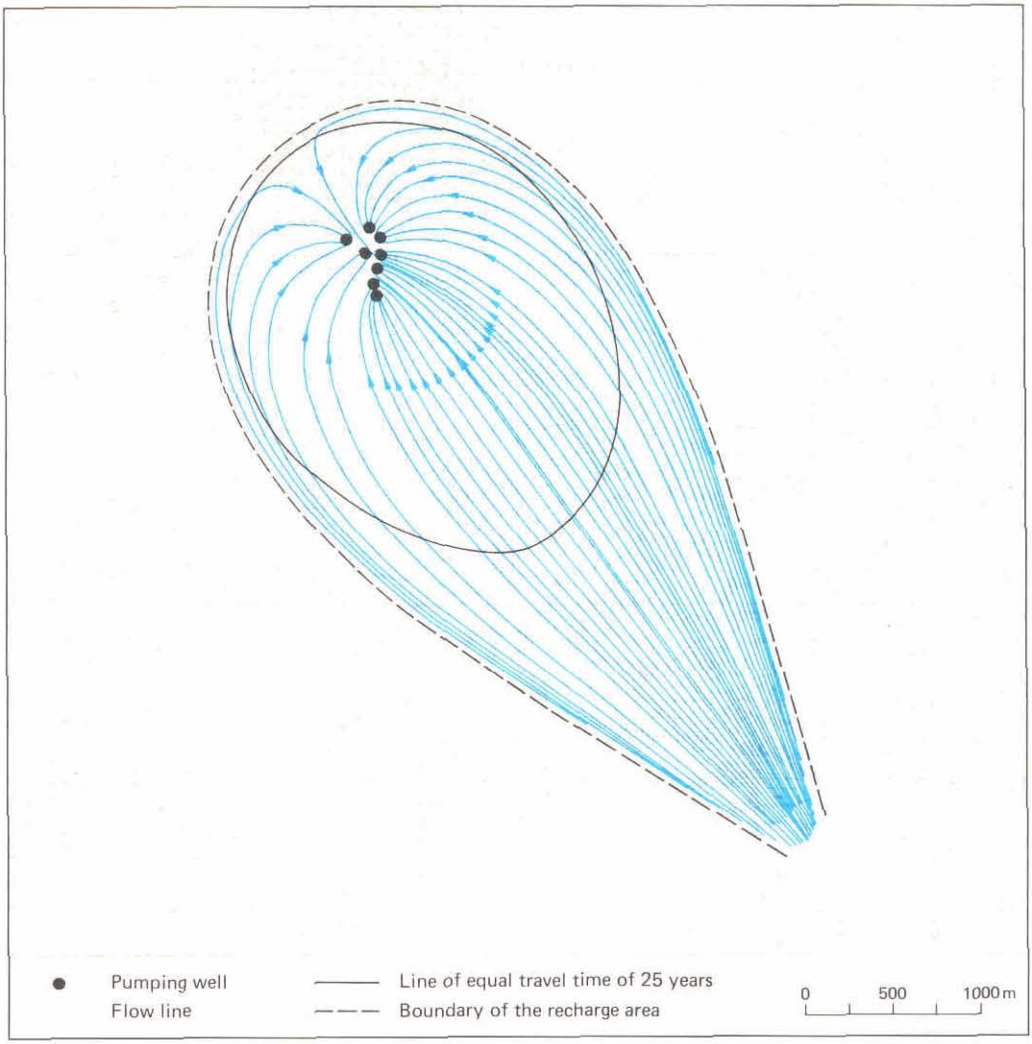
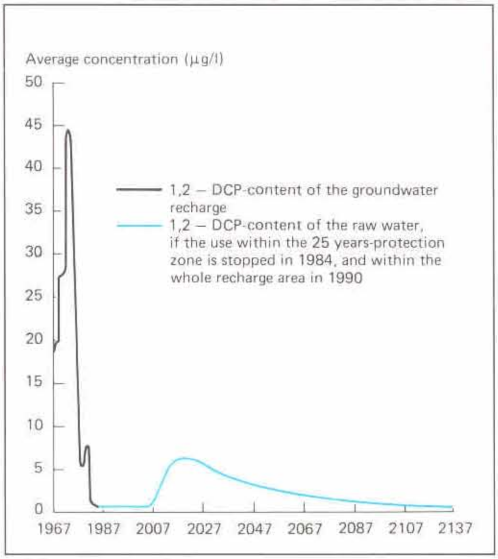


Figure A.6 Pumping site "Lochem" (Water supply company Oost-Gelderland). Groundwater flow lines, recharge area and line of equal travel time of 25 years

level of protection, to maintain the properties of soil and groundwater as required to perform its different functions. Besides this, the provincial authorities have to lay down a plan, indicating the main policy outlines on how to protect the quality of the groundwater, with a view to public water supply. In most cases, this implies an extra protection with respect to this specific function of the soil.
In the present plans, the delineation of areas with specific protection has been based on equal travel times (25 years has been chosen) of the groundwater (Fig. A.6) flowing to the pumping well(s). In most cases only horizontal flow is taken into account. At about half of the total number of abstractions of phreatic water, 20 to 40% of the abstracted water is protected, in this way (Table A.2).

As can be seen, this percentage may vary strongly from case to case, depending on the thickness of the exploited aquifer.
Consequently, the remaining portion of the water, originating from the rest of the recharge area, has no extra protection other than the

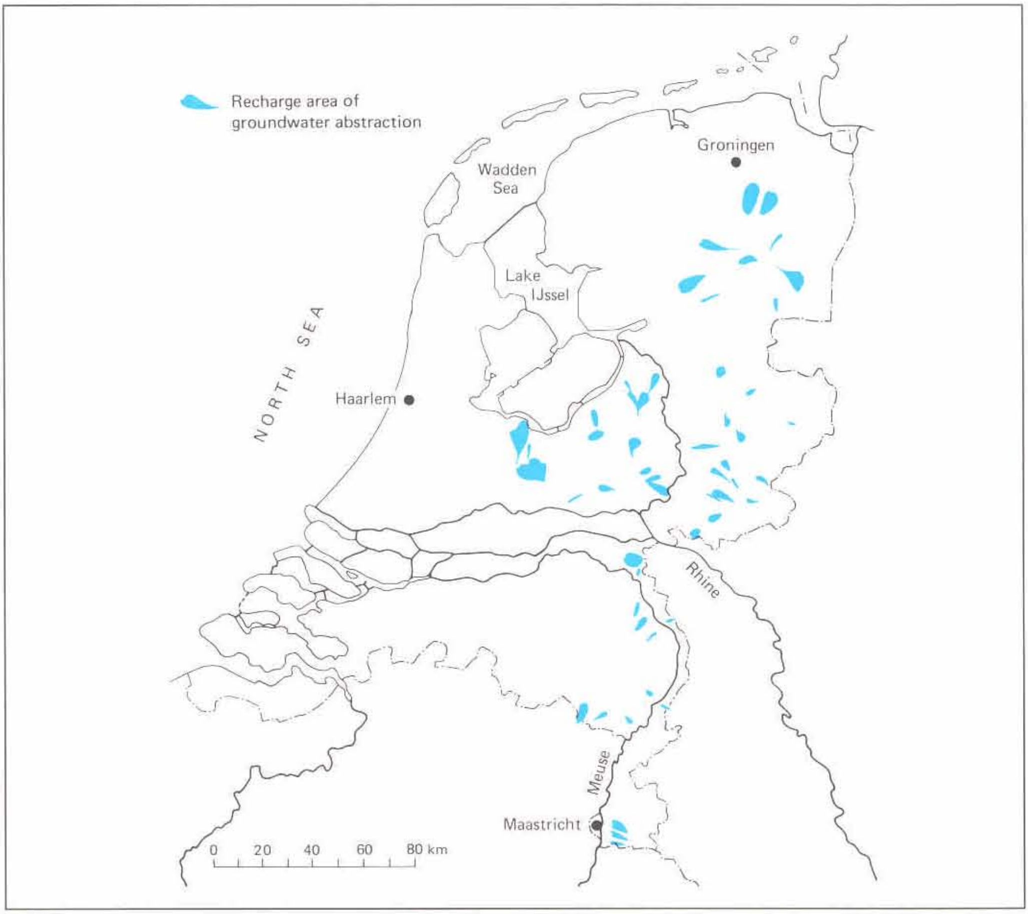
Figure A.7 Average concentration of 1,2-dichloropropene at pumping site Noord-Bargeres (province of Drenthe) for the period of 1967 - 2137



general soil protection level. For that reason, discussion is necessary of the underlying principles with respect to the determination of the dimensions of protection areas around pumping sites. Some points of this discussion might be:

– equal travel times versus parts of the withdrawn volume as a basis for the establishment of protection zones; this choice may be based on so called response functions, of which Figure A.9 is an illustration.

