

3.2 Civil engineering in The Netherlands

3.2.1 History

The colors of *Fig. 437* indicate the area in the Netherlands that would become submerged if there were no flood protection dikes. The flooding area as indicated is supposed to occur during modest river floods (up to 4000 m³/sec at the German/Dutch border) and a normal high tide at sea. However, it was not always like that. In 2000 years that area has increased into the current surface by rising external water levels and falling ground levels (see *Fig. 464*).

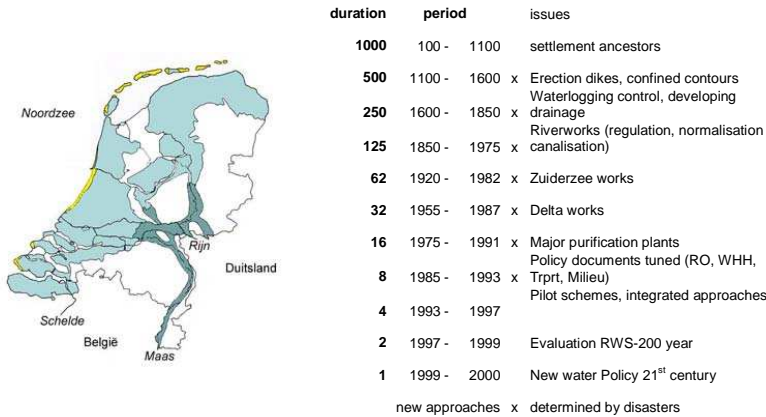


Fig. 437 Potential threads^a

Fig. 438 Reverse half time of the Dutch water management^b

To cope with regular floods Dutch water management started by erecting terps in the first millennium A.D. and dikes in the next 500 years. At that time the dynamic water surface was confined and the next 250 years the emphasis of water management became waterlogging control and drainage of reclaimed land. Then, in a period of 125 years the Dutch regulated, normalised and canalised their rivers. In a continuing half time of water management policy new priorities developed like Zuiderzee, Delta and purification works (see *Fig. 438*). In the last few decades all these continuing efforts were integrated by national policy documents, pilot schemes and evaluation for future safety.

Apart from its threats, water as a medium for trade and transport and as a military barrier for external attacks was also a crucial ally in the development of Dutch independence and perhaps a factor in keeping the nation out of World War I.

Water as military barrier

In the past, the Dutch have created again and again water corridors and water defence systems for the military defence of (parts of) the country. In addition, all major cities developed their own defence system, quite often this is still visible on today's maps of the old cities. In the east and south, huge wild peat areas offered some kind of natural protection against invaders from the east and south east. Where the sub soil contained solid sandy deposits, in other words where realistic chances existed that enemies could penetrate, military fortresses were developed (Nieuwe Schans, Boertange, Coevorden, Grol, Doesburg, Mook, Roermond, etc., see *Fig. 439*) Also along the southern flank of the river area cities developed as military fortresses against invaders from the south (Grave, Den Bosch, Hedel, Willemstad).

Water as primary connection

In parts of the country, through the ages there always have been various options to create water corridors during (threatening) wartime, in particular in north – south direction. These wet corridors were

^a RWS

^b author De Bruin

situated in between major military fortresses. To get these systems activated, a well designed (and maintained!) system of sluices, dikes and locks was developed, in combination with natural water systems that could provide sufficient inundation water during critical periods. Today, the remnants of these provisions are cultural elements in the landscape. Quite often money is spent on renovation and restoration, no longer for military reasons but to safeguard a cultural heritage.

Transport

Paved (or railed) roads in the water saturated soft soil areas in the Netherlands gradually started developing from the middle of the 19th century. Around 1800, the best, safest and quickest way to move from the government buildings in The Hague to the navy harbours in Den Helder and Hellevoetsluis was still taking a horse via the beach! That is a major reason why through the ages all the major waterways in the Netherlands were also used for shipping. Until late in the 20th century, most domestic transport of cargo and passengers was done by ship ('trekvaart', beurtvaart). In fact for all important routes and waterways specific (sailing) vessels were developed. The remains of this fleet are now the backbone of the leisure industry. Today, about 35% of all the cargo transport in the Netherlands is still going via waterways; compared to this figure in other countries this is extremely high.

The daily water management of major waterways as shipping routes is still crucial. Shipping developments on the international Rhine also determine the major nautical developments on Dutch domestic waterways. The historic and today's development of cargo transport on the international Rhine (in other words the economic importance of that river), has not been and is not determined by (fluctuations in) the Dutch economy, but first of all by the German economy. The Rhine is the major hinterland connection of the ARA ports (Amsterdam, Rotterdam, Antwerp), and shipping developments have been coordinated and controlled by the International Central Commission for Navigation on the Rhine (CCNR) since the defeat of Napoleon (1813 Waterloo, Vienna Congress 1815). It is the oldest still functioning international body in the world.

International trade

International trade always has been important for the development of the Netherlands. More in particular sea trade on a global scale. It has also determined the intensive navy orientation of society. It is remarkable that for the protection of the capital (Amsterdam, the old trade centre) the so called 'Stelling van Amsterdam' has developed, while for the military protection of the national government centre (The Hague) only a poorly functioning water corridor was available.



Fig. 439 Water as ally^a

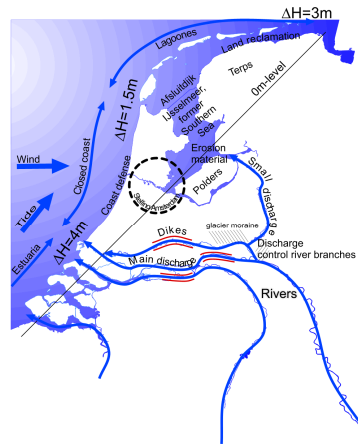


Fig. 440 Water as enemy^{b 88}

3.2.2 The distribution of water

The purpose of the Rhine canalisation (3 weirs in the Lower Rhine/Lek branch, plus some bend cuts in the upper reach of the IJssel river) was to gain more control, during low river discharges (of the Rhine at the German Dutch border), of the fresh water distribution via the two bifurcations (Pannerdensch Kop-PK-, IJsselkop -IJK-) to the rest of the country (see Fig. 441). Extra fresh water to the north is needed during the dry season, because the IJsselmeer (IJssellake) evaporates about one cm a day during a warm summer day, causing too many shallows in the navigation channels in the IJsselmeer after some weeks of a dry period. In addition, such a dry period often occurs in the growing season of crops in the adjacent polders around the IJsselmeer, so at that time an extra need exists for fresh water. More fresh water coming down via the IJssel (being the main feeder of the IJsselmeer) can be achieved by closing the weir at Driel.

^a author Bruin

^b author Bruin



Fig. 441 Weirs directing water northwards and southwards^a

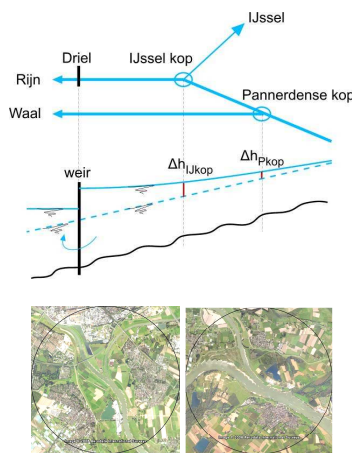


Fig. 442 IJK, PK, Weir of Driel regulating Dutch water distribution^b

The Driel weir is the most important fresh water tap of the country. By lowering (= partly or entirely closing the Lower Rhine) the so called visor gates, a backwater effect is noticeable till upstream Lobith, so also at both bifurcations IJK (more) and PK (less). Because the width of the major channel in the Waal branch is 260 m, and the width of the IJssel major channel only 80 m, the amount of discharge taken from the Lower Rhine will distribute over IJssel and Waal in the order of magnitude 40–60 % / 60-40 %, so as an average 50/50%. However, the lowering of the Driel weir is only possible if first the two other weirs at Hagestein (Lek) and Amerongen (Lower Rhine) are lowered, with the purpose to create sufficient navigable depth in the entire length of the river between IJK and the tidal zone near Rotterdam.⁸⁹

Salt water intrusion

Because the weirs are only closed during dry periods (low discharge of the Rhine at the German-Dutch border), the fresh water discharge coming down the Lek to Rotterdam will be minimised; as a consequence the salt water intrusion from the sea may harm the drinking water inlet east of Rotterdam along that river. This is not acceptable, so there must be compensation to minimise that salt water effect. It can be done by first closing the Haringvliet sluices, in a way that a backwater effect is created up till at least the Moerdijk zone. Then, all the fresh water coming down both the Meuse and Waal rivers will be sent north to Rotterdam and Hook of Holland. This surplus fresh water is sufficient to stop the salt water intrusion as mentioned.⁹⁰

So one can conclude that a strategic water management of the IJsselmeer is determined by the flush regime of the Haringvliet sluices, via the canalisation of the Lower Rhine.

3.2.3 The threat of floods

The major rivers and the sea always have threatened the Dutch society during severe floods. The tidal characteristics and the regime of the river discharges have determined the development of the flood protection systems in the country. Due to large scale drainage and reclamation over a period of many centuries, major parts of the land where peat deposits at the surface and in the subsoil exist(ed), have subsided. This process is still going on as long as the polders are kept dry with artificial means (pumps, see Fig. 470). Due to climate change, expectations are that the sea level will rise and the regime of the major rivers will change (higher peak flows, longer dry periods⁹¹). As a result, the dense populated areas in the western and centre part of the country will further subside and the river levels and sea level will rise (see Fig. 446).

^a author Bruin

^b De Bruin, Google Earth

In the past, dike breaches along the rivers have occurred frequently during floods, more in particular during severe winters when ice jams blocked the major streams. There are also well known examples of severe floods by storm surges from the sea, the last major attack was in 1953. During the last 50 years, strong political policy decisions on safety against flooding have determined how flood control measures (coastal defence systems, dike strengthening along estuaries, lakes and rivers) have been designed and implemented. Due to expected climate change, new standards and approaches for adapted policies are considered or already carried out (Room for the Rivers programme). Safety along the major rivers can only be achieved in concert with measures taken by riparian countries in all river basins situated upstream of the Netherlands.

