Flood Protection in the Danish Wadden Sea Area

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Abstract

In the Danish Wadden Sea area the main coastal problem is the risk of flooding while coast erosion only takes place in a few small localities and in larger measure at the peninsula of Skallingen. In the Danish Wadden Sea area some 100 km of dike protects the lowlying areas, the marsh areas, against flooding. Through the years the dike protection has been extended and reinforced.

Since the 1970s, the frequency of storm surges has been much higher than earlier in this century. These surges have worn the dikes and many reinforcements have been carried out, and two new dikes have been built protecting the towns Ribe and Højer.

The Danish dikes have always been green dikes, i.e. they are grass covered. They are rather easy to reinforce if necessary to withstand also a relative sea level rise caused by the green house effect, the continuing land subsidence in this area or possible more frequent and higher storm surges in the future.

Introduction

The Wadden Sea extends 500 km of the North Sea coast from den Helder in the Netherlands to the peninsula Skallingen in Denmark, the Danish part of the Wadden Sea being app. 70 km from the Danish-German border to Skallingen, fig. 1.

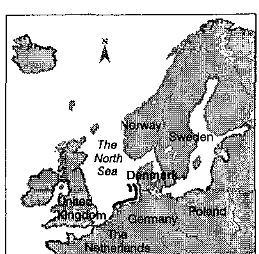

Figure 1. The Wadden Sea and the Danish part of the Wadden Sea.

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The Wadden Sea is dominated by the daily tide ranging from –0,7 m to + 0,7 m DNN (DNN is app. the same as the mean sea level, MSL) and by the strong in- and outgoing currents. At tidal low water app. 70% of the bottom of the Wadden Sea is dry.

Storm surges and floodings have influenced the landscape, the settlings as well as agriculture. In the Danish Wadden Sea, water levels above 3.5 m DNN are characterised as storm surges. In the last hundred years, the highest measured water levels during storm surges have been about 5 m DNN.

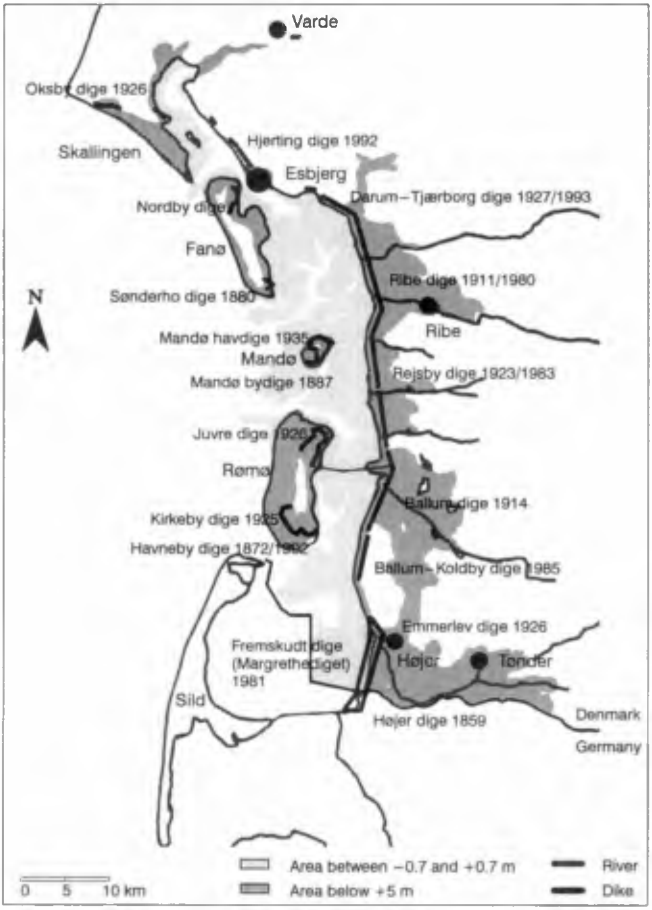


Figure 2. Upgrading of the dike system along the Danish Wadden Sea.