Figure A.8 Recharge areas of phreatic groundwater withdrawals



Thickness of aquifer (m)	Number of abstractions per thickness-class (%)	% of abstracted water, originating from the 25 year protection-zone
0 - 20	5 - 8	60 - 100
20 - 30	7 - 11	45 - 60
30 - 50	25 - 30	30 - 45
50 - 75	12 - 17	20 - 30
75 - 100	12 - 17	15 - 20
100 - 150	18 - 22	10 - 15
150	12 - 17	10

Table A.2 The quantity of protected water in the Netherlands, (phreatic groundwater withdrawals) by applying 25 year protection zones

– splitting-up in different protection-strategies for different types of aquifers and/or different (potential) diffuse sources of pollution.

The future

This discussion has to be seen in connection with the long response-times of the governing groundwater systems. This may result in groundwater contamination (depending on the

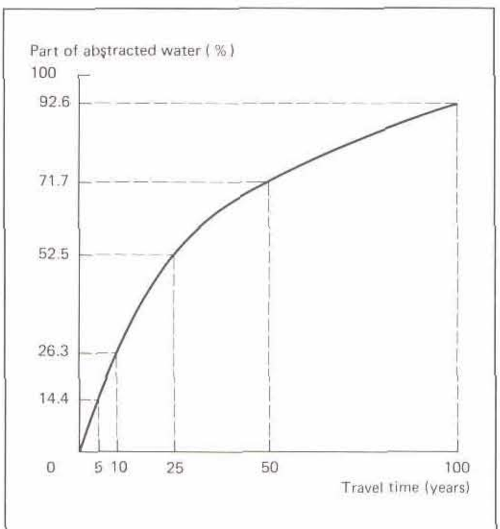


Figure A.9 Geohydrological response-function of the groundwater pumping site "Lochem" (province of Gelderland). Abstraction: 2.33 x 10^6 m^3 per year; porosity: 0.35; aquifer thickness: 30 m; natural groundwater recharge: 0.3 m per year

specific properties of the components and the hydrological system) during decades. Figure A.7 illustrates this for 1,2-dichloropropene, a non-active persistent component of the soil-disinfection agent 1,3-dichloropropene, which is frequently used against nematodes in potato growth in the provinces Drenthe and Groningen. This case, among others, has led to the start of the following investigations:
– tracing the influence of diffuse sources of pollution on future groundwater quality;
– development of tools (models and methods) to provide the policy with a sound basis with respect to protection of groundwater resources, and to be able to make predictions on future groundwater quality.

These developments have already resulted in a geohydrological classification of groundwater pumping sites with respect to vulnerability to pollution. In addition several computer programs have been developed for the calculation of pathlines and traveltimes of groundwater. These computer programs are applicable to different geohydrological situations and to the predictions of future water quality at pumping sites.

With respect to the prediction of future groundwater quality trends resulting from present or changing policy concerning soil and groundwater, the following objectives are pursued:
– Prediction of groundwater quality developments in general (not related to any specific function). Part of this problem is a profound analysis of groundwater flow systems. Recently, in view of this an investigation in the province of Drenthe has been started with an emphasis on hydrological systems analysis. Within this framework, modelling of different types of surface water-groundwater-relationships will be tackled.
– Prediction of future groundwater quality directed to pollutants such as nitrate, potassium, pesticides, at existing or new selected pumping sites.

The latter topic has resulted in completed predictions for 69 phreatic or nearly phreatic pumping sites with respect to the development of the nitrogen-content. Figure A.8 shows the recharge areas of the pumping sites. The actual situation with respect to the application of manure and fertilizers in agriculture leads to a steady deterioration of the water quality, as

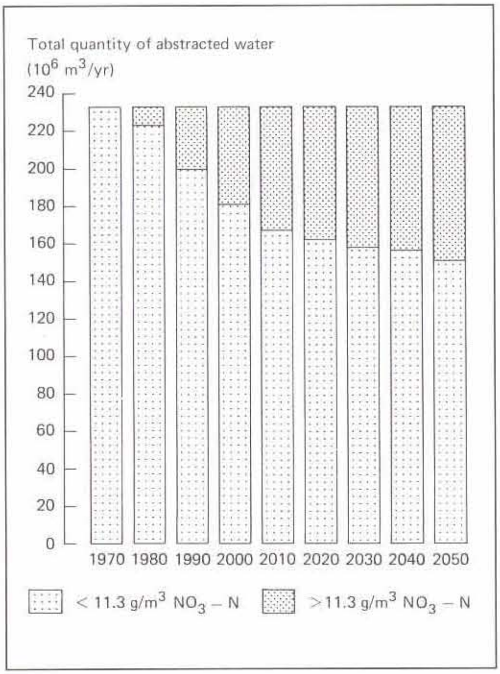


Figure A.10 Development of the NO_3-N content of the water, for 69 pumping sites with phreatic groundwater for the period 1970 - 2050

Figure A.10 illustrates, using the situation in 1986 (with respect to nitrogen-load) as a starting point. Based on the drinking water standard of $11.3\ g/m^3\ N\text{-}NO_3^-\text{-}N$, in the year 2000, groundwater withdrawal at 22 (out of 69 pumping sites) - equivalent to 45 million m^3 per year - will not be possible without additional purification provisions.
The trend, as depicted in Figure A.10, can only be broken by regulation within the whole recharge area of the pumping sites.

Artificial recharge and drinking water supply

Introduction
In the Netherlands infiltration of surface water in phreatic aquifers started on a small scale in 1940. In the 1950's large projects have been established to supply the most crowded, western parts of the country along the North Sea coast where abstraction of fresh groundwater is restricted due to salt water intrusion. Today, infiltration by surface spreading is approximately 160 million m^3 per year. When abstracted it serves 15% of the total supply of drinking water in the Netherlands. For several decades the possibilities of recharging deeper aquifers have been studied. At present research is directed to recharge wells because surface spreading results in serious opposition because of its environmental impact.

Open recharge
In the Netherlands 30% (Table 6.1) of supplied drinking water is produced from surface water (rivers Rhine and Meuse, lake IJssel) because sufficient fresh groundwater can not be abstracted. Half of this is pretreated and used as drinking water following artificial recharge. The other half is directly treated for drinking water or via storage reservoirs in order to guarantee an uninterrupted supply. The selective intake and the decomposition processes that occur, results in further improvement in the quality of the water.
With respect to artificial recharge, more than 90% is pretreated with at least coagulation, sedimentation or flotation and rapid sand filtration. Approximately 87% is transported over more than 50 km and more than 96% is infiltrated in a dune area near the North Sea coast. Locations are given in Figure A.11. Infiltration takes place in a regular system of dug canals or pits, natural valleys and ponds in shallow, unconfined aquifers that consist of fine grained sands. Infiltration rate is 0.2 m/d on the average. It increases if water quality is improved by additional pretreatment. Effective horizontal flow velocities for the water are in the order of 1 m/d, travel times in the range of 1 to 4 months. After it is retrieved the water is treated with aeration and rapid sand filtration and sometimes softening, activated carbon, slow sand filtration.

From open recharge to well recharge
Open recharge of aquifers has proved to be a valuable technique to turn surface water of unreliable and unpredictable quality and/or quantity into a safe source for water supply in an operationally reliable and simple manner. However in this way only phreatic aquifers can be used. At larger depth aquifers are thicker, so waterworks have tried to use these for some decades. Moreover, in the Netherlands recharge sites are not numerous and because basin-type recharge meets serious opposition (because of

Figure A.11 Locations of surface spreading facilities of waterworks in the Netherlands

its impact on the environment) resort to deeper aquifers is planned.

In the 1950's open recharge facilities could be and were constructed and operated in a dune area with little if any attention to the effects on the environment. Excavations caused a disturbance of landscape, subsoil and vegetation. Major plant nutrients in the recharge water (although pretreated) promoted excess growth of aquatic plants in the basins and uncontrolled terrestrial plants along the banks of the recharge facilities (Fig. A.12). Recharge and abstraction caused the groundwater level to change and fluctuate and this also affected the vegetation. However, in the last decades matters have changed substantially. The extent of pretreatment has increased and the dune area is increasingly considered an area of high natural value in which enlarged basin-type recharge capacity is not environmentally acceptable.

