CHAPTER 146

PREDICTION OF COASTLINE EVOLUTION FOR THE HOLLAND COAST

The Dutch Coast : Paper No. 7

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Abstract

The Coastal Defence Study, as executed in the Netherlands, involved a 100-year prediction for the coastline evolution of specific parts of the Holland coast. In order to create this prediction a mathematical two-line model was used. In this model the effects of wave driven as well as tidal transports are incorporated, also cross-shore transport is implemented. The model is calibrated using sand balances, derived from measurements of coastal profiles. Qualitatively correspondence is reached, but quantitative differences between model and nature remain.

1. Introduction

The mathematical prediction of the coastline evolution of the Holland coast for the Coastal Defence Study is based on a two-line model, as described by Bakker (1968) and in the Manual on Beach Nourishment (Pilarczyk,ed.,1986). The way of prediction is described by Dijkman et al. (1989); the present paper gives a condensed version of this report.

The Holland coast is the central one of the three parts (Rhine/Scheldt estuary, uninterrupted Holland coast,

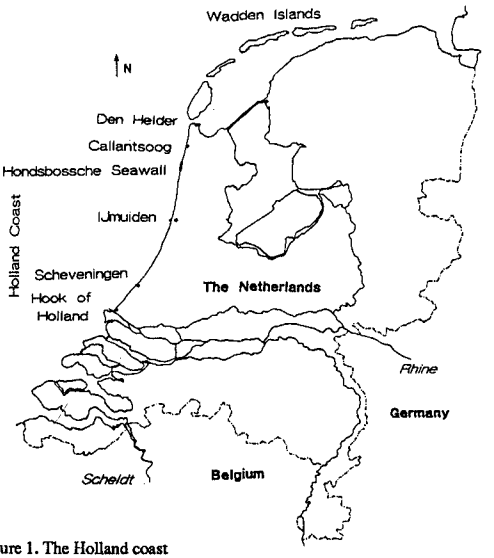

Figure 1. The Holland coast

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Wadden islands), into which the Dutch coast can be divided (see figure 1).Three harbors (Hook of Holland, Scheveningen, and IJmuiden) partition the Holland coast. The harbor moles of Hook of Holland and IJmuiden have a length of 3 km and therefore have a dominating effect on the coastal behavior.

2. The two-line model

The two-line model is based on a schematization of the coastal profile into two zones (see figure 2) :

- the inshore zone:MSL-5m to MSL-1m (MSL-1m represents the average low water level)
- the beach zone :MSL-1m to the local dune top (varying between MSL+10m and MSL+20m)