The present map of the Netherlands is fully determined by human intervention with the purpose of flood control and safety. One has to distinguish the rivers and the coastline.

The rivers

Along the rivers, the regulation, normalisation and sometimes canalisation (Meuse, Lower Rhine), in combination with (confined) flood plain management and dike structures (often but not always with a public road on top) have determined safety; as have the controlled discharge distribution over the various Rhine branches (Waal, Lower Rhine and IJssel) during all stages at two bifurcations (Pannerdenschepolder, PK; IJsselpolder, IJK) and the artificial drains at the downstream end of the rivers (Nieuwe Merwede, Bergse Maas, Keteldiep/Kattendiep. Note: the normalised major channels of the river branches are state owned; however the land in the flood plains is mostly owned by private people, including foreign landownership).

The coast

Along the coastline, one has to distinguish at least four major systems of coast development (see *Fig. 440*):³²

1. estuaries and (clay) island fixation in the south west;
2. a closed sandy coastline in the west (dunes);
3. a fully controlled lagoon in the centre with a primary (Afsluitdijk) and secondary (bunds around reclaimed polders) defence system, and
4. land reclamation in between sandy islands and a clay protection dike in the north (Waddenzee).

There is a littoral drift of the tide along the coast in northerly direction, tidal differences fluctuate between the southwest, the centre and the north east between 5m - 1,5m - 4m (see *Fig. 443*).

Levels and kinds of water

The line on *Fig. 441* between Sluis (Zeeuws Vlaanderen) and Eemshaven (Groningen) is exactly 45 degrees to the north arrow. It is a symbol, representing the 0-line (NAP, normal Amsterdam level, the one and only uniform chart datum in the whole country).

Fig. 443 shows the effort of increasing the elevation of dikes above the sea level along this line after the rare disastrous floods of 1953. They are mainly elevated to 4 metres above regular high tide (different along the coast). It shows also the ground level in Holland, as far as Amsterdam being even lower than the bottom of the IJsselmeer. The blue and red bars left in the drawing show the level of rivers and roads, canals and lakes in the polders. This representation indicates the logic of crossings by tunnels rather than by bridges even if the soil is weak, if dikes have to be crossed and if the densely populated area offers many spatial barriers.

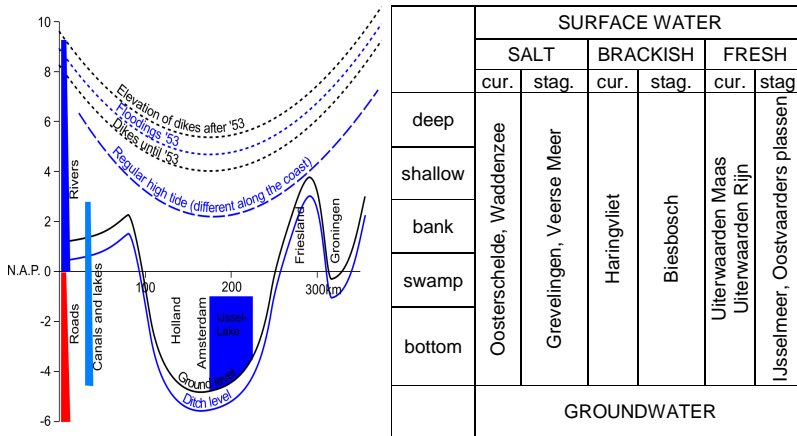


Fig. 443 Levels on the line of Fig. 441^a

Fig. 444 Kinds of water in the Netherlands^b

The many resulting kinds of surface water (deep, shallow, bank, swamp, bottom, salt, brackish, fresh, current, stagnant) in the Netherlands are an important basis for its ecological diversity (see Fig. 444).

Rainfall and seepage

Heavy rainfall and seepage determine also the design criteria of water management measures in the country. In populated and industrialised areas, a severe rainfall with critical intensity must be pumped out completely within a period of 24 to 48 hours.⁹³ This urges the need for adequate pumping and drainage systems in the flat and low situated areas where due to wind effects, proper drainage by gravity is impossible; in addition proper maintenance of these systems is necessary. This can only be achieved by proper supervision and effective enforcement, so also the institutional aspect of water management (legislation, rules and regulations, set up of management authorities, finances, skill and staff, etc.) is a matter of crucial importance.

3.2.4 Risks of flooding

February 1995

At Lobith in February normally a water level of approximately 10m NAP and 3000m³/sec is measured. But in 1995 it was approximately 17m NAP and 12 000m³/sec, the second highest discharge of the century (1925: 13 000m³/sec). Evacuation of 200 000 inhabitants was ordered by the Royal Commissioner of Gelderland Terlouw when floods threatened Betuwe area downstream of Lobith. One million cattle had to be moved. It caused extreme traffic jams on roads the like of which had never been envisaged. The dikes barely held out, becoming wetter and wetter.⁹⁴

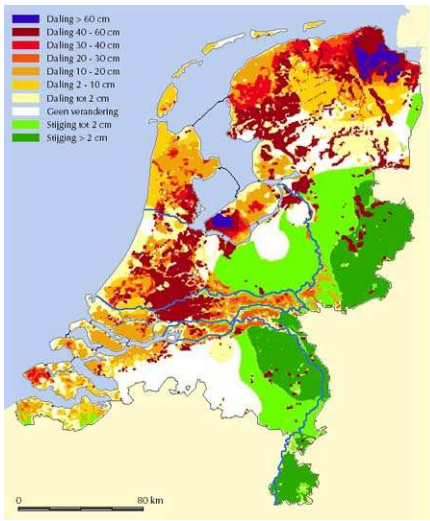
Active debate on safety

Afterwards, the real threat of inland floods raised public awareness and the need to make plans to increase safety.^c If the present state of inland dikes and other hydraulic circumstances is not changed, we apparently have to expect threats of a disaster like 1995 twice a century (a recurrence time of 50 years).

^a author Bruin

^b author Bruin

^c <http://www.ruimtevoorderivier.nl/upload/WAAL-MAATREGELLENBOEK.pdf>



Source:

Fig. 445 Subsidence expected by 2050^a

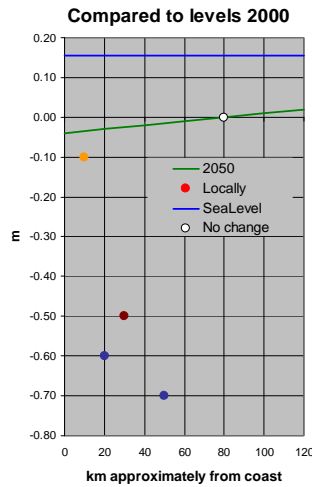


Fig. 446 Sealevel rise and subsidence expected by 2050

But the hydrological circumstances change. Perhaps we should expect more rain in winter (less in summer) as a result of climate change. Germany and Switzerland have drained their meadows so much, that any rainfall upstream reaches the river Rhine faster than ever. Moreover, the west of the Netherlands faces a general subsidence of at least -3cm until 2050 (locally -70cm, see Fig. 445).⁹⁵ Increasing the height of dikes along the rivers is necessary, but it does not solve the question how to drain the discharge into the sea while its level rises through climate change (15 cm by 2050?, see Fig. 446).

Normal distribution of maximal discharges

Looking at the average yearly maximal discharges^b of past years (see the 98 years in Fig. 447) you can calculate their average maximum discharge (6.6454m³/sec) and their standard deviation (2.1408m³/sec) to draw a 'normal distribution' based solely on these two numbers (see Fig. 448). From that normal probability distribution you can extrapolate the probability per class of 1000m³/sec wide (see Fig. 449).

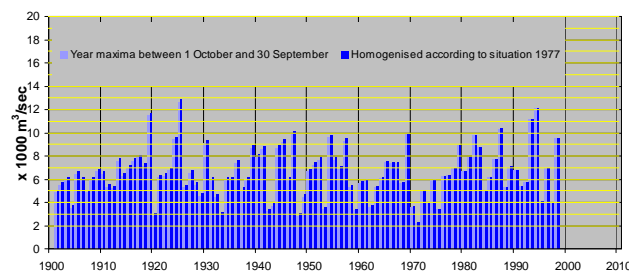


Fig. 447 Extreme discharges of the river Rhine per year

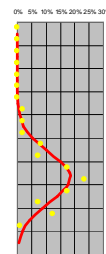


Fig. 448 Probability

^a RWS

^b http://www.rijkswaterstaat.nl/rws/riza/home/publicaties/rapporten/2002/rr_2002_012.pdf

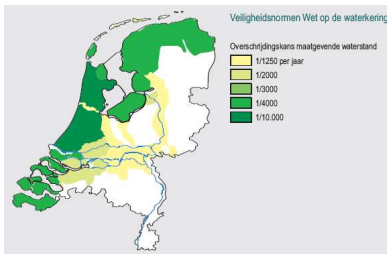
m ³ /sec year maximum measured in 98 years		m ³ /sec class	probability/year		Year/probability (recurrence time)	
average	6 645		↻			
standard deviation	2 141		↻			
		>1 000<2 000	0.58%	once in	174	year
smallest observed	2 280	>2 000<3 000	1.77%	once in	57	year
		>3 000<4 000	4.37%	once in	23	year
		>4 000<5 000	8.68%	once in	12	year
		>5 000<6 000	13.87%	once in	7	year
average	6 645	>6 000<7 000	17.81%	once in	6	year
		>7 000<8 000	18.38%	once in	5	year
		>8 000<9 000	15.25%	once in	7	year
		>9 000<10 000	10.18%	once in	10	year
		>10 000<11 000	5.46%	once in	18	year
		>11 000<12 000	2.35%	once in	42	year
largest observed	12 849	>12 000<13 000	0.82%	once in	122	year
		>13 000<14 000	0.23%	once in	439	year
		>14 000<15 000	0.05%	once in	1,961	year
		>15 000<16 000	0.01%	once in	10,881	year
		>16 000<17 000	0.00%	once in	75,115	year
		>17 000<18 000	0.00%	once in	644,950	year
		>18 000<19 000	0.00%	once in	6,887,859	year
		>19 000<20 000	0.00%	once in	91,495,720	year

Fig. 449 Normal probabilities per discharge class of the river Rhine

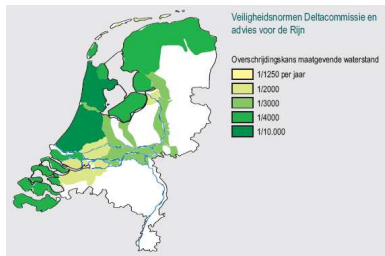
However, that is only a very first approach, because the formula for an asymmetrical distribution (see Fig. 367) or a distribution otherwise different from the normal distribution may fit the data better. The percentages are represented less precisely and eloquently than their reciprocal value: the number of years you can expect between two occurrences of that class (recurrence time). That measure has political value.