Experiments with recharge wells started in the 1950's. With no or little success, clogging of the wells being a serious problem. In the early 1970's a research programme has been organised

Figure A.12 Spreading basin in more detail, showing aquatic growth (algae) and unsatisfactory plant growth on the banks

to study systematically the causes of clogging. It was concluded that problems of severe clogging can be overcome and this has led to further proposals for resource development.

Research aspects of well recharge

The great difficulty of using recharge wells was always their rapid clogging. Whereas a basin may clog within years, a recharge well may clog in a matter of days or weeks. Because of this, research was for a long time directed mainly at overcoming the problem of clogging, with particular reference to causes, cleaning and design. Now, it looks as though the problems can be overcome. However, the clogging problem remains a matter of pretreatment and thus of costs.

Hydrological effects of borehole recharge become apparent only after several years so that experiments would take a long time and be extremely costly, hence the approach chosen was that of model simulation. An important aspect of underground storage by infiltration of prepurified surface water is the constant quality and temperature once recovered. Attention also focusses on storage build-up by displacement of native (salt or brackish) water, recovery efficiency and groundwater level fluctuations.

Not only clogging and hydrological aspects are studied. With respect to the environment several questions remain to be answered. If located in areas of environmental value, impacts mainly consist of loss of biotope. Impact on vegetation will be small because phreatic water

Figure A.13 Experimental recharge well of "Provinciaal Waterleidingsbedrijf van Noord-Holland", Castricum

will only be influenced if confining layers are lacking. If infiltration is interrupted, the time for which abstraction can be continued is restricted for reasons of groundwater level fluctuations or intrusion of poor quality groundwater. Impacts can be diminished if system controls and monitoring is automated. For instance backpumping the recharge wells - if clogging goes up - can be started using remote terminal instructions. Interference of borehole recharge with nature and landscape is less than that of open recharge (Fig. A.13) and thus the interests of water supply and recreation appear to be less incompatible. Within a few years several projects with well recharge on a scale of 4 to 8 million m^3 per year will be operational. Plans to start these pilot- projects are being developed. At present one project is under construction.

Lake Grevelingen: fresh or salt?

Introduction

Lake Grevelingen is a newly created lake in the south-west of the Netherlands. Its water management can be regulated in several ways and so a decision had to be made, whether the lake should become a salt water or a fresh water basin. To assist in making this decision a large (environmental) study was carried out. This study and some future developments are outlined in the following sections.

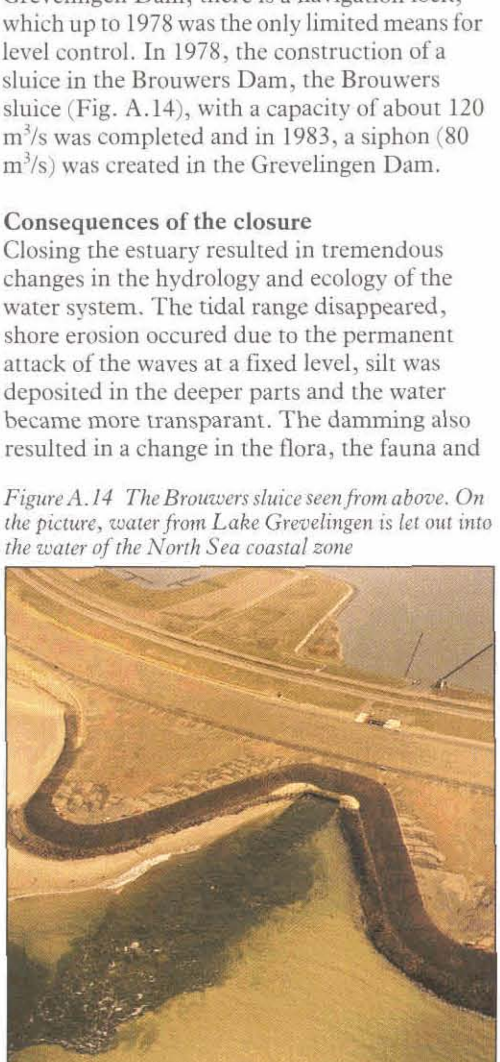
Lake Grevelingen

The former Grevelingen was an estuary open to the North Sea and the rivers Rhine and Meuse. The tidal range amounted to 2.5 m and the chloride concentration of the water fluctuated between 10 and 17 kg/m^3. This estuary was transformed into a lake as a part of the "Delta Project" (see page 20). The main purpose for the closure of the Grevelingen was, as for the whole Delta Project, to provide protection against inundation. For hydro-technical reasons the estuary was separated from adjacent waters by the Grevelingen Dam (1964) in the east and the Brouwers Dam (1971) in the west. The result was a tideless, salt water lake with a fixed level of 0.2 m below Mean Sea Level. In the Grevelingen Dam, there is a navigation lock, which up to 1978 was the only limited means for level control. In 1978, the construction of a sluice in the Brouwers Dam, the Brouwers sluice (Fig. A.14), with a capacity of about 120 m^3/s was completed and in 1983, a siphon (80 m^3/s) was created in the Grevelingen Dam.

Consequences of the closure

Closing the estuary resulted in tremendous changes in the hydrology and ecology of the water system. The tidal range disappeared, shore erosion occured due to the permanent attack of the waves at a fixed level, silt was deposited in the deeper parts and the water became more transparant. The damming also resulted in a change in the flora, the fauna and

Figure A.14 The Brouwers sluice seen from above. On the picture, water from Lake Grevelingen is let out into the water of the North Sea coastal zone



biological processes in the lake. Many species died out and some new ones appeared. The total number of species decreased and the planktonic food chains shortened. Mineralization processes and nutrient cycles changed. The residence time of the water in the lake was now several years, instead of several days. Between 1971 and 1978 Lake Grevelingen underwent a process of desalination due to rainfall and discharge of drainage water of the surrounding polders. An increase in the (ortho-) phosphate concentration occured. Nitrogen, another nutrient for algae, became limited in summer. All these physical and chemical changes were of great influence on the development of ecosystem of the lake. A new environment with new problems and potential for development was created and so special administrative agreements were made. In 1975 a land use plan was presented, in which nature and recreational areas were indicated. An important improvement to this plan was that ecological possibilities and values were taken into account. In 1986 this plan was implemented.

The first water management measures

Between 1971 and 1978, the chloride concentration fell from about 16 kg/m^3 to 12 kg/m^3. A further decrease in the chloride level would have impaired the ecological value of Lake Grevelingen, because many marine organisms would disappear. At the end of 1978, the Brouwers sluice was opened in order to increase the salt level to between 16 and 17 kg/m^3 and also to improve the water quality. In 1979, the sluice remained open during the whole year, which led to the intended salinity level, but also to a very stable salinity stratification, impeding oxygen exchange between the water layers and hampering a number of biological processes. By the end of 1979, the sluice management was evaluated, based on the first year of experience. It was decided to close the sluice in summer and open it in winter to prevent stratification and maintain a high salinity. The Brouwers sluice continues to be open from 1 October to 1 March.

Fresh or salt: an environmental debate

In the original plans of the Delta Project, a lot of attention was paid to the availability of fresh water for agriculture, while the disappearance of the shell-fish culture in the Eastern Scheldt was considered a great loss. Nothing was said about the loss of a unique estuarine ecosystem. Lake Grevelingen was expected to become a fresh water lake. However, the environmental consciousness grew in the seventies and the plans for a fresh water Grevelingen was debated as the value of a salt water basin was recognized. In 1979, a special project was started which focussed on the choice fresh or salt and the impacts of such a choice. A large number of government agencies and research institutes were involved. Five working groups were formed on the relevant topics: fishery, recreation, nature and ecology, agriculture and starting points/limiting conditions. The project was one of the first cases, in which the procedure of the bill on the Environmental Impact Assesment (EIA) was adopted.

Several alternatives - fresh and salt - were formulated and, after a broad study, three were selected:

1 a salt water basin, by using the Brouwers sluice (in fact the existing situation);
2 similar, but with a pipe-line from another (fresh) water basin, in order to supply water for agriculture to areas around Lake Grevelingen;
3 a fresh water basin, by letting in fresh water from the adjacent Lake Zoom in the east, by means of a siphon.