Large parts of the nearshore landscape are low lying and in risk of flooding if the dikes should breach, fig. 2. These low-lying areas are mainly 1 to 5 m above DNN, i.e. there are no areas below MSL. The areas are mainly used for agriculture but large parts of the two major towns Ribe and Tønder and also some villages are low-lying.

Severe Surges and Floodings

In 1362, the storm surge named "Grote Mandranke", i.e. "Great man-drowning" flooded the whole Wadden Sea area. Some sources mention up to 200,000 dead people, but this number has later been evaluated to be much too high. Still the flooding was indeed a disaster.

In 1634 another severe flooding caused 10,000 – 15,000 victims.

In Denmark, the last flooding where people drowned took place in 1923, where a storm surge unusually occurred in August. At this time, one of the dikes was being built and many of the workers were caught by the storm surge at the building site and drowned.

A severe flooding took place in 1953, app. 1,800 were killed in the Netherlands and 300 in England. In 1962 a storm flood killed 350 people in Germany. These two floodings did no harm in the Danish Wadden Sea area.

In 1976 and 1981, the two highest surges in this century occurred in Denmark, both with water level app. 5 m above DNN. These two surges are described below.

The 1964 Storm Flood Committee

After the disaster in the Netherlands and Germany in 1953 and 1962, a storm flood committee was appointed in 1964 in Denmark to evaluate the existing safety against flooding. As part of the work an extensive study concerning frequency and height of storm surges, hydraulic conditions, and safety problems was carried out. The first result of the work was the establishment of a warning and alert system. The work ended in 1975 resulting in an act of reinforcement of Ribe Dike to a safety level of 200 years and building of maintenance roads along most of the dikes. There was a difference of opinion whether Tønder Dike should be reinforced or a new forward dike should be built to achieve a safety level of 200 years against flooding of Tønder.

Ribe Dike and the Forward Dike at Tønder

A severe storm surge in 1976 ended the discussion. Denmark and Germany made an agreement on the building of a new dike in front of Tønder Dike continuing on the German side of the border also as a forward dike. The reinforcement of Ribe Dike was finished in 1980 and the new forward dike was finished in October 1981. Already in November 1981, a more severe storm surge than the one in 1976 struck the Wadden Sea. This only caused small local damages to these new dikes while large damages took place on the older dikes, one dike breached totally (fig. 9c). The profile of the two new dikes is shown in fig. 3.

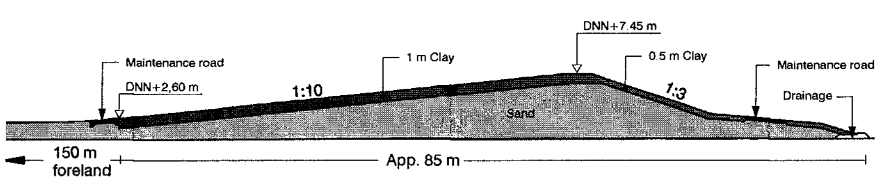


Figure 3. New dike design.

All the Danish dikes have always been green dikes i.e. covered by grass at the whole profile and no protection with stones, concrete, asphalt, etc.

The Dike Protection

Today, the dike length is app. 100 km.

The first dikes built some 500 years ago were only slight dikes functioning as so-called summer dikes, i.e. they protected the agricultural areas in the summer until the harvest was done. They would not protect against the more severe storms in the late autumn and winter. Most of the villages and sparse habitation were built either on natural higher areas or on artificially built rises.

