DOI: 10.2478/v10025-009-0007-8

JOURNAL OF WATER
AND LAND DEVELOPMENT
J. Water Land Dev. No. 12, 2008: 71–94

Water management and flood protection of the polders in the Netherlands under the impact of climate change and man-induced changes in land use

Bart SCHULTZ

Land and Water Development, UNESCO-IHE, P.O.Box 3015, 2601 DA Delft, the Netherlands,
e-mail: b.schultz@unesco-ihe.org

Abstract: Two-third of the area of the Netherlands is flood prone. Storm surges at the North Sea, floods in the rivers, failure of secondary dikes, as well as heavy rainfall may cause flooding. Most of the flood prone areas rely for their existence on drainage by pumping, because their surface level may be permanently or during floods up to several metres below the surrounding water levels. During the past decades climate change is generally felt as a reason for major concern. However, the impacts of climate change on increase in extreme conditions may be up to 45% per century. If we look at the man-induced changes in land use, due to increase in population and rapid increase in the value of public and private property, then one may observe an increase of 100–1,000% per century. One should therefore wonder what would have to be our major concern.

In the paper the relevant processes are described, based on some characteristic data on water management and flood protection in the Netherlands. It is shown that impacts of climate change on water management and flood protection may be expected, but that such impacts can easily be accommodated during improvement works on water management systems and flood protection provisions that from time to time will be required. It will be much more important to take carefully into account the risk of flooding in the planning of land use development, especially for valuable types of land use like urban and industrial areas, green houses and recreation areas.

Key words: *climate change, extreme rainfall, flood protection, flooding, land use planning, polder, water management*

INTRODUCTION

Two-third of the area of the Netherlands is flood prone. Storm surges at the North Sea, floods in the rivers, failure of secondary dikes, as well as heavy rainfall may cause flooding. Most of the flood prone areas rely for their existence on drainage by pumping, because their surface level may be permanently or during floods up to several metres below the surrounding water levels. During the past decades climate change is generally felt as a reason for major concern. However, the impacts of climate change on increase in extreme conditions may be up to 45% per century. If we look at the man-induced changes in land use, due to increase in population and rapid increase in the value of public and private property, then one may observe an increase of 100 – 1,000% per century. One should therefore wonder what would have to be our major concern.

In the paper the relevant processes are described, based on some characteristic data on water management and flood protection in the Netherlands.

DEVELOPMENT OF WATER MANAGEMENT IN THE FLOOD PRONE AREA

The history of water management in the Netherlands shows how the original natural landscape was transformed into a man-made landscape and has led to a never-ending struggle with the water. Water may come from all directions into the flood prone area: over land via rivers (floods), from the seaside (storm surges), from above (excessive rainfall) and from the subsoil (seepage). Human intervention is continuously needed to be able to survive (DE BRUIN and SCHULTZ, 2003).

The first inhabitants of the lowlands settled on the natural levees and creek ridges along the rivers and marshes, on the sandy grounds and the strips of clay behind the dunes. Later on, in the 10th century their descendants moved into the adjacent, huge peat areas further away from the rivers and the coastline. They lowered the groundwater levels in these areas, which were then situated a few meters above mean sea level. This first cultivation process was more or less completed in the 14th century. Until date this has left its in ineradicable mark on the landscape in the flood prone part of the Netherlands (Man-made lowlands, 2004).

In the 14th century local communities that had settled and developed in the first danger zone for floods, started connecting their local dikes. This was the beginning of collective dike construction that would last for several centuries. This second radical intervention in the natural water saturated alluvial lands generated a complicated hydraulic and hydrological chain reaction that presently is still going on and will go on in future (DE BRUIN and SCHULTZ, 2003). The cultivation of the peat lands caused a considerable drop of the surface level due to subsidence and oxidation in the course of the centuries, amounting to 4–5 m up till now (Fig. 1). It urged the need to reclaim the old cultivated grounds and transform them into 'polders'[1)], initially by means of small primitive sluices that could be opened at low outside water levels. In the course of the 15th century the windmills were to bring

[1)] A polder is a level area, in its original state subject to high water levels (permanently or seasonally, originating from either groundwater or surface water), but which through impoldering is separated from its surrounding hydrological regime in such a way that a certain level of independent control of its water table can be realized (SEGEREN, 1983)

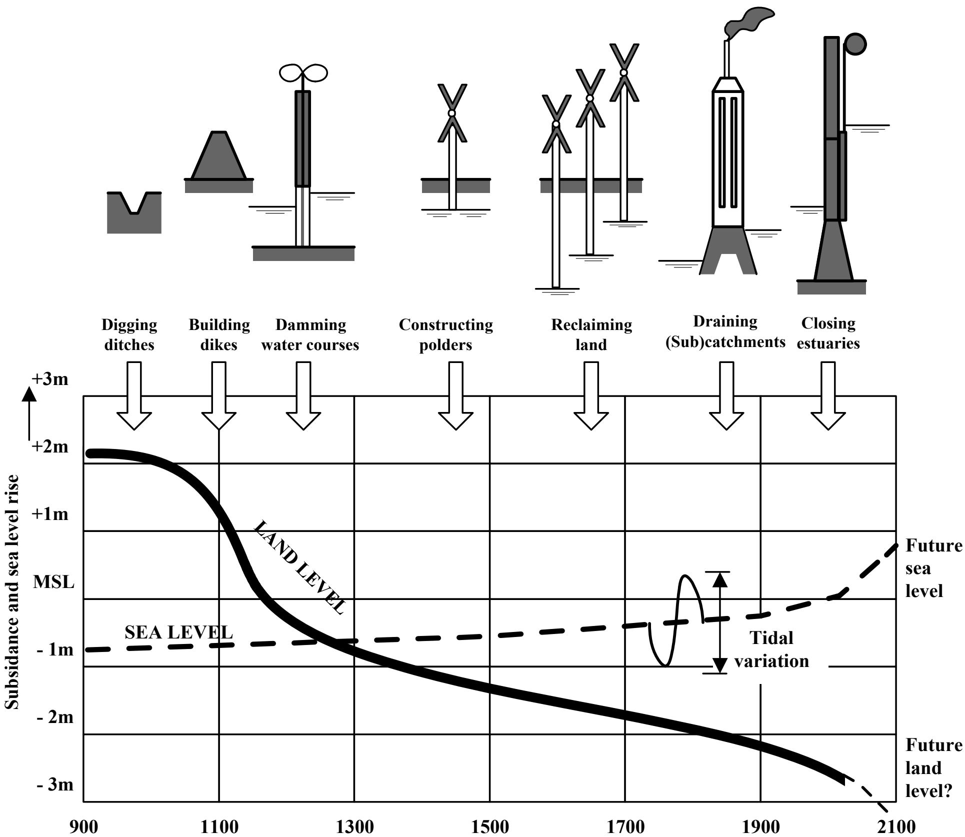

Fig. 1. Subsidence and sea level rise in the Netherlands (DE JONG *et al.*, 1999)

help. In the course of the 19th century these windmills were replaced by steam-driven pumping engines and in the 20th century by electric and diesel engines (SCHULTZ, 1982b).

For the drainage of the cultivated land numerous pumping stations are needed, in particular in those areas that are situated below mean sea level. The main system of normalized creeks, drains, lakes, collection and transport system for superfluous polder water has developed through ages, it still needs fundamental improvement and extension. This is mainly caused by the urbanization and industrialization, but also by the mechanization and further optimisation of agriculture and the diversification of rural land use. Especially during the last fifty years a considerable change in land use has occurred, in particular with regard to urban expansion, horticulture, development of industry and recreational facilities. In some cases special uses have been developed, such as Schiphol International Airport in the polder Haarlemmermeer, which was a lake of 18,100 ha that was reclaimed between 1840–1852 and has a surface level of about 3.5 m-MSL (Mean Sea Level).

