Coastal Protection and Dune Management in The Netherlands

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Abstract
Because dunes protect a large part of The Netherlands against coastal flooding and inundation, it is vital to guarantee the strength of these natural sea defenses. Besides sea defense, dunes have other functions. Sandy shorelines and dunes are frequently eroded. A legal framework has been developed that guarantees the required safety-level of dunes and protects the dune environment as well. Erosion of the coastline is compensated by artificial beach nourishment.
***Keywords**: Dunes, sea defense, artificial beach nourishment, floodplain, dike, erosion*

HISTORY

The Netherlands are located mainly in coastal floodplains. Because primary urban and industrial zones lie below the formal high water level, sea defense is critical. By the Middle Ages the inhabitants of The Netherlands defended themselves against the sea by constructing dikes mainly a long tidal in lets and rivers. Along the sea coast where a row or dunes existed, the construction or dikes was not required (Figure 1).

Even though the dunes eroded, t his recession was not regarded as a great problem. Dune areas are not important for agriculture; their primary use in former centuries was for hunting rabbits and mining sand. In some place s, however, the dune row became so narrow that remedial action became necessary. Along the coast or Delfland (between t he Hague and Hook or Holland) erosion was significant in the eighteenth century and a breakthrough among the dunes was reared. Such a breakthrough would ca use permanent inundation of wide, populated areas. Therefore, the construction of groins began in 1776 with the intention to stop erosion. Along this section groin construction continued until 1975 and today the entire coastal stretch is protected by groins.

Along other coastal sections in The Netherlands erosion control also became necessary.

Groins were constructed as the practice of choice, In a few cases it was necessary to build a seadike as in the large works encompassing the dike near the west point of Walcheren and at the Hondsbossche Zeeweering in the north of Holland, Other means to protect the coast were not then available.

Erosion continued in spite or the construction or groins and dikes. In the south or Zeeland (southern Netherlands near Cadzand), 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 t he dune at t he side or the sea, and moving the sand in a landward direction. The principle or this procedure is shown in Figure 2. This procedure docs not stop erosion (in some cases it may even in crease erosion), but the surety or low lying polders behind the dunes was guaranteed at the expense or the dune area. This was not considered to be a problem because of the low economic value of coastal dunes

Figure 1: Part of the Netherlands below sea level

CHANGES IN DUNE APPRAISAL

Today attitudes arc different and dunes play an important role in coastal zone management. First, better methods for determining safety of dunes were developed. In 1984 the "Technical Advisory Committee on Water-defenses" presented guidelines for the evaluation of dune safety as a coastal defense (TAW, 1986). In these guidelines a method is presented to calculate the strength of a dune during a storm surge. This method is based upon a normalized coastal profile after a storm-surge and an equilibrium of sand in this profile (VAN DE GRAAFF, 1986).

Al so, new techniques have been developed for coastal maintenance. Artificial beach nourishment has become important, partly as a byproduct of the dredging industry. Prices in The Netherlands are between US$ 1 - US$ 4 per cubic meter placed on the beach (RIJKSWATERSTAAT, 1987). These low prices made it financially possible t o switch from dune improvement at the landward side to improvement by beach nourishment.

A third 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.)*.

Because of the increased importance of dune areas, official Dutch policy is that the coastline will be maintained at its present location (MINISTER OF PUBLIC WORKS, 1988) but not at any cost. Therefore, this paper explores the cost factor in the decision-making process.

