Prepared for:

DG Rijkswaterstaat, RIKZ

Guidelines on the selection of CZM tools

Illustrated by applications t CZM problems on straight sandy coasts, and on irregular coasts

M. van Koningsveld

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1. INTRODUCTION AND SCOPE

1.1 COAST3D

The COAST3D project, a collaborative project co-funded by the European Commission's MAST-III programme and national sources, has run from October 1997 to March 2001. A consortium of 11 partners from five EU states (UK, Netherlands, France, Spain and Belgium) worked on the project, which had the following objectives:

- to improve understanding of the physics of coastal sand transport and morphodynamics
- to remedy the present lack of validation data of sand transport and morphology suitable for testing numerical models of coastal processes at two contrasting sites
- to test a representative sample of numerical models for predicting coastal sand transport and morphodynamics against this data
- to deliver validated modelling tools, and methodologies for their use, in a form suitable for coastal zone management

experimenters

Four field experiments have been successfully conducted, resulting in large amounts of high quality data on water-levels, currents, waves, sediment transport and bathymetric changes. The first two experiments took place at Egmond on a quasi-2D sandy stretch of the Dutch coast, with a pilot and main experiments in spring and autumn 1998 respectively. The second two experiments took place at Teignmouth on the south coast of England in spring and autumn 1999, where a rocky headland and a river mouth provide a strong three-dimensionality to the morphology, dominated by sand and shingle sediments. The data provide new understanding of coastal physical processes, which is valuable for coastal management both directly, and through the improvement of hydrodynamic and morphodynamic numerical models.

modellers

The field measurements were specifically designed to support testing, evaluation and further development of (numerical) hydrodynamic and morphodynamic models. For this purpose fieldworkers aimed to supply the modellers with adequate boundary conditions and a dense horizontal array of measurement points. To coordinate efforts, modellers and the experimenters worked in close interaction at the planning, experiment, and evaluation phases of the project.

end users

The models can be considered to be tools for Coastal Zone Management (CZM), and the comparison of the models with the data collected to be an important step in providing greater confidence in their use in practical CZM problems. Field measurements and monitoring in their own right, represent basic tools for CZM in many practical cases. Governmental agencies -end users participating in the project- continuously stimulated modellers and experimenters to demonstrate the usefulness of their tools for CZM.

1.2 CZM tools and guidelines: objective, target group and scope

The COAST3D objective to deliver tools and methodologies in a form suitable for coastal management has led to the development of guidelines.
The resulting guidelines have the specific objective

- to enable the coastal zone manager to make optimal use of the research results and available tools of the project COAST3D,

and the more general objective

- to contribute to bridging of the existing gap between coastal science and coastal management.

The guidelines are primarily targeted at *coastal managers at the level of regional engineers* within a national authority. At the same time, the contribution of COAST3D research groups to the production of the guidelines stimulated the awareness of their role in applicable research. As such, a secondary target group consists of coastal researchers, their managers and funders, and universities.

Within the range of potential CZM tools, COAST3D focussed on its "core business", i.e *technical design tools* (see Table 1.1)

Table 1.1 *Classification of CZM tools* *[shaded topics are the focus areas of COAST3D]*

Tools			examples	
Technical	• design tools	* data gathering	geological data	/ monitoring
			historical maps	/ process measurements
		* statistical analysis	empirical relations	/ statistical techniques
		* modelling	Large Scale models	/ process models
	• implementation		dredging / constructions / nourishment schemes	
Political / legal			policy / strategy / directives / legislation / standard(s)	
Socio - economic			information / education	

1.3 CZM guidelines in general

During the process of guideline specification the project has identified a gap between the problem-driven requirements of CZ managers and the science-driven goals of researchers. An illustration of this gap is a typical end user's statement like: *"I do not need your models, I need solutions for my problems"*. A statement which at first sight, many a researcher will classify as rather blunt.

The statement however, illustrates two important messages with regard to guidelines:

information analysis and communication

1. consider explicitly the link between guidelines and specific coastal applications; and
2. consider communication between CZ managers and researchers as an important subject in the process.

The first message involves the need for a systematic CZM information analysis (see Chapter 2), the second a vision on the communication process (see Chapter 5).

Considering CZM problems as the starting point, it is not enough to develop recommended procedures on HOW to use numerical models in coastal practice, it is just as important to specify WHAT type of model (or measurement- and analysis method) is applicable WHEN (i.e. to what type of problem). Guidelines for using available CZM tools should answer the following basic questions:

- WHEN to use, WHAT tools, and HOW to use these.

information need

Answering the **WHEN** question first of all, requires an analysis of the CZM problem(s) resulting in a specification of the information need. Part of this process is the definition of the problem and of the general objective and an analysis of its context and of its dimensions (see 2.2).

information strategy

Then, the answer to the question **WHAT** tools to use requires an information strategy (see 2.3). A strategy which is depending on

- the availability of data and tools and possibilities for monitoring and measurements,
- availability and (more important) the validity of numerical models, considering the spatial and temporal scales of interest, and of course
- the optimum combination of tools in terms of accuracy and cost.

information gathering

Finally, the question **HOW** to use the tools may lead to guidelines for each individual tool (see Appendix 1 and 2). Examples are:

- statistical analysis techniques (minimum data demands etc.),
- monitoring and measurement schemes (parameters, instrumentation, frequency and spatial distribution, accuracy etc.)
- methodology and procedures for applying individual numerical models.

1.4 COAST3D approach and outline of report

As a general introduction, Chapter 2 describes a generic approach to CZM information analysis.
The analysis method is illustrated on two case studies: Egmond (the Netherlands) (Ch. 3) and Teignmouth (UK) (Ch. 4).

Egmond The Egmond site is assumed representative for quasi-uniform sandy beaches dominated by breaker bars found on much of the coastlines of northeast France, Belgium, the Netherlands, western Germany, western Denmark and eastern England. Typical problems are related to coastal safety, and coastline maintenance.

Teignmouth Teignmouth, is considered typical of the irregular coastlines featuring tidal inlets, river and estuary mouths, headlands, and coastal structures, often without breaker bars, found in western and southern Britain, Ireland, northern and western France, northern Spain, Portugal, and Norway. Typical problems are related to maintenance of safe navigation and flood management.

The case descriptions are focussed on information analysis and the selection of CZM tools. For each location a hypothetical CZM problem is defined. Individual tools -as applied and developed within COAST3D- may play a role in solving the hypothetical problems. The basic contribution of the tools developed in COAST3D is the description of the physical state of the system.

A summary of tools used in COAST3D -measurement equipment and numerical models- and of guidelines on HOW to use the tools is presented in Appendices 1 and 2.

Applying the guidelines for information analysis to the example cases at Egmond and Teignmouth, discussions between researchers and end users in COAST3D revealed the gap between specialists and generalists. Based on this experience COAST3D developed a method to improve communication between the two groups, for the benefit of both.
Ch. 5 discusses the communication method.

2. GUIDELINES ON CZM INFORMATION ANALYSIS

2.1 Coastal management and research

Coastal managers have a continuous need for information related to the system under their control. Primary components of the coastal system are the natural subsystem and the antropogenic (socio economic and administrative) subsystem. Main interest for coastal management is the sustainable interaction between the two subsystems. With increasing demographic pressures, these interactions should be controlled properly. Any discrepancy between the actual and desired state of the coastal system, defines a CZM problem. The general objective of CZM is to prevent and mitigate these problems. Specialists may support coastal management by providing the required information. They may describe the system, explain occurring phenomena and reduce uncertainties in predictions of these phenomena.

In fact, the coastal management process involves a complex of information.
Perceptions on what information is relevant, may vary considerably depending on a given point of view. For a specialist in coastal behaviour, relevant information might be a set of equations or a model describing bar behaviour under the influence of waves and currents. For a coastal manager, it might be a decision recipe for designing shoreface nourishments. Despite the difference in perception, the link between both view points is obvious: knowledge from the former may be used for improvements of the latter. In practice however, potential benefits from specialist knowledge for coastal management are often difficult to recognise.

The previous example is illustrative of the present gap between the problem-driven requirements of CZ managers and the science-driven goals of researchers that needs to be bridged. The way to identify and overcome these differences is by communication. A way to establish effective communication is a methodical definition of the management's information need starting from a specific coastal management problem (VanKoningsveld *et al, -submitted-*)(See Fig. 2.1.1). Explicitation of this information need facilitates communication between CZ managers and specialist researchers by identifying potential research applications and research needs (more on communication in Chapter 5).

2.2 CZM information need

<u>*Phase I*</u>

problem and general objective

Starting point of the information analysis may be any coastal management issue; usually some kind of conflict between socio-economic -, physical - and administrative aspects of the coastal system. Specification of the problem (present vs. desired system state) and the general management objective implies important clues on the type of information required.

