Sea defence and flood protection in the Netherlands, anticipating increased sea-level rise

the Dutch approach to a continuous problem

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ABSTRACT

The 1400 km Dutch coastline is affected by sea-level rise. At this moment a legal framework is made to guarantee safety of the dikes also in future. Also a national policy is developed for compensation of all coastal erosion. Both measures should make it possible for the Netherlands to survive an increased sea-level rise.

ADDITIONAL INDEX WORDS: *Dunes, Sea defence, dikes, sea-level rise, coastal policy.*

INTRODUCTION

The Dutch coast

The Dutch sea-defence system is 1368 km long; 320 km sandy coast, 793 km sea dike and 255 km along tidal rivers. Sea-level rise has its impact on the full 1368 km. The 320 km long sandy coast along the North Sea is a dynamic coast. At some locations it is accreting, at other places there is erosion. The location of the erosion varies during the years. Behind the dunes are low lying polders (very often with a ground level even below the low water line), in which millions of people live. The coastal erosion endangers the strength of the dunes as a sea-defence. Erosion of narrow dunes (at some places the dunes are less then 200 m wide) can therefore not be tolerated in the Netherlands. Over a length of 40 km of coastline the dunes have no more than 10 m extra width available to cope with the erosion problem (this means that at, for example, a yearly erosion of only 1 m/year after 10 years the dune is not able any more to work as a sea-defence structure).

But the dune coast is not the only sea-defence line in the Netherlands. The Netherlands are in fact a delta of the rivers Rhine, Meuse and Scheldt. Many estuaries exist. In the Middle-Ages there were 13 estuaries and tidal inlets in the above mentioned 320 km long coast. Through these inlets and estuaries the storm surges could enter deep into the country. Dikes were built along the waters to protect the land from the daily movement of ebb and flood. The polders behind the dunes were artificially drained (by windmills). Extracting water from the soil caused subsidence. This made more pumping required, causing more subsidence. And all the subsidence made it necessary to increase the height of the dikes.

Increasing the dike height was often not done in time. So the Netherlands suffered from many floods, caused by the sea as well as by high river run-off.

In order to solve the problems of flooding in the Netherlands, in the Middle Ages special autonomous and independent authorities were formed with a special task to construct the dikes, to maintain all sea-defences and to build and manage all the pumping works. These agencies, the Polder Boards, still function. They collect their own taxes and have their own elected council and administration, chosen by the inhabitants of the polder. At this moment the Polder Boards are responsible for maintaining the dikes and the dunes as a primary sea-defence. However, they are not responsible for combating the coastal erosion. Erosion prevention is a task of the national government.

THE DIKES

Determination of dike height until 1953

In history determination of the height of dikes was always a problem. Usually dikes were designed at a crest level of 0,5 m above the highest known water level, with a surcharge for wave run-up. After a serious flood, most dikes in the coastal zone were improved. The height was increased up to a level related to the highest storm. However, because of bottom subsidence the crest height of the dikes became also lower in respect to level of the sea. After the second world war engineers and mathematicians warned that this approach is not correct, and that an extreme value statistic should be applied. The consequence of this approach would have considerable financial consequences, and no political decision was made.

The 1953 storm surge disaster

On february 1st, 1953 it stormed. The water-level rose to a level of 0.6 m higher than the highest observed storm surge (of 1894), with as consequence that 1365 km^2 was inundated and 1835 people were killed. 47300 houses were damaged, the total damage was 1500 million guilders (in 1953 1 U.S. $ was approx. 3.60 Dutch guilders). In comparison, in 1916 687 km^2 and in 1894 306 km^2 was inundated. Because most of this area was also below mean sea-level, after passage of the storm, the polders were still covered with water. Repairing 160 km of dike took more than a year at a cost of 380 million guilders. The total direct costs of the disaster were 2000 million guilders, which was 14% of the gross national product in 1952.

The main conclusion was: this should never happen again. A committee of specialists, the delta-committee concluded that dikes should be designed on a design storm-surge level with a given probability of occurrence. From economic considerations followed that storm-surge levels with a probability of less than 1/10,000 a year are the optimum for the densely populated central part of Holland. For the other provinces this value is 1/4000 a year. See figure 1. The shaded areas in this figure are protected from flooding by dikes or dunes; this part of the Netherlands mainly is lower than the daily high water level.