Risk acceptance

The Parliament of the Netherlands once decided to accept 1 casualty per million inhabitants per year caused by environmental disasters (accepted risk). So, the number of casualties per class of discharge causing floods has to be calculated to plan the measures to meet the accepted risk of that rare discharge. Which area is flooded by which discharge, and how many people live there? Many studies have been executed to get answers on that question. They make clear that 1 casualty per million inhabitants per year would lead to unacceptable measures producing other kinds of risks. So, the Parliament decided in 1960 to accept the higher risk of a disastrous flooding of rivers once in 1250 years.⁹⁶ In other areas surrounded by dikes (dijkkringen) that risk acceptance is lower or higher according to their economic value (see Fig. 450).



Source:
 Fig. 450 Current safety standards for floods (MNP, 2004)



Source:
 Fig. 451^a Proposed changes of safety standards (MNP, 2004)

However the 'human and economic value' has increased substantially compared to the costs of water safety management. So, these safety standards are in discussion (see Fig. 451).

Calculating and extrapolating recurrence time directly from data

If you number the discharges Q from high to low (rank number r), in 98+1 years of experience the first largest maximal discharge has a recurrence time of 99/1 year, the second (including the first!) 99/2 and so on (see Fig. 452).

year	m^3/sec	rank	recurrence time
	Q	r	$99/r$
1901	5 058	77	1.3
1902	5 715	68	1.5
1903	6 081	60	1.7
1904	3 731	89	1.1
1905	6 697	44	2.3
1906	6 121	57	1.7
1907	5 058	77	1.3
1908	6 101	58	1.7
...
1925	12 849	1	99.0
...
1992	5 758	65	1.5
1993	11 100	4	24.8
1994	12 060	2	49.5
1995	4 112	84	1.2
1996	7 004	38	2.6
1997	3 912	87	1.1
1998	9 487	11	9.0

Fig. 452 Ranking maximum discharge per year, calculating recurrence time

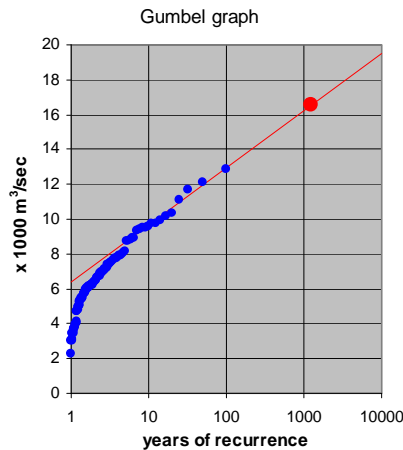


Fig. 453 A Gumbel graph of Fig. 452

If you plot them in a graph with a logarithmic x-axis (Gumbel graph⁹⁷, see Fig. 453) you can extrapolate the higher discharges to be expected roughly by a straight line.^b Fig. 453 shows a discharge of approximately 16 500 m^3/sec recurring every 1250 years with a big spot. So, for any river you can indicate every observation y on that graph if you know the last time that level was reached (x years ago)^c. Nearly any kind of theoretical probability distribution (like the normal one on page 212) will also produce a nearly straight line for the higher levels in the Gumbel graph. That method is used for many kinds of natural disasters like earth quakes and eruptions of volcanoes.

^a <http://www.rivm.nl/bibliotheek/rapporten/500799002.html>

^b http://www.humboldt.edu/~geodept/geology531/531_handouts/equations_of_graphs.pdf

^c Download Gumble paper from <http://geolab.seweb.uci.edu/graphing.phtml>

However, the slope 's' and elevation 'e' of the straight line chosen have great effect. In Fig. 453 a line with formula $Q(r) = s \cdot \ln(r) + b \text{ m}^3/\text{sec}$ was chosen, where $s = 1.43$ and $e = 6.36$.^a

3.2.5 Measures to avoid floods

Inundation?

One of the proposed measures is, to inundate indicated polders preventively in case of emergency. But a 1m deep polder of 1 km^2 ($1\,000\,000 \text{ m}^3$) would store $12\,000 \text{ m}^3/\text{sec}$ water only for 83 seconds at least if it is not sloping. In case of sloping you should half that capacity. If you would like to store $16\,000 \text{ m}^3/\text{sec}$ during a week to be safe for many centuries because you cannot discharge that amount into the sea because of sea level rising after these centuries, you need $10\,000 \text{ km}^2$ (a quarter of the Netherlands). However, you can reduce the needed storage because you still can discharge into the sea, be it at low tide or by huge pumps. But this simple and much too rough calculation shows at least the dimensions of the problem.

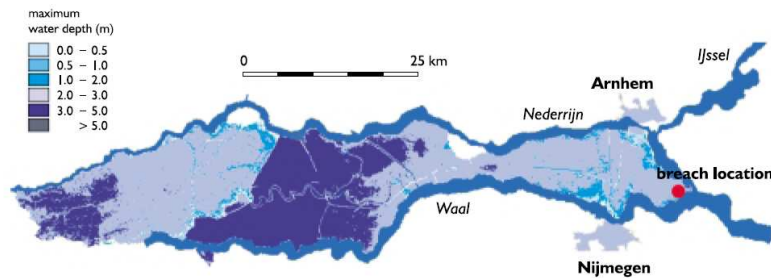


Fig. 454 Maximum water depth during a flooding in Betuwe along the Rhine after a dike breach and a peak discharge of $18.000 \text{ m}^3/\text{s}$ ^b

Other measures

So, construction of retention basins or more general widening of the riverbed in the Netherlands solely cannot be a substantial solution to avoid rare flooding in a river system. Dikes along the rivers have to be heightened, but which height is enough? Deepening the river (filled up quickly with sediment) or making the dikes higher increases the capacity to discharge, but moves the problem to the west where more people live. So, retention in the Rhine basin upstream has to increase to avoid extreme situations downstream. This is discussed by the international Rijncommissie Koblenz.

^a <http://team.bk.tudelft.nl/> > publications 2006 Hydrology.xls

^b <http://www.ncr-web.org/downloads/NCR18nl-2002.pdf>

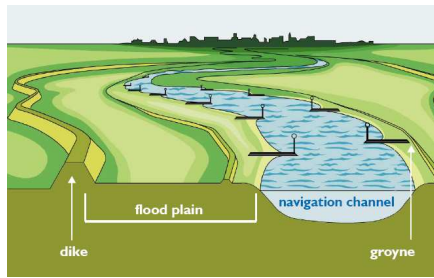


Fig. 455 Schematic representation of a low land river^a

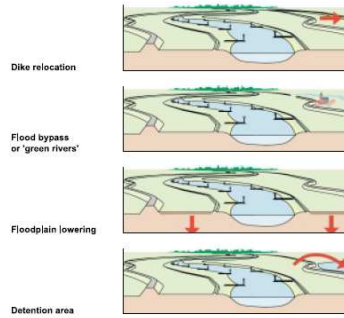


Fig. 456 Measures improving Rhine discharge^b

How to design for floods?

To be prepared for floods a landscape will have to be designed mainly as a natural area (see Fig. 457).

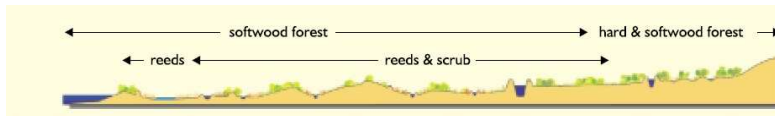


Fig. 457 Anticipated vegetation structure and land use along the Dutch Rhine as a 'green river'^c

Room for the river

On 19 December 2006 the Dutch Parliament accepted a Spatial Planning Key Decision (SPKD, in Dutch: Planologische Kernbeslissing PKB) concerning a series of measures along the rivers known as 'Room for the river' (see Fig. 458). However, the final set of measures should be determined by commitment of local stakeholders and administrators. To get that commitment Delft Hydraulics has developed a game to determine the effects of any single measure in solving the problem^d.

^a <http://www.ncr-web.org/downloads/NCR18nl-2002.pdf>

^b <http://www.ncr-web.org/downloads/NCR18nl-2002.pdf>

^c <http://www.ncr-web.org/downloads/NCR18nl-2002.pdf>

^d RWS download from <http://www.wldelft.nl/soft/blokkendoos/>

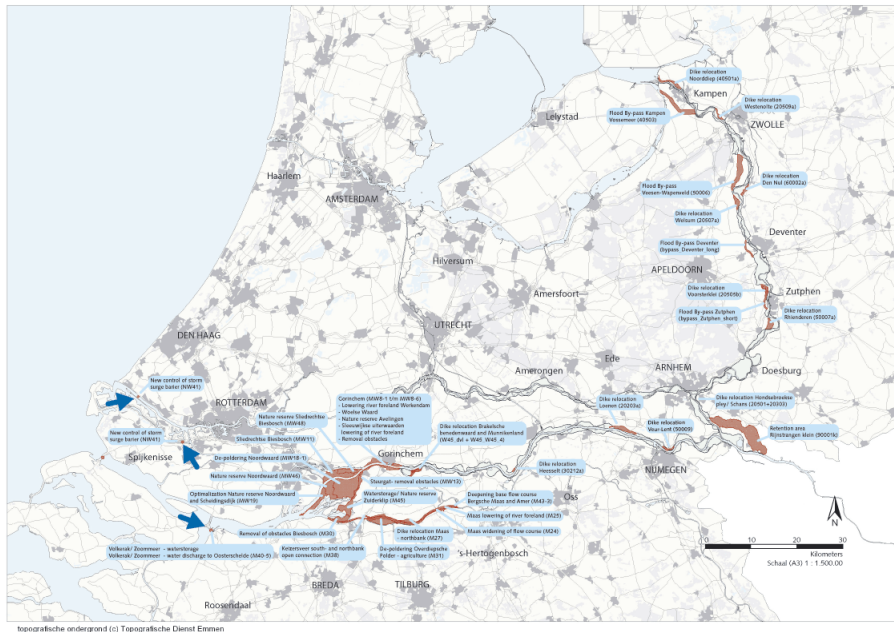


Fig. 458 A series of measures known as ‘Room for the river’^a

3.2.6 Coastal protection

Disasters stimulating major civil engineering works

As shown in the sketch map of the Netherlands (see Fig. 440), there are various major coast forms, differing fundamentally. For the design, strengthening and maintenance of the coastal defence, all these major forms need continuously specific tailor made attention. A universal fact is that disasters are needed to make progress. Also in coastal water management, tragic disasters have determined human intervention in developing the Dutch coast line. One can refer to the big flood in the southern part of the former Zuiderzee in 1916, when severe flooding occurred causing nearly 20 deaths and huge damage; this disaster accelerated the political approval of starting the Zuiderzeewerken (Zuiderzee works) designed by Lely. And of course the storm surge on February 1st, 1953, which initiated the Deltawerken (Deltaworks).