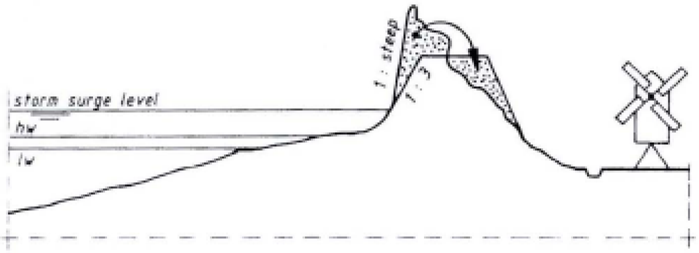

Figure 2: Dunes moving in a landward direction

AUTHORITIES INVOLVED IN COASTAL MANAGEMENT

In order to describe Dutch coastal policy, some elaboration is required for the authorities involved. Already in medieval times Polder Boards (in Dutch *Waterschap)* were formed for every low lying area. A Polder Board has jurisdiction over an area between 200 and 2000 square kilometers. They raise their own taxes and have a "parliament" chosen by landowners and homeowners of the polder. Decisions are made on a "one acre - one vote" system. In built-up areas fictitious acres are given, related to the value of a building. A Polder Board is responsible for dikes (sea defense and river dikes) and for water management (drainage system and pumping works). Maintenance and construction of dikes is financed by the Polder Board. In the Bill on Sea Defense and River Dikes (1988) it is stipulated that Polder Boards must make a report every five years to the central government on safety conditions of their dikes. The Polder Board receives a subsidy from the central government for their expenses. Subsidies are generally on the order of 20 - 40% because of the national interest inherent in their polders. The philosophy behind this system is that the dikes are to be paid by those who benefit from them, *i.e.*, the people living behind the dikes. People living on higher ground in the eastern Netherlands do not want to pay for dikes in the west. However, there is a national interest in polders because of national roads and railways going through the polder as well as national natural reserves. This national interest implies a national contribution to their costs. This contribution is paid as a subsidy for the expenses of the Polder Board.
The enclosure dams (Afsluitdijk , Oosterschelde-barrier, Haringvliet sluices, *etc.*, see Figure 1) are maintained by the central government because there are no polders directly behind these dams. Coastal maintenance *(i.e.* measures to keep the coastline in its present location) also is paid by the national government because coastal processes are on such a scale that they are beyond the scope of a Polder Board.
A special arrangement was made after the storm-surge disaster of 1953. By a special Act of Parliament all primary sea defenses and river dikes in The Netherlands had to be raised to a level that could withstand a storm having a probability of occurrence of *1/10000* per year for central Holland and 114000 for other provinces.
River dikes have to withstand a run-off with a probability of 111250 per year. The dunes (see Figure 1) are primary sea defenses. The works required under this Act were paid fully by the national government in the case of sea defenses and 80% for river dikes. The Polder Boards were responsible for the execution of the works. All sea defenses have to be raised to the required level in 1990. River dikes should be at the required level by the year 2000. The special enclosure works (Haringvliet Sluices, Oosterschelde Barrier, *etc.)* were built by central authorities. Under this Act many kilometers of dunes were reinforced by placing more sand just landward of the most seaward dune-row.

THE PRESENT SITUATION OF THE DUNES

Historically, dunes primarily functioned as sea-defense. Therefore, many dunes became the property of the polder board. While some dunes are owned by drinking water companies, dunes remain as sea-defenses 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 winter. Because of this policy, the dunes also became important natural reserves, although that was not the original intention.
Originally, some villages were built just behind (landward) the dunes. As coastal erosion occurred these villages became 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 at its present location. The production of drinking water by infiltration of river water from dunes is quite

important. Drinking water production companies also ask for dune protection. Beaches and dunes have very important recreational value not only for the inhabitants of The Netherlands but also for the densely populated Ruhr-area in Germany. 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 campgrounds.
Structures such as hotels and restaurants in the first dune-row are, of course, endangered by erosion. Dunes valued for ecologically important functions, remained in a semi-natural state while the rest of The Netherlands became urbanized, or used for intensive agriculture.
Recently, unsafe dunes were improved to fulfill safety requirements. Most improvements (mainly by placing extra sand behind the dunes) were designed in such a way that safety against inundation is guaranteed until *ca.* 2000. In the period 1975-1988 US$ 75,000,000 was spent for this purpose.
The three above-mentioned uses (drinking water, recreation and ecology) impact each other but they hardly have any influence on safety. Therefore these interrelated impacts are beyond the scope of this paper. Safety requirements, however, have impacts on these three functions. This, combined with changes in dune appraisal was the main reason to develop a new coastal policy.