For these three policies an analysis was made. The main factor is that inlet of fresh water from Lake Zoom results in the introduction of water from the river Rhine and Meuse. This water is contaminated with (micro-)pollutants and accumulation of some pollutants in the fresh water basin would result in a more or less eutrophic system, with its consequenses for the functioning of the ecosystem. In 1986 the government decided that Lake Grevelingen would remain a salt water lake. Environmental arguments were of great influence on this decision. For agricultural water supply a pipe-line was proposed to transport fresh water from Lake Zoom to areas around Lake Grevelingen.

Further developments

After completion of the works and after the decision fresh or salt was made, a new phase arrived with the need for the water management of Lake Grevelingen to be optimized and refined. This provides a method for finding the best water management strategy in which the

different interests of functions and "users" of the lake are taken into account, within certain (formulated) restrictions. Special objectives are:
- the maintenance of a relatively high salt level;
- low eutrophication;
- a minimum level of pollution;
- low stratification risk;
- maintenance of high transparency.

A further aim is to develop a stable system requiring as little intervention as possible. Several (ecological) studies are currently being carried out, in order to assess the impact of several water management strategies. For this purpose, a special ecological (mathematical) model has been developed. The nitrogen balance plays a major role in the functioning of the ecosystem of Lake Grevelingen. With the help of the model, the impact of the alternative management methods on the nitrogen balance can be estimated. Another mathematical model is used to predict stratification. In 1990, a final water management plan will be presented.

Biomanipulation: a useful tool in water management

Consequences of eutrophication on Dutch inland waters

Eutrophication is one of the most severe water quality problems in the Netherlands. Excessive nutrient loading caused algae blooms and deterioration of the aquatic communities. In recent decades aquatic plants have virtually disappeared from many places. Pike were once abundant here, living in clear waters with a dense vegetation. The Dutch lakes and ponds, such a characteristic feature of the Dutch landscape, are nowadays green and turbid. The system has lost its equilibrium. Aquatic plants have given way to algae, the pike to larger numbers of bream. Natural variety has disappeared.

Eutrophication policy

In inland waters the most promising strategy to solve the problem of eutrophication is to reduce the phosphorus loading of the water. Following the international agreements of the Rhine Action Programme measures in the Netherlands will be taken to reduce the phosphorus contents of detergents, to remove phosphate from the effluents of sewage treatment plants, to decrease industrial discharges and to lower the release of phosphorus from agricultural areas. This will lead to a 50% reduction (approximately 16000 tons/year) of phosphorus discharges by 1995. Despite these large efforts expectations of solving the basic problem of algae blooms are rather poor.

Biological feedback mechanisms

Biological feedback mechanisms form the basis for the expected delay in recovery of shallow lakes. Lowering the phosphorus loading of a lake might result in a direct positive biological response of the system, but usually a second step in the restoration process is needed because of the internal resistance of ecosystems to changes.

Biomanipulation in practice

How can we progress from the actual situation of turbid, algae-rich bream-infested water to a situation with clear water, a rich littoral vegetation and a strong pike population? This question was raised at the start of a study considering the possibilities of biological control methods in water management. Research led to the development of a system theory which proves to be very helpful in identifying the key elements in the foodchain to which measures should be directed to. The most promising measure to trigger a positive biofeedback

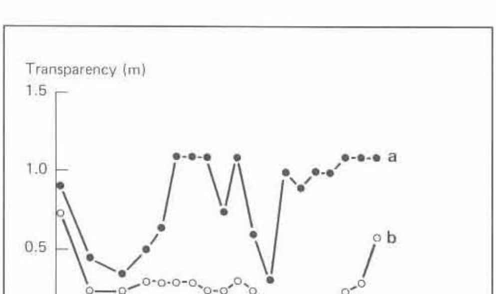


Figure A.16 Transparency in Bleiswijkse Zoom (province of South-Holland) in 1988 under different management strategies
a) bream stock reduced
b) control section

Figure A.17 Above: control section Below: bream stock reduced (ecosystem recovery)

process to be the artificial reduction of the abundant bream stock.
In the Netherlands attention focusses on the role of the omnipresent bream in hampering ecosystem recovery. This benthivorous fish increases nutrient concentrations and turbidity through its feeding strategy, thereby uprooting the scanty rests of aquatic vegetation, while the younger bream decimate the zooplankton, thus decreasing the grazing pressure on the algae.
As bream can live up to an age of 15-20 years the present heavy infestation of bream in the Dutch shallow lakes may result in poorer water quality for a long time.

Experimental fish stock management in three small lakes (Bleiswijkse Zoom, the pond Zwemlust and the Noorddiep) resulted in rapid ecosystem recovery (Fig. A.16), leading to a situation with clear macrophyte rich water (Fig. A.17). These macrophytes are considered a key factor in stabilising the newly formed equilibrium.
From these studies it is concluded that reducing the nutrient loading remains an essential precondition for solving the eutrophication problem, but it shows, that effective fish-stock management may be a very useful tool in speeding up lake recovery.
Regulating bream fisheries in the Netherlands are rapidly becoming a widely accepted method to combat eutrophication. Research will press ahead in the years to come. Attention will focus on the use of zebra mussels (filterfeeding) and bulrush and reed swamps (biological filtering, effluent polishing) as biological tools in water management. These biological tools may in the near future help in creating in the Dutch shallow lakes a socially desired, stable ecosystem.

Ecohydrological research and nature conservation

Introduction
There has been an increased awareness of both the consequences of land development for the natural environment and an increasing recognition of the value of ecological qualities for human wellfare. It is realized, that water management plays an important role in this context. Therefore, modern water management becomes increasingly complicated, facing progressively intensifying, diversifying and conflicting demands.
The growing awareness of the impact of water management on nature, calls for short term development of operational methods for the prediction of effects of water management measures on nature conservation. This need is stressed by the growing awareness of the impact of partially coinciding phenomena like manuring and atmospheric pollution.
In consequence, there is at present a certain urge for hydrological research to explore less traditional fields of interest. It has to bring the state of fundamental and operational knowledge about new fields to the same level as that regarding such well established ones as agrohydrology.
One of these new fields is ecohydrology, which deals with the importance of hydrology for wild plant and animal life. It concerns the integration of (geo)hydrology and ecology, specifically the ecological function of the hydrological cycle and of water management for ecosystems. It focusses especially on terrestrial and semi-terrestrial ecosystems.

Water and plant life
In general there exists a primary relationship between the abiotic environment and plant life. The relationship between animal life and abiotic environment is partially secondary, involving this plant life as an intermediary. For this reason the central field of study in ecohydrology is the relationship between water and plant. In this context the relationship concentrates on water as a common subject of hydrological research and water management and of ecological research and nature management.
A considerable part of the indigenous plantlife is characteristic for wet to moist conditions. Indeed, about 35% of the indigenous plant species of the Netherlands is groundwater-dependent, so-called phreatophytes, which habitually grow in moist to wet sites where they obtain their water supply from the saturated zone, either through direct contact or through capillary rise of groundwater into the unsaturated zone.
In addition, the occurence of more than half of the vegetation types at the level of alliances is exclusively or largely phreatophytic. These plant species and vegetation units are, in the nature of things, susceptible for water management measures that alter significantly the quantitative and qualitative groundwater regime in their site.
From the point of view of nature conservation, the appraisal of species increases with their rarity and vulnerability for communities and community complexes, it increases with the appraisal of the composing species and with greater species diversity and ecological complexity. The sensitivity of the environment to water quantity and water quality management measures varies in dependence on the further ecological differentiation among the plant species, that is their tolerance for stepwise alterations of site factors.