History

In the past, coastal and river works were done by trial and error and on a relatively small scale. If the works that needed to be done were simply too big and complicated, land was given up (again). In those days, coastal engineering was more or less a matter of “If we cannot do what we want, we will do what we can.”. Apart from not having proper large tools, current knowledge and practical experience were not enough to justify efforts in coastal development on any sort of large scale. Fundamental coastal research and model investigations were only developed in the Netherlands from the early 1930s. At that time, three major civil engineering works were developed, i.e. the Afsluitdijk (Enclosure dike, whereby the ‘Zuiderzee’ was renamed the ‘IJsselmeer’), the big lock for seafaring vessels at IJmuiden at the end of the Noordzeekanaal (North Sea Canal) and the completion of the Maaswerken (Meuse works; Julianakanaal locks, with the biggest head in the country). Till then, water related research for Dutch clients was often done abroad, for example in Karlsruhe (Rehbock laboratory).

^a <http://www.ruimtevoorderivier.nl/>

Zuiderzeewerken and Afsluitdijk

The preparations and design for the Zuiderzeewerken in the 1920s urged the need for developing a good mathematical basis for proper tidal computations, to be able to predict with sufficient accuracy changes in water levels along the coast of the Wadden Sea after the closure of the Afsluitdijk. In this respect in particular one name must be mentioned: Lorentz. He developed modern tidal calculations, needed to estimate the impact of the Zuiderzee works (Afsluitdijk) on the tidal regime along the northern Dutch coastline. In fact, one can conclude even after 75 years that the sandy bottom of the Wadden Sea has still not reached a new equilibrium since the closure in 1932, due to the severe changes in the tidal movements as introduced by human intervention at that time.

3.2.7 The Delta project

For all major infrastructure, political approval is necessary by means of a special law being adopted by Parliament. Such a law not only describes the need for the work itself, but also the financing and how institutions are required for design and implementation. The Delta Act was adopted in 1956, three years after the February '53 surge. At the time, repair to the damage and building of new structures was already going full speed ahead. So in fact the financing of those efforts had not yet been approved by Parliament till 1956. The country was in a sense at war, so military means were accepted. For nearly 25 years (in the period 1953 – 1977), the execution of the solid dams in the south west was never a real political question: the need for implementation was simply a political fact because 'safety first' was the guiding motive after the disaster in '53 when about 1850 people were killed. Only in the mid-seventies, when the last episode of the Deltaworks scheme started with the closure of the Oosterschelde (Eastern Scheldt), socio economic and environmental changes on a national scale prompted the need for a complete revision of the engineering approach to this major work (*Fig. 459*) showing many innovative coastal constructions.

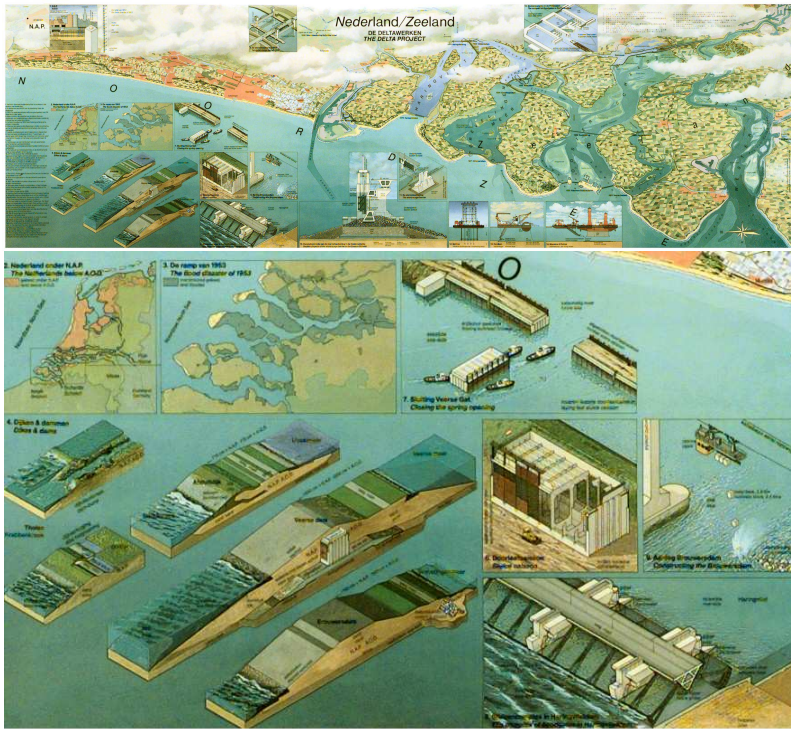


Fig. 459 Delta project^a

A variety of interventions

It is remarkable to notice the huge level of human intervention since 1953, needed to close the estuaries in the south west. As the crow flies over a distance of about 100 km between Hook of Holland and Cadzand/Belgian border, 9 different ways have been used for closing off tidal creeks and estuaries, involving (systems of) primary dams (years as mentioned indicate year of commissioning). From north to south they are: the Nieuwe Waterweg (floating movable barrier, 1998), Brielse Maas (sand supply, 1952), Haringvliet (sluices, dam and by passing lock, 1970), Brouwersdam (caissons and cable, 1968), Oosterschelde (open barrier, 1986), Veerse Gat (caissons, 1961), Westerschelde (open estuary, dike strengthening, 1985), Braakman (sand supply, 1951), and Zwin (gradually closed by natural phenomena).

In addition there are 6 other solutions for the closure of so called secondary dams (some of them located on a former tidal slack) in the Deltaworks scheme, for example the Hollandse IJssel barrier (a main steel gate and a second one just for safety reasons in case the first one has a failure, 1956), the Volkerakdam (caissons plus major locks, and sluices (1969), Grevelingen (cable, minimising the tidal volume in the Brouwershavense Gat before closure (1961), Krammerdam (major locks with a sophisticated salt/fresh water control system, 1982), Markiezaatdam (compartment dam of clay and sand with a lock, to minimise the tidal volume at the Oosterschelde barrier and to control water quality in the Scheldt-Rhine canal, around 1980), Zandkreekdam (sand supply, minimising the tidal volume in the Veerse Gat before closure, 1960). To complete the variety of closure works in this part of the Netherlands, one must also mention the Sloedam and the Kreekrakdam, both needed for the railway connection to Vlissingen (clay and sand dams, 1870).

Funding

Considering all this, in the 20th century the Dutch have reached apparently a point that can now be characterised as 'we can do what we want'. Such a huge and costly scheme could only be

^a Hettema and Horneijer, 1986

implemented because the Dutch society was prepared to allocate the necessary funds from its own resources, so political support remained consistently positive. On the other hand: if a country in the Third World were to ask a donor organisation (for example the World Bank) to finance a closure scheme in a complicated tidal area with at least ten solutions, this would never be accepted. Such an investment for the safety of only 200,000 inhabitants behind the structures is according to present standards of international donor organisations simply NOT considered as feasible (!).

Note that in 1990, Rijkswaterstaat was awarded the Maaskant Prize for the Deltaworks, in particular for the way the whole project is flexible in its spatial planning and technical set up, and for the way it has proven to be useful also for new sectors developed after the period of design and execution, for example leisure and environment. For more general information on these works, see the jury report.

3.2.8 The central coast line

The centre coast line of the Netherlands between Hook of Holland and Den Helder can be characterised by a system of sandy dunes. Because of the lateral drift in northerly direction along the coast, there is some continuous ongoing erosion of the sandy coastline (see Fig. 460). The effect over time is visible at the Hondsbosse Zeewering, where the original tow of the revetments at the seaside was constructed (stone construction, 1875) in line with the low water line on the beach in those days. Today, the low water coastline has moved over about 70 m in easterly direction.

Sand transport

In 1991, Parliament adopted a coastal defence law, giving the green light for regular sand supply (beach nourishment) to maintain the position of the low water line as it was in 1991. Since then, year after year, at some places along the entire coast, nourishment works are carried out outside the tourist season. Like the closure of the IJsselmeer by the 30km Afsluitdijk in 1932 this major project of the fifties caused changes of yearly natural sand transport in the North Sea and Wadden Sea. The sand moved mainly from the inland waters as growing islands in front of these works. To stabilise protruding beaches and islands, large amounts of sand from the sea had to be added artificially to these beaches (see Fig. 461).