In the first decades after the Second World War quality problems became manifest as well and required fundamental changes in institutional set up of the system of water management in the country, which have especially been implemented after the acceptance of the Law on Pollution of Surface Waters of 1970. Gradually ‘water’ became a limiting factor in spatial planning on a national scale.

Due to all these developments the population in the flood prone areas has increased from about 7 million in 1950 to about 12 million at present (Man-made lowland, 2004). The value of buildings, infrastructure and property has increased about six times during the same period and is at present about € 4,000 billion. Although the population is still only slightly growing, the value of buildings and property is expected to double in the next thirty years. Nowadays the Netherlands has a land area of 3,387,350 ha of which about 65% is flood prone. To a large extent this area consists of polders. Four types of polders may be distinguished (Fig. 2):

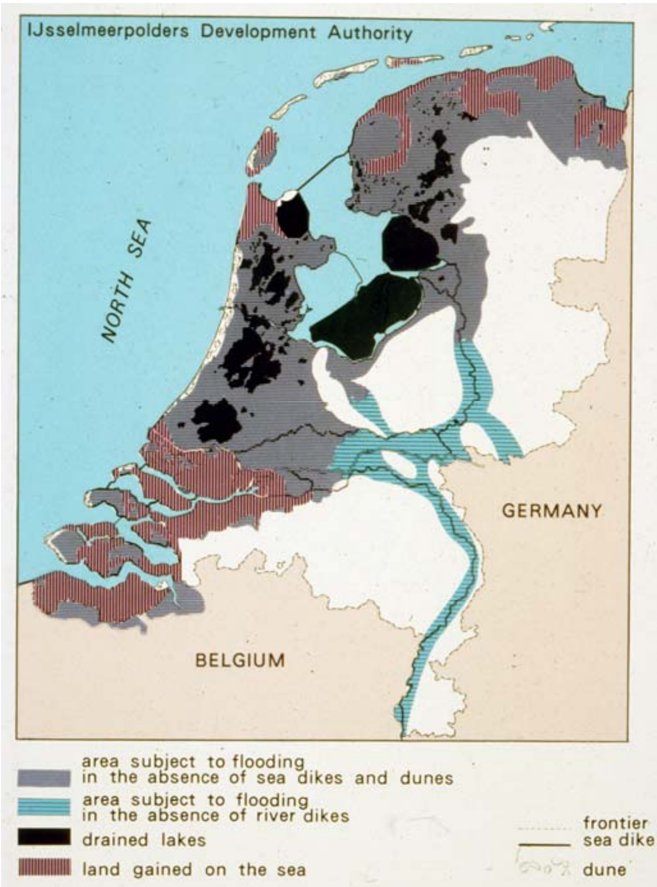

Fig. 2. The flood prone area in the Netherlands (SCHULTZ, 1993)

– areas subject to flooding in the absence of sea dikes and dunes;
– areas subject to flooding in the absence of river dikes;
– lands gained on the sea;
– drained lakes.

DEVELOPMENT OF FLOOD PROTECTION

The major river with respect to flood protection in the Netherlands is the River Rhine, followed by River Meuse. In this paper focus will be on flood protection with respect to River Rhine. The Rhine originates in Switzerland, with tributaries originating in Switzerland, Germany, France and the Netherlands. The river is both a rainfed and a meltwater river, it has a length of over 1,300 km and its basin covers a surface of 185,000 km^2. The greater part (65%) of the surface water of the Netherlands originates from it. The average discharge of the Rhine at Lobith – where the river enters the Netherlands – is 2,200 $m^3 \cdot s^{-1}$. At this discharge the water level there is almost 11 m+MSL (Man-madeVAN DE VEN, 2004; VAN BOETZELAER and SCHULTZ, 2005a; DE BRUIN, 2006).

High water levels have been the cause of many cases of flooding, of which the impacts have substantially increased due to land subsidence, population growth and increase in value of buildings and infrastructure. Over the centuries various measures have been taken and approaches followed to protect the flood prone area against flooding up to certain levels of safety. At a discharge of 10,000 $m^3 \cdot s^{-1}$ at Lobith a certain threat for the safety of the dikes along the Netherlands part of the Rhine and its branches may develop. High water levels in two of the branches of the Rhine can be noticed as far as halfway the polder Alblasserwaard – southeast of the city of Rotterdam – west of which is the 'delta-area', where high water levels are caused by storm surges from the sea. Here the river is so wide and there are so many branches that high upstream water levels have hardly any influence. Between the river area and the delta there is a transition zone where both high discharges and storm surges may cause high water levels. It is, however, highly improbable that a storm surge may coincide with a high discharge of the river, as storm surges occur in quite different weather conditions than high discharges of the rivers.

The first river flood that has been recorded was the bursting of the northern dike along the Lower Rhine system in 1233. About 1200, the surface level of the peat land north of the Lower Rhine system had already dropped considerably as a result of age-long, gradual land subsidence and oxidation (DE BRUIN and SCHULTZ, 2003). In the case of collapse of the northern dike along the Lower Rhine system, a very large area in the present provinces of Utrecht and South-Holland would be flooded. Between 1250 and 1600 bursting of dikes did not only occur more often but the flooded area became increasingly larger. This was partly as a result of the land subsidence in the peat areas. If the ground level in a large area had dropped to only some dozen centimetres above mean sea level, this entire area might be flooded in the case of a dike burst.

Apart from large cases of flooding, there were a lot of local cases too. From the dozens of floods, which swept the Dutch coast between 1250 and 1600, at least twenty led to large disasters. The worst disaster that ever hit the Netherlands was the All Saints Flood of November 1st 1570. This flood hit the entire coastal area. Following this flood many dikes were strengthened and many measures were taken to improve dike management (Man-made lowlands, 2004).

Because of the heightening of the dikes flooding became less frequent, however, those that did occur became disasters. Only in the sixteenth century an accurate description was found of a flood disaster, at which occasion there was quite a chain of related dike bursts and the entire river area was flooded. Similar disasters occurred repeatedly in the following centuries. Around 1800 severe flooding hit the river area practically every decade.

River flooding was of great concern in the first half of the nineteenth century. Several times broadly based commissions were set up that had to investigate how such disasters could be prevented. Not only were the dikes strengthened, but also the riverbed was improved during this period. In 1849 two inspectors of Rijkswaterstaat were assigned to study the plans of the two river commissions and the extensive literature on this subject. Their recommendation was that any river had to be brought in such a state that it could independently discharge the upstream water and ice. For that purpose they introduced the so-called standard width for the rivers. They determined the optimal width a river would have to fulfil. This width increased in the direction of the mouth. So the width of the Waal would have to be 360 m at the upstream, and 600 m downstream. These standard widths were based on practice. After 1848 due attention was given to river improvement. The increase in prosperity in the rural areas helped to promote a better maintenance of the dikes. The value of land had increased, which resulted in higher revenues for the waterboards. These additional funds were used to strengthen and heighten the dikes. From 1850 onwards, large improvement works were carried out in the rivers. These works aimed both at making the rivers suitable for the discharge of peak flows and ice, and at redesigning them into adequate shipping routes. The river dikes were not only heightened and widened, but also given a basalt slope at dangerous places. The idea was that by the dike reinforcements and the river improvements the danger for flooding from the side of the rivers was taken away for the greater part. This vision was too optimistic, which became clear from the flooding of 1926. As a consequence of this flooding, another large-scale strengthening of dikes took place. It was decided that all dikes along the Waal and the Lower-Rhine should be heightened to one metre above the highest water level of 1926.

Before 1960 high water levels and flooding, which were caused by ice dams, could occur locally. In particular, between 1650 and 1850 ice dams were the cause of many cases of flooding. Due to the warming of the water through the discharge of cooling water and busy shipping, the development of ice dams has become practically impossible these days (VAN BOETZELAER and SCHULTZ, 2005b).