<u>*Phase II*</u>

context

In order to put the coastal management issue in the proper perspective, it is essential to define the wider context of the problem (external dimensions or boundary conditions of the problem). Important are different aspects of the socio-economic context (present economical functions, social acceptance), the administrative context (legal, political, strategic aspects) and the physical context (environmental and technical conditions).

<u>*Phase III*</u>

dimensions

When the context of the issue (that can *not* be influenced) is known, it is possible to specify the internal dimensions of the problem (that *can* be influenced), both with respect to:

- socio-economic aspects; e.g. relevant user functions (safety, navigation, recreation etc.),
- administrative aspects; e.g. management strategies at different levels of administration,
- physical aspects; e.g. different physical parameters (dune width/height, coastline position, beach width, channel dimension/position, area of shoals, coastal structures, wave height/length/direction, current velocities/directions, sediment characteristics, etc.).

and to

- relevant time and space scales.

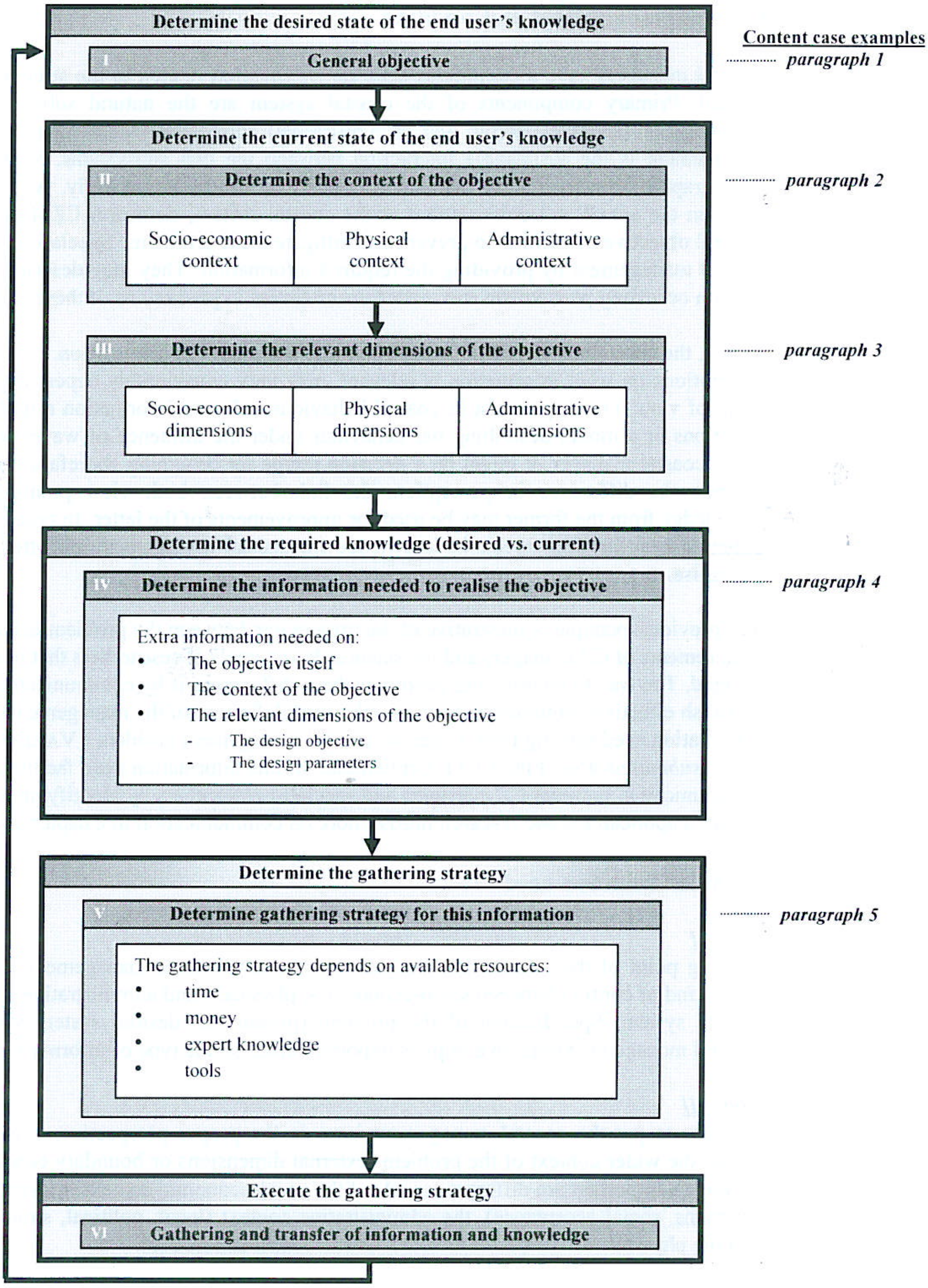

Figure 2.1.1. Flow diagram: iterative definition of the information need

time and space scales

CZM issues cover a wide range of time- and space scales (Fig. 2.1.2).
The quality of user-functions can be evaluated on different time and space scales. The quality on given time and space scales is often influenced by coastal behaviour on corresponding scales. A CZM issue like swimmer safety, for example, is influenced in particular by short term and local processes (e.g. the strength of wind-driven, tidal and rip currents). When adressing an issue like long term coastal defence natural processes like (accellerated) sea level rise and climate change become important. Thus the scale dimensions of a specific CZM issue indicate the scale of requested information.

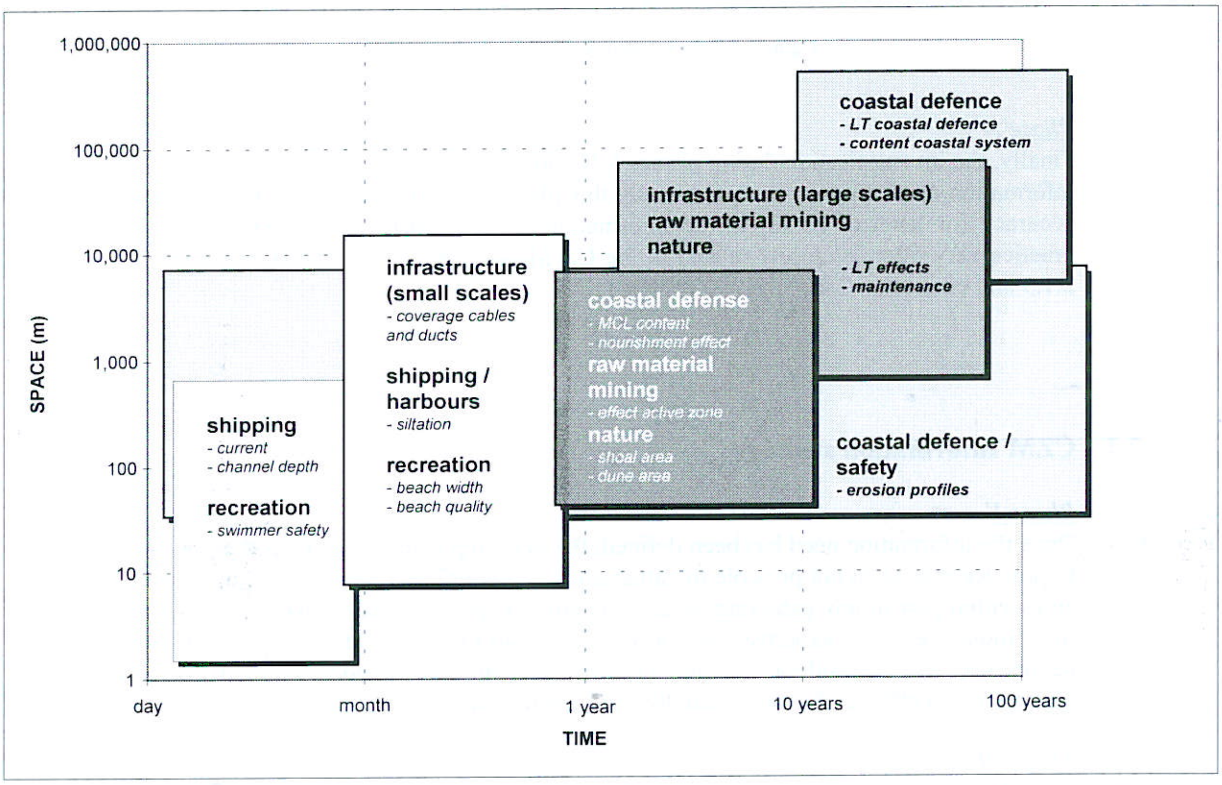

Figure 2.1.2. Range of CZM issues

design objective

Specification of the dimensions of the CZM issue not only implies a quantification of the problem, but also of the requested solution. The general management objective from Phase I should be transformed into a specific (quantitative) design objective. This design objective quantifying the 'desired' system state, is essential to enable objective decision-making.

coastal state indicators

To quantify the state of the system, a coherent set of coastal state indicators is needed.
Coastal state indicators quantifying the desired state of the system -or the design objective- are called design parameters. The decision which indicator(s) are fit to be design parameter(s) given a certain problem, is one of the most difficult considerations for coastal managers.
The quantifiable 'coastal state indicators' are considered crucial parameters to bridge the gap between coastal research and management : on one hand useful parameters for coastal managers to enable objective intervention, on the other useful for specialists as most aggregated projections of their study results.

