LARGE-SCALE COASTAL BEHAVIOUR IN RELATION TO COASTAL ZONE MANAGEMENT

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ABSTRACT

The development of coastal erosion management - addressing typical traditional erosion problems - towards coastal zone management - addressing the evaluation of alternative solutions to guarantee a variety of coastal zone functions on their economic time scale - has necessitated the formulation of large-scale coastal evolution (LSCE) models. Using the coastal evolution of the Netherlands in the Holocene up to the present as an example and a test case, Stive et al (1990) formulated such a LSCE concept. The (more generally applicable) model applies to quasi-uniform coastal stretches. It accounts for morphodynamic processes from the shelf to the first dune-row, and integrates over coastal units of approximately 10 km alongshore length. The added value, compared to earlier published concepts or models, lies in the full inclusion of cross-shore and alongshore processes, and in the distinction between a - with respect to sea-level rise - instantaneously responding active zone and a noninstantaneously responding central shoreface zone. Relevant differences have been found to exist between coastal cells on the "closed" and the "interrupted" coast. An important conclusion is that the cross-shore effective Bruun-effect is only of limited importance. This is especially true in the case of the interrupted coast. Longshore sand transport gradients are very large there. This is mainly related to the sand demand which is placed on coastal stretches adjacent to estuary mouths of those estuaries which tend to follow the sea-level rise.

1. Introduction

Initiated by coastal zone management questions in general and by the anticipated increase in relative sea-level rise in particular an interest is growing into larger scale, longer term coastal evolution processes. In view of this it is being realized and it will be argued in this paper that the more traditional coastal engineering approach (which focusses on coastal evolution processes of typical time- and space-scales of a year and a kilometer) is too limited in scope. In order to gain an understanding of large-scale, longterm coastal evolution, a variety of geo-morphological processes with a
diversity of time- and length-scales needs to be considered which, in turn, calls for the deployment of many specialisms. This approach has been applied in the Dutch Research Programme, called Kustgenese (Coastal Genesis, see Zitman et al, 1990). It has led to concepts for large-scale coastal evolution, which - stimulated by the need for a National Coastal Defence Policy Study (see Louisse and Kuik, 1990) - were materialized into a predictive, quantitative tool. The concepts are described in some detail in Stive et al (1990), and summarized in this paper. Since the Holocene evolution of the coastal system of the Netherlands provides important quantitative and qualitative data for the concepts, firstly a review of this evolution will be given.

2. Holocene evolution of the Dutch coast

On the basis of its morphology the present coast of the Netherlands may be subdivided into three coastal subsystems, which basically differ with respect to the dominance of particular physical processes (see Figure 1).

![Figure 1](attachment:image.png)

Three subsystems of the coast of the Netherlands (after Zitman et al, 1990)
In the South of the Netherlands we find the Zeeland area, which consists of peninsulas separated by estuaria and inlets. It is a Holocene based alluvial region which over the last millennia has experienced considerable variations in opening and closing of the coast, largely related to human agricultural activities. The present flood defence works in the region were initiated by the flooding disaster in the region in February 1953. They consist mainly of permanent closure works of the estuary arms, which have the delta now more or less changed into a relic. One of the arms, the Westerscheldt, is still open, being the shipping entrance to Antwerp. The Westerscheldt estuary mouth is a strongly active system of bars and gullies, with important impacts in the form of coastline undulations on the adjacent coastal stretches.

In the North of the Netherlands the Wadden Islands are located, which form a chain of barrier islands separated from the mainland by the Waddensea, a tidal basin with extensive tidal flats. These barrier islands are relatively longstretched and the tidal inlet channels between them are characterized by active delta systems. The Waddensea's present form was more or less reached a thousand years ago, when important breakthroughs were formed towards the former Almere lagoon in the center of Holland thus creating the Zuiderzee. A characteristic feature of the Wadden Sea region is its continuous sedimentation of the tidal flats in order to keep pace with relative sea-level rise, and its siltation along the Wadden shores. These processes are responsible for an important influx of sand, which is basically delivered by the adjacent coastal system. This is the cause of a structural retreat of the Wadden island shores.