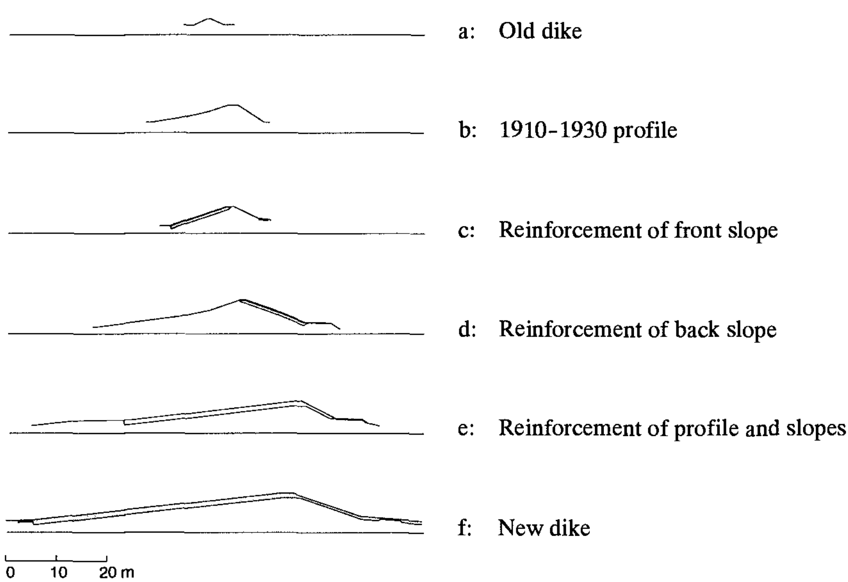


Figure 4. Evolution of dike profile

Fig. 4 shows the evolution in the dike profile since the first summer dikes, fig. 4a, to the newest dikes built some 15-20 years ago and shows the newer reinforcement of dikes.

The period 1910 – 1930 was very windy and some severe storm surges occurred. Because of this and the development in agriculture and habitation in the low-lying areas many new dikes were built, fig. 2 showing year of building and reinforcement, and fig. 4b showing the typical profile. The profile had a concave front slope with an average slope of 1:5 and a rather steep back slope 1:1.5 or 1:2. The strength against breaching has later been calculated to a safety level of 30-50 years.

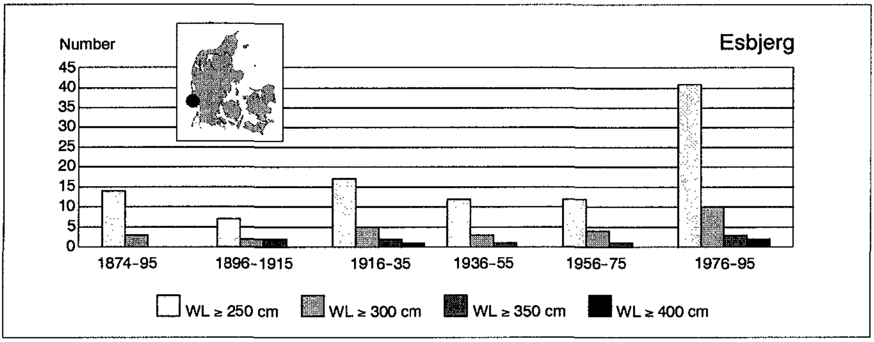


Figure 5 . Number of high water levels in 20 years periods.

The period from 1930 to the middle of the 1970s was rather calm. Since the middle of the 1970s there has been a "bad weather" period, fig. 5. Several storm surges have worn the dikes. It has been necessary to reinforce several of the dikes. These reinforcements have been made in different ways depending on the problem of the individual dike. Fig. 4c shows the reinforcement of the front slope with a clay cover to prevent erosion caused by wave attack. Fig. 4d shows a similar protection of the back slope but also a flattening of the back slope to prevent sliding and erosion caused by wave run over. Fig. 4e shows a reinforced dike profile with new flatter front and back slopes and reinforcements of the slopes with clay to protect against erosion from wave attack. Fig. 4f shows the profile of the new dikes in front of Ribe and Tønder.

Designing the Dikes

The principle of designing the height of the dikes is shown in fig. 6.

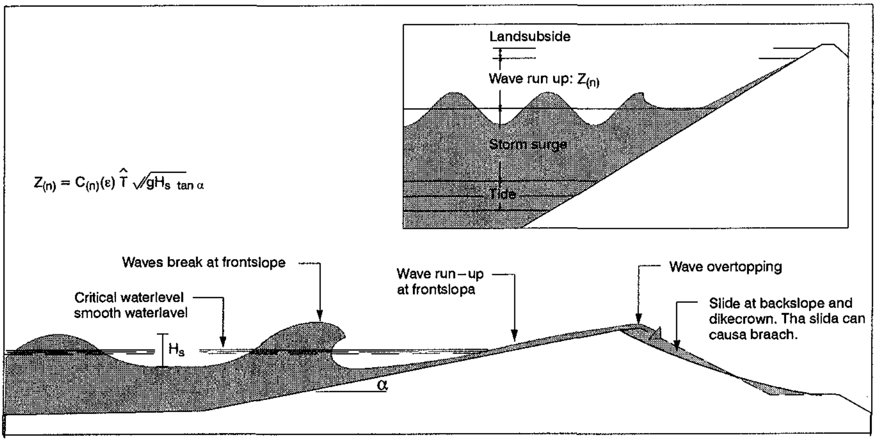


Figure 6. Design of dike height.