DUTCH COASTAL POLICY

The principles of coastal policy are (MINISTER OF PUBLIC WORKS, 1988a, 1988b):
(a) A polder is endangered when the sea defenses around the polder cannot withstand a storm having a probability of occurrence of 1110000 per year for central Holland, and 114000 per year for the other provinces.
(b) Responsibility for the safety of dunes rests with the Polder Boards. If the safety of a polder is endangered because of coastal erosion the Polder Board is authorized to undertake action by requesting the national government to improve the sea defense by coastal defense works.
(c) When the safety of low lying polders is endangered because of coastal erosion, a coastal defense work will be executed and paid for by the central government.
(d) Coastal defense works are to keep the coastline at its present location preferably by beach nourishment.
(e) If the coast is eroding and no polders are endangered, a decision on coastal maintenance works has to be made by the minister of public works, depending on the values present in the dunes and depending on the cost of the works.
(d) Works to maintain the coastline are paid mainly by the central government.

However, the decision to pay for such work depends on the intention and ability of local authorities to co-operate on a financial basis. The process of making such decisions is illustrated in Figure 3. An example is given later in this paper.

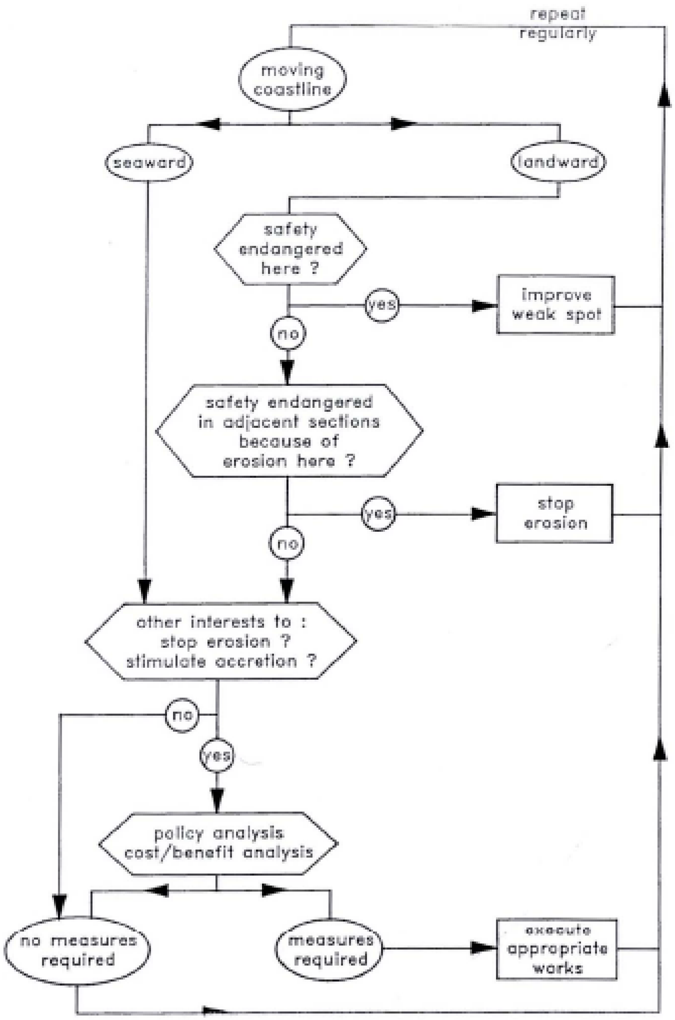

Figure 3: Decision making process for coastal works

On a national level these principles are presently being worked out in detail. A full inventory of the coastal zone is underway and many practical decisions have to be made. The result of this work will be available to parliament when discussing the Bill on Sea Defenses and River Dikes.