The 1/10,000 storm surge level was determined from extrapolation of all known water-levels at Hook of Holland (see fig. 1), and resulted in a design water-level of 5 m above mean sea-level. This figure has to be corrected for the various locations along the coast.

The Delta-committee advised that a dike should be designed in such a way that every cross-section can withstand this water-level, with the accompanying wave-run up in such a way that no serious damage to the dike will occur. The number of overtopping waves should be less than 2 %. For river dikes later an identical approach was followed.

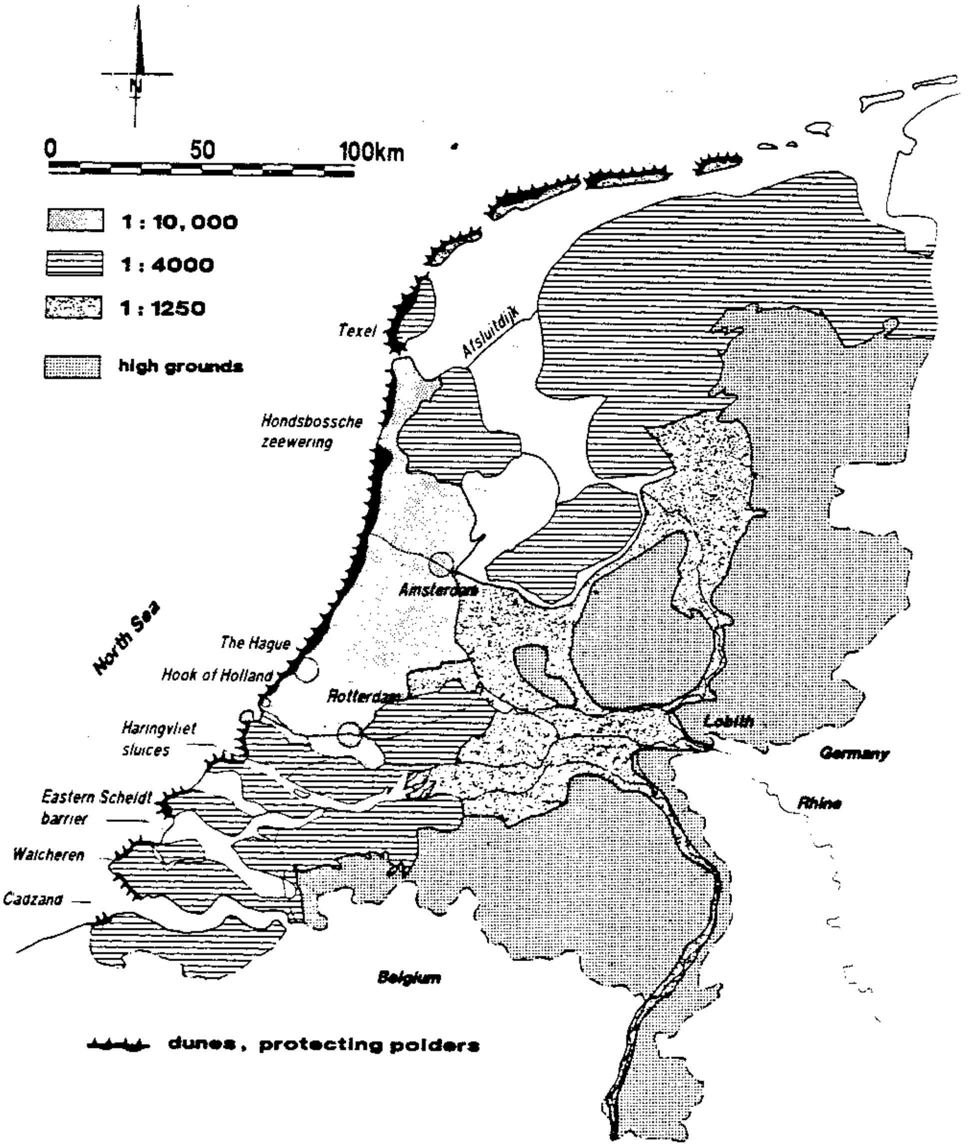

figure 1. Levels of safety and dike-circles

Legal framework for the sea defence system

The protection of land against flooding and inundation was based upon a wide variety of regulations, laws, decrees, etc. After the 1953 disaster the so-called "Delta Law" passed parliament. In this Law it was decided that all sea-defences in the Netherlands should be improved according to the recommendations of the Delta Committee. Also a number of estuaries and tidal inlets had to be closed, shortening the Dutch coastline with 700 km. The works had to be executed and paid by the national government. At this moment the major works are completed. Only the dikes around Rotterdam still have to be improved. Recently it was decided to change the plans by constructing a storm-surge barrier in the entrance to the old Rotterdam docks. Because of this barrier the dike-improvement works in the build-up area can be less [Verhagen and Volker, 1989]. The Delta Law focused on the construction of the dikes, not on the maintenance of the dikes.

Because we have reached the point in which all the sea-defences have the required strength, the task for the coming years is to maintain the reached level of safety. Thereforé a new Law is being prepared. At this moment the "Bill on sea-defence and river dikes" is presented to parliament. It is expected that this Bill will be accepted by parliament in 1990. This "Bill on sea-defence and river dikes" will also provide a basic legal framework for all coastal defence measures in the Netherlands. In this Bill the low lying part of the Netherlands is divided in so-called dike circles. A dike-circle is a low-lying area, which is surrounded by dikes, dunes and/or high grounds. Failure of one section of the sea-defence usually results in the inundation of a whole dike-circle. Each dike circle has a given required level of safety (a "level of safety" is defined as the probability of an event during which occurrence the dikes should guarantee safety; sometimes it is popularly explained as allowable inundation frequency). In figure 1 the required levels of safety are indicated. In this figure most of the 40 dike-circles of the Netherlands can be recognized. They are mainly separated from each other by rivers, canals and estuaries (or high grounds).

The levels of safety are laid down in the Bill on Sea-defence. The choice of a level of safety is fundamentally a political decision.

Sea dikes and sea-level rise