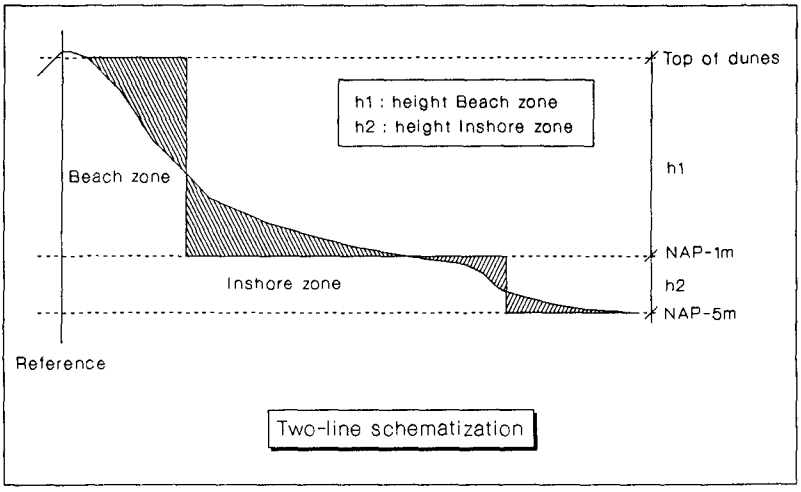


Figure 2. Two-line schematization

The model represents the area up to the depth contour of MSL-5m. This value for the lower boundary of the inshore zone is based more on practical (availability of measurements) than on theoretical considerations. In this zone the effect of the wave driven transport will dominate that of the tidal transport. At the seaside, there will be an interaction with the offshore zone: effects of cross-shore transports as well as tides can be important here. Sand losses due to the sea level rise and to wind transport over the dune tops are not taken into account.The sand quantity in either zone of a specific coastal profile is averaged. Doing so for several profiles, and connecting the so found values results (in plan view) in a couple of lines : the 'beach line' and the 'inshore line'.The mathematical basis of the two-line model consists of an equation of motion and an equation of continuity, this for each zone. The equations of motion consist of two components: the longshore and the cross-shore transports.In the following equations the indices 1 and 2 will be used to refer to the beach zone and the inshore zone respectively.

- Longshore transport:

$$S_i(x,t) = S_{tide,i}(x) + S_{0,i}(x) - s_i(x)\,\frac{\delta y_i(x,t)}{\delta x} \qquad \text{(eq 2.1a/b)}$$

for i=1,2 and with :

$S_i(x,t)$	(m^3/yr) total longshore transport at location x and at time t.
$S_{tide,i}(x)$	(m^3/yr) tidal transport at location x. This term has been determined for the present situation near the harbors and is assumed to be constant in time.
$S_{0,i}(x)$	(m^3/yr) constant component of the wave driven transport at location x This is the wave driven transport for locations x, where the coastal direction is parallel to the x-axis, and varies only with a gradient in the wave climate along the coast.
$s_i(x)$	(m^3/yr/rad) coastal constant at location x, giving the ratio between a change in coastal direction and the wave driven transport. This constant also varies only with a gradient in the wave climate along the coast.
$y_i(x,t)$	(m) distance between the x-axis and the beach line (i=1) or the inshore line (i=2), at location x and at time t.

- Cross-shore transport:

The cross-shore transport is modelled following the principle of the equilibrium coastal profile. According to this principle (under given conditions) an equilibrium profile will be formed in the long run. Applying this principle to the two-line schematization of the coastal profile the equilibrium profile converts into an equilibrium distance between the beach and the inshore line. Any occurring difference between the actual and the equilibrium distance results in a cross-shore sediment transport. The cross-shore transport is furthermore assumed to be proportional to this difference.

In formula: $S_y = s_y \cdot [W - (y_2 - y_1)]$ (eq 2.2)

With:

- S_y (m^2/yr) : cross-shore transport (positive when directed seaward)
- s_y (m/yr) : cross-shore transport constant, determining the timescale at which the equilibrium distance (W) is reached.
- W (m) : equilibrium distance between the schematized beach and inshore line.

- Continuity:

$$\text{Beach} : h_1 \frac{\delta y_1(x,t)}{\delta t} = -\frac{\delta S_1(x,t)}{\delta x} - S_y(x) + p_1(x)$$

$$\text{Inshore}: h_2 \frac{\delta y_2(x,t)}{\delta t} = -\frac{\delta S_2(x,t)}{\delta x} + S_y(x) + p_2(x)$$

(eq 2.3 a/b)

With : $p_i(x)$ (m3/m/yr) : sediment source in the beach zone (i=1) resp. the inshore zone (i=2).

Model boundaries

For the model the Holland coast was divided into three areas:
- Callantsoog to IJmuiden
- IJmuiden to Scheveningen
- Scheveningen to Hook Holland

These areas all stretch from one harbor mole to the other, except for the most Nortern border. Here the model was limited to Callantsoog, because of the influence of the tidal inlet near Den Helder becoming to strong in the more Northern region.

