CHAPTER 273

LONG TERM BEHAVIOUR OF THE SEDIMENT VOLUME INSIDE A TIDAL BASIN AFTER POLDERING

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ABSTRACT

The development of morphological reactions over time as a result of polderings has been investigated for the Dithmarscher Bucht (Bay of Dithmarsch), a tidal basin which is located in the North Sea/Germany. Two methods of parametrization have been used: the first method is based on volume-differences and the second one refers to the vertical differences of the topography. The results have been used for an estimation of the stability of the tidal basin with respect to an accelerated rise of the relative sea level.

INTRODUCTION

Tidal basins are transition areas between the mainland and the sea. They exist under special hydrological and sedimentological boundary conditions. On account of these special conditions, tidal basins have been formed along the Southern North Sea coast during the last 10,000 years (Bantelmann 1966 and Streif 1990). In most of the areas, the actual situation has been substantially influenced by human interferences, especially by land reclamation.

Besides coastal engineering aspects the Wadden Sea areas are an unique ecological system, which is essential as breeding and feeding ground for migratory birds on their East Atlantic Flyway (Lozán et al. 1994).

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An accelerated rise of the relative sea level is a realistic prospective; therefore the question about its effects on the long term behaviour of the Wadden Sea-tidal basins along the North Sea coast is important. Only if the morphology of the tidal basin is able to adapt to the changing hydrological conditions, is it ensured, that the whole system keeps its stability.

A tidal basin is a feed-back system which tends towards an equilibrium stage, determined by the hydrological and morphological boundary conditions. Changes in the relation between these boundary conditions lead to reactions of the morphology. The morphology compensates the non-equilibrium stage by more or less intensive accumulation or erosion processes. These adjustments proceed with a phase lack, depending on the quantity of the disturbance in relation to the system itself.

Comparable processes occur after cutting off (poldering) parts of a tidal basin. The daming reduces the catchment area of the tidal basin and alters the relationships between the hydrological and the morphological boundary conditions. Investigations of the morphological development after cutting off parts from a tidal basin led to calculations over time of the adjustment-ability.

The morphological reaction of a tidal basin, forced into a non-equilibrium stage by cutting off parts, can be compared with the effects of the changing hydrological boundary conditions as a result of sea level rise. Thus, the adaptability can be estimated qualitively for different values of sea level rise.

PARAMETRIZATION

The description of the morphological development has been based on two different methods for the parametrization. The parameters for the first method has been determined by calculating the difference between volumes. The second method is based on the averaged heights difference between bathymetric surveys of the morphology for successive stages. The introduced parameters are named "transpose-rates", for the first method as h_I and for the second one as h_A or h_E, with the dimension m/a. The transpose-rates which are presented and discussed in the paper represent mean yearly values.

Method N°. 1

The sediment volume V_I has been calculated above a fixed datum as horizontal reference level (Fig. 1). The reference level has been set below the deepest point of the topography for which morphological changes are recorded. For the total tidal basin

Dithmarscher Bucht, the reference level has been fixed at -22.0 m NN[4] and for the defined subareas at -12.0 m NN. The upper limit is 2.0 m NN[5]. The volume difference ΔV_I (Fig. 2) of two successive surveys are divided by the time period between the surveys Δt and by the area of the cross section A_I (Schroeder et al.1995b). This parameter is named "transpose rate h_I" (m/a):

$$h_I = \Delta V_I / (\Delta t_I \cdot A_{I,i+1}) = (V_{I,i+1} - V_{I,i}) / ((t_{i+1} - t_i) \cdot A_{I,i+1}). \quad (1)$$

The division by the cross section A_I provides a standardization of the parameter, which allows the comparison of catchment areas A_b with different sizes.