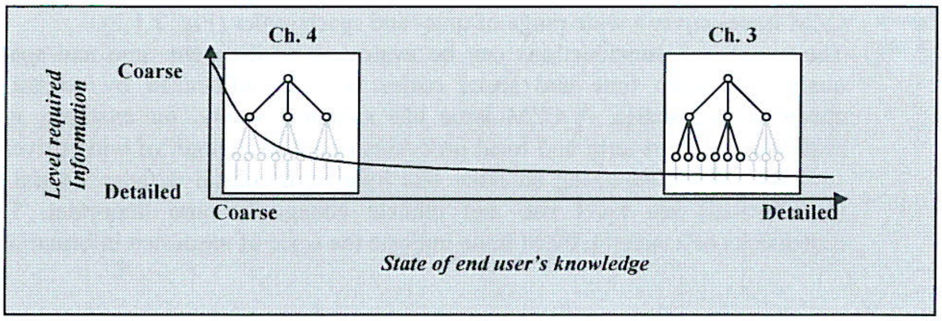

Figure 2.1.3. Progressing level of system knowledge.

Information need

Phase IV

Finally, the inventorisation during phases I, II and III leads to the specification of the actual information need. Important aspect during this phase is the definition of a required level of accuracy (or level of detail) in the information need; a difficult consideration, which in practice very often is closely related to the CZ Manager's state of knowledge (see Figure 2.1.3 and cf. section 2.4).

2.3 CZM Information strategy

information strategy

Phase V

Once the information need has been defined, the next step is to develop a gathering strategy. In practice it is often not possible to gather all required information. Prioritising is therefore an essential part of any gathering strategy. Choices depend on the availability of resources: time, money, experts, expertise and tools. Insight into the extent of required resources may be derived from considerations on (1) existing tools and methods and (2) on existing experience on effort and cost of actually applying the tools.

information gathering

Phase VI

Then, based on the gathering strategy information may actually be gathered. An overview of available tools and methods is given below. Guidelines on how to use the tools developed in COAST3D may be found in Appendices 1 and 2.

tools and methods

Generally, technical tools and methods for CZM concern:

- collation of background information,
- monitoring,
- measurements,
- modelling, and
- interpretation.

collation of background information

Basic requirement to any CZM study is the collation of background information. For the COAST3D studies this information was derived from

- Literature search (papers, reports, tide tables etc.)
- Historical charts, maps, photos and pictures
- Discussions with local officials (e.g. Harbour Commission, District Council, Waterboard)
- Discussions with local population (e.g. fishermen)
- Discussions with regional officials (e.g. MAFF, Environment Agency, County Council, Rijkswaterstaat)
- Discussions with regional universities (Plymouth, Delft)

Similar sources of background information will exist for most CZM sites.

monitoring Monitoring -defined as the routine measurement of basic parameters over medium to long periods of time (say 12 months or more)- provides essential information on boundary conditions and on temporal and spatial scales of the physical system. Insight into the natural variability of the system represents an essential reference for CZM decision making.

Monitoring requires an investment over a relative long period, implying an important cost factor and a risk of not obtaining useful results before a CZM decision has to be taken.

At some sites, some basic monitoring may already be in progress –e.g. for tidal heights. Parameters that might be monitored include:

- *Tidal heights, currents*
- *Wave heights, periods, directions*
- *Beach levels, nearshore/offshore bathymetry*
- *Sediment sizes*
- *Wind speeds and directions*
- *Suspended sediment concentrations/transport*
- *Bed forms/transport*
- *Water temperature, salinity, quality*

measurements Measurements -defined as short-term investigations of local and/or specialised parameters, typically over one tidal cycle, or perhaps a spring-neap cycle, or possibly before and after a storm- may be required to gain insight into specific ongoing processes. Often the need for such measurements will be dictated by the modelling approach that is proposed.

modelling To effectively support decision making in coastal management, any modelling must at least be able to reproduce the behaviour of the dominant morphological features or coastal state indicators (eg. for Teignmouth existing channel/sandbank system, of the existing beach, and of the existing sea outfall). There are many types of models. Even within models, there are several possible approaches.

Typical considerations with regard to models are:

- *What type of model to use, and why?*
  - ◊ *2DV, 2DH or 3D?*
  - ◊ *With/without stratified flows?*
  - ◊ *Finite Difference (with rectangular or curvilinear grid) or Finite Element (triangular grid)?*
  - ◊ *What area to be covered, and why? (e.g. model must extend beyond possible area of influence of proposed works)*

- *How to match grid element size to important features? (e.g. grid size in approach channel?)*
  - ◊ *What physical processes should be included, and why?*
    (e.g. wave current interaction, wetting/drying elements, sediment transport)
  - ◊ *What physical processes are omitted, can be ignored, or are impossible to model at present?*
    (e.g. swash zone sediment processes)
  - ◊ *What data/information is needed to set up model? (e.g. bathymetric data, boundary conditions)*
  - ◊ *What data/information is needed to calibrate/validate model?*
    (e.g. tidal currents at strategic locations)
  - ◊ *Which of these data/information requirements are "essential" or "desirable", and why?*
  - ◊ *What "added value" is provided by the "desirable" data? (e.g. bedform data from side-scan sonar)*
  - ◊ *What test conditions will be applied, and why? (e.g. waves/tides/scenarios).*

- *Operational issues*
  - ◊ *How user-friendly is the model? (research model or commercially released software?)*
  - ◊ *How costly is the model? (e.g. setup time, computing time per test?)*
  - ◊ *How much time is needed for the interpretation of the modelresults*
  - ◊ *How cost-effective is the test programme?*

Interpretation All the information/data/results from the above parts of the study need to be integrated and interpreted for the benefit of the CZ Manager.

Typical considerations with regard to analysis and interpretation of results are:

- *How to analyse/interpret measurement/monitoring data?*
- *How to extrapolate data (e.g. for extreme waves/tide levels)?*
- *How to predict:*
    - ◊ *Annual and/or maximum infill rates from few test runs? (Perhaps through use of monitoring data?)*
    - ◊ *Maximum/minimum beach levels?*
- *How to present the results to the CZ Manager?*
    - ◊ *Deterministic or probabilistic?*
    - ◊ *Sensitivity analysis and confidence limits?*
    - ◊ *Descriptive or prescriptive?*

2.4 CZM Information loop

The process of determining the information need and the consequent information gathering strategy encompasses in fact an information loop. Feedback of the results of the information strategy (see Fig. 2.1.1) will enable a further sharpening of working hypotheses, triggering a new, more detailed information need and a more advanced gathering strategy etc.

Figure 2.1.3 illustrates how this iterative process may result in a progression towards a more focussed and more detailed state of knowledge. Starting from a relatively coarse state of knowledge including only crude indications on the CZM design objectives, the definition of the information need by consequence very often will be global, requiring a coarse information strategy only (see e.g. Chapter 4). When the starting point of the analysis is an advanced and detailed state of knowledge, the consequent information need and gathering strategy may also be defined at a much more detailed level (see e.g. Chapter 3). The required level of detail, as requested by the CZ Manager, in each case ought to be leading.

3. STRAIGHT SANDY COASTS: A CASE STUDY

3.1 Egmond, the Netherlands: Example of a typical CZM case on a straight sandy coast

Egmond situated on the sandy coast of the Netherlands (see Fig. 3.1.1) is a holiday resort to a large extent depending on beach recreation. Maintenance of a wide and safe beach and protection of the boulevard in the central part of the village is of prime importance to the local authorities. Safeguarding against flooding is the responsibility of the regional Waterboard, prevention of coastal retreat is the responsibility of the Ministry of Transport, Public Works and Watermanagement / Rijkswaterstaat at a national level.
Since the 80's Rijkswaterstaat has tried to serve the combined national, regional and local interests by repeatedly applying of beach nourishments.

As a COAST3D-CZM **case study** we consider the situation where Rijkswaterstaat wishes to investigate the effectiveness of a potential alternative:

- implementation of a *shoreface* nourishment of order 2-3 Mm3, in order to extend the life time of a traditional beach nourishment.

Local authorities will insist that the design of the shoreface nourishment by Rijkswaterstaat will take account of the possible effects on their interests. To address these aspects the Regional Directorate of Rijkswaterstaat wishes to commission certain studies, possibly including field measurements, data analysis and modelling.