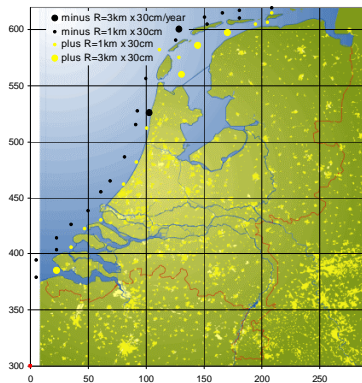


Fig. 460 Natural yearly sand transport^a

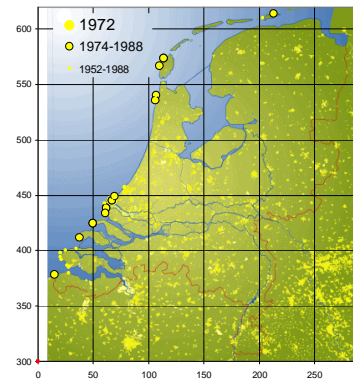


Fig. 461 Artificial incidental sand supply^b

Fresh water in dunes

Over their entire length, the sandy dunes are important for building up and maintaining a 'fresh water bubble' in the sub soil, floating on the salt groundwater underneath. This fresh water system is an extra (groundwater) protection against salt intrusion in critical areas behind the dunes, for example the Westland. In many cases, the fresh water volume in the dunes is artificially kept above certain levels for drinking water supplies in the west. The inlet water originates from the major rivers in the country, Rhine and Meuse, and is pumped through pipelines.

^a After: Waterman, 1992

^b After: Waterman, 1992

A special development is de Kerf, west of Schoorl (Noord-Holland). There, in the late nineties, the primary dune ridge was artificially cut to allow the penetration of salt water during rather high tides (about twice a year). The environmental development and habitat have been carefully studied and followed by many institutions since then.

The Afsluitdijk

The Afsluitdijk is presently being renovated, to meet the recent standards for flood protection and safety/reliability. Also the capacity of the sluices may be increased shortly. Sluices, bridges across the locks bypassing the sluices, and dike (alignment) had special design criteria for military reasons. They really have worked: in 1940, Kornwerderzand was the only place in Holland where the invaders could not get through. In the original design of the dam, space was reserved for the construction of a rail track as well. A deep cut for the planned track is still visible on the former island of Wieringen, alongside the motorway to Den Helder. The excavated clay from that deep cut has been used for the creation of the last refuge hill (terp) built in the Netherlands to date; at Wieringerwerf in the Wieringermeer. Indeed it was used by some locals after the German army blew up the surrounding polder dike at the end of WWII. Today, on top of that 'terp' there is a public swimming pool (again the world upside down).

3.2.9 The northern defence system

The sea defence system in the north is rather complicated, because of the sandy islands, the Wadden Sea with all its environmental and morphological extremes, the so called old 'Landaanwinningswerken' and the strengthened long clay sea defence dike between the Afsluitdijk and the Dollard. For the purpose of this chapter, the most interesting aspects are the auxiliaries in the sea coastal defence system, for example the ferry terminals, harbour law outs and terminal structures, the various breakwaters (Harlingen, Delfzijl), navigational aid systems, and the leisure facilities. They all can be used as informative and illustrative examples when designing a specific issue in relation to coastal engineering aspects. Whatever further intervention will be needed in the near future, the fact is that for the 21st century the situation of designing and constructing large scale works can now be described as 'are we still allowed to create what we can?'.

The historical value of the northern islands

Finally, a last aspect when it comes to coastal engineering, the logistics of the execution and implementation of impressive works. It deals with the supply of material in isolated and so far undeveloped areas. This can be illustrated with two examples from the past. For more modern and contemporary equivalents, everyone can use their common sense.

First, when visiting the Wadden islands in the north, many brick houses can be seen that have been built through the ages. This is remarkable, because there have never been brickyards on the islands. Even some lighthouses, like the famous Brandaris (Terschelling), were constructed exclusively with bricks. One may wonder where originally all those bricks came from.

This has everything to do with the flourishing Hanseatic League in the past. Wooden sailing vessels came from the Rhine basin, heading for the Hansa cities in the north and beyond (Baltic Sea). Bricks were transported by ship from brick yards in the river area (flood plain), and handled manually. In those days, where no machinery existed, this was done stone by stone by so called head loading. More astonishingly, each stone of the Brandaris light house must have been handled this way at least six times (or most probably even more), when being moved between the brick yard somewhere in the flood plain to its final place in the structure. En route they were brought on rather small vessels over dangerous and difficult waters.

Second, a similar development can be seen on a larger scale, for distant overseas destinations. The VOC vessels in the 17th-18th century took bricks as ballast on their journey from Holland to the Far East, for example to present-day Jakarta. When visiting the city today, one can still see the typical bricks and tiles of Dutch origin, used in the construction of buildings there.

Design with nature

To stimulate local inland movement of sand and clay from the sea (stopped after these 'hard' defence works) the policy of coastal defence has changed gradually into a 'design with nature' approach.



Fig. 462 Sluffer on the isle of Texel^a

This involves opening up some 'hard' defences where it is safe (sluffers) allowing the sea to come in, bringing sand and clay into these calm inland waters causing the development of beautiful dynamic natural areas calling the original state of the Netherlands to mind.

3.2.10 Polders

3.2.11 Need of drainage and flood control

History

Wetland areas may need drainage to be used for living and agriculture. The draining was started to obtain more space for these activities. The first method of draining was with the help of open ditches and trenches. The water was drained by sluices on lower lying waterways like rivers or at low tide at the sea (see Fig. 463). Later when the difference in height of water between the drainage area and the river or sea became too small or even negative, the land was drained by pumps (see Fig. 464 and Fig. 470).

A polder is a piece of land that forms a hydrographical entity. In low lying areas a polder is surrounded by embankments or dikes. Even a lake can be transformed into land (see Fig. 463). This reclamation is also called a polder because the groundwater level is managed in an artificial manner. Such land reclamations are always situated below the surrounding water level.

^a Google Earth

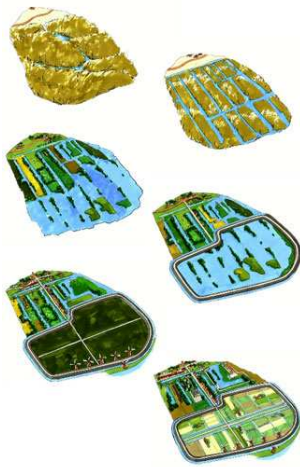


Fig. 463 A short history of polders^a

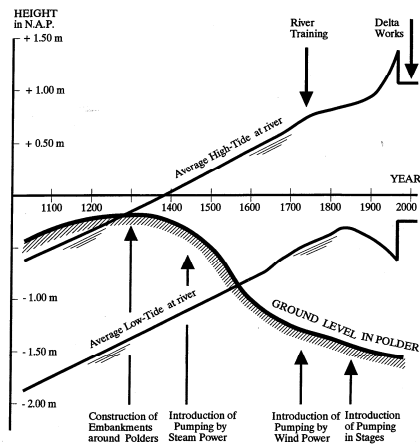


Fig. 464 Rising outside water levels and dropping ground levels^b

Draining an area starts a process of changes in the soil. The ground level will settle and drop depending on the type of soil. Peat soil will actually totally disappear by chemical processes and the ground level will be lowered by the equivalent of the thickness of the peat layer. Also the introduction of better methods and pumps will lower the groundlevel (see Fig. 464).

Desired groundwater levels

It is obvious that since the groundwater level is managed artificially, there are several desirable groundwater levels. The depth of the groundwater level depends on the activity that will take place in that area and the type of soil. For grassland a high groundwater level is no problem for growing, but having cattle on that land will be more problematical as the cattle will destroy the grass by walking on it and no food will be left. For crops the depth of the groundwater level is dependent on the type of crop. Grasslands may be wetter, dryland crops should be dryer than 1m below terrain (Fig. 465)

^a Source unknown

^b Ankum, 2003; page 71

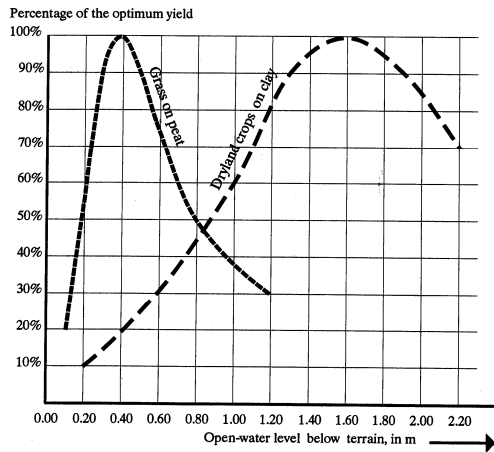


Fig. 465 Crop yields for different open water levels^a

Urban areas

For urban areas the groundwater level is kept at approximately 1m below ground level for different reasons such as foundations and wet crawl spaces. Also the construction of cables and pipes in the streets is easier under dry circumstances. (see Fig. 466).



Fig. 466 Flooding of a canal in Delft^b

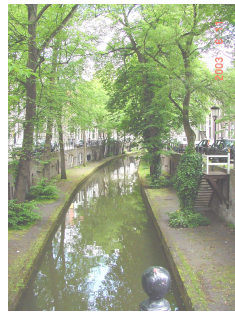


Fig. 467 Deep canal in Utrecht

Urban areas need dry crawl spaces to keep unhealthy moist out of the buildings but they need wet foundations as long as they are made of wood. Groundwaterlevel is often recognisable from open water in the area. In higher parts of the Netherlands like in Utrecht canals show a level of several metres below ground level (see Fig. 467).

The distribution of polders worldwide

Lowlands with drainage and flood control problems cover nearly 1 million km² all over the world (Fig. 468) and nearly half the world population lives there because of water shortages elsewhere (RWS (1998).

x1000 km2	1 crop	2 crops	3 crops	Total
North America	170	210	30	400
Centra America		20	190	210
South America	60	290	1210	1560
Europe	830	50		880

^a Ankum, 2003; page 53

^b Paul van Eijk

Africa		300	1620	1920
South Asia	10	460	580	1050
North and Central Asia	1650	520	20	2190
South-East Africa			530	530
Australia		310	120	430
				9170

Fig. 468 Area of lowlands with drainage and flood control problems^a

3.2.12 Artificial drainage

Inhabited or agricultural areas below high tide river or sea level (polders) have to be drained by one way sluices using sea tides or pumping stations (see Fig. 470, Fig. 473).

Fig. 469 is the oldest known example of draining by one way sluices at low tide dating from the 11th century.