Model parameters

- Wave climate

The wave climate used is derived from measurements in the period 1978-1984. These measurements lack direct information on the direction of wave propagation, only the wind direction is given. To overcome this problem a correction to the directions has been applied based on the correlation as proposed by Hokke and Roskam (1987), who found this correlation between the wind direction and the wave direction from measurements using Wavec-buoys. The so corrected wave climate significantly differs from the original 'uncorrected' one.
Wave data originating from three different sites (Eierland, IJmuiden and LE Goeree) have been used. A comparison between these three sites gives an impression of the variation of the wave climate along the Holland coast, see figure 3.

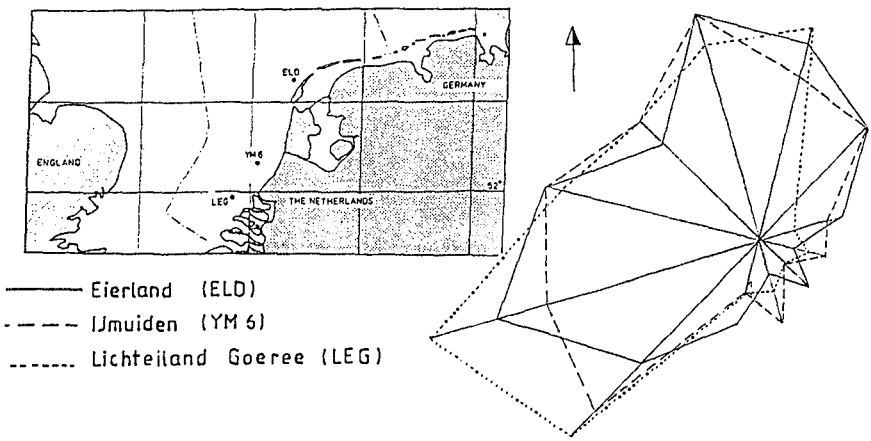


Figure 3. Variation of the wave climate

Furthermore the wave climate as now determined is valid for deep water with a depth of appr. 20-25 m. In order to obtain the required wave climate at shallower water (of appr. 10 m depth) the ENDEC program (ENergy DECay, Delft Hydraulics, 1988) was

used. This program incorporates the effects of breaking waves, refraction , shoaling, bottom friction and wind.

- Tidal influence

The tidal data have been taken from the HOKU model (HOllandse KUst, which stands for Holland Coast) (Delft Hydraulics,Hartsuiker,1988). The non-linear relation between tidal velocities and sediment transports has been compensated by using a morphological tide, which is found by multiplying the average tide with a 'tidal factor' (here taken to be 1.1).

In the direct surroundings of the harbors the influence of the tidal effects can be expected to be much more noticeable than at some distance from those harbors. This as a result of the converging/diverging tidal flows, causing sediment transport gradients and accessory erosion/accretion patterns. Qualitatively the formation of an eddy at the leeside of a harbor mole causes a reversal of the longshore transport in this region. For the opposite tide the longshore transport directed to the mole will remain constant until

a much smaller distance from the mole. The resulting effect of a complete tidal sequence will therefore be an accretion at a small distance to the mole, followed by an erosion that at growing distance from the mole becomes less noticeable.

The tidal effects are calculated in the vicinity of the harbors up to the point where the effect of the harbor mole is negligible. In between the harbors a linear interpolation has been used. The tidal velocities at the points in the grid are calculated for an interval of 30 min. (25 in total, covering 12 hours). The probability function for the orbital velocities caused by waves is determined for each grid point. For the fraction of time waves are breaking in this point there is assumed to be no contribution to the tidal transport for that particular combination of waterdepth, wave direction and wave height. Then with the Bijker formula, using both the orbital velocity distributions and the tidal velocities, a resulting tidal sediment transport is calculated. This tidal transport is assumed to be time independent. The results are shown in figure 4.

- Diffraction near the harbors

In the direct vicinity of the harbors the effect of diffracting waves around the harbor moles is an important factor. This effect is implemented in the model, however in a somewhat limited manner: the diffraction and refraction effects have been calaculated seperately. For the method used see Bakker et al. (1989).