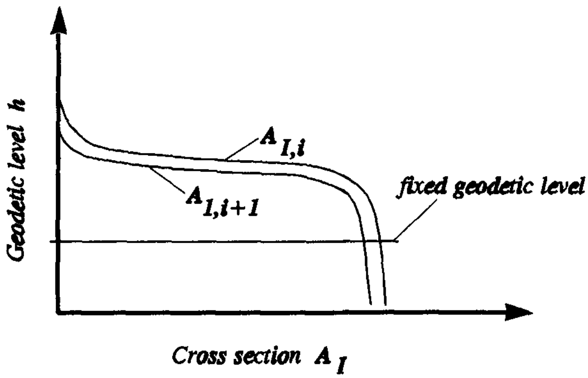

Figure 1. Idealized graphs of the geodetic level h over the cross section A_I

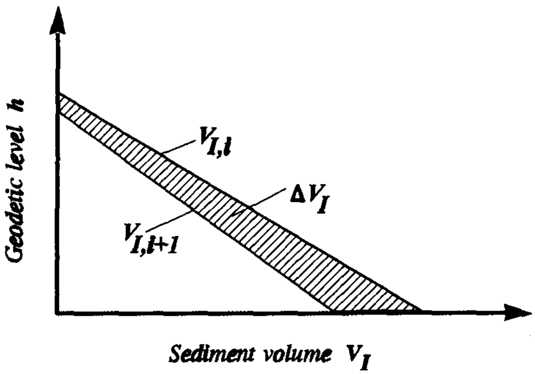

Figure 2. Idealized graphs of the geodetic level h over the sediment volume V_I

[4] NN = Normal Null = German ordnance-datum (app. MSL)

[5] MHW app. 1.55 m NN (min. HW/max. HW = 1.46/1.63 m NN; 1942 - 1990) at the tide-gauge Büsum (Fig. 6)

Method N°. 2

The second method leads to "transpose-rates" which have been determined separately for accumulation as "h_A" and for erosion "h_E". The calculation of these parameters is based on the heights of a standardized area-element (vertical difference). Therfore, the topography has been transformed into square grids (Fig. 3). The resolution of the grid has been fixed as 25 m in x- and y-direction, hence, one grid-element covers an area of 625 m².

The horizontal reference level of one grid yields as mean value of the "average node" H_i (mNN) of the heights of each grid node (see A, B, C and D in Fig. 4):

$$H_i = (A+B+C+D)/4. \tag{2}$$

The difference of the parameter H of two successive surveys (H_i, H_{i+1}) is the accumulation or erosion-rate ΔH_i in m for each grid element:

$$\Delta H_i = H_{i+1} - H_i . \tag{3}$$

This rate, divided by the time interval between the successive surveys, leads to the yearly transpose-rate of each grid element, either as accumulation ($\Delta H_{A,i}$) or as erosion ($\Delta H_{E,i}$). The sum of all elements with accumulation or erosion inside the defined investigation areas (total basin or subarea) yields to the "transpose-rate", which is indicated as h_A (accumulation) and h_E (erosion) with the dimension m/a:

$$\Sigma \Delta H_{A,i} / \Delta t = h_A \tag{4}$$

$$\Sigma \Delta H_{E,i} / \Delta t = h_E . \tag{5}$$

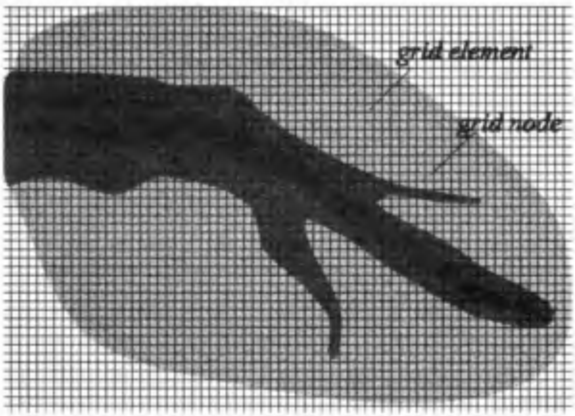

Figure 3. Idealized investigation area with grid

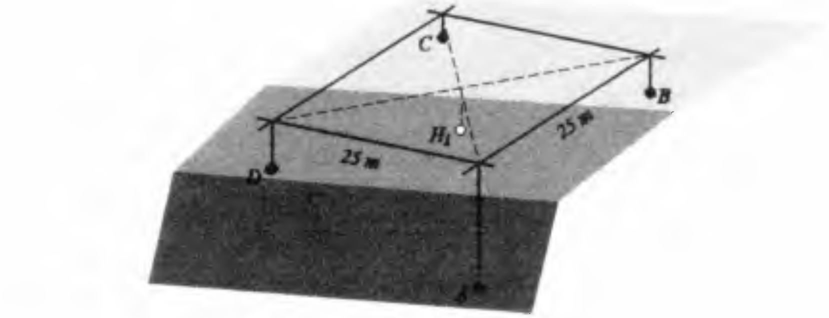

Figure 4. Idealized grid element with the grid nodes A, B, C and D and the average node H_i

INVESTIGATION AREA

The investigation area is called the *Dithmarscher Bucht* (Bay of Dithmarsch). It is located on the German North Sea coast on the West side of the German federal state of *Schleswig-Holstein* (Fig. 5).

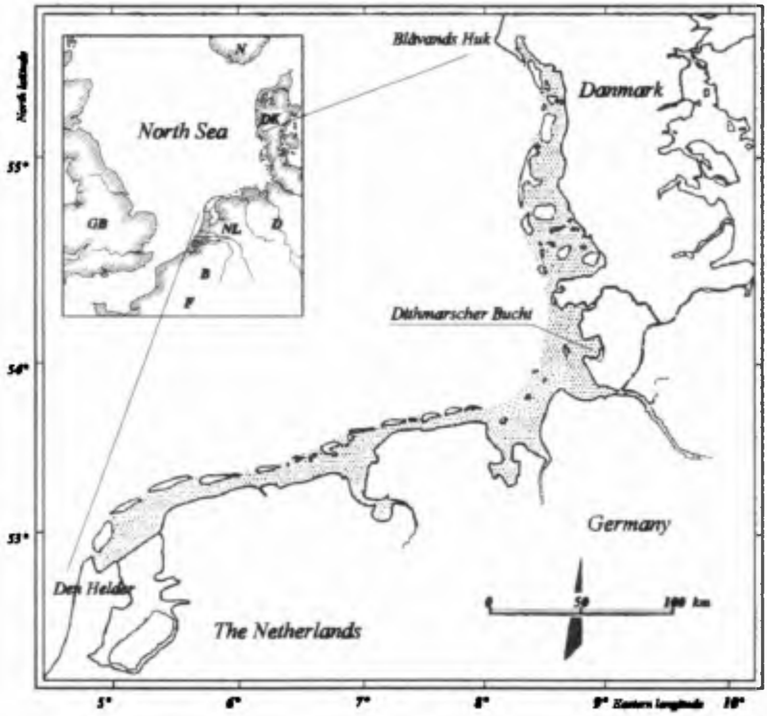

Figure 5. Location of the investigation area

The shape represents a single bay which opens towards the main wind- and wave direction. Inside the bay, the mean tidal range (semidiurnal tides) is 3.25 m (1942-1990); the dominate wind direction scatters around West. The mean offshore waveheight is about 1.00 m. The geological structure of the bay, developed during the Holozän-time-period, consists mainly of marine sediments (Fischer 1955).

The tidal basin had been reclaimed two times by poldering. The bay covered an area of approximately 157 km² before the polderings had been carried out. The first poldering (1972) reduced the bay-area (A_b) by about 16 km² and the second one (1978) by 26 km² (see dotted lines in Fig. 6).