In this Law it is also stated that the boundary values (such as water-levels) have to be recalculated every five years, and that dike managing authorities have to certify every five years that their dike still fulfills the requirements. So, they have to check the height of the dike, the quality of the slope protection, etc. In this way it is attempted to prevent that the effect of climatic changes causes surprises. Dikes will be adapted to the new situations regularly. This is the main reason that design water-levels, etc., are not given in regulation, but only their probabilities.

Adapting the dike height to a higher water level is technically no problem. We have quite a lot of experience in the construction of high dikes. There is not much difference if one lives 5 meters below sea-level or 6 meters. In fact in the Netherlands the infrastructure is available to cope with a sea-level rise. The only thing we have to do is to adapt the used value of 20 cm/century to a higher value. In the Netherlands the main problem is public acceptance. Especially in built-up areas increasing the dike height has a big influence on the cultural and social environment (houses have to be removed, etc.).

The system with dikes, elected Polder Boards, special laws and taxes, pumping works, etc., has been developed during the last 1000 years. In countries where such an infrastructure is not present, the problems to overcome sea-level rise will be much bigger then they are in the Netherlands.

Need for a coastal defence policy in the Netherlands

The dunes are also part of our sea-defence system. At this moment they are strong enough to withstand the design storms. As already stated, the quality of the sea-defence as a means to protect the polders from flooding is the responsibility of the Polder Boards. This makes the Polder Boards also responsible for the strength of the dunes [TAW, 1986].

However it is the responsibility of the national government to take care of the "foundation" of the sea-defence. In other words, the national government is responsible for the battle against coastal erosion.

The erosion problems are not only safety problems. Also at locations where the dunes are wide erosion causes problems. Of course at those points there is no danger for inundation of polders during storm surges. The dune area also has important other values. At a few places people live in the dunes. Historically dunes primarily functioned as sea-defence. Therefore, many dunes became the property of the Polder Board. While some dunes are owned by drinking water companies, dunes remain as sea-defences because the Polder Boards have special jurisdiction over them, even if they do not own them. For the most part the Polder Boards do not allow construction of houses in the dunes. At present there is little private property and permanent housing in the dunes. Only temporary buildings were allowed, which must be removed before each winter (the constructions may increase dune erosion during storms). Because of this policy, the dunes also became important natural reserves, although that was not the original intention.

