INTRODUCTION

The coastal zone has been inhabited by man, from the early days of its existence. The sea was a major source of food, the coastal plain offered space for human settlement and related economic activities. For that reason, many civilizations found their origin in Deltaic areas and it is expected that by the year 2000 some 80% of the largest human settlements will be found in the coastal zone. Obviously, these developments have a significant impact on the autonomous natural developments in the coastal zone, which calls for an integrated coastal zone management.

Coastal zone management aims at solving present and future problems in the coastal zone, by finding an acceptable balance between economic welfare and environmental well-being, using a careful analysis of the natural processes and socio-economic developments.

The Netherlands, one of the highly densely populated countries in the world, is an example of such a development.

The social and economic activities in the Netherlands were strongly hampered by the fact that most of the coastal plains were liable to flooding during high tides. Naturally, even nowadays, about 50% of the Netherlands is laying well below Mean Sea Level.

Presently some 250 Km of the Dutch coast consists of sandy beaches and dunes. The remaining 100 Km is artificially protected by dikes (Figure 1).

Coastal defences and dunes have been reinforced to be able to withstand a 1/10,000 year design condition. The Dutch coastal infrastructure is now ready to cope with the challenges of the 21st century. And obviously, these challenges are numerous. Due to the effect of climate changes, the sea level in the North Sea may rise some 0.6 m in the next century. This will cause an intensified attack on the Dutch coast, which now already suffers a net sediment loss of some 3 million m$^3$ per year.

This has stimulated the execution of an integrated coastal management policy study, the so-called "Coastal Defence Study; (Louisse and Kuik, 1990). The objective of this study is to develop an integrated approach to the coastal zone and its hinterland, including old/new land, taking into account the various social and economic functions with their respective physical infrastructure.
ELEMENTS FOR A COSTAL ZONE MANAGEMENT STUDY

General

The main objective of coastal zone management is to analyse the autonomous coastal processes and their interactions with the human activities, with a view to develop the best strategy for management of existing and future activities. The principle of the system is shown in Figure 2 (see also Van der Weide, 1989).

The following elements can be identified:

- the natural system, described in terms of physical, biological and chemical processes;
- the socio-economic system, described in terms of the various functions of the coastal system and the relevant infrastructure;
- the control system, which includes the political and legislative infrastructure, the executional responsibilities and the financial structure for coastal zone management.

The trigger for a coastal zone management study may be changes which are introduced in any, or in all of these elements. In order to investigate the impact of these changes of the system as a whole, the interactions between the elements should be known.

For instance, due to the effect of sea level rise, the hydrodynamic processes in the area are changed. Such changes should be obtained from the description of the natural system. The impact on the social functions and the infrastructure can, thereafter, be assessed and quantified. The same procedure is followed, when changes in the social system are planned by introducing new activities such as for instance dredging or gravel mining or by constructing new infrastructural elements, for instance harbours. The impact of these changes are obtained from their interaction with the autonomous natural processes and are quantified thereafter.
Through the control system, various scenario’s can be introduced, representing different coastal zone management policies. From a comparison of the various scenario’s the most promising alternative may be selected using technical, economical and socio/political criteria. The later aspect of coastal management studies is beyond the scope of the coastal engineer. His involvement should end after the quantification of the effects of the various scenarios.

The Natural System (the coastal zone)

The basic elements in the natural system are:
- water, including dissolved matter, which may be described by its chemical, physical and resultant biological properties;
- sediments, characterized by their physical, mineralogical and chemical properties and the related hydrodynamic and geotechnical parameters, such as fall-velocity, critical shear stress etc.;
- marine life, characterized by the type and quantity of the various species.

In general, the properties of basic elements are used to monitor the ecological conditions in the coastal area. They are further used as in input for the description of the processes active in the coastal zone. These processes are complex, because of the fact that often interactions between two or more processes have to be taken into account.