- Coastal constants

These are the constants (constant only in time, but varying along the coast as a result of a variation of the wave conditions along the coast) which determine the longshore wave driven sediment transport (S0,i and si in eq 2.1). Calculation of these constants is done using the following assumptions :

- The wave driven longshore transport between two depth contours is proportional to the longshore component of the energy-loss of the driving wave between those depth contours.
- The depth contours are parallel.

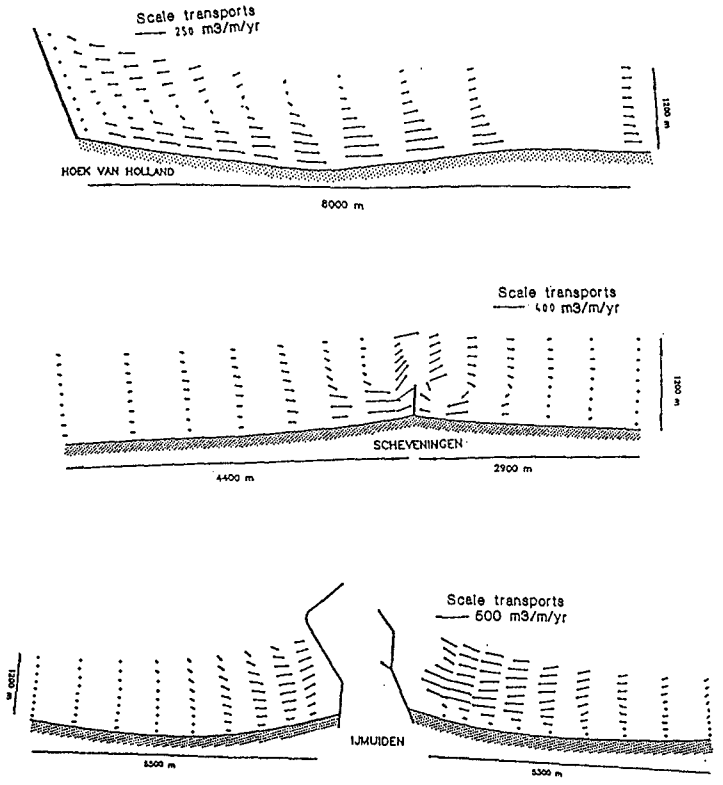


Figure 4.Resulting tidal sediment transports near the harbors.

The equation used to calculate the longshore transport is a variation of the CERC formula :

$$S = A*(n_{br}H_{br}{}^{2}c_{br}\sin(phi_{br})\cos(phi_{br}) \qquad \text{(eq 3.1)}$$

With S :longshore sediment transport (m^3/yr)
A :proportionality constant (-)
the wave characteristics at the breaker line:
n (-),H (m),c (m/s),phi (rad)

For a more detailed description of the method used see Svasek (1968), Bakker (1969) and Bakker et al.(1989).
The calculations were performed using the KC program (Kust Constanten, which stands for Coastal Constants, by Casteleyn, 1975) which includes diffraction and refraction effects. In order to compensate for the overestimated diffraction effects, caused by using

monochromatic waves, a reduction factor for the calculated diffraction effect has been applied, this factor is taken to be 0.75. (The difference between the calculated values in the diffraction zone and the value outside this zone is multiplied by the reduction factor). Originally the KC program gives values for the coastal constants for a one-line model, the necessary two line values are derived from the one-line values by assuming a constant ratio between the values for beach and inshore respectively. From calculations a ratio (beach:inshore) of 1:4 was found.
The only remaining unknown in the coastal constants is the proportionality constant A (see eq 3.1). This will be determined in the calibration of the model, just like the cross-shore coastal constants sy and W (see eq 2.2).