WHAT tools should be used WHEN?

- What studies are recommended and how could these studies be justified?

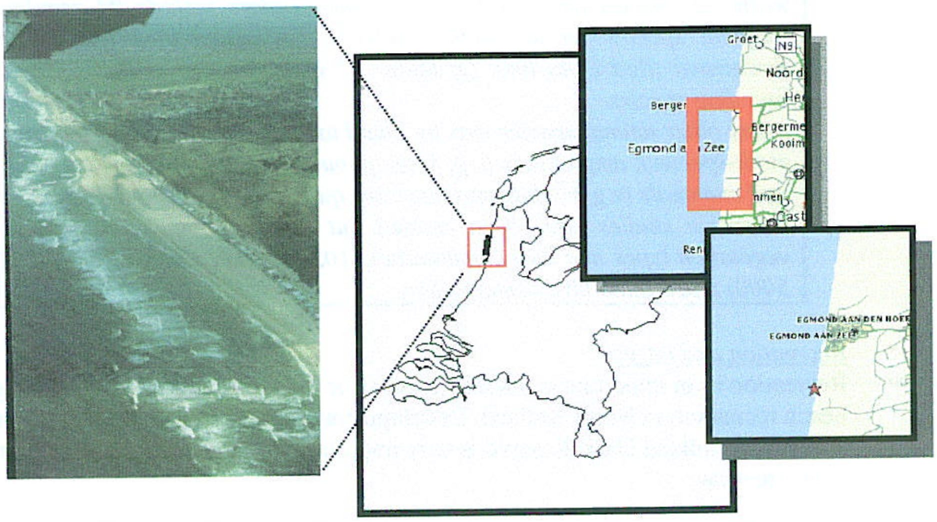

Figure 3.1.1. The Egmond fieldsite

3.2 Context of the problem

3.2.1 Socio-economic system

discussions with authorities

The coastal zone of Egmond represents several important economic functions: safety against flooding of the hinterland, drinking water supply, ecological values and recreation and leisure.

literature

Coastal safety

Providing safety against flooding of the hinterland, historically has been the primary function of the Dutch coastal zone. At Egmond coastal safety is at stake in the village itself, where the defined coastal defence strip along the coast reaches a cross shore width of only 100 to 200 m in the area in front of the village. Within this area some 50 permanent residential homes and apartment-complexes, one hotel, a parking lot and 1 school, and some 10 semi-permanent beach cafes and -restaurants at the dune foot represent important economic values.

The dune areas North and South of the village, have such widths that shoreline retreat does not affect the safety against flooding of the hinterland. However, structural coastal erosion would affect the natural values of these areas, their role in the supply of drinking water and for recreation and leisure.

literature

Drinking water supply

The dunes are an important storage of drinking water. Millions of people in the western part of the Netherlands are depending on the drinking water production from these areas. Developments in beach width affect the storage capacity the dune area.

literature

Ecological values

The dune areas around Egmond are an important nature reserve. The reserve owes its national and international importance for conservation to its great natural values. Although the reserve covers only 0.1% of the total surface area of the Netherlands, it holds more than half of the Dutch vascular plant species, 740 species in all and, in addition, 150 species of mosses and liverworts, and 244 species of lichens have been recorded.

The reserve is by far the richest for epiphytic lichen species in the Netherlands. It harbours a large number of threatened Red Data List species: 91 (17% of the Dutch total) vascular plants, 24 (9%) mosses and 45 (12%) lichens. Over two-thirds of the Dutch breeding bird species, breed in the reserve; 96 species are regular breeders, while 25 species are less frequent. Non-breeders include 94 regular and 82 less frequent species. In the Netherlands 48 threatened bird species are considered threatened (Red Data list). Of these, 47 species occur in the reserve, including 11 breeding species.

Many other animal species may be found too: insects (e.g. butterflies and two endemic moth-species), amphibians (e.g. large populations of the natterjack toad), sand lizards and mammals (e.g. rabbits and foxes are quite common) and 5-7 bat-species.

Extensive studies have been carried out on the composition and development of vegetation types and bird communities: 105 vegetation types were identified (scale 1: 5000) and 8 main bird communities.

literature

Recreation and leisure

Recreation is an important economic activity for the village. Egmond is the largest resort for beach recreation in North Holland. Developments in beach width directly affect this activity. The North Holland Dune Reserve is very important for large parts of the province as an area for recreation.

The changing attitude towards the countryside and towards nature is highlighted in the number of visitors. These days the number of visitors is estimated between 5 and 6 million per year, and the number is still increasing. Visitors not only come from nearby, but from all over the province. From adjacent communities, over 70% of the population visits the reserve frequently, usually more than once a week. Up to 255 of the people living up to 25 km away, visit the reserve at least once per month. In summer tens of thousands of tourists stay in the villages near to the reserve.

3.2.2 Physical system

literature *historical maps* *monitoring*

The coastline of the Netherlands is about 350 km long. Approximately 290 km consists of dunes and beach flats.

Egmond is situated on the Holland coast, representing the central part of the Netherlands' coast between Den Helder in the north and Hoek van Holland in the south. This coastal stretch is about 120 km long and mainly consists of sandy beaches and multiple barred nearshore zones. Beaches and shore-face almost completely consist of sand. More than half of the coastline is subject to erosion. The remaining part is stable or advancing. Major artificial works on the northern part of the Holland coast are the harbour moles at IJmuiden, south of Egmond, and the Hondsbossche Sea Defence near Petten, north of Egmond.

<u>Geomorphology</u>

literature

The nearshore zone at Egmond typically is characterised by two bars: an inner nearshore bar with crest heights between -1.5 and -2.5 m NAP (Dutch Ordnance Datum) and an outerbar with crests between -3.5 and -4.0 m NAP (cf. Fig. 3.2.1).

monitoring

Beaches have a width of 100 to 200 m; the dune area North and South of Egmond village has a cross shore width of 2.5 to 3 km.

measurements

Sediments are well sorted and composed of fine to medium sand with a mean grain size between 250 and 350 um