The central part of the coast of the Netherlands is called the Holland coast. Geologically speaking it is a recent, closed coastal system, since it was only formed during the Holocene some 5000 years ago. It is expected (Beets et al, 1990) that the Pleistocene based lagoon mouth positioned there, closed itself off during periods of a strongly decreasing rate of sea-level rise. Its basic contents are a relatively young (formed between 1000 and 1600 A.D.) dune system of variable width, covering an older dune system formed approximately 5000 year ago. By and large the coast has retreated over the last 2000 years, near Rotterdam and Den Helder the most and centrally less and less. Now - mostly due to human regulation - it has come to a standstill centrally and it is retreating under control in the North.

By studying the evolution of the Holland coast over the Holocene up to the present, as was done in Coastal Genesis Phase I, the following aspects were identified as important for the large-scale evolution (see also Zitman et al, 1990):

(1) the longterm geologic development indicates that both crossshore and longshore processes have played an important role in the evolution of the Dutch coast. Although their relative magnitudes and response scales have shown some variation on the geological timescale, their longterm orders of magnitude are approximately equal. The terminology cross-shore refers to the surfzone and the shoreface; in this respect it is emphasized that what counts is the exchange of sediment between shoreface...
and surfzone (the diabathic exchange) and the exchange of sediment between longshore coastal stretches both in the surfzone and on the shoreface (the parabathic exchange);

(2) the Subboreal (approximately 5000 C14 years BP) coastal advance of Holland and the subsequent formation of the Old Dunes are very likely related to a strong decrease in relative sea-level rise. The physical process responsible for the closing of the coast is similar to that of the behaviour of an underwater delta after closure of its tidal basin (Beets et al, 1990);

(3) the formation of the Young Dunes along the Holland coast some thousand years ago cannot be explained by longshore motions of sediment alone. The external conditions which may have initiated a diabathic exchange may be those related to relative sea-level rise fluctuations;

(4) tidal basins or estuary mouths bear important effects on adjacent coastal stretches. For instance the Waddensea tidal basins in dynamic equilibrium keeping pace with sea-level rise demand high amounts of sediment (Eysink, 1990), which are eventually delivered by the adjacent North Holland coast and the barrier island coasts.

3. Coastal evolution concepts

The difference in approach level between coastal erosion management - addressing typical traditional erosion problems - and coastal zone management - addressing the evaluation of alternative solutions to guarantee a variety of coastal zone functions on their economic time scale - is schematically indicated in Figure 2. This necessitates the distinction between coastal evolution models on a range of scales (Figure 3). Three spatial and temporal scales of coastal evolution may be distinguished (Stive et al, 1990):

(1) Large-scale coastal evolution (LSCE) with a morphodynamic length scale of 10 km and a time scale of decades, for which a conceptual model was developed, which is described below. The evolution character in this class can vary between mean trend (e.g. geological processes related), fluctuating (e.g. boundary conditions related) and asymptotic (e.g. morphodynamic constraints related) behaviour. This is typically the sort of model with which longer term predictions can be made, needed for a long term planning of coastal development both due to large-scale natural processes, such as an increasing sea-level rise or a changing climate, and to large-scale human activities, such as an estuary or tidal basin closing;

(2) Middle-scale coastal evolution (MSCE) with a morphodynamic length scale of 1 km and a time scale of years. Important distinctions in this evolution class are cyclic and damping coastline developments. Cyclic developments are for instance due to interactions between geometry and water motions in the low-frequency range, or due to (quasi-)cyclic channel-shoal shift patterns in estuary mouths. Damping developments are mostly due to human interferences like harbour moles, beach nourishments, channel dredging etc. This is typically the sort of model which
Figure 2: Interactions considered by Coastal Erosion Management (CEM) and by Coastal Zone Management (CZM).