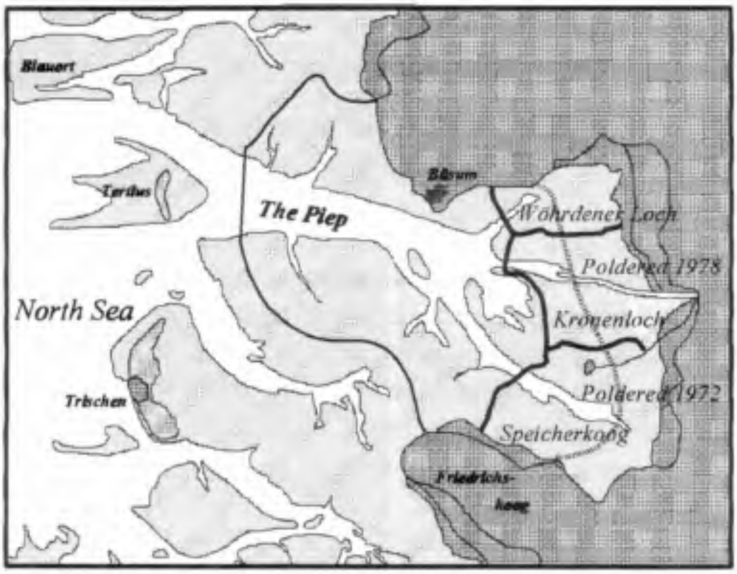

Figure 6. Investigation area *Dithmarscher Bucht* with poldered areas and the investigated subareas

With regard to the reaction of the bay as result of the polderings, the tidal basin has been split up into subareas according to the application of an applied empirical model (Goldenbogen 1994, Niemeyer et al. 1995 and Schroeder et al. 1995a). The subareas which include the poldered parts are shown on fig. 6: *Speicherkoog*, *Kronenloch* and *Wöhrdener Loch*. The total bay-area is represented by *The Piep*. During the investigation period from 1942 up to 1990 the *Dithmarscher Bucht* had been surveyed 9 times (1942, 1956, 1969, 1973, 1976, 1979, 1982, 1985 and 1990). The bathymetric surveys of 1942, 1956 and 1969 decribe an undisturbed topography. The surveys after the year 1973 are influenced by the poldering-means.

The morphological data for the *Dithmarscher Bucht* and parametrizations for "equilibrium stages" have been described by Schroeder 1994.

RESULTS

The following diagrams show the calculated transpose-rates h_I. The data (ordinate) has been plotted over the half period of an investigation intervall Δt_i (abscissa, Fig. 7).

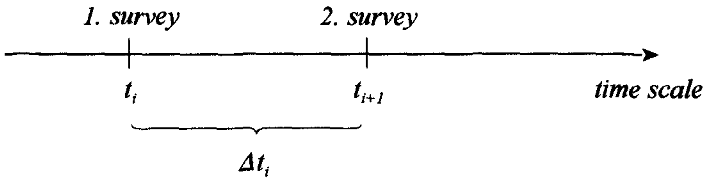

Figure 7. Definition of the investigation intervall Δt_i

Figure 8 shows data which are based on the the total difference of the sediment volume in accordance with the first method. During the period from 1942 up to 1969 the anthropogenic influences are negligible. The scattering of the results can be explained by natural effects and, additionally, in the case of the year 1956, by the quality of the bathymatric survey.