In general the following types of processes can be identified:
- aero dynamic processes, such as air-sea interaction, and aeolian (wind) transport of sediments;
- hydrodynamic processes, such as waves, tides and resultant water levels and currents;
- morphodynamic processes, such as sediment transport and related changes in the bathymetry and shore-line geometry;
- geodynamic processes, induced by geotechnical instabilities such as subsidence, earthquakes, liquefaction, sliding etc.;
- ecodynamic processes, describing the resultant changes in the ecosystem due to any or all of the foregoing processes and/or elements.

The various processes and their interactions have been described schematically in Figure 3.

The Socio-economic System

Functions of the coastal zone
Traditionally, the coastal zone has been an area of great social and economic activity. Depending on the hierarchy of the various functions the following categories can be identified:

- basic function • food production
  • water supply
  • energy supply
- social functions • housing
  • recreation
- economic functions • transport
  • mining
  • industrial development
- public functions • public transport
  • defence

The present and future situation should be described in terms of the areas used for the various activities and their inherent economic and social values. Presently data-base systems are being developed, known as Geographic Information Systems (GIS), which can be used effectively for the description of these data.
Infrastructure

Most of the activities in the coastal zone have to be supported by a physical infrastructure. Due to the impact on the natural system, and the cost, it is normally an important element in the coastal zone management study.

Depending on the effect on the coastal system, the following categories may be identified:

- **flexible structures**, often consisting of natural material such as sand and gravel, which are used to protect coastal areas from erosion.
  Examples of such structures are dunes, artificial shoals and beach nourishments. These structures have the smallest interference with the natural processes. They even may take part in it.

- **defensive structures** are made of more resistant material such as clay and rock or artificial elements like bitumen or concrete. They are used to maintain the present position of the coastline especially in the event of extreme wave and tide conditions.
  Examples are dikes and dune revetments. These structures normally do not interfere with natural processes, until an extreme condition occurs. In that case its protective function is activated and it starts to affect the coastal processes.

- **offensive structures** are designed to actively affect the coastal processes, in order to improve conditions for coastal activities. They are therefore designed of artificial material which can withstand the forces of nature. Examples are breakwaters and groins. Obviously, this type of structure has a large impact on the coastal system, which should be analysed with great care.
The Control System

For an effective coastal zone management, a control system is required. The control system formulates the objectives of coastal zone management, monitors the developments and takes appropriate long term and short term actions.

The following elements can be identified:
- The political system, which defines the long term objectives of coastal zone management and the criteria which should be applied for the analysis of various scenario's for coastal zone management.
- The legislative system, the total of the governing international conventions, national laws and regional/local regulation to enforce this policy.
- The financial system, which provides the necessary funding for coastal zone management activities.
- The executional system, which defines the scope of responsibilities for all activities related to coastal zone management.

Due to different historic developments, different social and administrative cultures and different financial conditions, each country has developed a different control system.

As the efficiency of the control system is of vital importance for the success of coastal zone management, its structure should be known to the coastal engineer. If the performance is poor and no improvements are possible, the limitations of the system, in responding the system changes has to be included as an additional boundary condition.

COASTAL DEFENCE STUDY FOR THE NETHERLANDS

As mentioned before, a large part of The Netherlands is situated below sea level and would therefore inundate if it was not protected by a coastal defence system: This system has been improved drastically in the framework of the Delta Works Project, which was initiated after the dramatic flood of 1953. It is expected that by the end of 1990, the entire coastline will have an accepted level of safety against flooding.

The need for maintaining this level of safety during the next decades led to a policy analysis study of the Dutch coast, the so-called “Coastal Defence Study”. This study was initiated in 1988 by Rijkswaterstaat (Ministry of Public Works of the Netherlands) and should lead in 1990 to the selection of a coastal defence policy of the next 5 years (Louisse and Kuik, 1990).

The main issues of the study were:
- to predict the development of the shoreline
- to describe the main implications of this shoreline behaviour
- to generate coastal defence strategies
- to assess the technical implementation of the strategies
- to determine implications of these strategies: benefits and costs.

Thanks to former and recent coastal research program, like Coastal Genesis and TOW, the data and models needed for the study could be adequately obtained.