3. The coastal defence works

There are three different defence methods in use along the Holland coast : groynes, the Hondsbossche Seawall and sand supplies.
The groynes partially block the longshore sediment transport. The effectiveness of the groynes has been roughly estimated by considering the depth to which they reach, in relation to the sediment transport distribution over the depth as found by Bakker (1969). In the model this has been accounted for by using a reduction factor for the coastal constants. Note that this method implies neglecting the impact the groynes may have on the tidal sediment transports : the tidal transports mainly take place at greater depths than the depths to which the groynes reach.
The Hondsbossche Seawall is a rigid seawall, below MSL-1m it is covered by sediment. At both sides of the seawall there are several groynes preventing this area from eroding too severely. In front of the Hondsbossche Seawall the beach zone does not really exist, in the model this has been accounted for by taking the coastal constants in this area equal to zero. In the inshore zone there can be some sediment transport. However, at both sides of the Hondsbossche seawall very strong curves in the coastlines occur, which are not varying too much in time. Therefore the coastal constant s2 must also be taken equal to zero for this area. This assumption can be backed up by the geological consistency of the bottom material in front of the Hondsbossche Seawall: there are some almost baring clay layers present there (de Mulder, 1983). This implies there can only be a constant transport along the Hondsbossche Seawall: what goes in on one side must go out the other.
The model does not implement the sand supplies, but does take these into account in the calibration of the model, see the next paragraph.

4. Calibration and output

The proportionality constant A, used in the calculation of the coastal constants (see eq 3.1), is used as the instrument to calibrate the model. The calibration is based on the measurements of the coastal profiles of the Dutch Coast on a yearly basis, as stored in the JARKUS database. These measurements are used to create sand balances for the specific parts of the Holland Coast. Some results are shown in figure 5, showing the relative amount of sand (relative to the first year) for three subareas.

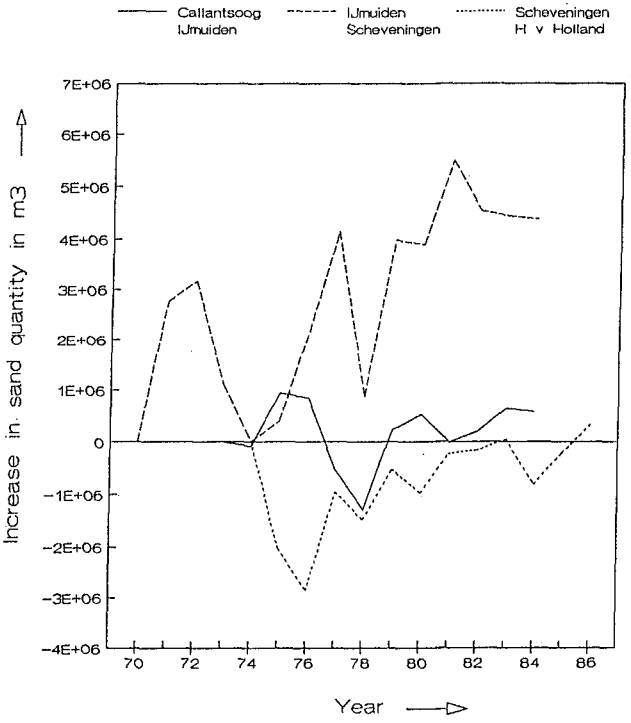


Figure 5. Sand balances for the Holland coast.

By making some assumptions these sand balances can be used to give an idea of the average sediment transports in the considered areas. The necessary assumptions:

- No sand leaking around the harbor mole near Hook of Holland.
- No sand from above the MSL-5m passes from one side of the harbor moles of Scheveningen and IJmuiden to the other.
- Equally distributed sand supply from deeper water over the MSL-5m line for an area between two harbors.

With these assumptions the following conclusions can be derived:

- Accretion of the area Hook of Holland-IJmuiden of 370103 m3/yr, or 6 m3/m/yr.(=p2 in eq 2.3).
  For the area IJmuiden-Callantsoog this accretion is 40103 m3/yr, or 0.9 m3/m/yr. This value has been neglected (p2=0 in eq 2.3). This relatively low value (relative to the value in the area Hook of Holland-IJmuiden) can be explained by the increase (going Northward from IJmuiden) of the Northward tidal flow in deeper water, 'consuming' the sediment which would otherwise come to benefit the area above the MSL-5m level.