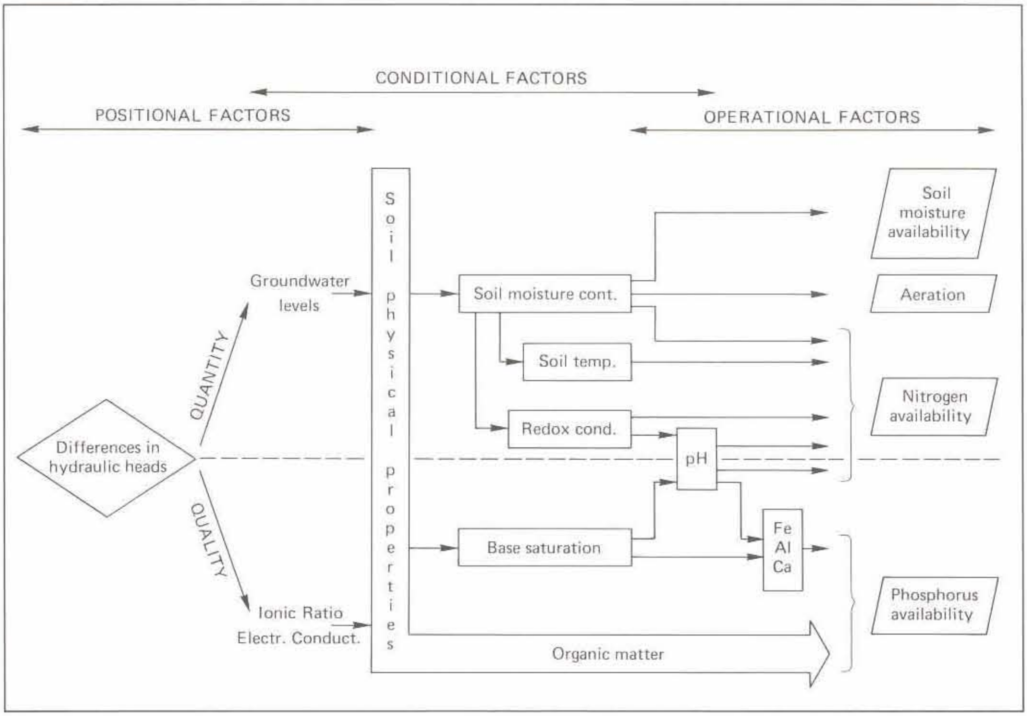


Figure A.15 Conceptual framework of the ecohydrological approach. Groundwater levels and hydrochemical composition (ionic ratio, electric conductivity) of any particular site are determined mainly by its topographical position in the landscape. They both have a distinct influence on conditions in the root zone. These conditions affect in turn the processes that control the fluxes of the main site factors in the plant's operational environment

The ecohydrological approach

Formal methods are available for the prediction of the effects of water management measures on quantitative aspects of hydrology and agriculture (e.g. soil moisture availability versus crop yield). Until recently this was not the case for prediction of corresponding effects on nature conservation. However, during the last decade knowledge about the relation between hydrology and (semi)terrestrial ecosystems has rapidly increased. This relation appears to be rather complicated. Research is focussed on water as a modulator for conditions of plant life. Approaches in ecohydrology range from empirical and correlative descriptions to more causal-analytical explanations. Since the first approach gradually evolves towards the latter, more fundamental one, this will be high-lighted here.

As the influence of the hydrological regime and water management on plantlife has a geographic/ topographic background, it involves various mechanisms and factors, and is in close interaction with the soil.

In the ecohydrological approach the plant environment is controlled by three factors at different hierarchical levels and scales (Fig. A.15). Site factors are operational at the level of the root environment. They are directly linked to plant physiology and are regulated by conditioning factors in the local environment. Both soil physical structures and the groundwater regime are providing the site hydrological and hydrochemical features, like groundwater level dynamics and macro-ionic composition of the groundwater. Those features are dependent on the prevailing differences between hydraulic head of the phreatic water and aquifer within the site. So the driving force that a site is exposed to, is said to depend on a positional factor, being the position of the site in a groundwater flow system somewhere between recharge and discharge areas as the ultimate poles of an ecohydrological field. The site produces the site factor demands of plants out of this ecohydrological field.

Ecohydrological research

There has been an increase in data availablity of the site factors required by indigenous plant species, but detailed data describing water - plant relationships are not fully developed. They include relative optimum values for a number of relevant site factors.

There is nowadays general agreement among ecologists that the availability of moisture and nutrients (especially nitrogen and phosphorus) for plants are the key factors in the root zone; for some species certain metal ions are also critical, and at relatively low concentrations.

Important for the variability of site factors are the so-called environmental dynamics in the root zone, to which is assigned a number of sensitive reactions of plant species set off by any change in water regime, however small. This was until recently a factor which was difficult to define. The capacity of the soil to buffer or temper the influence of changes in the groundwater regime on site factors such as phosphorus availability is now recognised. Soil acidity and metal ion activity is also a very important factor in this respect. This chemical buffering capacity in wet and moist sites is governed primarily by the hydrochemistry in relation to calcium, bicarbonate chloride and sulphate ions.

Arranging phreatophytes and phreatophytic communities according to their sensitivity to changes in the hydrological regime appears to be related to the impairment of the chemical buffering capacity, increases in soil nitrogen supply and lastly changes in soil moisture availability.

An important achievement of this new insight is that local site changes of species composition can be estimated from the regional catchment area.

Ecohydrological prospects

Ecohydrology is thus a new, interdisciplinary field in which hydrologists have to work together with soil scientists and ecologists. In close cooperation the hydrologists have to model and link up regional groundwater and surface water systems to local groundwater regimes and these ultimately to moisture conditions in the unsaturated zone. Part of this task will remain concentrated on a continued further development and operation of water quantity simulation models. An urgent new challenge is to generate a coherent series of operational simulation models for hydrochemistry and nutrient dynamics, which deal with non-conservative components and include complicated chemical and biological equilibria in the water-soil system.

In addition, a practical step-wise ecohydrological approach, starting from a general overview and then considering detailed aspects, requires a further elaboration of methods for the identification and analysis of water management problems. These aspects must be related to (semi)terrestrial ecosystems and methods for the analysis and description of water flow systems which can be linked with advanced hydrochemical simulation models. The hydrologists have in this field to deal with fundamental and practical problems of the different 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. It is most important that the resolution of local water quantity and quality models can be increased to a scale which fits the root system of plants. As it is expected that this gap can not be completely bridged in the near future, and that eventual solution may prove to be very laborious in practice, ecologists have to work from the other side and try to adapt the site concept to a smaller scale without loosing its essence.

These hydrological developments must enable soil scientists to simulate water-dependent soil processes relevant for plants and nature conservation. A classic problem, but certainly not the only one is the leveling of the many interdisciplinary barriers such as conceptual, cultural and terminological differences, and of the gap between theory and practice.

The ecohydrological approach indicates that it is almost impossible to distinguish the effects of water management from the impact for instance of fertilization and manuring, of atmospheric pollution (e.g. acidification) and of fluctuations in the climate, whether natural or man-imposed (greenhouse effect). Such phenomena may be related, for example, drainage for agricultural purposes may bring in its wake intensified use of fertilizing, manuring and pesticides, as well as increased ammonia emission.

This approach will assist the study of the environmental and ecological consequences of phenomena such as desiccation, wetting, eutrophication and acidification.

Mapping groundwater

Introduction

Almost the entire surface of the Netherlands has been developed and is in use for habitation, industrial production, recreation, agriculture or nature reserves. Under such conditions any change in land use will invariably lead to a conflict of interest. Advance knowledge and weighing of the consequences of human activities or decisions are therefore essential, with due consideration of the physical and chemical characteristics of the soil, the subsoil, and the groundwater.
For example: in one place waste disposal will lead to severe pollution of the groundwater whereas elsewhere the effects will be limited. Knowledge of the present groundwater quality, soil characteristics relevant to the behaviour of percolating pollutants and the flow patterns of the groundwater will enable the geoscientist to predict the consequences of various policies. Maps in this respect fulfil a key role. Subsoil phenomena maps represent a scientific interpretation of scarce data of one aspect for general purpose applications. In other cases maps are aggregations of different aspects for more specific purposes. An example of the former is a groundwater flow systems map. The latter is exemplified by a groundwater vulnerability map. Both represent a tremendous value to the user in time and money and enable him to direct his effort to his specific problem. Countrywide mapping moreover has additional advantages. It provides all users with a uniform base of knowledge and therewith comparable problems in different parts of the country can be attacked in a comparable way. Further it provides the mapping organization with an insight in availability of data and gives the opportunity to advise on data-acquisition to provide a consistent dataset for the entire country.

Because of the interactions between surface and subsurface phenomena, mapping of the subsoil in the Netherlands is of paramount importance. In most interactions groundwater is involved either as a raw material, an intermediate between different interests, or as a burden. This has led to intensive mapping of different phenomena related to groundwater and this resulted in the following types of maps:
- relation with agricultural production;
- groundwater map, mainly structural data relevant to groundwater flow;
- groundwater vulnerability to pollutants;
- geohydrological systems and groundwater quality;
- relation to natural vegetation policy and management;
- geohydrological changes and drought effects;
- strategic groundwater use.