Dunes valued for ecological important functions, remained in a semi-natural state while the rest of the Netherlands became urbanized, or used for intensive agriculture.

Beaches and dunes have very important recreational value not only for the 14 million inhabitants of The Netherlands but also for the densely populated Ruhr-area in Germany. For them, the Dutch coast is the nearest coastal recreation area. Beaches are generally not affected by coastal erosion. In principle coastal erosion only causes beach problems if a fixed structure such as a sea-wall lies behind the beach. In the dune areas there are recreational facilities such as camp grounds. Structures such as hotels and restaurants in the first dune-row are, of course, endangered by erosion.

Originally, some villages were built just behind (landward) the dunes. As coastal erosion occurred these villages gradually became located closer to the sea (several times in history this required the removal of a village to a new location further inland). Today, in The Netherlands, demolishing houses because of coastal erosion is socially and politically unacceptable, although in some cases it would be economically acceptable. Therefore, the presence of villages near the sea requires a policy that maintains the coastline in its present location.

In the Netherlands the dunes are also used for the production of drinking water. Because ground water in large parts of the Netherlands is brackish, it cannot be used for drinking water. In the 19th century the public water works of the big Dutch towns started to pump drinking water from the fresh-water lenses in the dunes. At this moment the natural supply from these lenses is not enough any more, and the lenses are supplied with river water (mainly from the Rhine river), which is infiltrated in the dunes and recovered later. Coastal erosion endangers the high investments in the drinking water pumping areas.

THE SANDY COAST

Coastal erosion

The dune coast is a flexible sea-defence against the North Sea. Characteristic is the continuous movement of sand in the coastal zone. There is an exchange of sand between the subaerial and subaquatic part of the beach. Currents and waves move the sand on the shore in cross-shore and longshore direction. This process may cause a loss of sand from the sea-defence zone to adjacent coastal sections or to neighboring inlets.

Because of these processes there is a continuous movement of the borderline between land and water. Erosion and accretion alternate with each other. Erosion nearly always causes problems.

There are two types of coastal erosion.

* A fast, extensive erosion caused by quick erosion of dunes during storm surges
* A slow, chronic erosion, which is not so striking, caused by sea-level rise and other morphological phenomena. The chronic erosion moves sand out of the coastal defence zone. An increased sea-level rise may cause an increased chronic erosion. In that case also the coastal profile will adapt to the new waterlevel by moving in a landward direction.

In the Dutch situation the fast erosion during a storm surge is a problem for the Polder Board, because its affects safety. The chronic erosion is a problem for the national government.

In the past chronic erosion was often not prevented. Therefore the Polder Boards, responsible for sea-defence, improved the dunes by placing more sand behind the dunes on the landward side. This caused considerable damage to nature.

In some cases the dunes became so narrow that is was necessary to construct a seawall or a sea dike. The consequences of the construction of seawalls and dikes was that the safety of the polders was guaranteed, but the beaches in front of the constructions disappeared. Trying to control the erosion many groins have been build. Also the effect of groins was not quite satisfactory. When they were located near tidal gullies they were able to keep the tidal current out of the coastline, preventing extra erosion of the beach in that way. Near coastal sections where the tidal current is not so strong, the effect of groins in controlling erosion appeared to be minimal.

Erosion continued in spite of the construction of groins and dikes. In the south of the Netherlands, several polders were permanently flooded due to coastal erosion in the 19th century. In many dune fields it was customary to maintain the dunes at the required strength by moving them landward. This was accomplished by making the seaward slope of the dune-front somewhat more gentle, lowering the dune at the side of the sea, and moving the sand in a landward direction. The principle of this procedure is shown in Figure 2. This procedure does not stop erosion (it may even increase erosion), but the safety of low lying polders behind the dunes was guaranteed at the cost of the dune area. This was not considered to be a problem because of the low economic value of coastal dunes. [Roughly a dune is safe if a minimum profile (both width and height) is available; moving sand landward maintains that profile].