Fig. 469 The oldest one way sluice found in the Netherlands and its modern principle^b

^a Ankum, 2003, page 2

^b Ankum, 2003, page 68 and 38

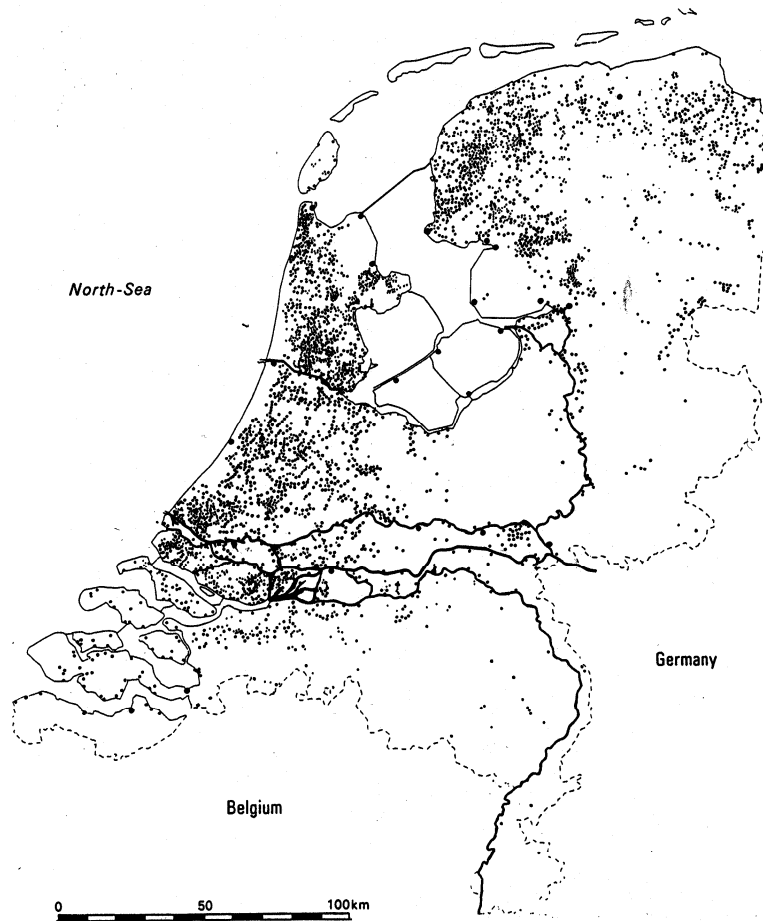


Fig. 470 Pumping stations in the Netherlands^a

One way sluices lose their purpose when average sea and river levels rise and ground level drops mainly because of the subsidence of peat polders (Fig. 464). Drying peat oxidates and disappears and so the ground level of the polder will drop below river or sea level.

The area is divided in smaller entities or compartments that are surrounded by belt canals (boezemkanalen), protected by dikes and internally drained by races (tochten), main ditches (weteringen), ditches (sloten), trenches (greppels), and pipe drains. As the system of outlet canals(boezemkanalen) transports the water from the land to the river or the sea and they are all connected with each other it is also possible to use these waterways for shipping. The area is made accessible for shipping traffic by locks.

^a Ankum, 2003, page 78

Compartments

Fig. 471 shows the belt system of Delfland and the compartments. Each compartment has its own sluice or pump and outlet canal or 'boezem'.

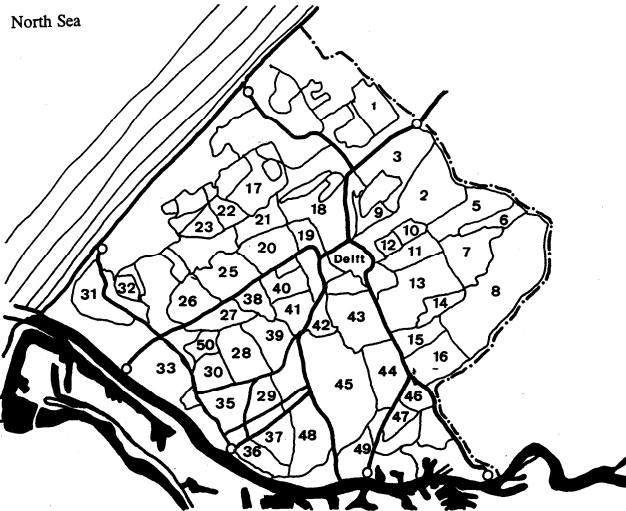


Fig. 471 The belt ('boezem') system of Delfland^a

Methods of impoldering or pumping step by step

The reclamation and drainage of the polders is done by pumps. The pumps are driven by wind, steam or electricity depending the technical knowledge of the time. The methods used depend on the depth of the polder. Draining marshland is often done by one step of pumping or even by a one way sluice when the land is adjacent to a tidal river or the sea. But after settling of the soil in the course of time it can be necessary to use more steps for pumping. Especially when the only force to drive the pumps was by wind, rows of windmills were used for draining the polder. The most famous row of windmills in the Netherlands are those of Kinderdijk in Zuid Holland.

The methods used for draining polders with different altitudes are pumping at once from the deepest part using gravity by collecting first the water from the deepest level or draining step by step compartments separated by dikes and weirs saving potential energy (Fig. 473).

^a Ankum, 2003; page 62

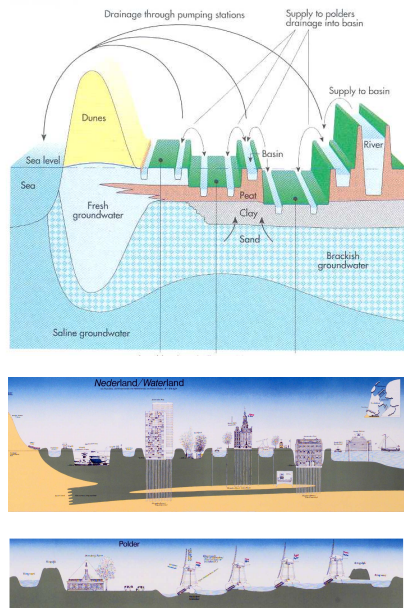


Fig. 472 Lowland system^a

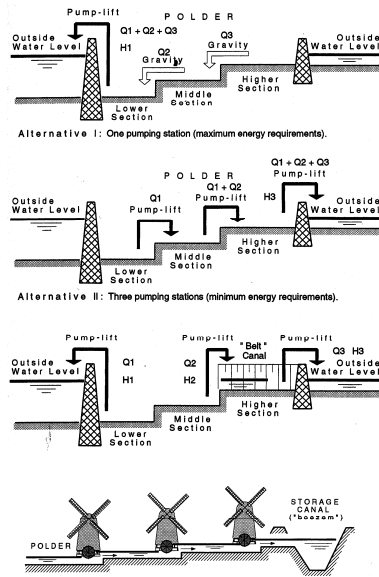


Fig. 473 Drainage by one to three pumping stations, in earlier times by a 'row of windmills' ('molengang')^b

^a Huisman, Cramer et al., 1998 page 36 ; Veer
^b Ankum, 2003; page 76 and 55

3.2.13 Configuration and drainage patterns of polders

Polders are optimally drained by a regular pattern of ditches (see Fig. 474, Fig. 475).

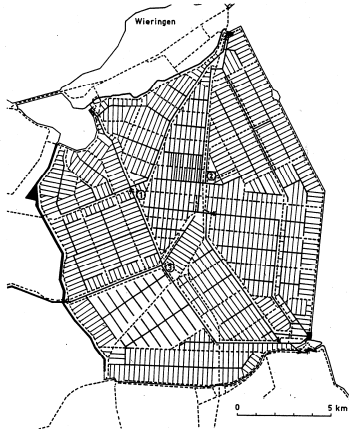


Fig. 474 Wieringermeer polder^a

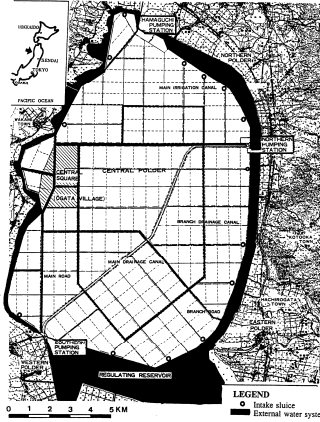


Fig. 475 Hachiro Gata Polder in Japan^b

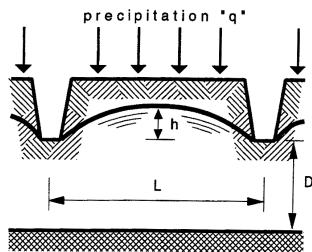


Fig. 476 Variables determining distance L between trenches^c

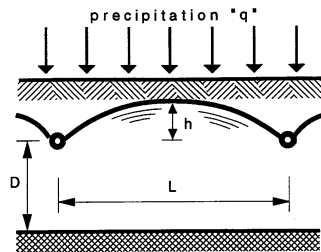


Fig. 477 Variables determining distance L between drain pipes^d

Calculation of distance for drains in a polder

The necessary distance L between smallest ditches (see Fig. 476) or drain pipes (see Fig. 477) is determined by precipitation q [m/24h], the maximum acceptable height h [m] of ground water above drainage basis between drains and by soil characteristics. Soil is characterised by its permeability k [m/24h] (see Fig. 478).

$L = 2\sqrt{(2kh/q)}$ is a simple formula to calculate L. If we accept $h = 0.4\text{m}$ and several times per year precipitation is $0.008\text{m}/24\text{h}$, supposing $k = 25\text{m}/24\text{h}$ the distance L between ditches is 100m.

^a Kley 1969

^b Ankum, 2003 page 42 and 82

^c Ankum, 2003; page 36

^d Ankum, 2003; page 36

<i>Type of soil</i>	<i>Permeability k in m/24h</i>	
gravel	>1000	
coarse sand with gravel	100	1000
coarse sand, fractured clay in new polders	10	100
middle fine sand	1	10
very fine sand	0.2	1
sandy clay	0.1	
peat, heavy clay	0.01	
un-ripened clay	0.00001	

Fig. 478 Typical permeability k of soil types

However, the permeability k [m/24h] differs per soil layer.

To calculate such differences more precisely we need the Hooghoudt formula described by Ankum (2003) page 35.

3.2.14 Drainage and use

Parcel ditches are used as property boundaries. In this way agricultural and urban activities are easily to separate from each other. Any use has its own requirements for parcel division. Systems of parcel division have to take dry infrastructure into account. Different network systems have to be combined in the polder for a good completion of drainage as well traffic.