The design water level varies from a 50 year storm surge level to a 200 year level, depending on the areas protected.

Fig. 7 shows the frequency of extreme water levels at Højer in the southern part of the Wadden Sea in front of Tønder.

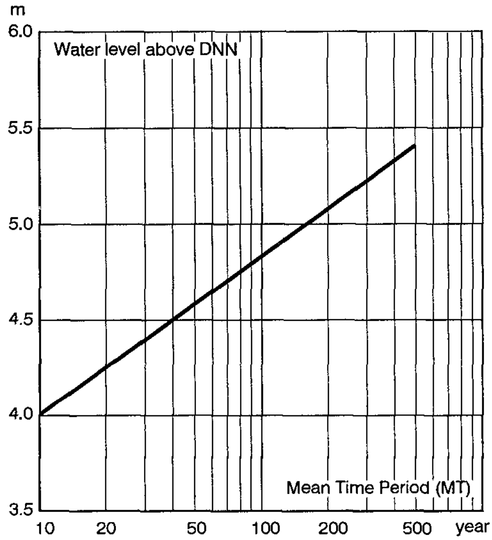


Figure 7 . Frequency of extreme water levels at Højer, 1920-1996.

The wave run up is added to the design water level. The run up depends on the gradient of the front slope, see fig. 6. The run up is app. proportional to tanα so the flatter front slope, the smaller wave run up. When reinforcing the dikes, the front slopes are built with a gradient of 1:7 to 1:10 to reduce wave run up but also because the erosion of the front slope by wave attack will be much reduced when the slope is flatter that 1:6.

By the reinforcements, the back slope is also flattened typically from 1:2 to 1:3, while this prevents sliding if wave run over should occur.

In this part of Denmark, the relative land depression is taken into account when designing the dike height. Fig. 8 shows why this has to be taken into account. During the Ice Age the ice covered the eastern and northern part of Denmark. In fact the whole Scandinavia except the south-western part of Denmark was ice-covered. The ice depressed the earth beneath. Since the melting of the ice Denmark has tilted, where the north-eastern part rises and the south-western part subsides. When designing the new dikes to a safety level of 200 years the dike height is added 20 – 30 cm to take this subsidence into account.

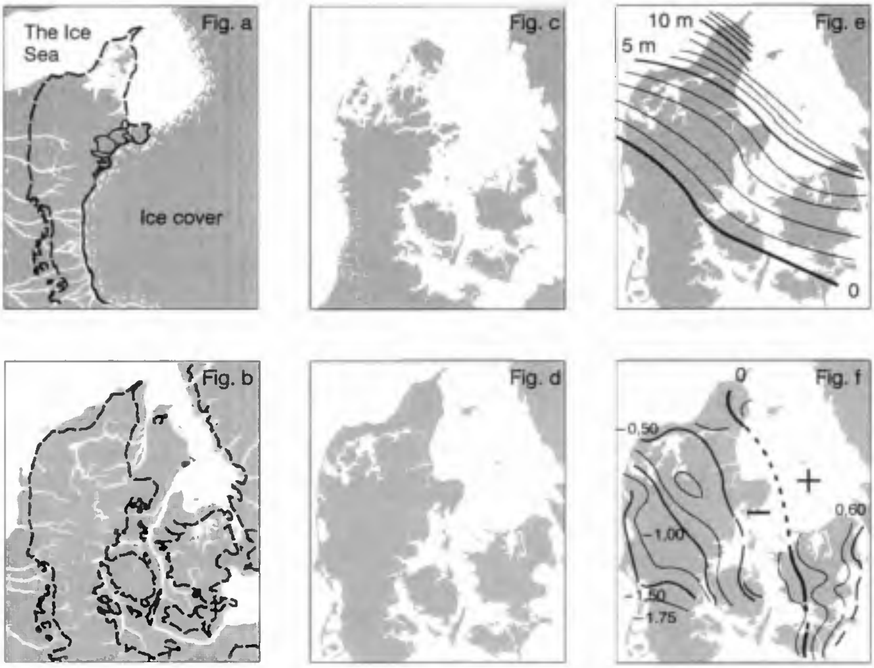


Fig. 8a Postglacial Period approx. 10,000 B.C.