Coastal defence policy is mainly focused on the part of the coast that is protected by dunes (255 kilometer). The influence of the sea results in a gradual erosion of the shoreline at a fair number of places. An acceleration of relative sea level rise, as a consequence of the green-house-effect, would result in an even faster weakening of the coastal defence at these places.
With the predicted position of the shoreline (up to 2090) an evaluation was made of the impact of shoreline retreat on the level of safety against inundation of the polders (the part of the country lying below MSL).

At this moment there is already 18 kilometer of dune-coast for which within 10 years the safety can not longer be guaranteed.

If no measures are taken this length increases in time, even for the present day sea level rise, being 20 cm/century (Figure 4).

It is expected, due to the greenhouse-effect and the consequent warming-up of the earth, the relative sea level in the North Sea may rise with about 60 cm per century. In case of an unfavourable scenario this may amount to 85 cm per century (Figure 5). Thermal expansion of the seawater contributes for about 50% and the melting of the ice-layers for about 40%. Bottom subsidence is responsible for about 10% of the relative rise.

These two scenarios of sea level rise (60 cm and 85 cm) cause a more severe effect on the safety of the coastline (Figure 4), and additional measures should be taken.

A number of strategies against coastal defence has been formulated. The strategies have one feature in common: safety against inundation of the low country behind the dunes must always be warranted. The strategies lead to "alternatives" when they are completed with measures for coastal defence.

Four alternatives are distinguished:
- admission of further retreat of the coastline, except for the places where just minimum safety can be guaranteed: "Withdrawal (W)"
- counteract further coastline retreat at places where economical functions like water supply, recreation, etc. are present or where valuable nature area is threatened: "Selective erosion control (S)"
- counteract further shoreline retreat at all places where coastline erosion occurs: "Full erosion control (F)"
- counteract further shoreline retreat at all places where coastline erosion occurs: "Full erosion control (F)"

Measures for coastal defence for these three alternatives consist of solutions with sand, i.e. beach nourishments and in specific situations reinforcement of the dunes by supply of sand at the landward side of the front dunes. In this way the natural character of the coast is not affected.
Figure 5. Average Relative Sea Level Rise for the Scenarios A (20 cm), B (60 cm) and C (85 cm per century)

- seaward expansion of the coastline at places where the coastal defence is relatively weak with the objective of improving the coastal defence: "Seaward expansion (E)"
  This alternative is more offensive than the others.
  In this alternative structures of hard material, like groins and dams are chosen.

To identify the implications of the various alternatives, a policy analysis model was built. This model enables systematic evaluation of a broad range of alternatives. The main line of the evaluation with this model is:
- to bring in the predicted shoreline (over a period of 100 years from 1990 on);
- to check whether safety and/or other requirements (imposed by the coastal defence alternative W,S,F or E) are met;
- to compute the amount of sand needed to compensate for undesirable shore-line retreat;
- to determine the effects of the shoreline for the undefended areas.

The implications of the various alternatives are expressed in terms of:
- reduction of the length of shoreline where measures against erosion need to be taken;
- reduction of the loss of dune area;
- total costs for measures for coastal defence;
- specific costs for measures against erosion.

Inaccuracies in the results due to methods and predictions are calculated.

The length of coast that need to be protected increased for alternative W as a function of time (Figure 6). The same holds (to a less extent) for the costs. They amount to about 35 million guilders per year (Figure 7).

Alternative F shows a rather constant level of length of coast that need to be protected as a function of time (Figure 6). The costs of this alternative amount to about 60 million guilders per year in the year 2000.

The alternative Selective erosion control (S) leads to intermediate effects, both with respect to length of coast where measures need to be taken.
Acceleration of sea level rise from 20 to 60 cm/century results in an increase of costs for measures against erosion and loss of dune area of 25 per cent. The extra costs and losses of dune area for a scenario of 85 cm/century, including changes in wave climate, amount to about 80 per cent with respect to the case of 20 cm/century sea level rise.
MODELING OF COASTAL PROCESSES

In order to predict the coastline behaviour with or without coastal defence measures, use can be made of a morphodynamic model.