The onshore transports found here compare reasonably well to those found by Stive (1990). The value Stive proposes, is a bit larger : approximately 10 m3/m/yr, almost constant over the entire Holland coast. However this value is derived for an onshore transport over the MSL-8m line, where in this paper the transport over the MSL-5 line is considered.

- The optimum value for the proportionality constant A is 500, determined for the area Hook of Holland - IJmuiden. This value is about a third of the conventional values! With the proportionality constant A now determined, the longshore transports can be calclated, the results are shown in figure 6.
  Again, comparing the so found longshore transports to those found by Stive (1990) a reasonable agreement is found, see Dijkman et al.(1989).

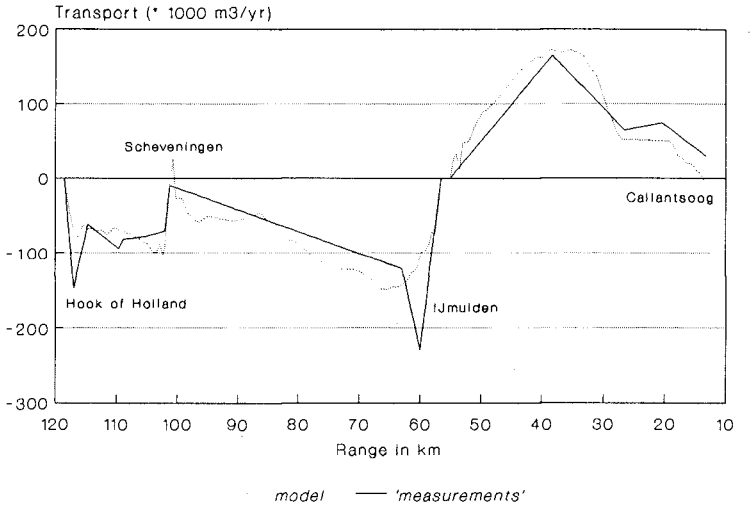


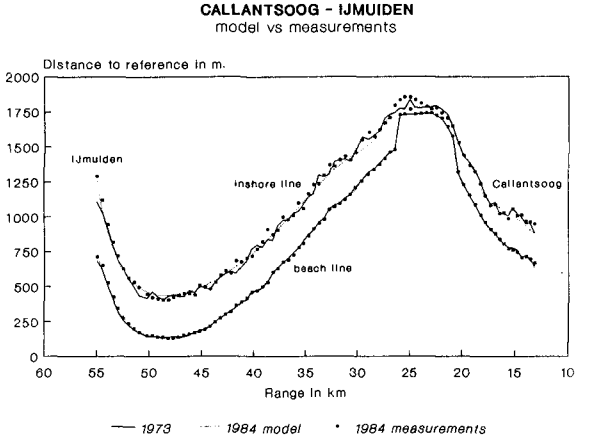
Figure 6. Calibration of the longshore transports.

- The coastal constant for the cross-shore transport, sy (at a depth of MSL-1m) is found to be in the order of 0.05 m/yr (for the region Hook of Holland - Scheveningen) to 0.10 m/yr (for Scheveningen-IJmuiden). These results were found by using a value of 280 m for the equilibrium distance between beach and inshore line. In the model a constant value of 0.10 m/yr is used.

Other scenarios, for instance large offshore transport caused by rip-currents and tidal currents in the immediate vicinity of the harbor moles, have been elaborated with respect to their consequences for the coastal development. (The report by Dijkman et al. (1989) shows results). However, these scenarios had to be rejected because of the coastal behavior according to these scenarios proved to be unrealistic.