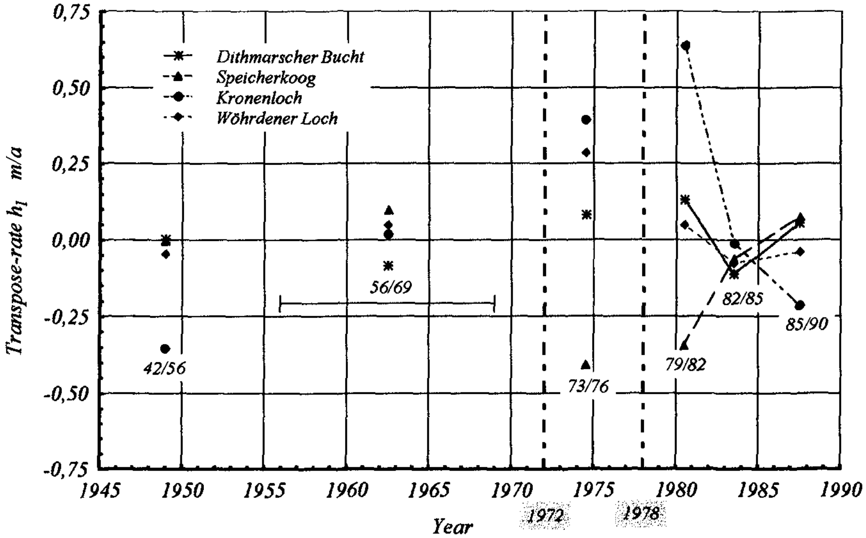

Figure 8. Transpose-rate h_I versus investigation intervall Δt_i

The first poldering was carried out inside the subarea *Speicherkoog* in 1972 (Fig. 6). The value of the subarea *Speicherkoog* shows a distinct tendency of erosion as a result of the first poldering, whereas the other subareas, as well as the total tidal basin, are characterized by accumulation.

The second poldering was carried out in 1978. This poldering extends over the subareas *Kronenloch* and *Wöhrdener Loch* (Fig. 6). After the second poldering, the tendency of erosion continued inside the subarea *Speicherkoog*. The transpose-rate inside the subarea *Wöhrdener Loch* decreased in the range of the average values, as monitored during the undisturbed period before 1969. Only the transpose-rates of the subarea *Kronenloch* increased significantly. However, already during the second investigation intervall from 1982 to 1985, the values for this subarea also decreased. All values indicate a low erosion-tendency. The erosion effects continue for the subarea *Kronenloch* during the last interval (1985 to 1990). The results for the last interval scatter within a range which is comparable to the values during the undisturbed investigation period before 1969.

A similar development display the results for the accumulation rate h_E gained by the second method (Fig. 9).

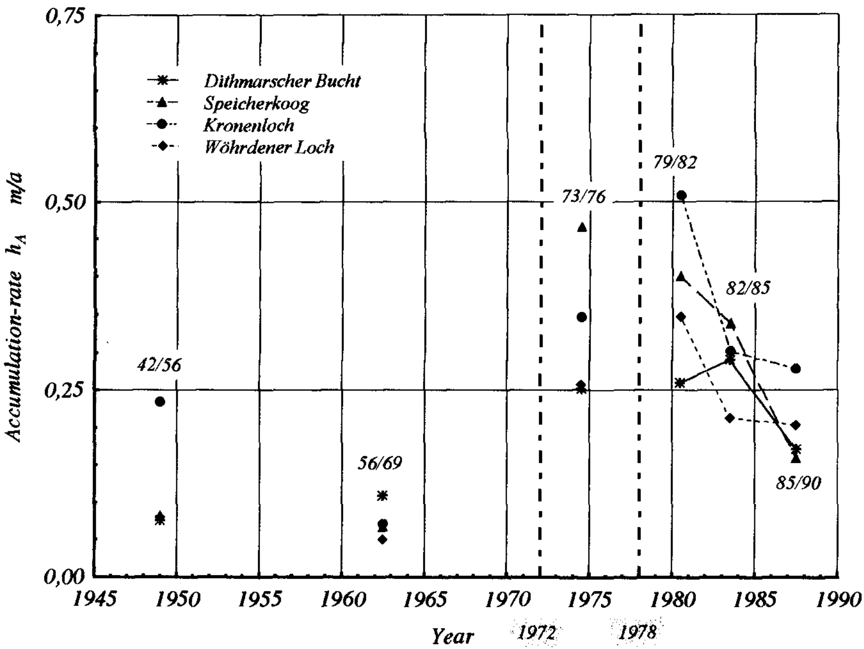

Figure 9. Transpose-rate h_A versus investigation interval Δt_i

The value increased after the first poldering. The subarea *Speicherkoog*, where the poldering was carried out, shows the highest value. This value decreased after the second poldering, whereas the transpose-rates of the subarea *Kronenloch* and *Wöhrdener Loch* increase. The next investigation-interval indicates a reduction of the values for all subareas. During the following interval, this tendency continued for the subarea *Speicherkoog* and also for the whole tidal basin, whereas the subareas *Kronenloch* and *Wöhrdener Loch* show more or less constant accumulation-rates.