In order to develop such a model for a specific problem, the following stages should be identified:
- definition of the problem,
- identification of relevant physical processes,
- model design,
- calibration and verification

In general, knowledge of the relevant processes may be obtained from experiments, from theoretical analysis or from a combined approach. This is shown schematically in Figure 8 (Van der Weide, 1989).

![Figure 8. Techniques for Problem Solving](image)

When the physical understanding of the processes is low, phenomenologic models are used, based upon a generalized description of the various phenomena. This understanding may be improved by using any or all of the following approaches:

- empirical studies, resulting in empirical relationships;
- theoretical studies, resulting in a more or less refined description of the physical processes by means of numerical models;
- hybrid studies, resulting in a theoretical model, in which empirical parameters have to be used, obtained from experiments or field observations.

Ultimately a mathematical model should be developed, which is properly calibrated by means of experiments and field measurements.

The selection of the type of model depends on a number of criteria, such as the technological possibilities and the required degree of accuracy.

A generalized flow-diagram of morphodynamic models is shown in Figure 9.
Starting from the boundary conditions (waves, currents, geometry and sediment characteristics) first the resultant coastal hydrodynamic processes are modeled. This includes wind and tide induced currents, wave induced currents and wave action.

The next step is to compute the sediment transport as a result of these currents. In this respect two components are normally taken into account, cross-shore and longshore transport.

Finally, the resultant morphodynamic changes are computed, using the continuity equation of sediment.

Initially at DELFT HYDRAULICS, empirical models were used to describe the coastline development as a function of the longshore transport using the longshore wave energy flux as an input (so-called one-line model). At a later stage, these models were improved by computing the wave induced velocity field, which then was used as an input for sediment transport computations.

More recently, theoretical 2DH-models have been developed at DELFT HYDRAULICS to describe the combined wave and velocity field in the coastal zone. In combination with empirical models for suspended and bed-load transport, the morphodynamic processes can now be quantified more accurately.

As an example, the application of a 2DH-morphodynamic model is given for the development of the ebb-tidal delta of the Grevelingen Estuary in the Netherlands (Figure 10).

This tidal basin has been closed in 1971, which had an impact on the morphology of the outer delta. Basically, the morphology of a tidal delta is the result of two physical processes. Firstly, the tidal motion is the estuary results in tidal currents perpendicular to the main coastline. These currents, together with river discharges, cause a seaward-directed movement of sediment. Secondly, the asymmetry of wave propagating towards the delta induces a landward-directed sediment movement. The possible dynamic equilibrium between these two processes is disturbed when the estuary is closed.

Consequently, the available sediment is redistributed over the area with a tendency towards the coast. This resulted in development and growth of offshore bars as well as the siltation of former tidal channels.

In order to simulate this development, use was made of the mathematical model COMOR (Steijn et al., 1989). COMOR is an acronym for COastal MORphology. It is a compound system of mathematical models for the simulation of morphological processes in coastal areas. It interconnects its various constituent models for waves and currents to result finally in an initial sediment transport and
The computational grid is curvilinear and therefore very flexible (Figure 11). Several transport formulae can be used in COMOR. Here, use has been made of the Ballard formula, which accounts for both wave-asymmetry ("cross-shore") and current-induced ("longshore") transport components.
In order to hindcast the morphological changes in the area after closure of the estuary (1970-1975), sediment transport rates for four different wave conditions were computed. From the sedimentation/erosion pattern, found from the hindcast, it can be concluded that the model reproduces the observed morphological changes in the area well (Figure 12): formation of longshore bars in combination with deltafront erosion, levelling of the relief in front of the barrier and a steady siltation of the channels.

![Figure 12. Comparison of Simulated (left) and Observed (right) Morphological Evolutions in the Grevelingen Outer Delta; 1970-1975](image)

When comparing the computed sedimentation/erosion pattern with the observed one, it should be kept in mind that part of the channel siltation in front of the closure dam is due to import and settlement of silt, which was however not incorporated in the model.