5. Results

Figure 7 shows the calibrated coastal development between 1973 and 1984, for the area Callantsoog to IJmuiden. On the left-hand side one observes the effect of the harbor mole of IJmuiden, and between the ranges 20 to 25 the effect of the Hondsbossche Seawall.
Figure 8 shows predictions found in this way for the years 2020 and 2090.
Finally the same results are presented in a different manner, namely with the reference as the initial situation. Figure 9 shows the development of the beach-line, figure 10 that of the inshore line.
Results for the area IJmuiden to Hook of Holland are not presented here, they can be found in the report by Dijkman et al. (1989).



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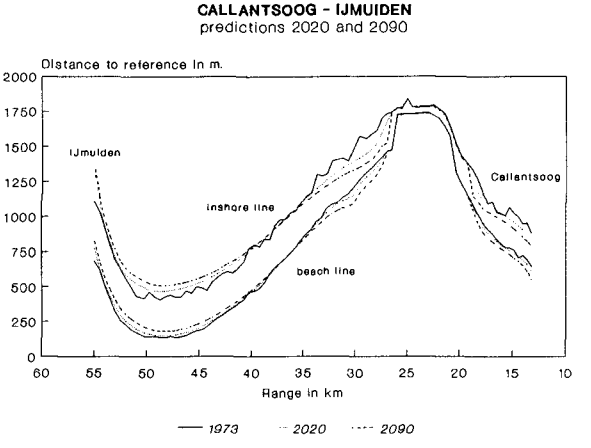

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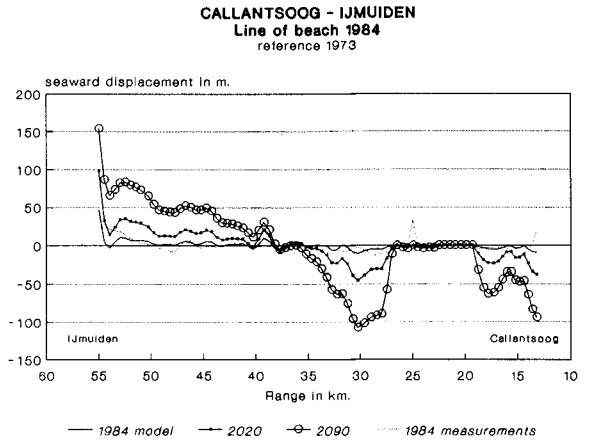

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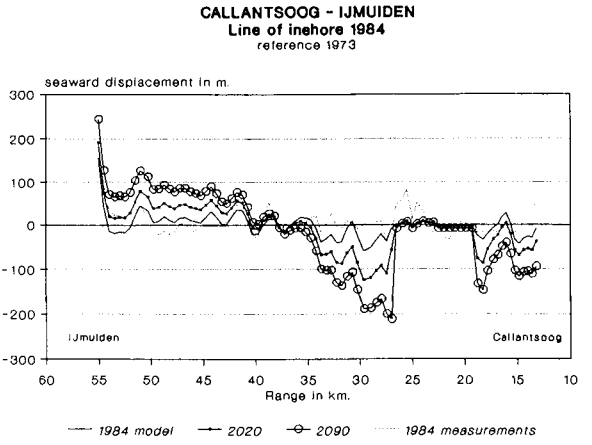

Figure 10.

6. Conclusions

- The results (certainly for an area with harbor moles) strongly depend on the wave climate used (Dijkman et al, 1989). Therefore not only the accuracy, with which the present wave climate is known, but also the accuracy, with which the future wave climate can be predicted highly determines the accuracy of a prediction of the coastline evolution. Accurate wave data (especially concerning wave directions) are vital for accurate coastal prediction.
- The proportionality constant A (giving the ratio between the sediment transport and the longshore component of the wave energy flux, see eq 3.1) found here, is much lower (about a third) than more conventional values.
- The use of the two-line model as an instrument to create a prediction of a coast-line evolution is in creating a qualitative picture giving eroding and accreting areas, but limited in its quantitative accuracy.

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