The data of the erosion rate also indicate clear trends (Fig. 10). The undisturbed period is followed by an increase of the values except for *Kronenloch*. Over the last two investigation intervals the values decrease, including those for the *Kronenloch*. During the last interval (1985-1990), the value scatter already in the range of the undisturbed period before 1969.

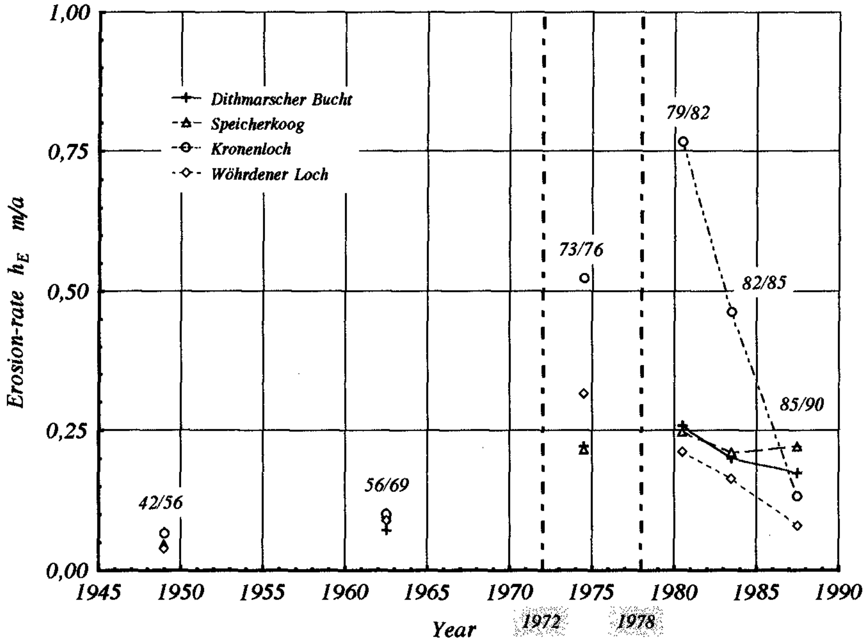

Figure 10. Transpose-rate h_E versus investigation interval Δt_i

CONCLUSIONS

The results allow estimations concerning the morphological reactions of a tidal basin on the changes of geographic boundaries by poldering (reduction of the bay-area leading to a disturbance of the equilibrium condition with respect to the tidal volume as hydrographical boundary condition and the cross-section/area-size as morphological boundary condition). The discussed results show comparable reactions of the described parameters over the whole investigation-period from 1942 to 1990.

The results concerning the development of the *Dithmarscher Bucht* over the last three investigation intervals from 1979 up to 1990 (time period after the polderings) showed, that after approximatly 5 years, the parameter-values had decreased, in part, more than 50% of the maximum values after the polderings. The assumption can be drawn that after 5 more years there will be no significant distinction between the anthropogenic and the natural influences of the transpose-rates. With respect to the strongly decreasing tendency of the investigated transpose-rates, the prediction seems to be reliable, that after one to two decades, the influences of the anthropogenic impacts (disturbance of the "equilibrium stage" by poldering) will fade away and the adaptation to the anthropogenically-created new boundary conditions will reach the new equilibrium.

The results indicate the *Dithmarscher Bucht* as an area with strong accumulation. Comparable investigations, decribed in literature, came up with similar results (Wieland 1984, Siefert 1987, Niedoroda et al. 1994), and Unsöld 1974 with respect to the regeneration after dredging.

With regard to a tranfer of the described results to other tidal basin-areas, the available sediment capacity of the area is one of the main restricting factors that has to be taken into account.

The investigation have shown that, for the tidal basin *Dithmarscher Bucht*, there will be no danger concerning the stability of the morphology with respect to changes of the forcasted or feared hydrological boundary conditions, even if the acceleration of the relative mean sea level rise should reach the IPCC-best-estimate-values (IPCC 1990) of about 60 cm in hundred years.

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