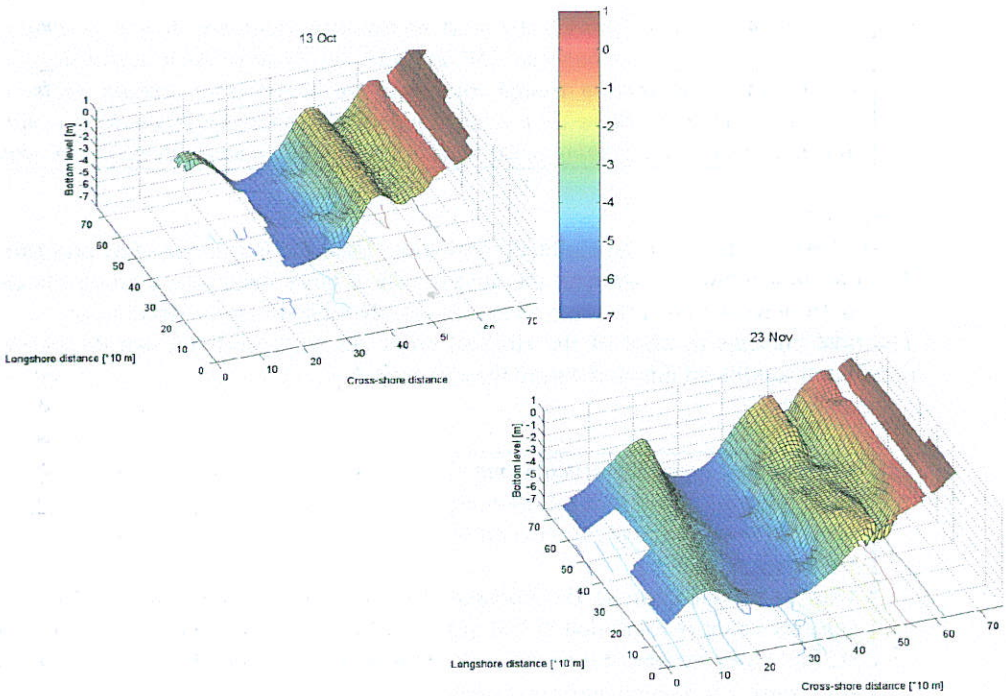

Figure 3.2.1. Bathymetry Egmond field site

The shoreface of the Holland coast has a concave profile; the central area with a slope of 1:165 and a transition depth at –15 m NAP. The lower shoreface below -8m NAP is smooth and does not show any barred features.
The upper part of the shoreface is the nearshore zone. This area is characterised by multiple nearshore bars The amount of bars differs along the coast. In the Egmond area, the nearshore is characterised by an inner nearshore bar -located most landward- , and an outer nearshore bar -located most seaward- . The crest of the outer nearshore bar is almost straight and lies below a mean water depth of -3.5 to -4.0 m NAP. The crest of the inner nearshore bar has an irregular longshore morphology with most of the time a crescentic appearance, and lies below a mean water depth of -1.5 to -2.5m NAP. Periodically some rips appear in the inner nearshore bar. These rips have a longshore spacing of about 200 to 500 m. The cross-shore bar crest spacing is fairly constant in time at about 300 m.
The beaches at the Holland coast have a width of 100 to 200 m (dune foot to low water line) and an average slope between 1:35 and 1:60. The morphology of the beach is often characterised by the occurrence of a swash bar. This swash bar is generated during low to moderate energy wave conditions and disappears during high-energy wave conditions. Beach states at Egmond ranges between the longshore bar-trough system and the reflective system (see for classification of beach types .
The dune area at Egmond has a cross-shore width of about 2.5 to 3 km. The maximum height of the ridge of fore-dunes is about 16 m. This ridge of fore-dunes has an artificial straight alignment. Most of the landward-located dunes are well developed parabolic features.
The sediments near Egmond are well sorted and composed of fine to medium sand with a mean grain size between 250 and 350 um. Most of these sediments of the bed surface in the nearshore trough and near the swash area contain shells or shell fragments. Overall, there is a coarsening of the sediment from deep water to the intertidal beach and a fining of the sediment from the intertidal beach to the dunes.

Waves, tides and currents

Monitoring

Interpretation

Most of the winds along the Holland coast come from the North Sea. The prevailing wind direction is southwest. However, the storms with a large wind set-up along the coast are coming from northwest. The wave climate is closely related to the wind climate.
The tidal currents in front of the Holland coast are northward directed during the flood period and southward directed during the ebb period.

The Holland coast is located along the southern part of the semi-enclosed North Sea and is characterised as a mixed-energy coast. A mixed-energy coast implies that both the wind waves and the tides act on the sandy sediments and induce the morphological responses.
Most of the winds along the Holland coast come from the North Sea. The prevailing wind direction is southwest (23%), followed by west (16%), east (13%) and northwest (12%) . However, the storms with a large wind set-up along the coast are coming from northwest. The wave climate is closely related to the wind climate.
The tidal currents in font of the Holland coast are northward directed during the flood period and southward directed during the ebb period. The semi-diurnal tidal curve is asymmetrical with a flood period of 4 hours and an ebb period of 8 hours near Egmond. This tidal asymmetry is mainly caused by an interaction between the M2 and M4 tidal components. The mean semi-diurnal tidal range along the Holland coast lies between 1.5 and 2.0 m, with a value of 1.65 m near Egmond. At this site, the maximum range occurs at spring tide (2.0 m) and the minimum range occurs at neap tide (1.4 m).

Shoreline development at Egmond

historical maps Historical maps show a shoreline retreat around Egmond of about 160 m between 1600 and 1750 and a further retreat of about 130 m between 1750 and present. The total historic landward retreat rate of the shoreline thus has been about 0.74 m.year^{-1}.

monitoring Observations of shoreline positions along the Holland coast over the last 140 years indicate a significant difference in trends for coastal stretches to the South and to the North of Egmond. The stretch to the South showing an average shoreline progradation rate of 0.20 m. year^{-1}, and the northern stretch between Egmond and Den Helder a shoreline retreat of about 0.95 m.year^{-1}

> *The development of the shoreline position over the last centuries near Egmond is derived from three maps of the village, drawn in 1686, 1718 and 1864. The shoreline in front of the village shifted 30 meters landward in the first period (1686-1718) and 100 meters in the second period (1718 - 1864). Other numbers of shoreline retreat are based on a comparison of three maps of the Holland coast. The following shoreline migration rates were determined near Egmond: a shoreline retreat of about 160 m between 1600 and 1750 and a further retreat of about 130 m between 1750 and present. The total landward retreat of the shoreline is thus about 0.74 m.year^{-1}. The shoreline retreat southward of Egmond was less pronounced, the shoreline retreat northward of Egmond increased to the north (to Den Helder).*
>
> *The changes in shoreline positions along the Holland coast over the last 140 years gave three regions, the southern stretch between Hoek van Holland and Den Haag with a shoreline retreat of about 0.35 m.year^{-1}, the central stretch between Den Haag and Egmond with an average shoreline progradation rate of 0.20 m.year 1, and the northern stretch between Egmond and Den Helder with a shoreline retreat of about 0.95 m.year^{-1} . At the Egmond field experiment site, the shoreline, defined as the lines of the dunefoot, the mean high-tide and the mean low-tide are almost stable.*

3.2.3 Administrative system

Coastal policy

Until 1990 coastal policy in the Netherlands was mainly aimed at maintaining the primary function of beaches and dunes:

- the protection of the hinterland against flooding by the sea.

In the late 1980s a more general awareness had grown that structural erosion also affected other functions of the coastal zone:

- ecological values,
- recreation,
- drinking water supply,
- residential and
- industrial interests.

Therefore in 1990 a new national coastal policy was adopted aiming both at safety against flooding and at sustainable preservation of the values of dunes and beaches. In order to achieve this the coastline must be maintained within certain margins.

The new so-called 'Dynamic Preservation' policy intends to maintain the seaward boundary of The Netherlands minimally at its 1990 position and to preserve natural dynamics of the coastal zone as much as possible. The main method to counteract structural erosion is nourishment with sand.

Coastal state indicators

To make the Dynamic Preservation policy operational a quantifiable coastal state indicator has been developed: a quantitative definition of the coastline. A so-called Basal Coast Line (BCL), delineating the coastline position of 1990, represents the desired state of the system. The actual state of the system is defined by a Momentary Coast Line (MCL).

A yearly test procedure including a Test Coast Line (TCL), compares the actual state of the system is with the desired state. Any (negative) difference between the TCL and the BCL implies an objective indication to the Coastal manager to decide on intervention.

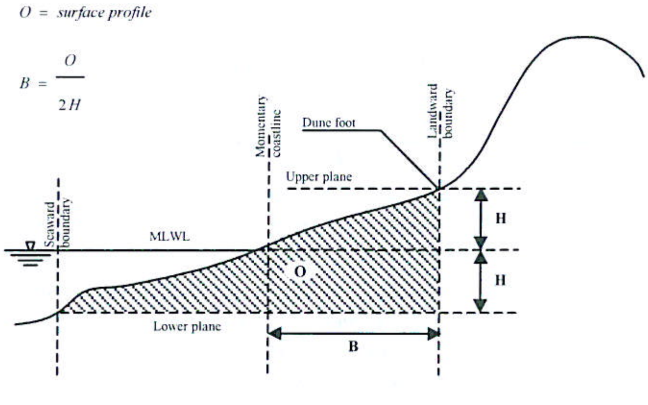

Figure 3.2.6. Calculation method Momentary Coastline (MCL)

The yearly test procedure implies three coastline definitions:
Momentary Coastline (MCL), Basal Coastline (BCL) and Test Coastline (TCL).

The definition of the actual coastline in a cross-shore transect in any given year -the Momentary Coastline (MCL)- is closely related to the total sand volume in the depth zone between dune foot and approximately -5m below NAP (cf. Fig. 3.2.6).

The BCL represents the desired state that is used for the actual management of the coastline. It has been defined as the average position of the coastline in 1990. This average position is derived from an extrapolation of the linear trend that can be determined from the positions of the 10 MCL-points in the years 1980 to 1989.

The position of the TCL is determined in a similar way as the BCL. The position of the TCL of the year T can be determined by extrapolating linearly on the positions of the MCL in the years (T-10) until (T-1). The current state of the system can now be compared with the desired state, by comparing the TCL with the BCL. This comparison is an indicator of the expected coastal state in the year T. A TCL that moves landward of the BCL is an indication for the responsible coastal authority to consider intervention.

Present practice

The Basal Coast Line has been officially delimited along the Dutch coast by the so called POK's, provincial administrative coastal authorities representing both local, regional, provincial and national interests.
Basis for delimitation of the BCL have been calculations according to the defined procedure at intervals of 250 m alongshore. For some parts of the coast however, advice by the POK has led to the official decision to deviate from the calculated BCL position. At some locations with very broad dune areas no official BCL has been delimited at all, or at a more landward position. At locations like Egmond, with high safety risks in a narrow coastal stretch, the official BCL has been delimited at a more seaward position.

In the framework of the Dynamic Preservation policy, at Egmond several beach nourishments have been implemented since 1990. The average design lifespan of the nourishments was (and is) 5 years. The lifetime of the beach nourishments at Egmond however, has proven to be significantly shorter than at other parts of the Holland coast: the average return period of nourishments appears to be two years.