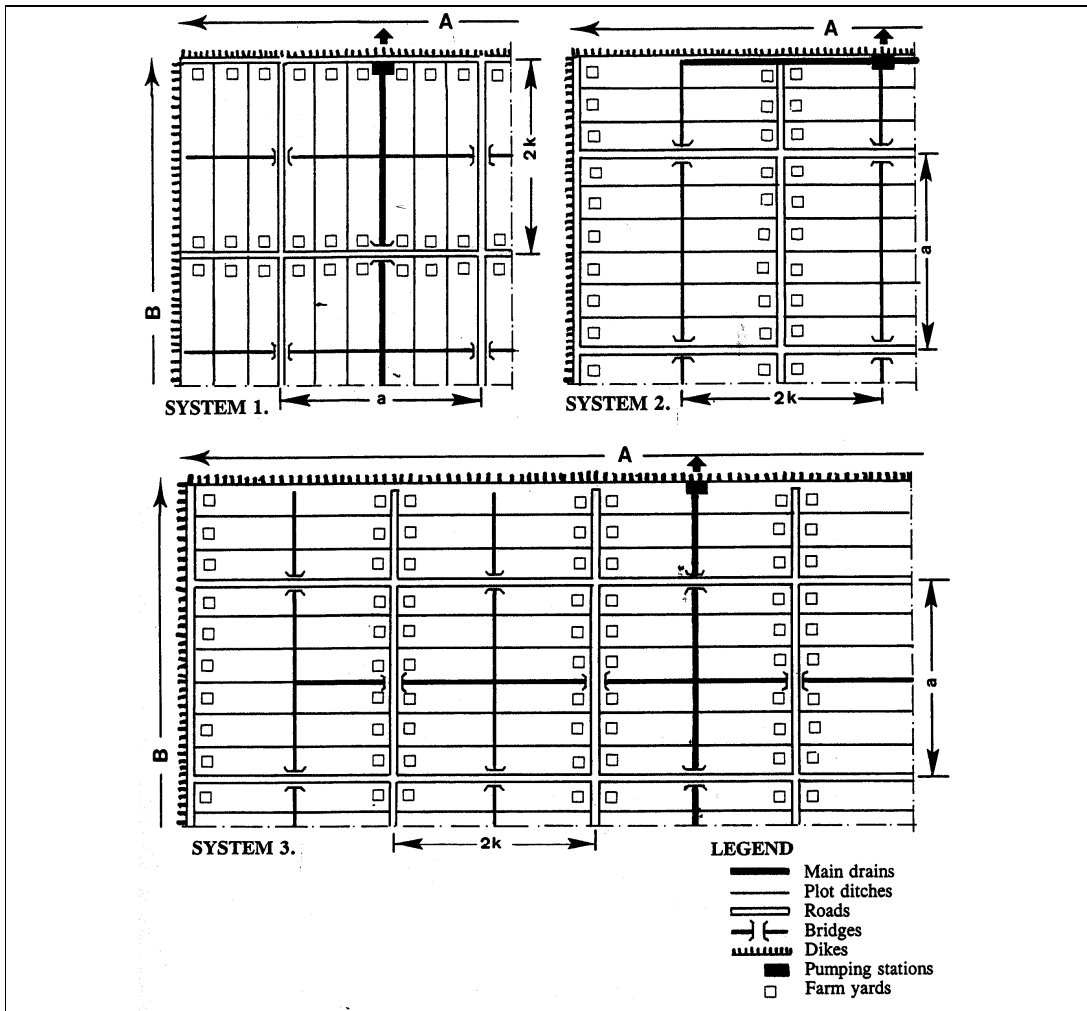


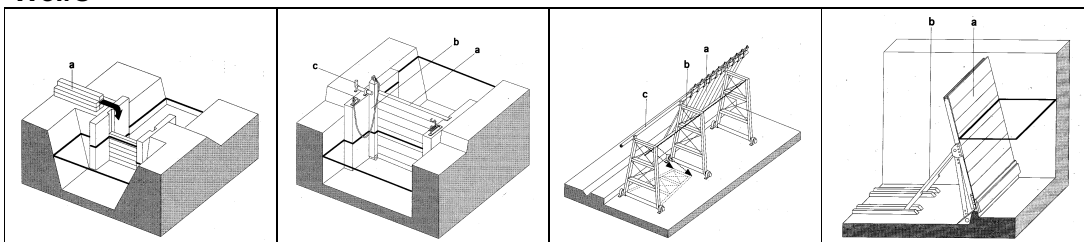
Fig. 479 Alternative systems of plot division in polders^a

We will elaborate that in 3.4.16.

3.2.15 Weirs, sluices and locks

There are many types of water level regulators elaborated by Arends (1994) (Fig. 480, Fig. 481, Fig. 482).

Weirs



^a Ankum (2003) page 59

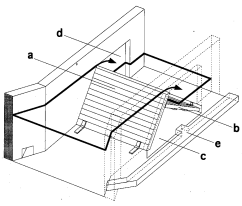
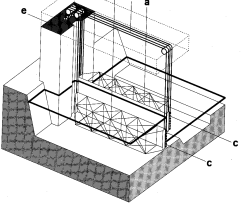
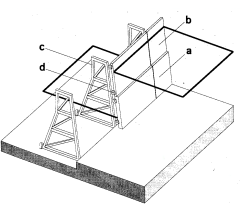
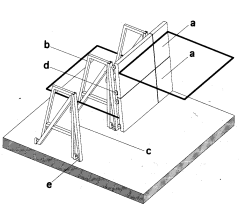
Schotbalkstuw	Schotbalkstuw met wegklapbare aanslagstijl	Naaldstuw	Automatische klepstuw
			
Dakstuw	Dubbele Stoneyschuif	Wielschuif rechtstreeks ondersteund door jukken	Wielschuif via losse stijlen ondersteund door jukken

Fig. 480 Types of weirs^a

Sluices

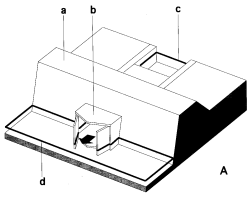
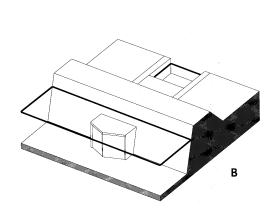
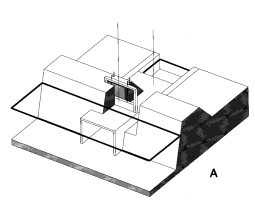
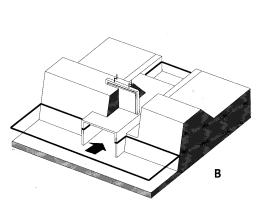
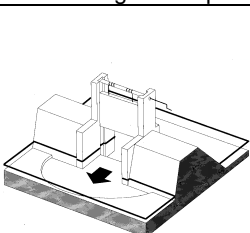
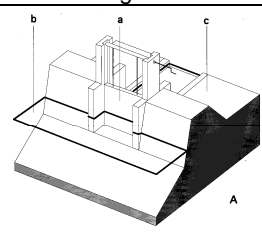
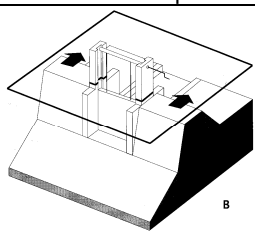
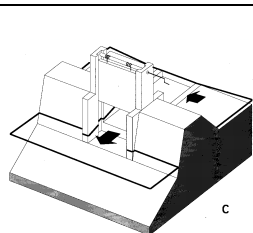
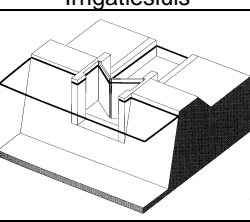
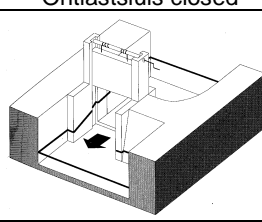
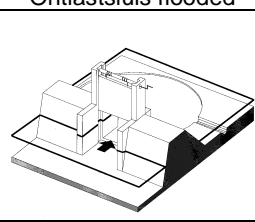
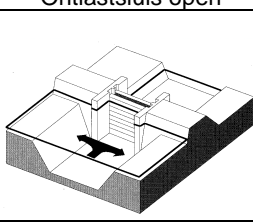
			
Uitwateringssluice open	Uitwateringssluice closed	Inlaatsluice open	Inlaatsluice closed
			
Irrigatiesluice	Ontlastsluice closed	Ontlastsluice flooded	Ontlastsluice open
			
Keersluice	Spuisluice	Inundatiesluice (military)	Damsluice (military)

Fig. 481 Types of sluices^b

^a Arends (1994)

^b Arends (1994)

Locks

To allow accessibility of shipping traffic you need locks at every transition of water level.