Large-scale dike reinforcement started again after the flooding disaster of 1953 when large parts in the southwest of the Netherlands were flooded and 1,835 people died. The so-called Delta Project included the closure of coastal inlets and estuaries. Along the whole coast and in the region of the downstream rivers the flood protection structures were strengthened in an unprecedented way. For the first time the level of protection in a certain region was normative. For Central-Netherlands the flood protection structures had to give a protection against a storm surge from the sea with a chance of occurrence of one in 10,000 per year. For the river region the opinion was that the dikes had to be strong enough to resist a flooding, which had a chance of occurrence of one in 3,000 per year. By that time this standard was considered to belong to a discharge of the Rhine of 18,000 $m^3 \cdot s^{-1}$ at Lobith, which later on proved to be an extremely high discharge. From then on this new standard of dike reinforcement is referred to as 'Normative High Water'. In the river region there developed, however, a strong criticism with respect to the planned strengthening of dikes. The opinion was that the new dikes would have a very negative impact on the beauty of the landscape and cultural heritage. Because of this the standard was adjusted to a chance of occurrence of one in 1,250 per year. To this standard belonged a discharge of the Rhine of 15,000 $m^3 \cdot s^{-1}$ at Lobith. Furthermore, at the execution of dike reinforcements due caution had to be exercised with respect to the existing nature and scenic values of the river area. However, there was still no large-scale strengthening of dikes in the river region. This had two causes. The central government did not make enough money available and there was much distrust between the water-boards, on the one hand who made plans for dike reinforcements, and the activists, on the other hand, who mobilised their forces for landscape conservation.

At the end of December 1993 and in January 1995, very high water levels occurred in the rivers. In 1993 there was especially damage in the Meuse valley in the province of Limburg. In January 1995 the Netherlands were surprised again by very high water levels on the rivers. The Rhine had a discharge of 12,000 $m^3 \cdot s^{-1}$ at Lobith and in the branches of the Rhine the water level was even about 25 cm higher than in 1993. The safety of the dikes was not trusted, because certain dike sections still had a safety level with a chance of occurrence of only one in 100 per year. 240,000 people and one million cattle were evacuated from the river region. Fortunately the dikes did not fail. Since 1995 structural measures have been taken. An emergency act was passed in Parliament, which was called Delta Plan Great Rivers. In this act it was laid down that the entire dike reinforcement programme along the rivers had to be completed before 2000. Based on this act the dikes in the river region were indeed strengthened very quickly at the previously prescribed chance of occurrence of one in 1,250 per year. Now they protect the river region against high water levels belonging to a discharge of the Rhine of 15,000 $m^3 \cdot s^{-1}$ at Lobith.

In the second half of the 20th century, the safety along the landside of the sea-coast was improved by a drastic shortening of the coastline by constructing the Zuiderzee and the Delta Project. The provisional tailpiece of these large-scale projects was the construction of a movable storm surge barrier in the open river connection between Rotterdam and the sea, the Nieuwe Waterweg (completed in 1997).

ROOM FOR THE RIVER

Already during the execution of the dike reinforcement along the rivers, it was questioned whether this had to be continued in future. It was realised that it might be possible that the rivers would have to discharge more water in future due to climate change. The opinion was that alternatives for heightening of the dikes had to be sought. These were looked for in the concept ‘Room for the river’ (2000). In this concept the aim is to lower flood levels by enlarging the river cross-section. This can, for example, be achieved by lowering of groynes in the river beds, digging up the areas of higher ground, or by making channels in the river forelands or the floodplains, by replacing road accesses and railways on dikes by bridges, by digging at several places, and even by moving certain dike sections inland (Fig. 3). In addition, there were plans for controlled flooding of certain areas, the so-called emergency flooding areas, when there would be the threat of dike breaches. In order to prepare a principle decision on the works to be done in the branches of the Rhine the procedure of the so-called National Land Use Policy Decision has been completed and was approved by Parliament in January 2007. It has a similar status as an act. To achieve the objectives the government has allocated € 2.2 billion for safety against high water levels in the river region. This policy decision was based on a detailed review of the safety situation in the Netherlands, an Environmental Impact Analysis on various alternative options and an economic analysis in which costs and damages with respect to flood management have been taken into

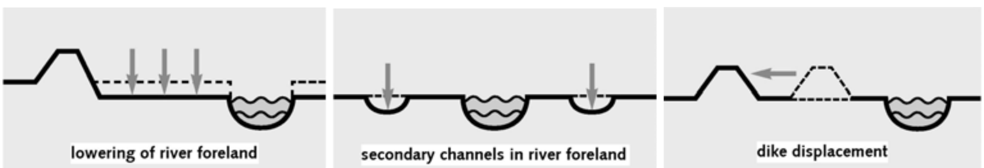

Fig. 3. Examples of creating ‘Room for the River’ (VAN MEEL *et al.*, 2005)

account. Starting point for the policy decision was the existing safety standard of a chance of occurrence of one in 1,250 per year. However, in light of possible more extreme river discharges due to climate change the related discharge of the Rhine at Lobith was raised from 15,000 to 16,000 $m^3 \cdot s^{-1}$. In addition it was taken into account that by the turn of this century flood defence plans would have to take into account at the same chance of occurrence a discharge of 18,000 $m^3 \cdot s^{-1}$ and a rise of the mean sea level of 0.60 m. Within the framework of the long-term, various options are available, which, apart from accommodating larger discharges, also give opportunities for regional development along the rivers, such as waterfront housing, recreation and nature conservation developments. The decision was based on an integrated development plan with the main objectives of flood protection, landscaping and improvement of environmental conditions (VAN MEEL *et al*., 2005).

During the past years, it has also been questioned whether the water can be retained upstream during high water levels. However, the lowering of the water level that can be achieved in Germany is estimated at only 10 cm near Lobith at the most, and this is insignificant for the protection of the Netherlands river region.

DESIGN STANDARDS FOR WATER MANAGEMENT AND FLOOD PROTECTION

The present-day design standards for water management and flood protection provisions were developed in the 1950s, especially as far as flood protection is concerned after the severe flooding in the southwest of the Netherlands in 1953. During the coming years these standards will be reconsidered. It is, however, not yet clear to what extent they will be modified. Distinction is made in standards for the design of water management systems and for flood protection provisions.

DESIGN STANDARDS FOR WATER MANAGEMENT SYSTEMS

The water management systems in the polders of the Netherlands are basically drainage systems. In dry periods there is generally the possibility to apply irrigation as well, but this doesn’t really play a role in the design. The water management systems consist first of all of a system for the agricultural area. Additionally, there are various systems for the sub-areas, i.e. urban areas, forests and nature reserves. The various systems can be characterized by a number of main elements, which, depending on their value and interrelation, determine the functioning of the system. The main elements of the water management system for the agricultural area are the distance between the subsurface pipe drains or open field drains, the subsurface drain depth or the depth of the open field drains, the preferred water level, which is called polder water level, the percentage of open water and the pumping capacity

(Fig. 4) (SCHULTZ and WANDEE, 2003). The main elements of the water management system for the urban area are the diameters of the sewers, the width of the urban canals and their distance, the preferred water level in the urban area and the top width of the discharge weir or the pumping capacity (SCHULTZ, 1982a).