The high frequency of beach nourishments, incorporating high cost and frequent negative effects on beach recreation, illustrates the need to investigate a potential alternative; the implementation of a shoreface nourishment, in order to extend the life time of a traditional beach nourishment.

3.3 Dimensions of the problem

Socio-economic dimensions

Nourishments at Egmond aimed at maintaining the coast line, implicitly are designed to serve other interests as well: reduction of safety risks regarding the boulevard in the central part of the village, and regarding residential and economic interests in the coastal zone.
Important function in this respect is beach recreation, requiring wide, safe beaches and safe swimming conditions.

Physical dimensions

Egmond is situated in the middle of the coastal cell, located between the Hondsbossche Sea Defence and the harbour moles at IJmuiden.
For the effects of a shoreface nourishment the area of interest is order 5 km along shore and 1 km cross-shore. This area is characterised by the presence of a two-bar system. The outer bar being less mobile than the inner bar.
The areas around Egmond village are structurally eroding with the speed of order (1 m per year). Bed material of the shoreface consists of fine sand, comparable in size to the beach sand. Along this sandy semi straight coast, rip currents occur at regular interval in the order of 1 km along shore.
The latter represent important features with regard to maximum local current speeds affecting swimmer safety; the former the main dimensions regarding nourishment design and beach characteristics.

Administrative dimensions

The Dynamic Preservation policy with its Basal Coast Line concept represents the most relevant context from an administrative point of view.
The Basal Coast Line as a dominating coastal state indicator, implies the importance of the sand volume in the depth zone between dune foot and ca -5 m NAP as an objective reference for CZM's decision making.
The fact that the officially established BCL at Egmond, deviates from the physically more suitable, calculated BCL, represents a notable consideration in the design of any intervention.
The artificial bastion shape of the coastline resulting from the established BCL, might very well explain the relative short lifespan of beach nourishments at Egmond.
A re-consideration of the delimited BCL theoretically might provide a solution. The established BCL, however, is regarded contextual information in this particular example and therefore this option will not be part of the research in this case. Explicitly distinguishing what is part of the problem and what is part of its context is an important means to focus interaction with specialists.

3.4 Information need

The starting objective

The dimensions of the problem derived in 3.3 indicate that the general objectives of the CZ Manager in the Egmond case would be:

- maintenance of the coastline at Egmond
- safeguarding of safety against flooding, including reduction of economic risk
- maintenance of a wide and safe beach, and
- a guarantee for safe swimming conditions.

Making these objectives operational asks for the definition of quantitative design objectives, based on quantitative coastal state indicators (or design parameters).

design parameters

The Basal Coast Line concept offers a good example of such an indicator to define the state of the coastline. Further specification of the design lifetime and the geographical dimensions of the design solution, leads to the required design objective.
Information on bathymetric developments and on hydrodynamic (esp. waves) boundary conditions, over the period of years to decades, and at a spatial scale of several kilometres alongshore and one kilometre cross-shore, is needed to quantify the objective.

Considering the issue of safety against flooding requires the definition of a safety indicator. Information on the present safety approach will be necessary. Additionally, information might be required on historic storm surge levels and (simultaneous) observations of dune erosion. Based on this information a design objective ought to be specified.

Recreational issues concerning beach width, - quality and swimmer safety, likewise first of all require a quantification of objectives and a definition of indicators (parameters).
Information on the natural variability (at the time scale of months) of beach width (positions of dune foot and low water line), beach quality (sand characteristics) and the size and frequency of rips (including maximum current speeds), is a necessary ingredient to define both indicators and objectives.

- *Nourishment information*

Designing a nourishment involves a set of parameters:

- *nourishment width and length*
- *nourishment volume*
- *nourishment position along - and cross shore*
- *design wave conditions*
- *design current conditions*
- *the initial morphology*
- *the type of nourishment material*

To evaluate the effectiveness of a nourishment requires the definition of a design objective. The available BCL methodology indicates the need for:

- *data on the morphology in the system of interest,*
- *a benchmark for the water level (e.g. NAP),*
- *predetermined horizontal planes*

- *Beach width information*

Determining the width of the beach is a rather tricky affair. One needs to measure from dune foot to waterline. Both quantities are non-trivial. For a beach width design parameter we thus need:

- *a definition of the position of the dunefoot*
- *a definition of the position of the waterline*

To evaluate the resulting beach width design objective requires:

- *a quantitative reference for a minimum beach width*

- *Swimmer safety information*

Determining the safety for swimmers in the coastal area in front of Egmond, one of the most important parameters is the maximum offshore directed currents that could occur, where and when. For a swimmer safety design parameter thus require:

- *an indication of the offshore directed currents present in the area*
- *an indication of the water quality (temperature, ingredients)*
- *a definition of the wave conditions*
- *a definition of the wind conditions*

To evaluate the swimmer safety a quantitative design objective asks for:

- *a quantitative reference for a maximum offshore directed current that is still regarded permissible*
- *a quantitative reference for a minimum quality of the water that is still regarded permissible*
- *a quantitative reference for maximum wave conditions*
- *a quantitative reference for maximum wind conditions*

3.5 Information strategy

After delineating the information need, an attempt may be made to define a strategy to gather the required information in the COAST3D case study on straight sandy coasts Egmond. Although both socio-economic, physical and administrative contexts have been considered, the definition of an information strategy will focus on COAST3D's 'core business', i.e. physical aspects and technical design tools only.

Available tools

Available expert knowledge and available CZM tools determine the basis for an actual strategy to follow. Each technical CZM tool as described in 2.3, may contribute to the example case of Egmond. For each tool the potential contribution will be illustrated in the following subsections, based on COAST3D experience and – results.

Collation of background information

The present state of knowledge on the physical system at Egmond is rather detailed.
The same accounts for the knowledge on design objective and state indicators related to Dynamic Preservation of the coastline. However, the lack of knowledge on specified indicators and objectives with regard to e.g. safety, beach widths and safety requirements for swimmers, indicates the importance to collect further background information.
Recent and historic data on storm surges and dune erosion may provide a basis for the definition of safety parameters.
Recreation stakeholders may provide their perception of what they would feel is an adequate beach width. Literature reporting on other beach resorts may yield additional information on this topic and on parameters with regard to swimmer safety.

Monitoring

A yearly monitoring program of the Dutch coastal zone JARKUS, has been established in 1965. At spatial intervals of 250 m, each year bottom profiles are recorded to depths of -6 m; at spatial intervals of 1000 m, on a three year basis profiles are recorded to depths of ca. -12 m. The JARKUS data have been used to devise the BCL methodology and currently, present the basis for the yearly test procedure of TCL (see 3.2.3).
Continuing the JARKUS monitoring and analysis of it's data is essential to handle CZM problems like the Egmond case.

Information on a more detailed spatial and temporal scale is required to study the impact of nourishments and the natural variability of beach characteristics, of rips and of bar morphology. For this purpose, ARGUS video cameras may be useful providing synoptic information over the coastal zone (see appendix 2). As such, ARGUS cameras enable observations of extreme events like dune erosion due to storm surges.

Measurements

Detailed information on morphologic and hydrodynamic characteristics of the beach, specific bars or rips, may be obtained from measurements by a vehicle like the WESP (see appendix 2).
In addition local wave and current data may be derived from measurements with specific instruments. COAST3D experience is given in Appendix 2.
Another possible measurement could concern the bed material across a coastal profile. It may be interesting to find out if there is a difference in grainsize over a coastal profile. If it turns out that coarser material is located nearer to the shoreline one could suggest that the effectiveness of a nourishment is influenced by the used grainsize.

modelling

In addition to the information from observations, models may fill gaps in knowledge both in space and in time. Model hindcasts generate synoptic information of recent and historic developments; model forecasts may assist in estimating design alternatives. The type of model to use is depending on the character and scale of the problem. Regarding the information need in the Egmond case this leads to the following considerations.

Nourishment behaviour on a time scale of years, may be studied by assuming along shore average behaviour of bars. Two dimensional (2D) profile models seem appropriate for this purpose.
Estimates of rip effects on the effectiveness of nourishments and swimmer safety, require a more three dimensional (3D) approach on smaller time and space scales, using 3D field models.
Beach dynamics and the study of storm surge effects on dune erosion ask for specific models including processes in the 'dry' part of the profile.
Appendix 1 depicts COAST3D experience with a range of profile and area models at the present state-of art.

interpretation

The analysis and interpretation of monitoring- and measurement data and of model results is supported by several statistical techniques.
With respect to the nourishment problem in the Egmond example case, aggregation of results is essential for evaluation and interpretation of measurements and model results. Cubing of the profiles provides insight in redistribution of the nourished sand. Vertical cubing –based on the definition of vertical boundaries- gives more information than horizontal cubing. The latter method makes it hard to distinguish between movement of the nourishment and offshore migrating bars.