The starting point of this policy is safety. All dunes should always fulfill safety requirements first. If a dune is no longer able to protect the polders, improvement is obligatory. In consultation with the Polder Board and other local authorities the Minister of Public Works decides what kind of improvement is to be done. Preference is given to beach nourishment, although if too expensive other solutions may be preferred.

This occurs where deep channels experience excessive sand losses. Also, a solution will be chosen which optimally supports other functions in the dune area. Examples of other solutions include the construction of beach walls, groins to keep tidal channels away from the coastline, etc. If erosion occurs in an area with no direct threat of polder inundation there is no legal obligation to control erosion. In such cases a detailed inventory of all functions in the dune area has to be made, as well as a cost estimate of the works which might be executed. A policy analysis follows.

In cases where there is a relatively wide row of dunes (see Figure 4) the approach is: the safety of the polder meets the required10^{-4}–level (Bill on Sea Defense and River Dikes, 1988), and dunes I and II are strong enough to provide this degree of safety. Suppose dune-row I alone can provide safety to 10^{-3} storm only. From analysis, this level of safety is high enough for a coastal village, because of dune-row I fails, only the village will be inundated and not the low-lying polder. Thus the requirements of the law are fulfilled. Strengthening protective works on the basis of the Bill on Sea Defense would not be executed. However, there is a different policy when coastal erosion threatens the village. From a policy analysis the "housing" function is valuable. Consequently, it will be decided by the Minister of Public

Works to "stop" erosion (by means of beach nourishment), but not to increase the strength of the first dune row.[1]
In Figure 5 the situation is different. The area between dune rows I and II, used as a car park for beach visitors, needs to be safe only to a value of 10^{-1}. Moreover, because of erosion dune-row I will disappear. "Stopping" erosion is expensive because erosion is caused by a landward movement of a deep tidal gully. Beach nourishment is not feasible here. The only applicable method to stop erosion completely is placing stone protection works along the underwater shore which is extremely expensive. It can be concluded that in this case no strengthening works are required based upon the law on sea defenses, but also that stopping erosion should not be attempted because protection is too costly with respect to the values to be protected. The car-ark can be moved into the polder area. While this costs money, it is less expensive than coastal protection and no other functions are endangered.

Figure 4: Situation in which erosion should be controlled

Figure 5: Situation in which erosion will not be controlled

PRACTICAL OPERATIONS
Along the entire Dutch coast, a measuring line perpendicular to the coast is defined every 250 m. On this line a profile is measured annually. This is done from ca. 800 m seaward of the msl-line until and including the first dune-rows. The underwater area is measured with an echo sounder; the section above low water is done with aerial photogrammetry.
Below low water data are collected every 10 m apart, above low water a distance of 5 m is used. These data are available in a national database and can be used by coastal managers as well as by scientists. The system has been operational since 1963. The measurements are taken and maintained by the national government.
The most recent soundings are used for testing the safety of dunes. For the last 5 - 10 years for every profile a dune erosion calculation is made. This is done by determining the equilibrium profile according to VELLINGA (1983):

$$\left(\frac{7.6}{H}\right) y = 0.47\left[\left(\frac{7.6}{h}\right)^{1.28}\left(\frac{w}{0.0268}\right)^{0.56} x + 18\right]^{0.5} - 2.00$$

in which

H is the significant deep water wave height (m)
w is the fall velocity of the sediment in stagnant water (m/s)
x is the distance from the dune foot, in seaward direction (m)
y is the depth below storm surge level (m)

The erosion extends from

$x = 0$ and $y = 0$ (dune foot at storm surge level)

down to

$x = 250\ (H/7.6)^{1.28}\ (0.0268/w)^{0.56}$ and
$y = 5.72\ (H/7.6)$

The principle of the dune erosion prediction model is shown in Figure 8. The erosion profile has to be situated in such a way that the eroded quantity is equal to the accreted quantity. With this model, the