None of these maps could have been made without the geological and the soil base maps, which are available at 1:250 000 and 1:50 000 scales. The soil map moreover contains a classification of groundwater level fluctuations as related to soil properties.

Available maps

Although the need for archiving and mapping of groundwater related data was recognized in the beginning of the century actual reconnaissance and mapping activities started in the 1950's. It concerned the relation between water management and crop growth. The result depicts mean summer and winter groundwater levels as well as data on drought sensitivity and degree of salinization. The map is on a 1:200 000 scale and is still a valuable description of the groundwater situation in the period 1952-1956. A more general systematic reconnaissance and mapping started in 1968, which will result in a groundwater map of the Netherlands in 1989. It is on 1:50 000 scale map sheets and each map is accompanied by an explanatory report. Mapped themes are piezometric contours of different aquifers, depth and thickness and hydraulic properties of aquifers and aquicludes. Also the hydrological base and the fresh saline water transition are indicated. Water quality is mainly expressed in chloride content and hardness. The groundwater map gives an overall picture of the hydrogeology of the Netherlands, it gives a good insight for a first approach of regional or local problems and it is a collection point of all geohydrologic data. It has a widespread use. Today environmental pollution is so widespread that a different approach is required which quantifies biochemical and chemical processes as well as physical processes. This has led to a systematic survey of soil characteristics relevant to the behaviour of pollutants. The characteristics of the unsaturated and saturated zones overlying the upper aquifer have been mapped at a scale of 1:400 000 for the entire country (1987). The information was obtained from existing data in archives and reports and from soil and geological maps. The characteristics mapped were: thickness, carbonate, clay, organic matter, cation exchange capacity and travel time of percolating water. The maps can be used to delineate areas susceptible to the leaching of various substances, for example, nitrate, heavy metals and organic pollutants. The quantitative information on the maps allows them to be used in the modelling of groundwater quality.

New developments

Groundwater flow systems can be classified according to their spatial extent into a hierarchical set of, for example, regional, subregional, and local sub-systems. In local flow systems an infiltration area borders on the redischarge area and sub-regional flow systems comprise one or more local flow systems. Regional systems have the greatest extension and comprise several local and sub-regional flow systems.

Within hydrological flow systems, various systems characteristics (water quality, water temperature, etc.) can be distinguished. Analyses of the interrelationships between these features provides information about the spatial extent of flow systems. The insight provided by such a survey of flow systems directly enables the user of the map to estimate the effects of possible interventions (withdrawal of water, rearrangement of drainage, waste disposal, enforcement of protection zones, land use, etc.). It also provides boundary conditions for mathematical modelling of flow and transport to quantify expected effects.

Geohydrogical systems are being mapped on a scale 1:250 000 to provide a general overview in a few years time. About 30% of the area has been mapped to-day. Furthermore a systematic mapping will be pursued in the coming 12 years at a scale of 1:50 000.

A recent development is mapping the supra-regional groundwater flow systems at a scale 1:600 000 to support proposals for national policy with respect to areas of great natural value. At the other end of the scale a mapping initiative will start for the operational management of natural reserves. The response of small areas of groundwater to developments elsewhere has led to the conclusion that for these areas eco-hydrological features should be related to regional groundwater flow systems at a scale of 1:50 000.

In many cases groundwater mapping also requires some basic research before phenomena can be presented in a reliable way. The following gives an example of such a mapping project in the province of Limburg.

In an area or 1500 km^2, about 600 samples were taken of the upper 20 cm layer of the groundwater. These samples were analysed for various macro-nutrients including nitrate, phosphate, potassium and chloride, and also heavy metals. The influence of horizontal groundwater flow was found to be negligible. It has been established that over short distance there is a great variability in the composition of the groundwater. As a result mapping of groundwater quality requires large numbers of samples. But in spite of this spatial variability, statistically significant relationships between groundwater quality and land use and soil factors have been established. By means of these relationships it is now possible to map groundwater quality.

Maps are important as a tool for geoscientists. They are a means of preserving and presenting information and knowledge resulting from tedious reconnaissance studies of specific themes or from combination of different themes, often already well documented, for a specific purpose. They let the scientist give shape to his observations and hypotheses and provide a means of communication in the information chain from observer, interpreter to planners and decision-makers.

For the benefit of groundwater in the Netherlands many mapping operations have been executed or are under way and it is that they will anticipated continue to maintain their importance. None the less, geo-information systems will and already do have a considerable impact on the production and on the use of maps. Certainly the combination of themes to direct information to planning and decision making is enhanced tremendously by the use of geographic information systems. This will result in maps being used in greater quantities, but at the same time become more and more selectively produced for specific purposes from databases throughout the country. Provided data collection and archiving is maintained many of these mapping activities can be executed more efficiently. The Dutch institutes involved in mapping activities have enthusiastically embraced these new opportunities.

Application of remote sensing in hydrology

The role of remote sensing

An integrated approach is essential for modern water management to enable the careful development and control of water systems with regard both to their resource potentials and the interests of society. The complexity and

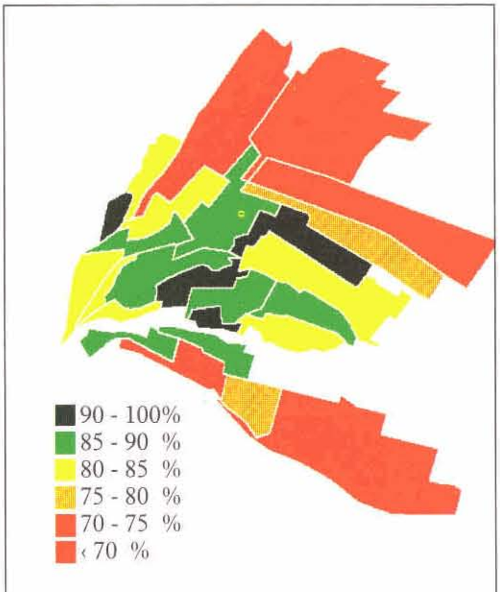


Figure A.18 Percentage of area irrigated for the Rio Tunuyan Irrigation Scheme in Argentina derived from LANDSAT MSS-images taken on 27 February 1985

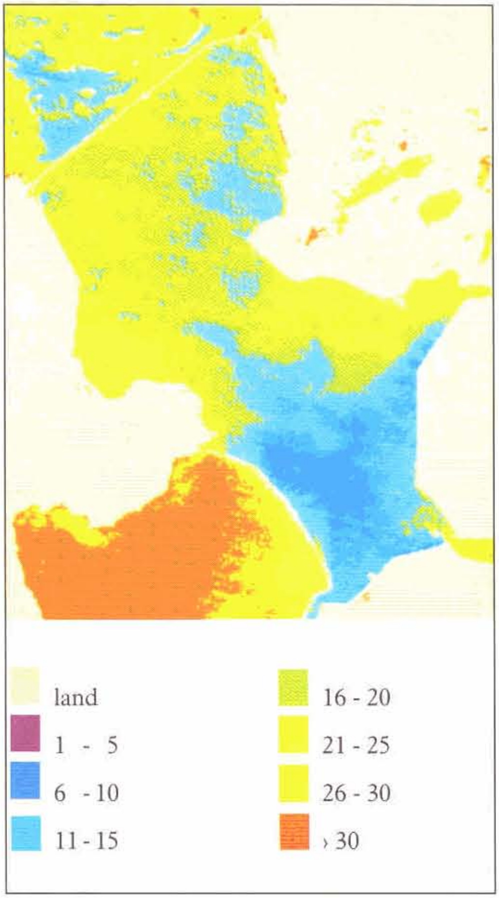


Figure A.19 Map of suspended solids concentration (mg/l) in Lake IJssel as derived from a LANDSAT Thematic Mapper image taken on 5 July 1987

variability of water systems create a great demand for information to secure proper management. Information is required on the processes that occur and on the state of water systems, including the way they are being influenced by human activities. Remote sensing can contribute significantly to the available information. For example, areal patterns of the soil's physical and hydrological conditions can be directly observed and with successive synoptic images, remote sensing provides the opportunity to monitor temporal changes over large areas.