Figure 3: Coastal evolution scales (after Stive et al, 1990).
is used to identify the impact of coastal works on the coastline development;

(3) Small scale coastal evolution (SSCE) with a morphodynamic length scale of 100 m and a time scale of storms to seasons. In this class of development it is the local (on the scale of the wave length) variability of topography and hydraulic conditions which interact to result in short-term, often rhythmic, coastline fluctuations. Generally, these fluctuations seem to have little interaction with the longer-term structural coastline evolution. This is typically the sort of model which is used for the more detailed design of coastal defence works.

The formulated approach to LSCE can only be done under adoption of inductive concepts (Stive et al, 1990). The state-of-the-art in deductive modelling (i.e. models deduced from basic physical process knowledge) just about enables one to make predictions of SSCE. While in predictions of MSCE inductive concepts (i.e. model concepts inferred from observed or through analogy expected behaviour) commonly are included, this is certainly the case in predictions of LSCE (see Figure 4). The author shares the viewpoint that the two approaches do not exclude one another, on the contrary: "induction is really the inverse process of deduction" (Jevons, 1958). So, in the formulation of the large-scale coastal evolution concept detailed process knowledge should be combined with inductive knowledge. In this context it may be appropriate to also note the following point of view. In literature on the principles of scientific approach to physical process-research reference is made to another possible distinction between research approaches, namely the logical, reductionistic (left brain, Yang) approach versus the intuitive, holistic (right brain, Yin) approach. In this case also, the author favours an approach which combines the strength of both approaches.

Figure 4 Dominance of research approach
In the formulation of the large-scale coastal evolution concept by Stive et al. (1990) this combination of viewpoints is applied to arrive at a LSCE concept. The concept is in principle derived for the Dutch coast, but is expected to have some generality for sandy dune coasts and barrier island coasts. The concept further applies to (quasi-)uniform coastal stretches or cells of several km's length, of which it is assumed that the longterm average coastal profile (from the dune to the shelf) and wave, current and sand transport conditions and gradients vary only weakly alongshore. Relatively important interruptions due to river delta's, harbours, shipping channels, headlands, submarine canyons are either point sources or a principal boundary to the cells. Cross-shore three units are distinguished, i.e. the active zone (the upper shoreface, extending from the first dune row to 8 m waterdepth), the middle and lower shoreface (from 8 m to 20 m water depth) and the inner shelf (below 20 m water depth). The waterdepths mentioned are approximate figures for the Holland coast and depend in general largely on the wave climate. The important transition of the active zone to the middle shoreface is defined as the depth above which profile changes occur as observable from profile measurements over one average year. Alongshore two types of coastal cells are distinguished, i.e. cells on the closed coast and cells on the interrupted coast. The former category is formed by those coastal stretches which develop unaffected by coastal interruptions due to estuary or tidal basin mouths, under alongshore relatively slowly varying offshore hydro-meteor conditions. In contrast, the latter category is strongly affected by these interruptions; a tidal basin in dynamic equilibrium keeping pace with the sea-level rise for instance (see Eysink, 1990), may be the cause of a structurally retreating coastline in adjacent coastal stretches. It is found that alongshore gradients of net sediment transport may differ an order of magnitude between these categories. The variety of physical processes which may act on these two categories of coastal cells is summarized in Figures 5 and 6. Also, an indication is given of the relative frequency and intensity of the processes.

The morphodynamic processes are integrated over the three distinguished units, resulting in transport gradients over their control volume, under adoption of inductive concepts concerning the morphodynamic response characteristics of these units (see Stive et al., 1990).

According to the above concept of LSCE the "present" (i.e. averaged over the last 5 to 10 years) dynamic coastal sediment budget for the whole of the Dutch coastal system has been drawn up (see Figure 7). As explained it is based on a combination of deductive physical process knowledge and inductive concepts, with the latter supported or verified by observations. On the considered time and space scale the dynamics of the model are of a weakly varying character. With hydro-meteor scenarios involving wind, wave, tide, surge level and mean sea-level predictions for the next decades as input parameters it was used as a basis for predictions (Louisse and Kuik, 1990).