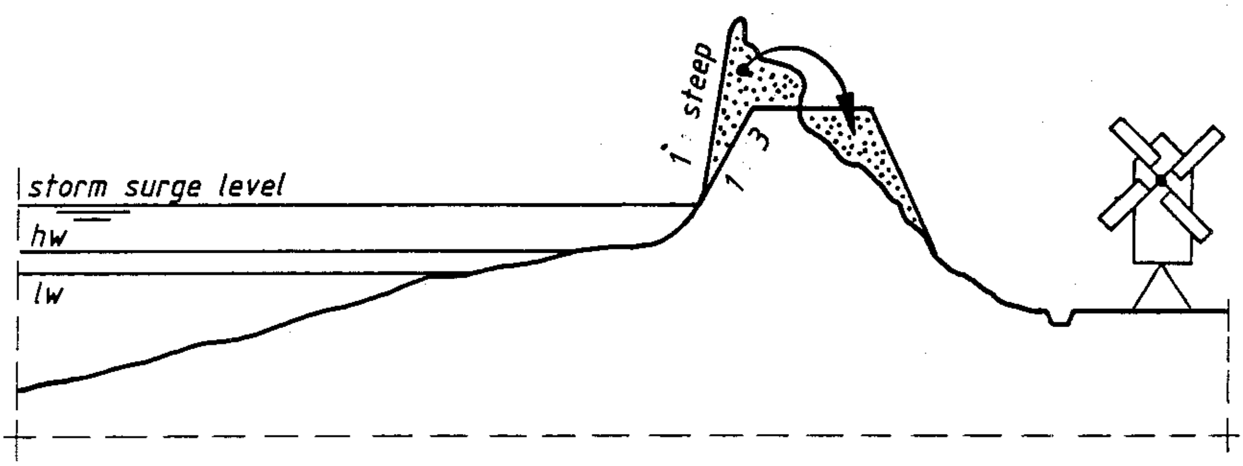

figure 2.: improving dunes by movement of sand

Changes in Dune Appraisal

Today attitudes are different and dunes play an important role in coastal zone management. An important factor is the new regard of dune areas. Dune areas now have a much higher value because they are used as a source of drinking water (by infiltrating river water). They have a very important recreational value (camping grounds, daytime recreation) and they are critical areas from an ecological point of view (rare plants and animals, breeding grounds, etc.).

In the past years the nourishment projects were executed on an ad-hoc basis by the national government and not by the sea-defence authorities. This is caused by the fact that they are generally large projects and that sea-defence was very often not the main reason for the nourishment plan [Rijkswaterstaat, 1987].

Because also the sea-level is rising it is to be expected that the erosion problems along the coast will increase. At the same moment the ecological and recreational pressure on the dune area will increase. These points made it necessary to define a national policy on coastal defence and erosion management.

Impact of sea-level rise

According to our present knowledge the impact of sea-level rise on the coast has two effects:

* First it causes a relatively deeper underwater shore. In order to compensate for that, there is a need of sand on the inshore zone. If this sand is not available from the sea bottom in a quantity which is big enough, this will cause loss of sand in the dunes. The sea-dunes, the row of dunes just adjacent to the beach, becomes narrower and moves landward: The direct effect of sea-level rise. This effect will occur along the entire coastline.
* The second effect is an increase of some of the erosive processes; an indirect effect. There will be an increased demand of sand from those coastal sections located near tidal inlets. Because of the rise the basins behind the tidal inlets will become relatively deeper, consequently they are no longer in equilibrium. This means that also in the basins there will be sedimentation. This sediment has to come from the coast. Especially in those cases where in-

creased sea-level rise is combined with a change in the wind climate a significant increase of erosion the coastal sections near tidal inlets is expected.

An increase of the sea-level rise will cause that a greater part of the coastline will erode. The sectioms which are now already eroding will suffer an increased erosion. For the areas near tidal inlets we expect an increase of erosion with approx. 0.5 m/year; for the other coastal sections this will be in the order of 0.2 m/year.