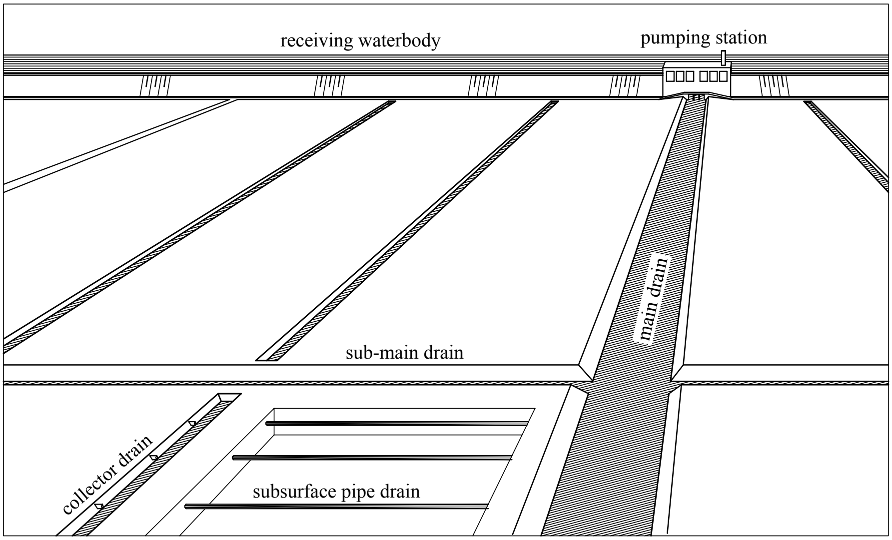

Fig. 4. Schematic layout of the drainage system in a polder (SCHULTZ and WANDEE, 2003)

In the polders groundwater management is of great importance for the growth of crops. Because of the shallow groundwater table, precipitation is quickly acted upon. The open water level can influence the groundwater. Some polders, e.g. the IJsselmeerpolders, have more or less separated systems of groundwater and open water, while the polder water level is generally lower than 1.40 m-surface and the aerated – permeable – layer is not deeper than upto 1.00 m-surface.

The design requirements and calculation methods for field drainage systems have actually only been developed since 1930. The field drainage requirements are in general related to the depth of the groundwater table. When calculations were made, steady state conditions were assumed, which have led to an installation of the open or subsurface field drains such, that sufficient drainage is guaranteed.

Originally, field drainage generally occurred by means of trenches and/or open field drains. Open field drains usually have a depth of less than 0.60 m and are installed at 8–20 m spacing, or more. Usually they discharge via a pipe in the collector drains. The bottom of the open field drains generally lies above the polder water level. Since the beginning of the 20th century subsurface pipe drains have been increasingly used in the polders with a clay soil. For the subsurface pipe drains originally clay tiles were used, followed by smooth PVC pipes and the nowadays commonly used corrugated PVC pipes. The subsurface pipe drains are generally located at 0.9–1.0 m-surface. A range of materials has been used in the course of time as an envelope around the pipe drains. We can distinguish mineral, organic and synthetic envelopes. In the polders Eastern and Southern Flevoland subsurface drains without an envelope are used extensively.

The hydraulic transport system of a polder can consist of collector drains, submain drains, main drains and/or structures, like fixed or movable weirs. From a water management point of view, in principle the system has a double purpose, viz. water storage and the transport of water to the pumping stations. The hydraulic transport system is usually based on agricultural land use. Other land uses, particularly urban areas, industrial areas and green houses, which have especially been realized since the 1950s in a number of polders, require a hydraulic transport system of their own and therefore quicker discharge. This may have resulted in adjustments to the hydraulic transport system in the agricultural area. In many cases complete separate hydraulic transport systems have been made for urban development in older polders, which are pumped directly at the system of canals for superfluous polder water. The hydraulic transport system may also serve as water supply, drinking water for cattle, a natural barrier for cattle and the main drains for trade and recreational ships. For the discharge, the following aspects of the hydraulic transport system are especially of importance: structure of the system, polder water level and percentage of open water. The alignments of collector drains, submain drains and main drains are influenced by the surface level, the dimensions of the parcels and by the location of the pumping stations, which in turn is also dependent on the surface level. The parcel is the elementary building block for the lay out of a polder. A parcel is generally a rectangular piece of land, bordered on the long side by a collector drain. On one short side the parcel is usually bordered by a submain drain, into which the collector drains discharge, and on the other short side by a road, along which the farm buildings are usually located. The width of a parcel is determined by the drainage of the land. The width in particular has been subject to alteration over the years.

Because of the difference in operation of the field drainage and hydraulic transport systems, there generally is no clear relationship between these systems. Due to this drainage and discharge requirements are considered independent, on the condition that discharge does not hamper the field drainage. Discharge criteria have always been used, because demands were made upon the polder water level. Calculation methods have been used since the middle of the 19th century. As a rule they determine the polder water level and its exceedance, as well as the percentage of open water. In the polders this has resulted in characteristic data as shown in Table 1.

Over the centuries in polders, windmills, steam engines, suction-gas-engines, diesel engines and electro-engines have been or are being used as driving mechanisms. Since the beginning of the 20th century more and more diesel engines and

Table 1. Characteristic dimensions of different types of polders (SCHULTZ and WANDEE, 2003)

Type of polder	Percentage of open water	Polder water level in m-surface	Pumping capacity mm·day^{-1}
Peat polder	5–10	0.20–0.50	8–12
Old clay polder			
– meadows	3–10	0.40–0.70	8–12
– arable land	5–10	0.80–1.00	8–12
IJsselmeerpolders	1–2	1.40–1.50	11–14
Urban polder	3–8	1.50–1.80	15–30
Greenhouse polder	3–10	0.80–1.00	20–30

electro-engines have been used. At present the greater part of the polders is pumped with electro-engines. In the larger polders a combined diesel and electro pumping is generally used. Various methods have been used through the ages to determine the needed pumping capacity. Generally these methods were based on the requirement that the excess water of a certain wet period had to be pumped out during the same period. With windmills it meant that one windmill pumped a maximum surface of 600 ha. For a long time the required pumping capacity with steam pumping was determined at 8 mm·day^{-1}. The present pumping capacity is 10–14 mm·day^{-1}. The capacities may be higher in smaller polders (Tab. 1).

With regard to polders, the influence of sub-areas on the amount of surplus water is generally limited. Only if the sub-area had taken up a very significant percentage of the area of the polder, would adjustment of the pumping capacity be necessary. As a rule, the relevant area had pumping directly on the system of canals for superfluous polder water.

The quantity of water to be drained from a polder – and the pumping capacity needed for this – is first of all determined by the amount of surplus water. This surplus water is produced primarily by precipitation, further by seepage and occasionally by water through shiplocks, water leakage from hydraulic constructions and inlet water. The amount of surplus water is reduced by evapotranspiration and in some exceptional cases by downward seepage. For the design of water management systems for polders, the amount of surplus water is of significant importance. The following must therefore be identified:

- amount of surplus water which will be present in one year;
- amount of surplus water under design circumstances;
- influence of sub-areas on the amount of surplus water.

The quantity of precipitation, as well as its variation throughout the year, the quantities expected under design conditions and the area reduction effect of extreme rainfalls are of importance. The quantity and variation of precipitation are especially important to determine the total quantity of water to be removed. The quantities under design circumstances are of importance in determining the dimensions of the hydraulic transport system, as well as the required pumping capacity. The area reduction effect is, under Dutch circumstances, only of importance in the largest polders in determining the sizes of the main drains and the pumping capacity. Since the beginning of the 20th century design periods have been selected in different ways in order to determine the amount of surplus water from the precipitation and evaporation data. For several decades now rainfall-duration-frequency curves have been used (Fig. 5).