Fig. 8b Continental Period approx. 8- 6,000 B.C.

Fig. 8c Littorina Sea Period approx. 5-2,000 B.C.

Fig. 8d Present situation

Fig. 8e Relative landrise for the Littorina Sea

Fig. 8f The present vertical Land movements in mm/year

The new dikes were designed in the late 1970s. Therefore the relative sea level rise caused by the green house effect has not been taken into account, but it will be rather easy to do this at coming reinforcements of the dikes when the relative sea level rise in the future may be well calculated. In fact the dikes just have to be heightened in the same way as when taking the land subsidence into account.

Fig. 9 shows photos of damages of dikes after a storm surge. Fig. 9a shows damages of the front slope, fig. 9b shows damages and sliding of the back slope, fig. 9c shows dike breach, and fig. 9d shows the situation of wave run over during a storm surge.

The damages and floodings caused by a storm surge depend not only on the surge level but also on the duration of the surge.

The two surges in 1976 and 1981 nearly reached the same maximum water level, app. 5 m above DNN, fig. 10. The rise in the water level happened very quickly (1 m/hour) in 1976 but the duration of water level above 3.5 m was only 4.5 hours while the surge in 1981 rised more slowly with 0.4 m/hours and had a duration of app. 7 hours with water level above 3.5 m DNN. These courses meant that in 1976 there was only short time to evacuate people, there were many damages on both dike front slopes and back slopes but because of the short dura-

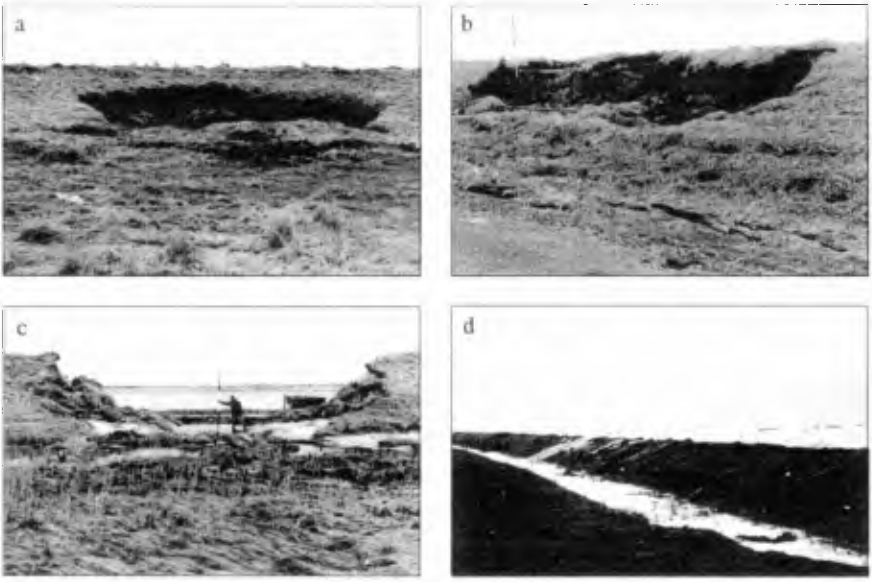


Figure 9. Examples of damages, breach, and wave run over.

tion no dike breach took place. In 1981 the storm surge was predicted very good and the evacuation of people happened without prohlems hut hecause of the long duration of the surge many and severe damages happened to the dikes and one of the dikes breached totally.