[1] In the Netherlands generally a safety level of 1/500 per year for coastal villages in dune areas is accepted. This means that houses may be damaged by a storm surge with a probability of occurrence of 11500 per year, provided that this surge will not cause permanent inundation of polder areas.

dune foot after a design storm surge can be determined. For a given measuring line safety is assessed by calculating the "dune foot after design storm surge" in all measured profiles for the last 5-10 years. These points can be plotted in a diagram as a function of time. Through these 5-10 points a linear regression line can be drawn which allows extrapolation for 2-3 years. In this way the dune foot which would be formed after a design storm in the future years can be calculated.
Thus, it can be determined if the dune is still strong enough as a sea defense structure. For a more detailed description of this method refer to VAN DE GRAAFF (1986) or to the Guidelines (TAW, 1986).
Testing of safety has to be done by the Polder Board. In principle, they have to determine how safe the dunes are and in which year safety may be compromised. When they expect problems in the near future the Polder Board informs the national authorities and a technical solution is developed.
The national authorities (Rijkswaterstaat) use the sounding data to calculate coastal regression. Coastal regression is calculated using volume integration of the sand in several zones. For gentle profiles, volume integration is executed in zones with a fixed horizontal width *(e.g.,* from the low water line to 200 m seaward). For steep coastlines (along tidal channels) volume integration is done in zones with a fixed vertical width *(e.g.,* from the low water line until the 5 m depth contour). The resulting quantities are plotted in time-diagrams (see Figure 6 and Figure 7). Based upon these diagrams a prediction is made for the quantities to be expected in the near future. Predictions of future coastal profiles (and thus of future coastlines) are based upon predicted future quantities. However, at many places in The Netherlands long-term coastal regression is not linear but is influenced by sand waves with a periodicity of 50-100 years with an amplitude of 50-250 m. These waves move along the coast and may have a considerable impact on coastal predictions (VERHAGEN (1989) and RIJKSWATERSTAAT (1987, page 99).

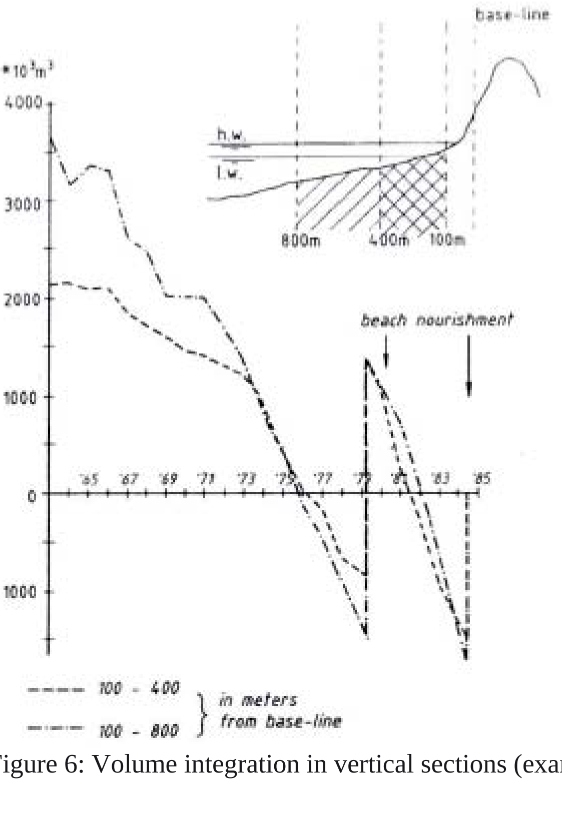

Figure 6: Volume integration in vertical sections (example from Texel)