After the verification, a forecast of the morphological development of the Grevelingen outer Delta for the period 1986-1987 was performed. The results are given in Figure 13.

A first analysis of the sedimentation/erosion patterns, in combination with physical knowledge gained from actual field information, shows that:
- the formation of longshore bars continues,
- the siltation of former tidal channels is almost completed,
- apart from an onshore-offshore sediment movement there is a net sediment transport directed from West to East
- the topography has not yet found its new equilibrium state.

This yields that the evolutions observed in the last 15 years continue, but at a slower rate.

Finally, it is concluded that numerical models can be useful tools for the prediction of morphological evolutions, however, field data are essential for validation. Moreover, a forecast requires careful interpretation of the model results, based on a good insight in the physical processes.

**OFFSHORE SAND NOURISHMENT**

Beach nourishment is becoming more popular as an effective and flexible method to compensate coastal erosion. Since beach erosion is often the result of erosion of the foreshore nourishment of this foreshore seems to be a logical alternative to beach nourishment. It may be expected however, that this method is less effective in terms of cubic meters required to stabilize a beach. At the other side the execution is so much simpler that the method may still compete with beach nourishment. Therefore a study was executed (Roelvink, 1989) to assess the effectiveness of offshore nourishment schemes.
Figure 13. Numerical Model Forecast of Grevelingen Outer Delta; 1986 - 1987

The study was executed by simulating the behaviour of an offshore nourishment of 100 m$^3$/m$^1$ placed at a depth of 3, 5, 7 and 10 m in a number of representative profiles along the Dutch coast.

the following schematizations are applied:
- the influence of longshore transport gradients is neglected, as it is assumed that the nourishments stretch out over at least some kilometres;
- three-dimensional phenomena on a scale of hundreds of metres are assumed to have no influence on a larger scale;
- swash-effects near the waterline and aeolic transport are neglected;
- the spectra of wave height, period and direction and the water level fluctuations are schematized to daily mean values of the significant wave height and peak period. A time series of these values as recorded on a nearby light vessel at 20 m depth over one year is used as (periodic) sea boundary condition;
- the remaining vertically two-dimensional system is simulated by the numerical model CROSTRAN, which is based on a number of schematizations.

The basic concept of the two-dimensional cross-shore morphological mode CROSTRAN (Stive, 1986) is as follows: the wave energy distribution over the profile is computed with a 1-dimensional energy decay model. The wave-driven flow field is assumed to depend locally on a number of characteristics of the irregular wavefield, such as wave energy, dissipation rate and mass flux. The flow parameters required by the transport model are then calculated from these local wave parameters, after which the transport distribution over the profile can be computed. By solving the mass balance the vertical rates of change are calculated; the bottom changes after a certain timestep are computed using an appropriate numerical scheme, after which the calculation continues with the new bottom profile.

The net transports in cross-shore direction can be directed both offshore and onshore, since the following mechanisms are taken into account:
- wave-induced mean flow near the bottom;
- flow asymmetry due to vertically asymmetric wave shape.

From a comparison of the profile development with and without an offshore nourishment the following conclusions have been drawn.

The costline evolution of the coast of Holland area can be positively influenced by nourishment of the upper shoreface. The effectiveness increases with decreasing nourishment depth. The time needed to reach the maximum gain of the nearshore zone increases with increasing nourishment depth. Nourishment on depths greater than approx. 8 m is hardly beneficial to the nearshore zone within the studied period. This is illustrated in Figure 14.

![Figure 14. Effectivity of Offshore Nourishment for the Nearshore Zone (200 m from Waterline) After 5 Years for Different Nourishment Depths](image)

The effectiveness, being that part of the nourished sand volume that benefits the nearshore zone (from 0 to 200 m seawards), after 5 years is for nourishments at a depth of 7 m, 5 m and 3 m respectively 25%, 40% and 55%.
REFERENCES