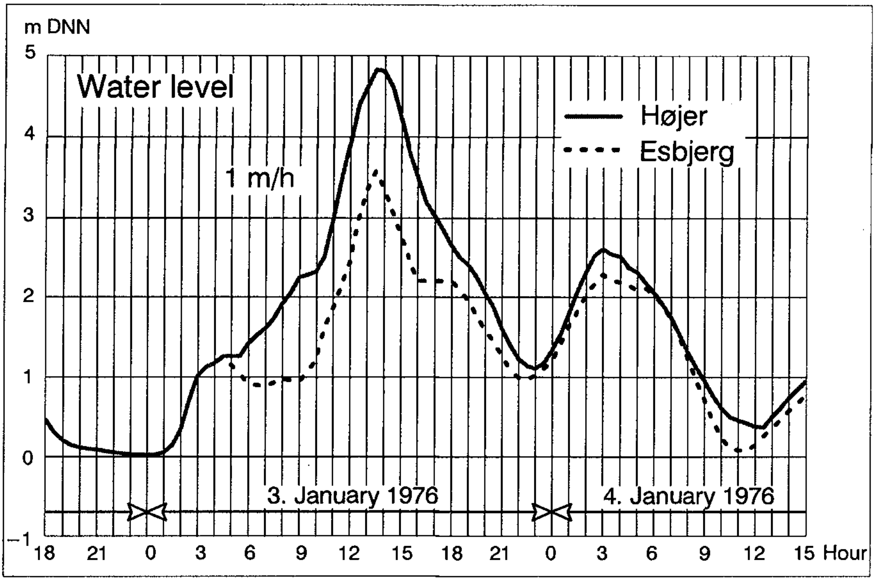
At the storm surge in 1976, the water level in the northern part of the Wadden Sea at Eshjerg was much lower than only 50 km more south at Højer, fig. 10. This example shows the great differences in the maximum storm surge level there can he in different localities in the Wadden Sea under the same storm. These differences depend on how the passage of the centre of the low air pressure takes place and the magnitude of the air pressure.

Flood Warning and Alert

As one of the results of the storm flood committee, a flood warning and alert system was established in 1975. The warning is based upon numerical models for the water levels. The water levels are monitored at five localities in the Wadden Sea and registered at once at the Danish Coastal Authority (DCA) and the Danish Meteorological Institute (DMI).

The models are run hy routine several times a day and if the predicted water levels exceed certain levels the relevant authorities and the press are informed. Depending on the predictions different levels of warning are introduced where the alarm situation is the most severe and implies evacuation of people from the flood threatened areas.

The overall system is managed by DCA, DMI, and the police in the county.



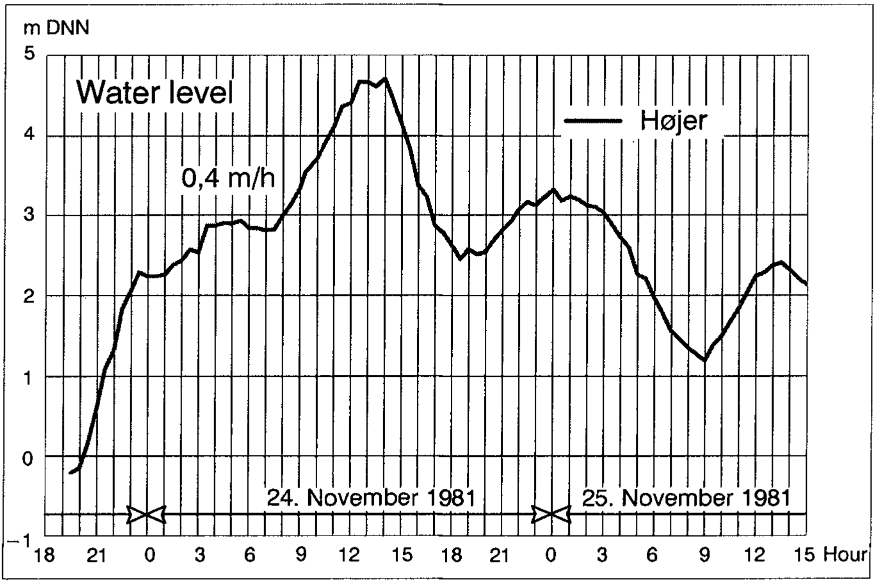


Figure 10. The courses of 1976 and 1981 storm surges.