Satellite images are now available both on a global and on a detailed scale. For monitoring purposes weather satellites such as NOAA,

which supply reflection and thermal images with a detail of 1000 m are available on a daily basis. Earth observation satellites like SPOT and LANDSAT Thematic Mapper reflection images with a detail of 10 m to 30 m can also be obtained. However, because of the poor temporal resolution and the frequent cloudy conditions in the Netherlands, only a few images per year are available. For these reasons the use is limited to mapping purposes and monitoring of long term development in water systems. As a result a crop inventory is applied for the whole country based on the interpretation of satellite images.
The first European remote sensing satellite equipped with radar instruments is planned to be launched in the early 1990's. Surface water, flow and wave patterns will be investigated with

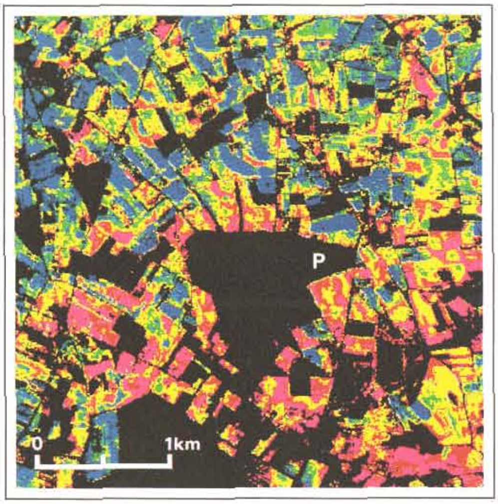
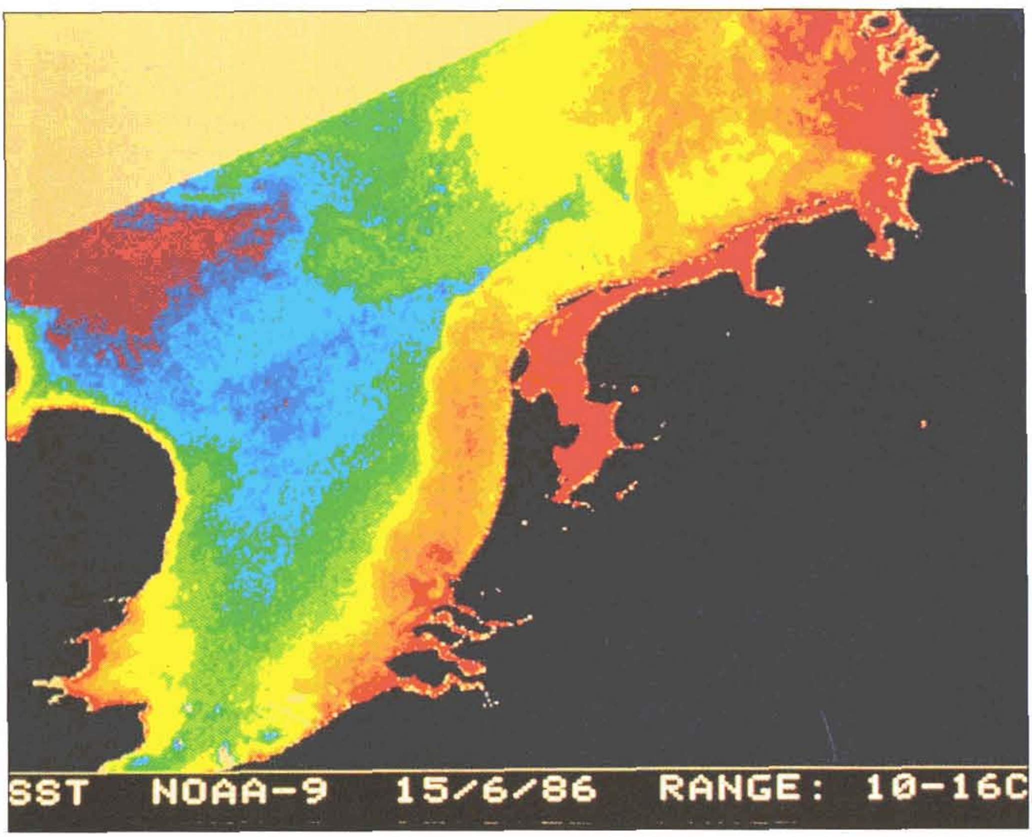


Figure A.21 Evapotranspiration map of a research area near a pumping station (P) from reflectance and heat images of 30 July 1982. Transpiration decreases from blue, green, yellow, red to magenta. Black means unclassified

Figure A.20 Sea surface temperature map of the North Sea processed from a NOAA-weather satellite image acquired at 15 June 1986



these images as well as the possibilities to determine soil moisture conditions.
In the Netherlands different types of satellite systems are used operationally and only detailed thermal images from satellites are missing. As a result methods have been developed in the Netherlands for using remote sensing from aeroplanes monitoring both surface waters and agricultural areas.

Monitoring of surface waters

Remote sensing imagery can be used for environmental monitoring. Thermal infra red techniques are operationally used by the Ministry of Transport and Public Works for detecting illegal discharges. Water pollution observations are frequently carried out over the North Sea using aeroplanes equipped with cameras, a multi-spectral scanner and a side looking airborne radar.
The operational use of satellite imagery is used for investigating water quality and quantity. Areal patterns of water quality parameters such as suspended solids and algae, and information about water movement contribute to the understanding of environmental processes. Remote sensing imagery can also be applied for optimizing monitoring networks.
Figure A.19 illustrates suspended solids of Lake IJssel as derived from LANDSAT Thematic Mapper image taken on 5 July 1987. The inflow of the river IJssel with higher suspended solids concentrations and the lower concentrations in the southern part of the lake provide information on the input, transport and sedimentation of suspended solids and the attached micropollutants (heavy metals and PCB's) in the water system. These concentration maps can be used as input for mathematical models of the water movement and suspended solids transport. The concentrations on the Lake Marken are remarkably higher due to differences in water depth and bottom composition.
Moreover, it has been shown that information on the growth of water plants can be obtained which is a good indicator of the improvement of water quality in shallow lakes.
Thermal images of the NOAA weather-satellite supply information about the sea surface temperature (Fig. A.20) which under clear sky conditions can be provided several times a day. This makes it possible to monitor differences in water temperature and to establish trends in the dispersal patterns of the sea and in the water temperatures, which provides important information for climatic studies. The reflection images of NOAA supplies information on the presence and transport of floating algae layers in eutrophic inland waters.

Monitoring of agricultural crops

A method has been developed to map crop evapotranspiration from digitally derived reflection and thermal images. Remote sensing used in this way provides detailed information about the regional distribution of evapotranspiration on flight days (Fig. A.21). Crop water status can also be analysed applying agrohydrological simulation models. Moreover, geographic information systems enable model calculations to be integrated with existing maps to provide maps of model simulations. Evapotranspiration estimates obtained with remote sensing can be used to verify the simulation results.
Models have the advantage that evolution in time can be described. But they have the limitation that actual field conditions have to be schematized. Remote sensing gives improved spatial information and it was found that important improvements of the hydrological description of an area could be achieved by combining remote sensing with hydrological model simulations.
Remote sensing can also be used to collect information on different aspects of land use. Although this information may not be directly applicable for irrigation management, it has been shown that the mapping of irrigated land with LANDSAT-type satellite data is an accurate and cost-effective approach. Especially in arid areas, such as Argentina, mapping of actually irrigated areas is straightforward. Furthermore the relatively low frequency of cloudy days guarantee a high re-visit frequency. Figure A.18 shows the distribution of irrigated land for the Rio Tunuyan Irrigation Scheme in Argentina. The irrigated area may be assumed to be equal to the cultivated area. The image clearly shows that the water is not uniformly distributed. In general with increasing distance from the irrigation inlet the percentage irrigated acreage decreases. With remote sensing, information about the actual water distribution in irrigation districts can be obtained. A method

currently being developed to evaluate and optimize the water distribution of large irrigation schemes using satellite remote sensing in combination with hydrological modelling.

Geographic information systems and remote sensing

As a result of the successful integration of hydrological models and Geographic Information Systems (GIS) simulation results can be mapped automatically. GIS provide a wide range of opportunities for handling multi-source data. Remote sensing has proved to be a valuable tool for testing models and delivering input to information systems. Of particular importance in this context is the Integrated Land and Watershed Management Information System (ILWIS). The general objective of ILWIS is to contribute to the improvement of the availability and quality of information on which watershed management can be based. The system is tailored for use with microcomputers which are available in most developing countries.