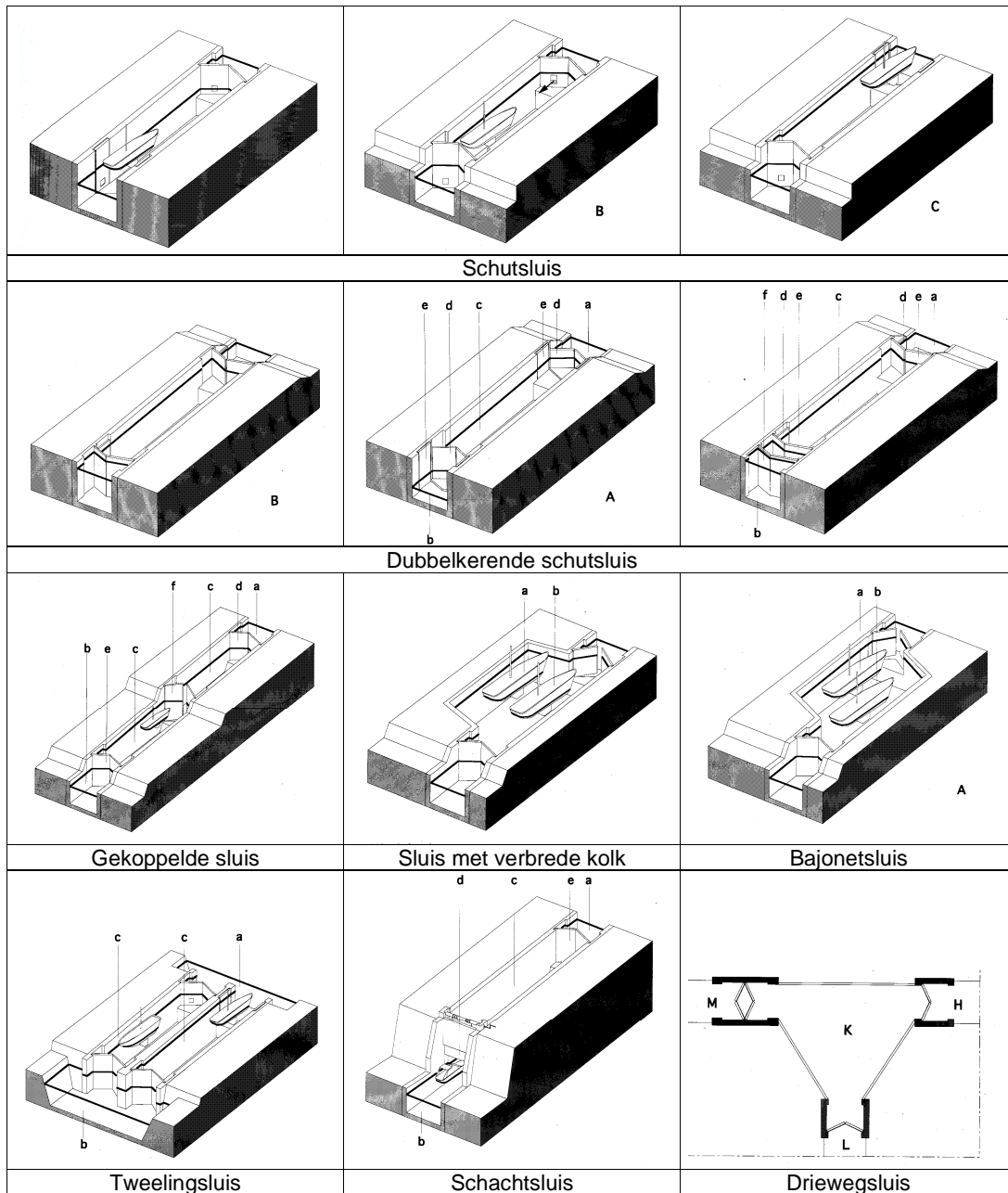


Fig. 482 Types of locks^a

Entrance and exit

Any regulator, culvert, sluice, lock or bridge requires a structure with entrance and exit of water needing space themselves (Fig. 483).

^a Arends, G.J.(1994) Sluizen en stuwen (Delft) DUP Rijksdienst voor de Monumentenzorg

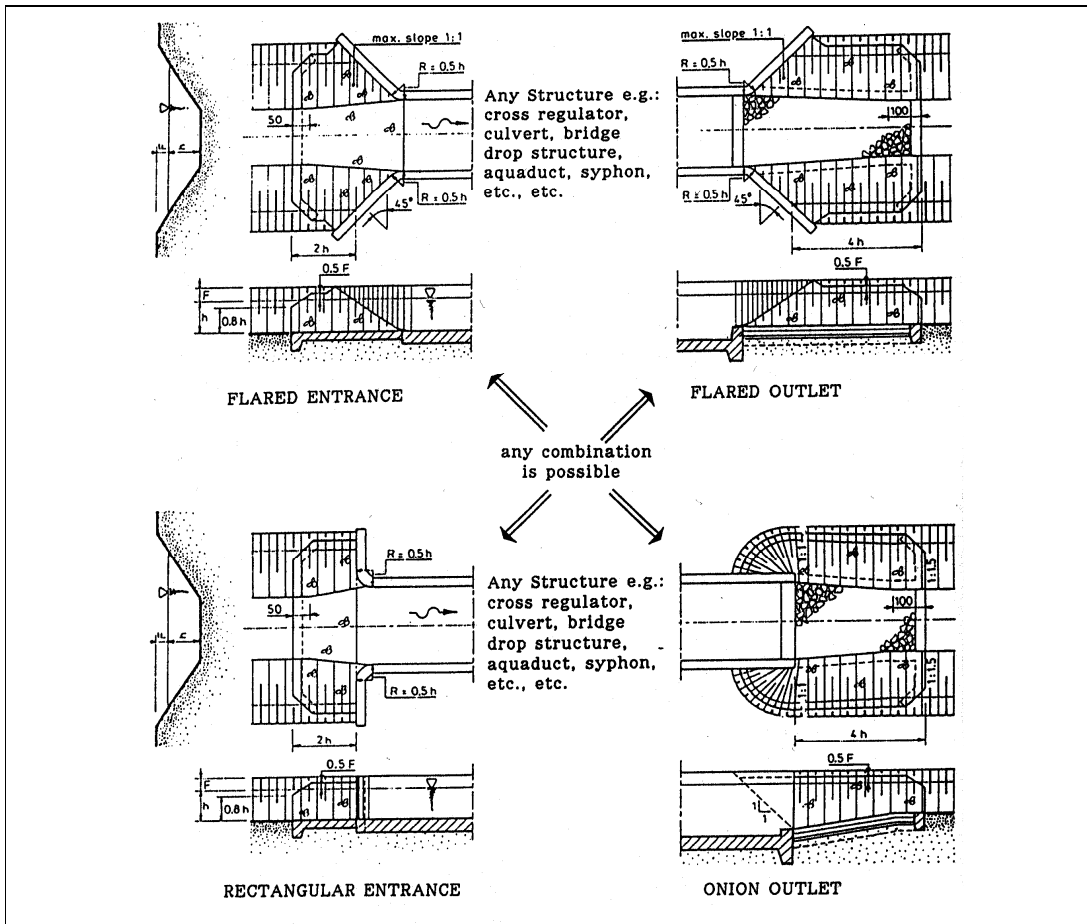


Fig. 483 Samples of the 'entrance' and 'exit' of a structure^a

3.2.16 Water management tasks in the landscape

Civil engineering offices are involved with many water management tasks (see Fig. 484).

^a Ankum (2003) page 164

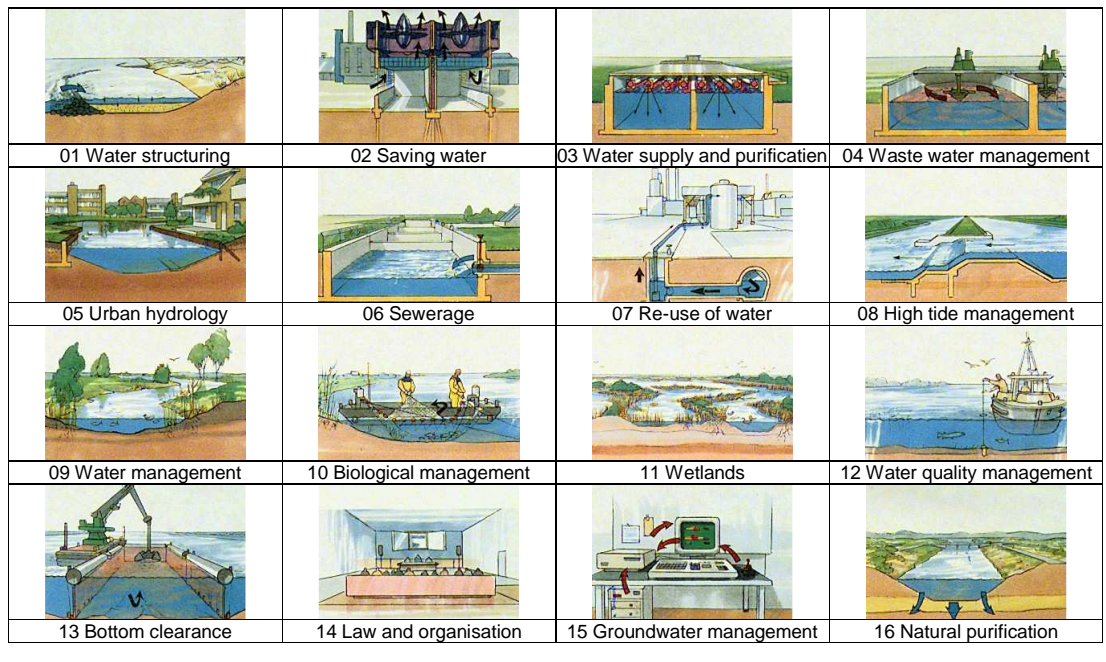


Fig. 484 Water management tasks in lowlands^a

3.2.17 Local water management maps

For a long time now, maps have existed of The Netherlands showing the areas governing their own water management (Waterschappen)^b, and their drainage areas (Fig. 485 above). Overlays show hydrological measure points (Fig. 485 below left) and the supply of surface water (Fig. 485 below right).



^a Das (1993)

^b http://www.uvw.nl/pagina_6390.html

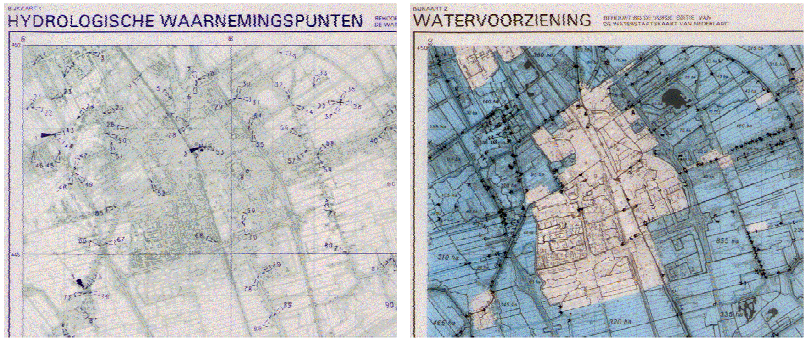


Fig. 485 Hydrological maps of Delft and environment^a

On the first map you can find the names of compartments, pumping-stations, windmills, sluices, locks, dams, culverts, water pipes. However, these maps are no longer available in hardcopy anymore by fast development of GIS in the nineties.

^a RWS, 1985, 1984