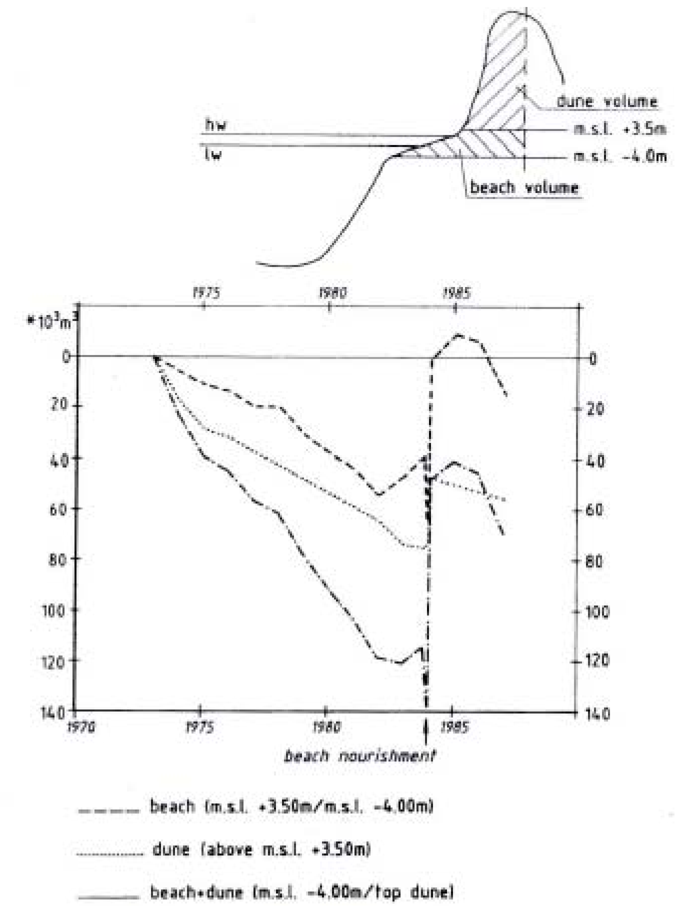

Figure 7: Volume integration in horizontal sections (example from Walcheren)

If coastal erosion is expected in the next several years, it is determined how much it will cost to stop the erosion by means of artificial beach nourishment, or with some other means. When it is known how much it costs to stop erosion, a procedure is initiated in which the various authorities involved (Polder Board, national governments, province, county) will give their opinion on the problem, and what their financial involvement will be.

Example
This process can be explained using an example. In the south of The Netherlands near Cadzand a coastal section did not have the required safety level. The Polder Board prepared a plan to strengthen the dunes (at the landward side) in order to obtain the required level of safety. The project was estimated to cost 4.3 million US dollars. Because a weak tidal channel causes some erosion and stone protection at the dune foot prevented natural feeding of the beach from the dunes, the beach was very narrow, and beach width was expected to decrease in the next five years t9 almost zero, A plan with artificial beach nourishment would give a wider (and higher) beach and require less sand behind the dunes. Also, the unit price of the sand would be much less. This alternative was estimated to cost 7.3 million and for stimulating economic development in this area, leaving a gap of 1 million U.S. dollars. It was decided to use a special tender for both plans. Because of the rock-bottom prices in the dredging industry at this moment, the lowest bid for the alterative was 6 million U.S. dollars. Knowing these figures, the Minister of Public Works decided to have the alternative executed using the additional funding. The remaining difference was paid by the national government.

CONCLUSIONS
A new appraisal of dune areas combined with safety demands has resulted in a new national policy to maintain the coastline at its present location, preferably by beach nourishment. This is to be financed by the national government. However, the coastline will not be maintained at any cost. If no danger of inundation is present a policy-analysis of the values in the dune area is to be made. Based upon the data of the analysis, financial contributions from other authorities, and of course, available money in the national budget, the Minister of Public Works decides whether a coastal protection work will be

executed. If there is a danger of inundation the Minister of Public Works is obliged by law to have coastal protection works executed.

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