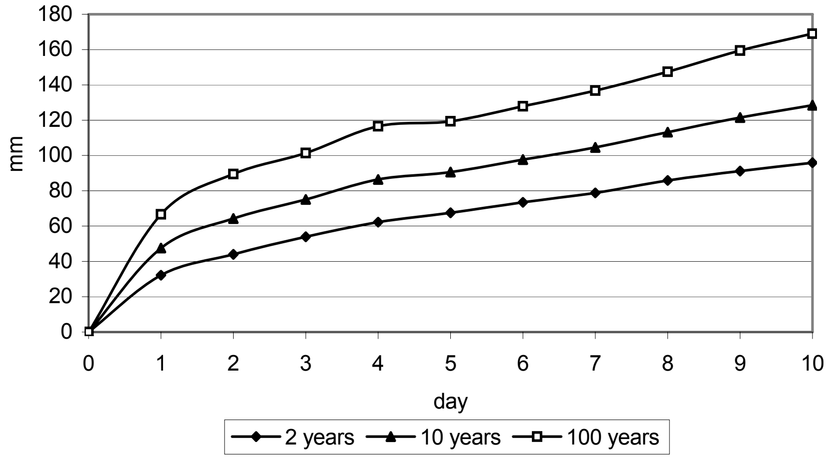

Fig. 5. Rainfall duration frequency curves for station Hoofddorp (1960–2001) (SCHULTZ and WANDEE, 2003)

In the polders seepage can form an important part of the total amount of surplus water. We can distinguish between dike seepage and deep seepage. Seepage usually amounts to less than 1 mm·day^{-1} counted over the total area of the polder. Therefore the amount of seepage generally has only a limited influence on the capacity of the pumping station, but a more substantial influence on the total amount of water that has to be pumped out and therefore on the operating costs.

DESIGN STANDARDS FOR FLOOD PROTECTION PROVISIONS

With respect to flood protection a difference is made between: floods due to storm surges at the North Sea, river floods, and inundation due to extreme rainfall. Related to the different types of floods, different design standards for flood protection provisions are applicable in the Netherlands. In addition a distinction is made in primary dikes and secondary dikes. The developments with respect to flood protection have been described in the previous sections. For the primary dikes this has resulted in a required level of safety as shown in Figure 6.

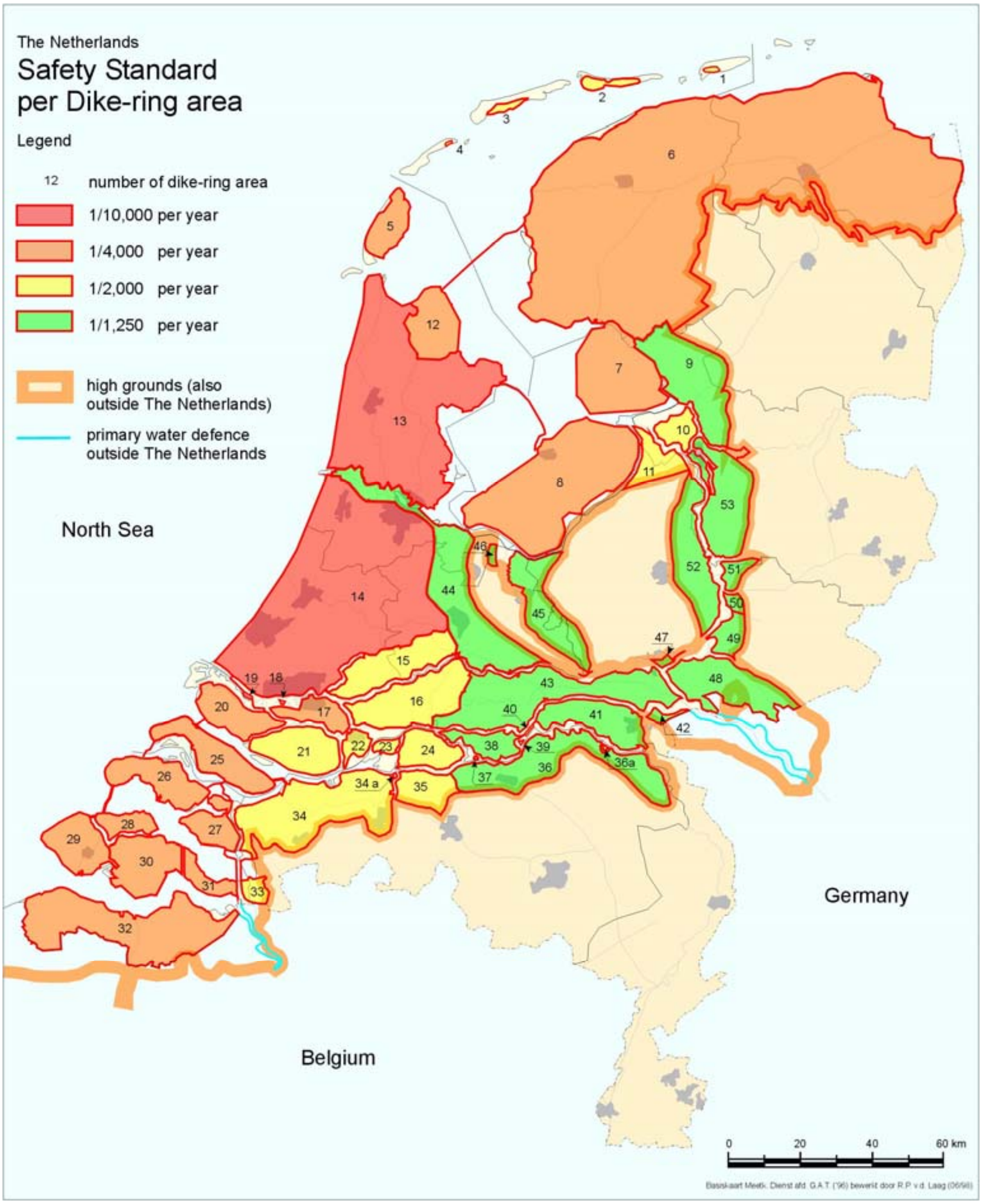

Fig. 6. Dike ring areas and design standards for flood protection provisions
(Towards a new safety…, 2000)

For the safety of the secondary dikes there are no strict rules, but the recommended levels of safety range between chances of occurrence of 1/500 per year to 1/1,500 per year, dependent on the land use in the concerned area.

ANALYSIS OF POSSIBLE IMPACT OF CLIMATE CHANGE AND MAN-INDUCED CHANGES IN LAND USE ON WATER MANAGEMENT AND FLOOD PROTECTION

Recently the Intergovernmental Panel on Climate Change (Climate change…, 2007) has published new estimates on the possible impacts of climate change. Local institutions have made additional estimates. These estimates have caused a lot of concern in societies. However, one should strongly wonder why climate change would have to be the main reason for concern. If we look at man induced changes in land use in the flood prone areas, then changes, especially due to urbanisation and industrialisation take place at a much more rapid speed than climate change. In this section the possible impacts of climate change on water management and flood protection in the Netherlands will be illustrated, together with the expected impacts of man induced changes.

ANALYSES OF THE WATER MANAGEMENT CONDITIONS IN THE FLOOD PRONE AREAS

In addition to the temporary storage of surplus rainwater in the unsaturated zone, which may be quite significant (SCHULTZ and SAIFUL, 1987), temporary storage occurs especially in the collector and main drains. The question is to what extent the present water management systems are already working at their capacity, or if there is still room in these systems. In order to get an impression of the present conditions and to analyse the effects of urbanisation and of vertical differences between urban and rural areas on the water management in polder areas Schultz and Wandee analysed actual pumping data of the Northeast polder and fluctuations in the open water level in a theoretical polder under different percentages of urban area and different vertical levels of the urban compared to the rural area (SCHULTZ and WANDEE, 2003).

The Northeast polder is one of the IJsselmeerpolders (SCHULTZ and VERHOEVEN, 1987). The polder fell dry in 1945. It is provided with three drainage pumping stations. The installed capacity of the pumping stations enables to remove a water layer of 14–15 mm·day^{-1} counted over the total area of the polder, which is 48,000 ha. Daily data of the discharge by the pumping stations are available for the period 1945–2001. In Figure 7 the frequency distribution of the pumped amounts of water during the said period is shown.