<u>*Considerations on priorities*</u>

Apart from the availability of tools and knowledge a decision on an information strategy is depending on available resources: time and money.

Boundary conditions: Time and money

Considering the Egmond case, the Regional Directorate representing the regional CZ Manager, has only limited budget available and will therefore be seeking best value for money from these studies. Also there is limited time available for these studies. To ensure efficient allocation of funds, priorities must be set in case not all required information may be gathered first time round.

In general it is important to have indications of the relative value versus the relative cost of the different tools or of different combinations of tools. Although presenting indications in general terms is hardly possible, the following considerations seem of importance.

- Observation of offshore wave characteristics often appears the bare minimum of required measurement efforts, to provide boundary conditions for a model application.
- Detailed bathymetric measurements are essential to enable a satisfying calibration of the present state-of-art of morphodynamic models.

4. TIDAL INLETS, RIVER- AND ESTUARY MOUTHS : CASE STUDY

4.1 Teignmouth, UK : example of a typical CZM case in an estuary mouth

Teignmouth is a popular holiday location situated at the mouth of the river Teign on the South coast of England (see Fig. 4.1.1). Tourism and leisure represent a very important local industry. The town has an active port located inside the estuary of the River Teign, and safe navigation into the port must be maintained over the shifting outer sandbanks

Maintaining a safe navigation channel has been the subject of many studies in the past. All the proposals studied over many years were eventually rejected because of cost, and it is very unlikely that any scheme to stabilise the entrance channel and/or to increase available depths could be justified today, in terms of its commercial viability.
Nevertheless, as a purely hypothetical case for the purposes of the COAST3D project, we will imagine that the port authority today wishes to investigate the commercial viability of providing access for vessels of greater draft. Any such investigation would necessarily have two main components:

In order to satisfy its shareholders, the port authority would have

- to determine the most cost-effective way of providing and maintaining a deeper approach channel.

In order to satisfy the planning authorities and other interested organisations, the port authority would have

- to demonstrate that the deeper approach channel and its associated maintenance system would not adversely affect other interests.

WHAT tools should be used WHEN ?

In order to answer questions from its shareholders and from the planning authorities, the port authority would wish to commission certain studies, possibly including field measurements, data analysis, and modelling :

- what studies are recommended and and how could these studies be justified ?

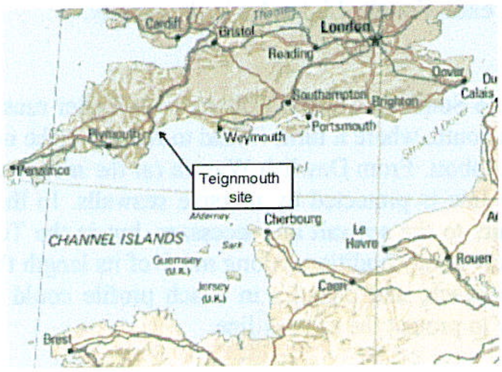

Figure 4.1.1a Geographical location Teignmouth

Figure 4.1.1b Aerial photo Teighnmouth (Copyright South West Water)

4.2 Context of the problem

4.2.1 Socio-economic system

Coastal Zone Management at Teignmouth is a complex web of interacting issues. The development and management of the estuary mouth affects the following interests and functions :

Safety against flooding

About 20 hectares of the town of Teignmouth is built upon the geological spit which partly closes off the entrance to the estuary of the River Teign (Fig. 4.1.1). This relatively low lying land contains very many houses, shops, hotels and leisure and tourism facilities, as well as many of the service industries for the harbour and fishing fleet. On its seaward side, the continuous seawall (last upgraded in 1977) protects the low lying land against flooding by wave overtopping during high tides and strong easterly gales. The seawall (Fig. 4.2.1) also gives protection against erosion. The seawall is fronted by the sand and shingle beach, and changes to the beach profile could alter the effectiveness of the seawall in limiting wave overtopping. Flooding can also occur from the estuary side, due to overflow during exceptionally high tides in the estuary. Low flood walls around the harbour area provide some protection against this type of flooding. Flooding at Sheldon could also occur during high tides in the estuary.

Teignmouth has functioned as a harbour for at least a 1000 years, and many of its buildings are several hundred years old, particularly some of the houses and inns along the west-facing shoreline of the geological spit which partly encloses the estuary entrance. This area is prone to flooding during exceptionally high tides in the estuary, and flood defence walls are necessary to protect the historic buildings and neighbourhoods.

Navigation and harbour

Navigational access into the Teign estuary, for commercial vessels, fishing vessels and pleasure craft, is controlled by the available water depths in the complex area of bars, banks and channels just outside the estuary entrance. As mentioned earlier, the banks and bars are constantly changing, and numerous studies have been carried out over the years to try to understand these movements, and to devise schemes to try to stabilise the entrance channel. None of these schemes has ever been implemented, and at present the channel depth is maintained by drag-dredging almost every day of the year. The channel location however continues to vary. Any shoreline management schemes suggested in the SMP (Shoreline Management Plan) should clearly not reduce available water depths, or increase the instability of the entrance channel.

The commercial docks are located on the north bank of the Teign estuary, on the outside of a sharp bend where the main channel is diverted southward by the presence of the geological spit which partly closes off the entrance to the estuary. The docks and their supporting services provide an important local industry. The docks are located on relatively low lying land, which could be flooded during exceptionally high tides in the estuary.

Transport and infrastructure

The main line railway from London to South Devon and Cornwall via Exeter runs along the coastal margin from Exeter to Teignmouth, where it turns inland to run along the north shore of the Teign estuary up to Newton Abbott. From Dawlish Warren (at the mouth of the Exe estuary) to Teignmouth the railway line is protected by massive seawalls. In the Dawlish area constant maintenance and repairs to the seawall are necessary, but in the Teignmouth area the Brunel Seawall is in relatively good condition. Along much of its length the seawall is fronted by the sand and shingle beach, and changes in beach profile could affect the stability of the seawall and its ability to protect the railway line.

Recreation

Teignmouth is a popular location both for beach users (walkers and bathers) and for water sports users (sailing, powerboats and jet skis). Beach usage takes place both on the main seafront and on the estuary shorelines. For all these users the quality of the beach and of the coastal and estuarine waters is an important consideration in their decision to visit Teignmouth rather than any of the adjacent resorts. Tourism and leisure represent a very important local industry.

The South West Coast Path is a popular hiking trail passing through Teignmouth.

Again the main issue here is protection of the shoreline against erosion. It is more of an issue to the south of the Ness headland, where there is no man-made protection of the relatively soft cliffs, along the top of which the Coast Path is routed. It is obviously undesirable to carry out any works in the area which would accelerate the erosion of these cliffs. To the north of Teignmouth the path is protected by the Brunel Seawall.

Fisheries

Shellfish industry in the river Teign must not be affected adversely.

Deposit of materials at sea

Sewage from Teignmouth and Shaldon is disposed of through a long sea outfall into Lyme Bay. The effectiveness of that outfall must not be reduced

4.2.2 Physical system

Location

The town of Teignmouth lies on the south coast of the county of Devon in South West England. It has a busy commercial port and local fishing fleet, and is a popular location both for beach users and for water sports. The town is on the western edge of Lyme Bay, and the shoreline faces east south east into the English Channel, and is largely protected from Atlantic storms by various headlands to the south. Like many other beaches in south west England and in Wales, the beach at Teignmouth is contained between two headlands. To the north, longshore sediment supply is blocked by a prominent headland 'The Parson and Clerk'. About 2½ kilometres to the south is the estuary of the River Teign, which flows out hard against a further prominent headland, 'The Ness'. The location of Teignmouth is shown in Figure 4.1.1.

Figure 4.2.1. Sea wall at Teighnmouth

Along its full length the beach at Teignmouth is backed by a seawall: over the northern 1½ km this is the Brunel Seawall, which supports the main railway line into South Devon and Cornwall, and prevents further erosion of the relatively soft cliffs. Part way along this seawall is Sprey Point, where a section of the seawall protrudes beyond Mean Water Level and provides some interruption to the natural sediment transport regime. Along the southern part of the beach the seawall protects the town of Teignmouth from coast erosion and flooding by the sea (Fig. 4.2.1).

The present seawall was constructed in 1977: at its southern end the seawall terminates at Denn Point, but the beach continues for a short distance to form a spit which partly closes off the entrance to the Teign estuary and the Harbour quays
The estuary of the River Teign extends upstream to Newton Abbott, about 7km due west of Teignmouth. River discharges are very low in summer, but typically reach a peak of about 100 cumecs in Autumn and Winter. The estuary has extensive intertidal mudflats, and is typically about 500 metres wide at High Water, except at the entrance which is only about 150 metres wide.