Impact of chronic erosion on safety

At this moment all the dunes along the Dutch coastline fulfill the requirements of a safe coastal defence system. Along the coast of central Holland the dunes are able to withstand a one in 10.000 year storm. But at some places the dunes are just wide enough to fulfill the requirements. In 1990 42 km of the Dutch coast are so narrow that 10 m erosion will make them no longer fulfill the requirements. If no measures are taken against the chronic erosion, within a few decades many kilometers of the Dutch coast, especially in the south western part of the country are not safe enough. An increased sea-level rise will increase this problem.

Impact of chronic erosion on other functions in the dune area

The dune area consists of approx. 420 km^2. The Dutch dune area is one of the biggest coherent dune areas of Europe. It is a unique natural reserve of international value. A great part of it is subjected to the Law on Natural Reserves.

Locally and regionally the dune ecological system has a variety of qualities. Dunes with small lakes, (freshwater)marshland, dry areas, shrub, moor and woodlands are varied with "normal" beachgrass or dry grasslands, strongly influenced by human activities.

Besides its natural values, the dune area is also of economic value as a production area of drinking water and for recreation. It is used as urban area and at a few places as industrial area. Most of these functions are just behind the sea-dunes. Locally one finds in the sea-dunes a restaurant of some houses. Fortunately the sea-dunes are urbanized only on a few locations.

The sea-dunes are a very specific element of the dune area. The most important function of the sea dunes is to act as a sand buffer for dune erosion during storm surges. By a landward movement of the coastline, the sea dunes move landward, and the user functions and natural values of the dune area are strongly affected.

Finance

The Polder Board raises its own taxes. From this income the Board finances the construction and maintenance of dikes. Because fighting chronic erosion is a task of the national government, beach nourishments cannot be paid from the Polder Board taxes. The costs of combating erosion has to be covered from the National Budget. However there is no structural budget item. Beach nourishments in the past have always been financed on an ad-hoc basis. In order to be able to have a long term policy in this field, it is obvious that money for beach nourishment has to be available also in future. The only way to do that is by establishing a special item on the National Budget for coastal maintenance.

STRATEGY TO A COASTAL POLICY

The problems

In the past all attention was paid to improvement of the sea-defence system, and not on erosion control .Therefore no general policy was developed regarding coastal maintenance. If the dunes were wide enough, there was no problem. Coastal erosion was only a problem, when the safety of low-lying polders behind the dunes was endangered. Because nowadays the dune areas itself are regarded as very valuable, erosion is always a problem. From various groups from society there came a strong pressure to stop the erosion. Some 10 years ago it became therefore necessary to nourish a few beaches on places were there was no need for beach nourishment from a strictly "sea-defence point of view". In other words, nourishment had to be done on places where the dunes were wide, and were there was no danger of inundation of polders. The legal framework in the Netherlands formally could not provide a basis for these nourishments. Neither there was a component in the National Budget for financing such non-safety related nourishments. Financing these nourishments was therefore always a problem [Verhagen, 1990]. It is clear that in the near future more nourishments will be be required. For a long term policy regarding coastal maintenance, it is therefore necessary to have a fixed amount of money available in the National Budget.

The real problem is how to get such a fixed amount of money on the National Budget. Otherwise it is not possible to do the job. The responsible department (Rijkswaterstaat) followed a step-by-step strategy, using signals from society, leading to a strong public opinion favoring coastal maintenance on a national scale. The following steps were taken:

1. For a case where there was a strong pressure from the public, a detailed policy-analysis was made, to see what amount of money would be realistic to spend on beach maintenance project in relation to the values lost if erosion would continue at that place.
2. From that analysis followed that beach nourishment was a socially well acceptable solution for the erosion problem. Also the costs proved not to be excessive.
3. An analysis was made of the costs of beach nourishment projects in the past. Ample publicity was given to the results. Special leaflets were made and distributed to policy makers in society.
4. The next step was that the Minister of Public Works asked for a policy analysis on coastal management. The study for this policy analysis was performed by Rijkswaterstaat, assisted by specialized institutes (like Delft Hydraulics) and universities. An inventory of all available knowledge regarding the Dutch coastline was made, forecasts were made on the expected sea-level rise and on the development of the coastline for the next century. Maintenance methods and costs were analyzed. This study took approx. one year and resulted in a set of 20 technical reports. On the basis of the technical reports, a discussion memorandum was produced in which 4 different management strategies were presented. These strategies were presented to parliament and other groups for discussion [Rijkswaterstaat, 1989]. Public hearings were held. The strategies are discussed later in this paper.
5. After the discussion the minister of public works makes a choice from the alternatives and present the decision to parliament for