From Figure 7 it can be derived that 89% of the time 3 mm·day^{-1} or less have been pumped out, which is less than one fifth of the installed capacity. 98% of the time 7 mm·day^{-1} or less have been pumped out, which is about 50% of the installed pumping capacity. During the 56 years of operation the pumping stations have worked only two days at full capacity. Although water levels are only available for part of the period, these data show that exceedance of more than 0.30 m above the

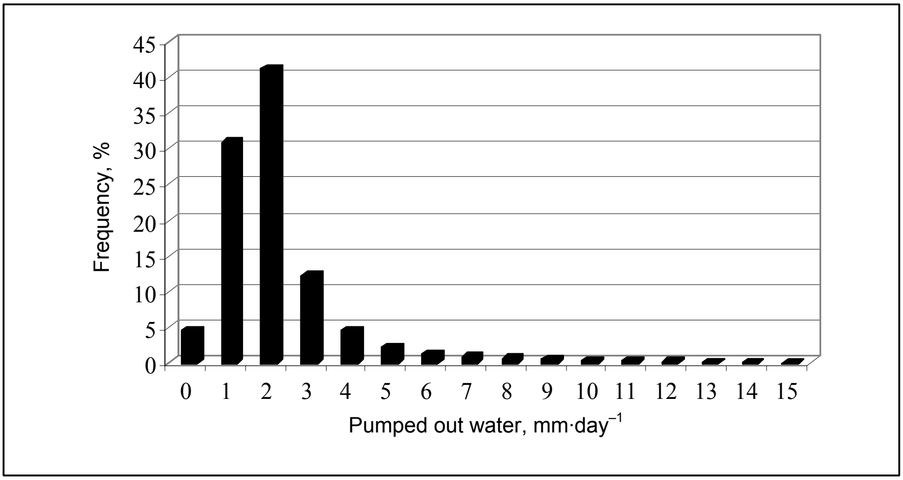

Fig. 7. Frequency distribution of the pumped amounts of water from the Northeast polder

preferred water level of 5.70 m-NAP almost never has occurred (Man-made lowlands, 2004). While the preferred water level in this polder, with predominantly clay soil, is at least 1.2 m-surface, an exceedance of the preferred polder water level with 0.30 m under extreme conditions will not do any harm. Although the Northeast polder is not representative for all the polders, the results show that there may be quite some room in the water management systems of the polders under extreme conditions. This may be the more expected while in the older polders larger percentages of open water have been applied than in the Northeast polder.

In polder areas the value of property per unit area is much higher in the urban areas compared to the rural areas. For the polder Southern Flevoland it was found in 1990, for example, that the total value of public and private property in the urban areas was about € 3 million per ha, while the total value in the rural area it was only about € 15,000 per ha (SCHULTZ, 1993). Since then the difference became even more pronounced. The invested capital in property in the Dutch polders is estimated at € $4 \cdot 10^{12}$ (4 trillion). Duplication is expected over the next thirty years. In order to keep the damage due to excessive rainfall under extreme conditions as low as possible it is therefore advisable to situate the urban and other high value areas, or elements at a certain level above the surrounding rural area.

In their analysis of the effects of urbanisation in a polder area Schultz and Wandee analysed some theoretical examples for respectively a clay polder and a peat polder (SCHULTZ and WANDEE, 2003). The polder areas were considered to be completely flat. Although the simulations have been done in a quite simplified manner and possible soil storage during extremely wet periods has been neglected, the trends in the results are clear. For the clay polder the results showed that when the preferred water level in the urban area is 0.25 m above the preferred water level in the rural area, which implies that the street level in the urban area is 0.35 m above the surface level in the rural area, in fact no inundations have to be expected in the urban area, when the percentage of urban area in the polder is up to 10%. In these conditions occasionally an inundation of the rural area could be expected, but only in exceptional cases an inundation of the ground floor of the farmhouses. When this ground floor would be situated a little higher, say 0.10, or 0.20 m no inundation would have to be expected. For the peat polder more frequent inundations in the rural area may be expected with little difference in the urban area, as long as this area doesn't take more than 10% of the total area. This increase in possible inundations in the rural area is primarily caused by the relatively high polder water level, which is required to prevent a too rapid subsidence of the peat soil.

For the Netherlands the estimates regarding the increase in extreme rainfall can best be based on the Climate change scenarios 2006 of the Royal Netherlands Meteorological Institute (KNMI). Based on this publication the estimated increases in one-day precipitation that may be expected by 2050, relative to 1990, at the 10 year return period varies in the different scenarios between 5 and 27%. SCHULTZ and SURYADI (2007) extrapolated these figures linearly to a 100-year period and came to 8–45%. Although one may wonder if this approach is correct, due to lack of better information, they applied the ratios of 8 and 45% to the rainfall data of Hoofddorp for the period 1960–2001 (Fig. 8). Based on these data the same theoretical clay polder has been used as was done by SCHULTZ and WANDEE (2003). The result is shown in Table 2.

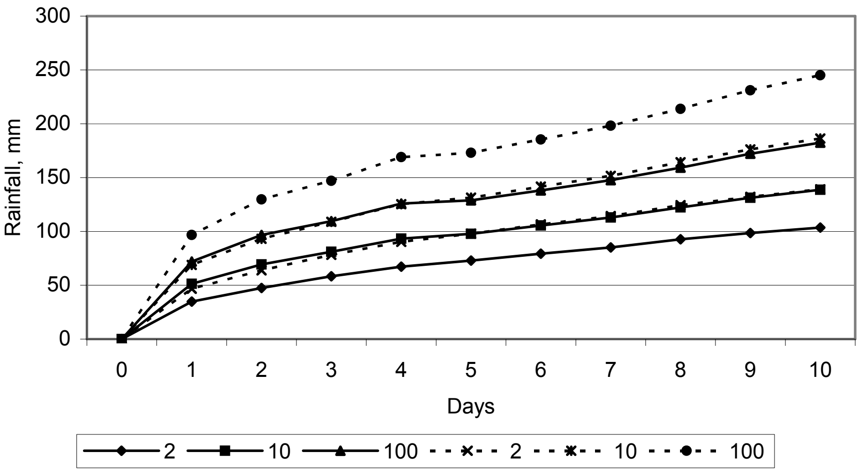

Fig. 8. Modified rainfall duration frequency curves for Hoofddorp (see Fig. 4), based on increases in extreme rainfall of respectively 8% (continuous lines) and 45% (dotted lines), as derived from the climate change scenarios for 100 years

Table 2. Exceedance of preferred water levels in a clay polder for the present conditions, as well as for respectively 8% and 45% increase in extreme rainfall (SCHULTZ and SURYADI, 2007)

Item	Present situation (based on SCHULTZ and WANDEE, 2003)											
Width urban weir, m	36				66				316			
Percentage of urban area	5				10				50			
Difference in level, m	0		0.5		0		0.5		0		0.5	
Days/frequency	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Streets	7	0.05	2	0.01	8	0.05	3	0.02	36	0.23	17	0.11
Footpath and squares	3	0.02	0	0.00	5	0.03	1	0.01	25	0.16	15	0.10
Houses and buildings	1	0.01	0	0.00	2	0.01	0	0.00	24	0.16	12	0.08
Green areas	1	0.01	0	0.00	2	0.01	0	0.00	20	0.13	10	0.07
Rural area:												
Road	6	0.04	6	0.04	9	0.06	8	0.05	57	0.37	89	0.58
Agricultural area	4	0.03	4	0.03	4	0.03	4	0.03	44	0.29	61	0.40
Farm house	1	0.01	1	0.01	3	0.02	3	0.02	25	0.16	36	0.23
Item	8% increase											
Streets	15	0.10	3	0.02	19	0.12	6	0.04	67	0.44	29	0.19
Footpath and squares	10	0.07	1	0.01	11	0.07	3	0.02	48	0.31	21	0.14
Houses and buildings	8	0.05	0	0	10	0.07	1	0.01	43	1.28	20	0.13
Green areas	8	0.05	0	0	10	0.07	1	0.01	44	0.29	21	0.14
Rural area:												
Road	10	0.07	11	0.07	12	0.08	13	0.08	119	0.78	182	1.19
Agricultural area	7	0.05	7	0.05	9	0.06	10	0.07	87	0.57	128	0.83
Farm house	4	0.03	4	0.03	4	0.03	4	0.03	50	0.33	70	0.46
Item	45% increase											
Streets	82	0.53	29	0.19	120	0.78	49	0.32	749	4.88	477	3.11
Footpath and squares	45	0.29	22	0.14	72	0.47	31	0.20	616	4.02	368	2.40
Houses and buildings	41	0.27	20	0.13	62	0.40	25	0.16	587	3.83	342	2.23
Green areas	42	0.27	21	0.14	65	0.42	28	0.18	599	3.90	354	2.31
Rural area:												
Road	104	0.68	106	0.69	128	0.83	129	0.84	950	6.19	1144	7.46
Agricultural area	82	0.53	83	0.54	99	0.65	102	0.66	834	5.44	1007	6.56
Farm house	44	0.29	46	0.30	99	0.65	61	0.40	664	4.33	780	5.08

Total number of days of simulation from 1960 to 2001 = 15 341 days.
n = number of days of inundation, % – frequency.