Results of the actual coastline predictions are omitted here, since they are not considered to be of interest in this context. One of the most generally interesting results though is the relative impor-
Figure 5 Overview of sediment transport processes in a coastal cell along the closed coast (after Stive et al, 1990)

Figure 6 Overview of sediment transport processes in a coastal cell along a coast interrupted by a coastal inlet (after Stive et al, 1990)
tance of the several sources and sinks that contribute to the displacement of the active zone (and therewith of the shoreline). A quantification of the several effects as found for the Holland coast gives the following result:

<table>
<thead>
<tr>
<th>Effects</th>
<th>Closed coast</th>
<th>Interrupted coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>sea-level rise direct (Bruun-effect)</td>
<td>15% &gt; 40%</td>
<td>5% &gt; 10%</td>
</tr>
<tr>
<td>sea-level rise indirect (estuary-pull)</td>
<td>-</td>
<td>55% &gt; 61%</td>
</tr>
<tr>
<td>feeding by shoreface</td>
<td>65% &gt; 46%</td>
<td>25% &gt; 20%</td>
</tr>
<tr>
<td>dune formation (loss over first dune row)</td>
<td>10% &gt; 7%</td>
<td>5% &gt; 3%</td>
</tr>
<tr>
<td>longshore drift (wave-driven)</td>
<td>10% &gt; 7%</td>
<td>10% &gt; 6%</td>
</tr>
</tbody>
</table>

Note: ">" stands for changing to

Table 1 Relative importance of absolute contribution to active zone displacement on the Holland coast for a sea-level rise of 0.2 m/century > 0.6 m/century (after Stive et al, 1990).

Figure 7 Present sand balance of the Dutch coastal system (after Stive et al, 1990)
From these results, several conclusions were drawn of which two are mentioned. Firstly, it follows that the Bruun effect is generally of minor importance. Only in the case of a triplication of the present rate of sea-level rise on the closed coast sections does it become important. Secondly, wave-driven longshore drift is of minor importance in general. These conclusions may contribute to the ongoing discussion of the relevance of sea-level rise for coastal erosion.

4. Discussion

The above described coastal evolution model after Stive et al (1990) contains important elements of earlier published work. Without striving for completeness, and certainly not fully aware of all the existing literature in this field, the following categories of references are mentioned. For the "Bruun Rule" aspects reference is made to Bruun (1962), Edelman (1968, 1970) and Dean and Maumeeyer (1983). For the exchange processes between the shoreface and the active zone reference is made to Niedoroda et al (1984) and Wright (1987). For a discussion of coastline recession models and especially the relative importance of cross-shore and longshore effects reference is made to Everts (1985), Pilkey and Davis (1987) and Galvin (1989).

The conceptual model as presented, however, does contain several aspects which make it differ from and more extensive compared to earlier suggested models or concepts in the following sense:

- in cross-shore direction the model introduces next to the active zone, which instantaneously follows the relative sea-level rise, the (central) shoreface which responds non-instantaneously to the relative sea-level rise;
- the model fully includes longshore effects, not only those induced by wave-induced longshore drift variations, but also those induced by coastal inlet systems.

Especially, the quantification of the several effects makes the presented model contribute importantly to the ongoing discussions on the effects of relative sea-level rise on coastal recession. From the present application to the Dutch coastal system, it is found that the cross-shore Bruun effect is generally less important than other effects such as shoreface feeding or alongshore effects due to estuary inlets. Since the Dutch coast covers a variety of systems, these conclusions may be of more universal value than the length of the Dutch coast in first instance would seem to justify.

Finally, it needs to be mentioned that the results of these studies enabled the Dutch coastal researchers to identify several research aspects for further study, for instance:

- the morphodynamic behaviour of the shoreface, with specific emphasis on the sediment exchange with the active zone;
- the degree of profile invariance of the active zone relative to mean sea-level.

These and other questions are being addressed in the framework of the Coastal Genesis Programme Part II. In this context it is important to point out the following. The resulting coastline development is assumed to be due to a superposition of the abovementioned three scales of evolution. Here, there is a fundamental research question.
This concerns the assumption that smaller scale phenomena are not interacting with or initiators of larger scale phenomena. The degree to which this is indeed true will largely determine the degree of predictability of coastal evolution.

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