approval. This was done in May 1990. The chosen alternative is Full Erosion Control, with a few amendments. For example in areas where there is a wide sand bank in front of the dunes, this sandbank will not be maintained. When approval (including the budgetary) is granted by parliament, the national coastal management policy is effective.

Alternatives for a coastal defence policy

Alternatives for a coastal defence policy in any case must meet requirements concerning safety against inundation. Additionally demands concerning protection of other functions in the dunes can be made. Presented are four alternatives to parliament and public: Withdrawal, Selective erosion control, full erosion control, seaward expansion.

alternative 1: withdrawal

If nothing is done, the coastline will erode. This is not acceptable on locations where the dunes have only marginal safety. Everywhere where the dunes are wider, erosion can be allowed until the minimal dune width is reached.

This alternative is the minimal proposal. The coastline of the Netherlands will be determined by the natural erosion. Only at those locations where the safety of the polders is in danger, action will be taken. Generally the action will be beach nourishment, but also other solutions are possible (like the construction of a high sea-dike). After some years artificial headlands will be formed along the coast (the coast between the headlands continues to erode). The costs to defend these headlands will increase in due course.

If erosion continues, there is the possibility that villages in the dunes (not in the polder-area) have to be removed to a more inland location. This has happened often in the past centuries. Also damage will be caused to recreational areas, natural reserves and the drinking water production. The loss of land in the next decade will be in the order of 350 ha (800 acres) and 20 km of coastline has to be defended by beach nourishment or other means.

In a few cases also the dunes has to be improved on the landward side. This improvement will in value approx. 100 ha (220 acres). In this alternative all sea-dikes and groins will be maintained in the same way as it was done until today. A landward reconstruction of these structures has proven to be more expensive than maintenance on the present location. This alternative will cost 35 million guilders per year (18 million US $/year).

alternative 2: selective erosion control

The second alternative is control the erosion in a selective way. Here also safety is the primary aspect. But erosion is not only controlled in case of danger for inundation of polders, but also when important other functions are at stake. Because there are many functions in the dune area, some choices have to be made. What has to be protected, what is "important" ? In this alternative the following choices have been made:

- all villages in the dune area will be protected;
- natural reserves with an (international) high value will be protected;
- infiltration plants for drinking water production will be protected;

- investments for recreation will be protected (hotels, etc.).

The expected loss of land in the next decade will be approx. 100 ha (220 acres), 60 km of coastline has to be protected and the cost are 45 million guilders per year (23 million US $/year). The details of this alternative have to be worked out on a regional level.

alternative 3: full erosion control

The coastline of 1990 will be maintained. Erosion will be compensated fully by beach nourishment. A small strip will be available for natural fluctuations of the beach. Nourishments will be performed on the beach, but probably also just in front of the beach, on the inshore zone. There will be no loss of land, 140 km of coastline has to be protected by nourishment. The costs are 60 million guilders per year (30 million US $/year).

alternative 4: seaward expansion

This alternative is a more active one than the other alternatives. In this alternative the dunes which have a marginal safety are improved by making more beach in front of them. This will be done by the construction of very long groins and other construction in the sea. This alternative has not yet been worked out in the same detail as the other ones, therefore the cost-indications are more tentative. The main purpose of this alternative is not the creation of extra land. Most of the constructed accretions are on locations were they do not have a high economic value. The purpose is improving the sea-defence. It is a more offensive policy than the other ones.

Also 140 km of coastline requires protection in this alternative. The costs are approx. 80 million guilders per year (40 million US $/year).

Method of analysis

To allow a good political discussion on the subject, and to inform decision makers on all aspects of the four alternatives a policy analysis approach was followed. For the four alternatives it was computed what would be the effects on coastal defence, on nature, on recreation, etc. and what would be the costs.