Based on the above results SCHULTZ and SURYADI (2007) analysed for the 45% increased rainfall conditions what this would mean for the pumping capacity, or the percentage of open water, if the present design standards of 0.40 m exceedance of the urban and polder water level at a return period of 10 years would be maintained. For this purpose the rainfall duration frequency curves as shown in

Figure 8 were used. For the theoretical clay polder this has resulted in the required increases in pumping capacity and percentages of open water as shown in Table 3.

Table 3. Required values for pumping capacity or percentage of open water, due to a possible increase in extreme rainfalls with respectively 8 and 45% in 100 years under the present day design standards

Increase in extreme rainfall %	Pumping capacity		Percentage of open water	
	present value mm·day^{-1}	required value mm·day^{-1}	present value	required value
8	11		5	
8		13	5	
8	11			5.8
45		24	5	
45	11			9.7

Based on such scenarios it can be stated that under the worst climate change forecast (45% increase in the extreme rainfall values) without increased pumping capacity, or an increase in the percentage of open water the frequency of inundations will substantially increase. However, especially increasing the pumping capacity, together with rising of the urban area compared to the rural area will be the most effective measure.

One may expect that over the years the percentage of open water in the urban areas will not be substantially increased, while this would imply loss of high value land. However, within the urban area substantial improvements can be obtained when the difference in levels between the green areas, the roads and the buildings will be increased. When this is being done, the first areas that will be inundated during extreme rainfall will be the green areas, and it will not be a big problem when these can occasionally not be used for one or two days.

The results imply that in the development of new urban areas and reconstruction works in the rural areas more attention would have to be paid to the vertical differences between the different elements in the urban and rural areas than is the case at present. Pumping capacities can be gradually increased when the need arises. In this way possible future impacts of climate change can be easily and timely accommodated.

Therefore the major problem remains the substantial increase in value of buildings and infrastructure in the polders and to a certain extent also the increase in population. With respect to these developments it will be of major importance to develop the design standards in such a way that the resulting water management systems will be designed more or less at the economic optimal level. This implies that the total of costs for construction, operation and maintenance of the water management systems and the damage due to waterlogging or inundation will be minimal. In these computations the expected population growth and increase in value of buildings and infrastructure over the lifetime of the water management systems will have to be taken into account as well.

NEW APPROACH TO DETERMINE PROBABILITIES OF FLOODING OF DIKE RING AREAS

Nowadays most dikes are at strength in accordance with the safety standards of the Water Defence Act (1996). Over past years a method to determine probabilities of flooding of dike ring areas has been developed. This method is based on the consideration that a safety approach would have to be based on estimates of the flooding risks. In doing so the probabilities and consequences of flooding would have to be considered together and in coherence. Until the present day dikes have been designed on the basis of a high water level with a certain chance of exceedance. The probability of flooding of an area, however, is that it will overflow due to the collapse of one or several dike sections around the area. The new method to determine probabilities of flooding is therefore based on three pillars (Towards a new safety…, 2000):

- a dike ring approach, in which the strength of a dike ring – consisting of dikes, engineering structures and may be dunes – is considered as a whole;
- taking equal account of various types of failure mechanisms of a dike ring;
- discounting in advance all uncertainties when calculating the probabilities of flooding.

Based on this approach it became clear that hydraulic structures in dike bodies would require more attention, while there is insufficient knowledge on the status of older constructions and on the reliability of manual operation of hydraulic structures (Towards a new safety…, 2000). Hydraulic structures might therefore make up a weak link in the dike ring. In calculating the probabilities of flooding, the dike ring area is considered instead of a dike section only. The method also takes account of the possibility of different types and location of failure mechanisms, like weak subsoil, seeping of water through the body of the dike, untimely closure of gates of sluices, or shiplocks (Fig. 9). Calculations on the probability of flooding for a dike ring area showed the weak links in the dikes and indicated how gradual improvements will contribute to a better protection against flooding in future.

When evaluating the acceptability of the probability of flooding in an area the potential damage caused by flooding and danger for the population are pivotal. The Delta Commission acknowledged this already in the 1960s, which in the end resulted in a differentiated safety approach. A following decision on the protection of the Netherlands against high water levels will again involve the consideration of the costs of safety measures and the expected benefits of reducing the probabilities of flooding – less damage. With respect to this it has to be realised that since the

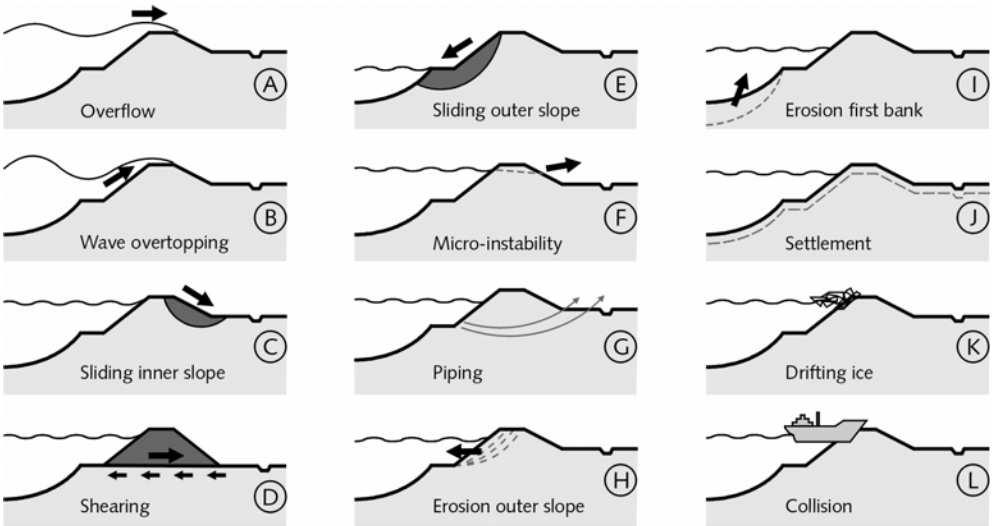

Fig. 9. Dike failure modes (Technical…, 2000)

development of the present standards in the 1960s, the value of buildings and infrastructure and the number of people in the flood prone areas has significantly increased. At present a study is going on to analyse what would be the optimal levels of protection when these aspects would be taken into account, as well as on how such developments may go on in future. Initial results show that indeed on this basis the safety levels, especially in the central and western part of the Netherlands would have to be substantially increased. However, to come with firm recommendations such a study would have to take into account the new approach to determine probabilities of flooding of dike ring areas, which may have cost implications for the works to be done.