Administration of the Dikes

Most of the dikes are funded by the State, others also with contribution from the local authorities. The maintenance is managed by local dike committees and one of the new dikes by the Regional Authority. Twice a year the dike committees and the Danish Coastal Authority inspect the dikes to point out possible damages or other aspects that can influence the safety of the dikes. Each dike committee then takes care of the repair.

Preservation of the Wadden Sea

Today, the Wadden Sea and the Wadden Sea coast are preserved and classified as a RAMSAR area. The preservation assumes that new dikes will not be built and reinforcements of the forelands in front of the dikes are not allowed, even though this would improve for the dike safety. In some localities where a narrow foreland is eroded this means that it can be necessary to protect against further erosion with solid constructions as stone revetments. Through the years sedimentation fields have created new foreland.

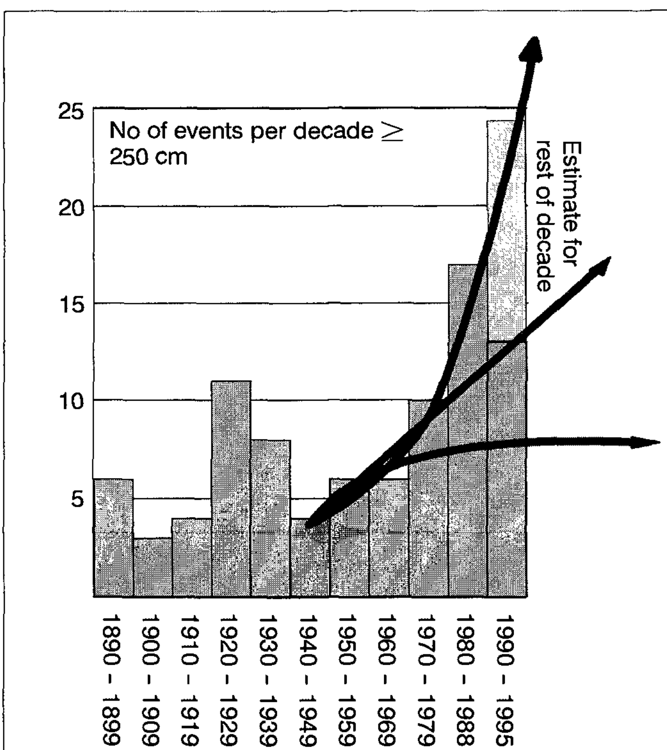


Figure 11. Future challenges.

The Future

The development in the Wadden Sea is observed carefully. Water levels are measured continuously at five localities and wave registration takes place at four localities. The Wadden Sea was surveyed in the 1960s. A similar surveying is carried out these years for calculation of changes in the bottom level of the Wadden Sea. The southern part of this surveying is carried out in co-operation with the German authorities. The dikes are surveyed every five years. A working group with participation of the Danish coastal Authority and the two counties in the Wadden Sea area evaluates the safety level of the dikes on the basis of settlement of the dikes/land, recalculation of the wave climate, update of storm surge statistics and co-ordination of results from a new national precision levelling.

By means of these continuing studies it will be possible to follow a possible sea level rise because of the green house effect and also if the Wadden Sea bottom should rise within the same or less time.

At this moment (1998) it seems that the bad weather period which began in the middle of the 1970s might have ended now, however, it is too early to state this on the basis of the last few calm years, so in fact we do not know the future challenges. They may be as sketched in fig. 11 where the future impact (number of surges) can be everything from the average impact of this century to a continuing of the bad weather period with addition of a general rise in the sea level because of the green house effect and of course the problem with the continuous land subsidence of this area.

Conclusions

The safety level against flooding of the lowlying areas varies from app. 40 years to 200 years based upon the statistics of storm surge levels since 1920. During the last 20 years there have been more frequent and higher storm surges than before, there may occur a general rise in the sea level caused by the green house effect and the relative land subsidence of the area will continue.

These parameters are studied carefully so it is possible to reinforce the dike protection as soon as it is necessary for maintaining the safety level against flooding.

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