A computer model was made with a description of the coastal zone, with all the functions of the coastal zone and with the ability to compute coastal erosion as a function of time and sea-level rise. From a coastal engineering point of view the model is quite simple. It is more or less a curve fitting program using measured erosion rate data. But it is possible with this model to compute the coastline for example in 2020, if only beach nourishment is executed in front of villages and towns, assuming a sea-level rise of, for example, 60 cm/century. Knowing the coastline of 2020, the model counts how much land is lost with nature reserve, with recreational facilities, with individual houses, etc. Also the maintenance costs are calculated.

As a basis of the model an inventory of coastal knowledge regarding the Dutch coast was made, and published in 20 technical background reports, with a total size of approx. 4000 pages. These reports are available to the public. They are only available in Dutch. A list is referred to the appendix.

With this model a wide variety of alternatives was computed. Finally only the four alternatives mentioned before were presented. For the four alternatives three variations in sea-level rise have been computed. The present rate of sea-level rise (20 cm/century) is used in the costs mentioned above. Besides, two scenarios with increased sea-level rise have been studied. One with a sea-level rise of 60 cm/century and one with a sea-level rise of 85 cm/century plus an additional change in the wind-climate (mainly a change in the wind direction).

This resulted in the following data:

	20 cm/century	60 cm/century	85 cm/cent+wind
1. withdrawal	100 %	110 %	155 %
2. selective control	100 %	110 %	160 %
3. full control	100 %	115 %	165 %

Table: Extra costs for the alternatives 1/3 due to increased sea-level rise.

Implementation of the coastal defence policy

Implementation of the coastal defence policy after approval of the parliament still causes some technical problems. One of the problems is where to find the sand needed for erosion control. At this moment sand is mainly used from offshore area, 20 km outside the coastline. Also sand is used dredged from entrance channels, and from natural tidal channels.

CONCLUSIONS

The sea-level rise has two major effects on the Dutch sea-defence system. The first effect is on dikes. The dikes have to be improved continuously. A legal framework is prepared to cope with that problem. The basis is a five-year cycle of defining new hydraulic boundary values (waterlevels) and testing if all dikes fulfill the requirements. Maintenance of the dikes is done by special authorities with their own taxes to pay the costs. Technically it is expected that all problems can be solved (It does not make much difference if one lives 5 meter below sea-level or 6 meter below sea-level !!).

The second effect is increased coastal erosion. A decision has been made by the government to maintain the coastline at its 1990 position. Chronic erosion will be compensated by beach nourishment programs. The costs of the beach nourishment programs will be paid from the National Budget.

Actual designs of sea-defence structures like dikes, sluices and locks are still based upon a 20 cm/century sea-level rise. However, lee way is reserved for future works, if the sea-level rises more than 20 cm/century as it did during the last decade. Structures are built in such a way that improvements can be made quite simple in case of a rising sea-level.

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APPENDIX

List of background reports on the Dutch coast
Reports are available in Dutch from Rijkswaterstaat, Tidal Waters Division, p.o. box 20907, 2500 EX The Hague, The Netherlands.

1. Sandsystem of the coast; a morphological characterization
2. Situation in 1990; type of coast and location of the coast
3. Coastal maintenance; costs of basic maintenance
4. Inventory of dune-functions
5. Coastal predictions; predicted coastlines 1990-2090
6. sea-level rise; hydro-meteo scenarios
7. Dunes as a sea-defence; the impact of coastal changes on safety
8. Dune functions; impact of coastal dynamics
9. Inventory functions of the inshore area; interaction with sea-defence
10. Mining sea sand; the influence of borrow-areas on the coast
11. Beach and dune nourishment; effectivity and costs
12. Groins and pile-groins; evaluation of their effect
13. Big civil works; influence on the coastline
14. Inshore nourishment; an alternative for coastal defence
15. Monitoring the coast; present situation and future
16. Hard sea-defence; sea-dikes, harbor areas and beach walls
17. Policy-analysis model
18. Results of calculations with the policy-analysis model
19. Innovative coastal defence
20. Coastal defence seaward of the coastline