THE FUTURE

The Dutch population has now become rather stable, only a modest increase in number is foreseen in the future. At present the population around 16 million. For the next 50 years, some scenarios have been developed: it is expected that the population will further increase between 17 (minimum scenario) and 20 million (maximum scenario) in 2050. To survive in this highly developed and industrialized society in the long term, proper spatial planning and effective water management are crucial. As shown the impacts of climate change on water management and flood protection that may be expected can be easily accommodated during improvement works of water management systems and dikes that from time to time will be required. It will be much more important to take carefully into account the risk of flooding due to sea or river floods and inundations due to extreme rainfall in the planning of land use development, especially for valuable parts like urban and industrial areas, green houses, cultivation of flowers and vegetables, and recreation areas. Design standards will have to be developed and applied in such a way that the resulting water management and flood protection systems will be designed more or less at the economic optimal level.

The question as to whether the Netherlands is safe enough, what measure should be maintained to establish this, and whether the currently defined safety approach still meets acceptable standards, will have to be answered by the politicians. However, as long as population is growing, the value of buildings and infrastructure is increasing, the sea level is rising, extreme river discharges and rainfall intensities may increase, and finally land subsidence will continue to a certain extent, the Netherlands will always have to update and improve its flood protection provisions.

History has shown that again and again new measures had to be taken in answer to new developments, cases of flooding, or unforeseen consequences of former interventions. There is no reason to suppose that in the future such reactions and activities will come to an end. Anticipating future developments – rather than only reacting to them – will be the challenge. New developments will have to be reckoned with and there is no prospect of a permanent situation.

REFERENCES

1. BOETZELAER M. VAN, SCHULTZ B., 2005a. Historical development of approaches and standards for flood protection along the Netherlands part of River Rhine. In: Proc. History Workshop Frankfurt am Oder, Germany, 19 May 2005.
2. BOETZELAER M. VAN, SCHULTZ B., 2005b. Recent developments in flood management strategies and approaches in the Netherlands. In: Proc. 2nd Yellow River Forum, 17–20 October 2005, Zhengzhou, China.
3. BRUIN D. de, SCHULTZ B., 2003. A simple start with far reaching consequences. Irrigation and Drainage 52.1.
4. BRUIN D. DE, 2006. Similarities and differences in the historical development of flood management in the alluvial stretches of the Lower Mississippi Basin and the Rhine Basin, Irrigation and Drainage, Special Issue on Integrated Flood Management.
5. Climate change 2007: the physical science basis, 2007. Summary for policy makers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
6. JONG J. de, HUISMAN P., PAUWELS H., POWEL R., 1999. How to maintain the sustainable development in The Netherlands? In: Sustainable development of deltas. Eds H. Oudshoorn, B. Schultz, A. van Urk, P. Zijderveld. Proc. Intern. Conf. at the occasion of 200 year Directorate-General for Public Works and Water Management, Amsterdam, the Netherlands, 23–27 November, 1998. Delft, the Netherlands, Delft University Press.
7. KNMI climate change scenarios 2006 for the Netherlands, 2006. KNMI Scientific Report WR 2006-01. De Bilt, the Netherlands, Royal Netherlands Meteorological Institute (KNMI).

8. Man-made lowlands. History of water management and land reclamation in the Netherlands, 2004. Ed. VAN DE G.P. VEN. 4th ed. Matrijs, Utrecht, the Netherlands.
9. MEEL P-P.A. VAN, VAN BOETZELAER M.E., BAKKER P.C., 2005. Spatial planning key decision Room for the River. In: Proc. 3rd Intern. Symp. Flood Defence. Nijmegen, the Netherlands, 25–27 May 2005.
10. Room for the river, 2000. The Hague, the Netherlands, Min. Transp., Public Works Water Management.
11. SCHULTZ B., 1982a. A model to determine optimal sizes for the drainage system in a polder. In: Polders of the world. Vol. 1. Keynote Intern. Symp. Wageningen, the Netherlands, ILRI.
12. SCHULTZ B., 1982b. From natural to reclaimed land. Land and water management in the polders of the Netherlands. In: Polders of the world. Keynote Intern. Symp. Wageningen, the Netherlands, ILRI.
13. SCHULTZ B., 1993. History of the water management of the polders in the Netherlands. 5th Special Session on the History of Irrigation, Drainage and Flood Control. Trans. 15th Congr. ICID. New Delhi, India, ICID.
14. SCHULTZ B., PREECHA W., 2003. Some practical aspects of the new policy on water management in the Netherlands polders. In: Proc. 9th Intern. Drainage Workshop. Utrecht, the Netherlands, 10–13 September 2003.
15. SCHULTZ B., SAIFUL A., 1997. Optimisation of water management in polder Flevoland. In: Water: economics, management and demand. Eds M. Kay, T. Franks and L. Smith. Proc. 18th ICID Eur. Region. Conf. Oxford, United Kingdom, 1997. London, Great Britain, E & FN Spon.
16. SCHULTZ B., SURYADI F.X., 2007. What is the real problem? Water management in the drained lakes of the Netherlands under the impact of climate and man induced changes. In: Water resources management and irrigation and drainage systems development in the European environment. Proc. 22nd Eur. Region. Conf. September 2–6, 2007. Pavia, Italy.
17. SCHULTZ E., VERHOEVEN B., 1987. Drainage works in the Zuiderzee project. ICID Bull., 36. 2.
18. SEGEREN W.A., 1983. Introduction to polders of the world, polders of the world. Final report. Wageningen, the Netherlands, ILRI.
19. Towards a new safety approach. A calculation method for probabilities of flooding, 2000. Delft, the Netherlands, TAW.

STRESZCZENIE

Gospodarowanie wodą i ochrona polderów przed powodzią w Holandii w aspekcie globalnych zmian klimatu oraz antropogenicznych zmian użytkowania ziemi

Słowa kluczowe: *polder, gospodarka wodna, ochrona przeciwpowodziowa, gwałtowne opady, zmiana klimatu, planowanie przestrzenne*

Dwie trzecie powierzchni Holandii jest narażonych na powodzie. Sztormowe spiętrzenia wód na Morzu Północnym, wysokie stany wody w rzekach, awarie obwałowań rowów czy obfite opady mogą powodować powodzie. Użytkowanie obszarów narażonych na zalewanie zależy od stałego odwodnienia i od pompowania wód, ponieważ ich powierzchnia może (trwale lub tylko w czasie zalewu) znajdować się do kilku metrów poniżej poziomu otaczających wód. W ciągu ostatnich

dziesięcioleci zmiany klimatu są postrzegane jako główny powód do niepokoju. Jednakże, wpływ zmiany klimatu może spowodować straty w wyniku wzrostu zjawisk ekstremalnych do 45% na stulecie. Jeśli spojrzymy na wywołane przez człowieka zmiany w użytkowaniu ziemi spowodowane przyrostem zaludnienia i gwałtownym wzrostem wartości infrastruktury to stwierdzimy, że przyrost strost może wynieść od 100 do 1000% na stulecie. W związku z tym należy zapytać, co powinno być przedmiotem naszej szczególnej troski?

W oparciu o charakterystyczne dane dotyczące gospodarki wodnej i ochrony przeciwpowodziowej w Holandii opisano w pracy wyniki analiz prognostycznych. Wykazano, że można oczekiwać wpływów zmian klimatu na gospodarkę wodną i ochronę przeciwpowodziową, ale te wpływy dadzą się łatwo uwzględnić przy pracach związanych z usprawnianiem systemów gospodarki wodnej czy środków ochrony przeciwpowodziowej, które od czasu do czasu trzeba będzie podejmować. Daleko bardziej istotne będzie zwrócenie szczególnej uwagi na ryzyko powodziowe w planowaniu przestrzennym, zwłaszcza w odniesieniu do zagospodarowania cennych obszarów takich jak tereny miejskie czy przemysłowe, obiekty ekologiczne czy tereny rekreacyjne.

Received 26.11.2007

Reviewers:
Prof. Magdalena Borys
Prof. Jarosław Napiórkowski