Acknowledgement

A group of specialists, members of the National Committee for IAHS, has prepared the various cases and contributed with enthusiasm to the contents of this annex. Their names are mentioned with gratitude.

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Annex 2

General background information

Population and government

The population of the Netherlands amounted to 14.45 million (January 1985) as against a mere 5.1 million at the turn of the century. Over the past decade the annual natural increase in population averaged 4 per 1000. The present population means an average of 426 people to each square km of land. Almost 50% of the people live in the very densely populated western part of the country, the so-called Randstad. The Netherlands are a constitutional monarchy with a parliamentary system. The Dutch Parliament (States General) comprises of two Houses: the Upper House (75 members) and the Lower House (150 members).
The Netherlands are subdivided into twelve Provinces. The last one (Flevoland) has been founded very recently (1 January 1986) and comprises the reclaimed land of the Lake IJssel. The provinces vary considerable in size and population. The general administration of each province is carried out by a Provincial Council, a Provincial Executive and a Queen's Commissioner.
The third level of government is the local level: the Municipality. All towns and villages are part of one of approximately 740 municipalities (per 1 January 1985). Each municipality has a Council headed by a Burgomaster and Aldermen.
As discussed in Chapter 8 another type of public body is the "Water Board". The water boards are in fact a form of decentralized government. Many of them are predating the settlement of towns and some even go back to the 12th Century. At present around 200 water boards are existing of which 18 are responsible for water quantity and water quality matters. Eight specific boards have been created which are only in charge of water quality matters.
In three cases the responsibility for water quality management rest with the provinces themselves.

Working population

On 1 January 1984 the total working population in the Netherlands amounted to 5.9 million of which 14% was unemployed. Of the total working population almost 170 000 are foreign workers. The number of people working in the various sectors of the economy has drastically changed since 1900 (Fig. A.1). The changes indicated in Figure A.1 are very characteristic for a highly industrialized country. The strong decline in people working in the agricultural sector is evident, just as the shift of emphasis to the service sector.

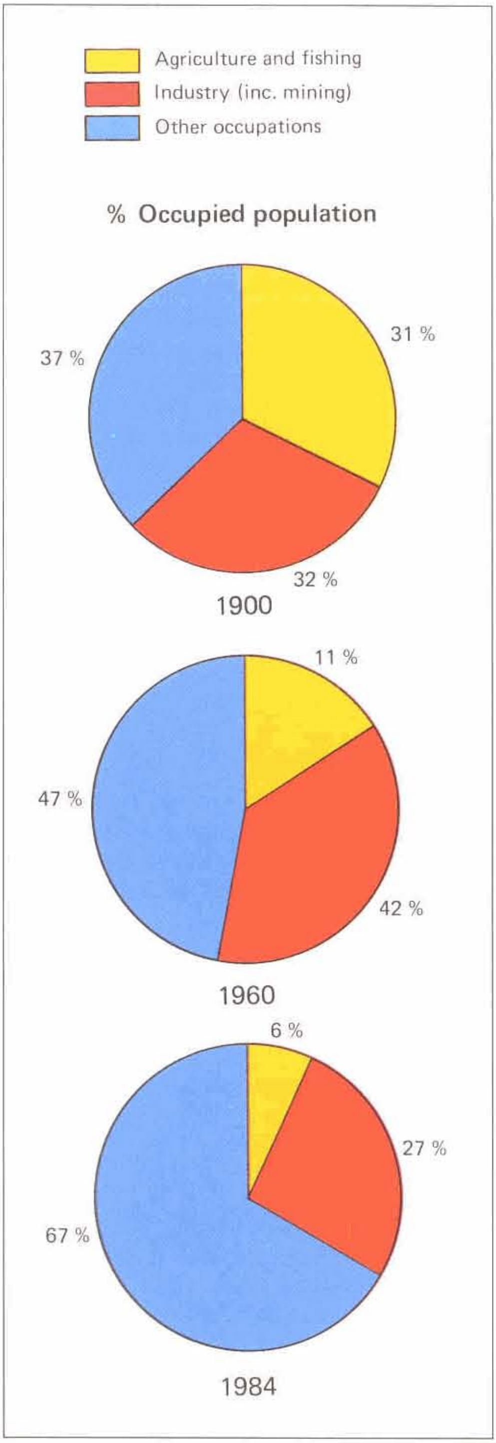

Figure A.1 Percentage of people working in the various sectors of the economy

National income

The national income of the Netherlands amounted in 1984 to just over 317 000 million Dutch guilders. The division of this amount over the various sectors is given in Table A.1. The economy of the Netherlands has a long and pronounced international orientation. The historical interest rise of foreign commerce and industry. It must be stated that the finds of oil and in particular of natural gas have been extremely important for the Dutch economy.

Table A.1 The division of the national income (in Dutch guilders x 10^9) over the various sectors in 1984 (Central Bureau of Statistics)

1	Business sector		288.1
–	agriculture	14.6	
–	industry/raw material	86.5	
–	public utilities, building construction	26.1	
–	trade, traffic and other services	160.9	
2	Government sector		46.3
3	Interest and others		- 17.0
4	National Income (NNP, factor costs)		317.4

Natural gas and oil

In the northern part of the Netherlands, near the village of Slochteren, in 1959 one of world's largest natural gas fields was discovered (estimated total capacity 200 x 10^{10} m^3). The importance of natural gas for the nations energy situation becomes clear from Table A.2.

Table A.2 The Dutch energy consumption in 1963 and 1984

Energy source	Energy consumption (in %) 1963	1984
Coal	44	5
Natural gas	2	54
Oil	54	36
Nuclear	0	4

In 1984 the production of natural gas was around 85 000 million m^3 of which 53% (= 45 000 million m^3) were exported. The value of this gas export amounted to Dfl 16 400 million. In addition to these export earnings a further Dfl 22 000 million can be added, the amount that the Dutch would have had to pay if they did not have their natural gas. The natural gas and oil reserves, divided into proven and unproven categories, are presented in Table A.3.

Table A.3 Reserves of natural gas and oil in 10^{11} m^3 (at 15°C and 1.013 bar abs) as on January 1st 1985

Natural gas	Total	Proven	Unproven
On-shore	19.0	14.3	4.7
Off-shore	2.7	1.2	1.5
Total	21.7	15.5	6.2
Oil			
On-shore	0.4	0.1	0.3
Off-shore	0.2	0.1	0.1
Total	0.6	0.2	0.4

Trade balance

Until about 1970 it was never possible to match the value of the imported goods with that of the exported ones. However, this was transformed by the large export of natural gas from 1970 onwards. In 1984 the value of total imported goods amounted to Dfl 198 000 million, whereas in that year the value of the exported products amounted to Dfl 210 700 million. This results in a trade balance surplus of Dfl 12 700 million. With respect to the export of goods the Dutch economy benefitted greatly from the establishment of the European Community (EC).
In 1984 the export to the EEC-countries amounted to 72% of the total Dutch export, whereas the import from these countries amounted to 53% of the total import.

Table A.4 The value (in Dutch guilders x 10^9) of the exported products of some sectors in 1984 (Central Bureau of Statistics)

Products		Dfl x 10^9	% of total export
1 Metallic		50.7	24
2 Agricultural/ horticultural		49.7	24
- dairy	17.5		
- arable	14.2		
- horticulture	9.9		
- fisheries	1.5		
- others	6.6		
3 Chemical		35.2	17
4 Mineral oil		31.8	15
5 Natural gas		16.4	8

Table A.4 shows the exports of some main sectors. Table A.4 shows that the exports of agricultural/horticultural products accounted for around 24% of total export. Since imports of agricultural/horticultural products amounted to around Dfl 34 500 million the trade balance for these products shows a surplus of Dfl 15 200 million. This figure exceeds the difference between the value of total exports and imports.

Dutch harbours

The Dutch have been merchants for many centuries and trade brought much prosperity to the country. Most famous in this respect is the 17th century, called the Golden Age. For the shipping the availability of good harbour facilities has always been of eminent importance. It is not surprising, therefore, that though the Netherlands are very small they still have the biggest harbour of the world: Rotterdam, the port to Europe. Amsterdam harbour is also of national importance. A summary of the number of ships and their tonnages are given in Table A.5.

Table A.5 Some figures concerning the harbours of Rotterdam and Amsterdam for 1985

Harbour	Number of ships	Tonnage (10^6 tonnes)
Rotterdam	30 000	250
Amsterdam	4 500	29.5

Annex 3

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(valid on 1 April 1989)

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