As a result of the interaction between estuary processes and coastal processes, there are a number of bars and banks on the seaward side of the entrance into the Teign estuary. These bars and banks are constantly changing, and Teignmouth's beach and estuary system have been the subject of considerable interest since as early as the mid 19th century. One such early hydrographic survey of the area was made by Spratt (1856), who documented cyclic movements of the bars in the estuary mouth. This theme was later taken up by Craig-Smith (1970) and Robinson (1975) who monitored bar movements at the entrance to the harbour for 10 years to establish the cyclic nature of the process.

Waves, tides and currents

The mean tidal range at Teignmouth is 1.7m on Neaps and 4.2m on Springs, Tidal currents at a location 1km offshore do not generally exceed about 0.2-0.3 m/s. However in the entrance to the estuary, off Denn Point, tidal current speeds typically reach 2m/s, 0.3 m above the bed, close to mid-flood and mid-ebb.

As a result of the strong flows, tidal flow patterns close inshore are quite complex. At the beginning of the ebb, the stream flows out past Denn Point and then swings north eastward to join the anticlockwise circulation in the western part of Lyme Bay. This current increases during the second quarter, but changes direction slightly during the 3rd and 4th quarter, tending to hug the south side of the estuary mouth. This occurs as the tidal stream in Lyme Bay reverses in direction, which happens at about 2 hours before Low Water. During the first half of the flood, the flow in this part of Lyme Bay is to the south, and during this time the flood current into the estuary builds in speed. Approximately 2 hours before HW, the current in Lyme Bay again reverses in direction, and causes an eddy to form behind the Ness headland. Flow velocities of Denn Point are generally less on the flood than on the ebb, although Robinson(1975) still reported values of up to 2.2m/s at mid tide on the flood. The result of the flood tide eddy is that there is a more southerly flow just off the Denn beach than northerly flow, and this residual current maintains the flood channel which exists between Spratt Sand and the Denn beach.

The location of Teignmouth, and the orientation of the shoreline relative to the prevailing winds, mean that the largest waves result from strong easterly gales. However such winds are rather infrequent, Fig.4, and significant waves greater than 0.5m typically occur for less than 10% of the year. For the rest of the time there can be low swell activity at the site.

Sediment transport and beach morphology

To the north of the estuary mouth and its associated bars, Teignmouth beach generally has a relatively flat dissipative low tide terrace (slope less than 1%), and a steep reflective upper beach (slope about 12%). The low tide terrace extends approximately up to Mean Low Water, and often has a shallow bar. On the lower beach, and further offshore, sediments are generally fine sands, with a median diameter of about 0.2mm. On the upper beach, the sediment is mainly coarse sand, diameter 0.4mm, with some shingle also present. The beach in this area is groyned, and the predominant direction of sediment transport is south westward, presumably as a result of longshore currents generated by waves from the east .Near to the estuary mouth and its associated bars both the morphology and the sediment transport patterns are much more complex. Reference has already been made to the cyclic movement of the bars and banks in this area, which appears to be the result of interactions between the regular effects of tidal currents and the intermittent effect of storm waves.

Tthe Ness Pole protrudes from the Ness headland, while the Outer Pole forms further to the north. Inshore of this, the Inner Pole forms which becomes the Horseshoe Bank closer in. It is these Poles which are suggested by Spratt (1856) and Robinson (1975) to move in a cyclic pattern. A further bar between the estuary and the beach, known as Spratt Sand, appears to be relatively stable. Observations by Robinson over a ten year period suggested that it takes approximately 40 months for the complete cycle to repeat itself.

Sediment tracer studies have been carried out in the past near the entrance to the estuary by Robinson and by HR Wallingford to investigate the sediment movements in the area. Both studies concluded that sediment transport on the Denn Beach, on the northern flank of Spratt Sand, and in the low water channel between them, was south westward towards the estuary entrance while on the southern flank of Spratt Sand the transport was seaward. In the same study, HR also concluded that Teignmouth Beach was basically fed with sediment from the south, presumably driven by strong northerly currents during the late flood tide, especially when combined with waves from a generally southerly direction. Having arrived on the beach, it was suggested that this sediment was then re-worked south-westward by easterly waves, feeding the anti-clockwise sediment circulation of the bars and banks at the estuary entrance. However it is fair to say that the cyclic behaviour of the bars and banks is still not completely understood.

4.2.3 Administrative system

Coastal policy

The UK has a very long and very varied coastline, and the management of that coastline is carried out by a large number of organisations. In England and Wales responsibility for sea defences lies with the Environment Agency, while responsibility for coast protection rests with Local Government Authorities and landowners. The UK coastline also includes a large number of river and estuary mouths, and a few tidal inlets. A high proportion of these mouths and inlets contain ports or harbours, ranging from very large commercial ports (such as Felixstowe in Suffolk) to small fishing or yachting harbours (such as Bude in Cornwall). Some of these harbours are owned by the Local Authorities, but mostly they are owned by private or public companies. As well as the jetties and quays, the Port or Harbour Authority is also responsible for safe navigation into and out of the harbour, and therefore it carries some responsibility for the management of the mouth of the estuary and the adjacent coastline. At many of the UK estuaries there is either an inter-tidal or sub-tidal bar across the mouth which hinders navigation. Most port or harbour authorities would like to be able to increase available water depths across the bar, if it was economically viable. However the bar often provides a pathway for longshore sediment transport on the adjacent coasts to bypass the estuary mouth. Consequently any plans to increase navigation depths could have an effect on the adjacent coasts, and any schemes such as beach nourishment on the adjacent coast could have an effect on navigation depths.

Shoreline Management Plans (SMP)

Partly in order to resolve potential conflicts, and to maximise the co-operation between sea defence authorities, coast protection authorities and port and harbour authorities (as well as conservation and other bodies), Shoreline Management Plans have been developed which cover the whole of the coastline of England and Wales. Each SMP covers a discrete length of coastline, and its purpose is "to provide a large-scale assessment of the risks associated with coastal processes and to present a policy framework to reduce these risks to people and the developed and natural environment in a sustainable manner" (Shoreline Management Plans, A guide for coastal defence authorities, MAFF, July 2000). Each SMP is developed in partnership by the relevant authorities, and a major task is to identify constraints and opportunities for both development and improved (or maintained) flood defence and coast protection.

For example, materials dredged from the entrance channel to a harbour may provide the opportunity for beach nourishment on the adjacent coast. Each SMP delivers a policy which is unique to that length of coastline, but lies within the national strategy to reduce the risks of flooding and to discourage inappropriate development in areas at risk from flooding or coastal erosion. Therefore, from each SMP different types of schemes (e.g. beach nourishment, seawalls etc.) arise, which are then studied during the Strategic Planning stage, and are finally detailed during the Scheme Design stage.

Considering the socio-economic context as depicted in 4.2.1, the Shoreline Management Plan for Lyme Bay and South Devon (which includes the Teignmouth area) has identified that the main coastal management issues at Teignmouth are:

- *To protect the developed areas of Teignmouth and Shaldon*
- *To maintain the main line railway link in its present location*
- *To maintain the continuity of the South West Coast Path*
- *To not impinge on navigational access in the Teign estuary*
- *To protect the docks at Teignmouth*
- *To ensure that the Teign shellfish industry is not affected adversely*
- *To maintain bathing beach quality*
- *To protect listed buildings at risk and conservation areas.*

Coastal Zone Management at Teignmouth is a complex web of interacting issues. Any improvement suggested in respect of any one issue has to be examined in the context of the possible effects on all the other issues. This is likely to be the case for CZM in almost all tidal inlets and river and estuary mouths.

Methods of improving the entrance to Teignmouth have been studied many times. The earliest was in 1838 when the famous civil engineer John Rennie submitted a report to 'The Chairman and Commissioners for Maintaining and Improving the Port of Teignmouth', in which he described:

"FIRST

> *The history of the Port of Teignmouth and the possible causes of its formation.*

SECONDLY

> *Its present state together with the various tides, currents, winds and soundings, and the present defects.*

THIRDLY

> *The most advisable plan for removing them together with an estimate of the expense."*

Rennie identified the main problem as a bar which is formed opposite the mouth of the river when easterly gales prevail, and he recommended that "a breakwater jetty should be projected from near the southern extremity of the Den in a direction SE. It should be approximately 150 yards in length and reach 2-3 feet above high water at springs."

Needless to say, the breakwater was never constructed, but several other studies were carried out over the years, and in 1970 studies were commissioned to investigate the commercial viability of providing for vessels with a greater draft. This would mean that the depth along the approach channel would have to be greater, and also that the depth at the quayside would have to be increased.

On the basis of physical model studies, the construction of a training wall was suggested to stabilise the approach channel. This would have been 500 metres long, in a direction due east from the southern tip of the Denn.

All the proposals studied over many years were eventually rejected because of cost, and it is very unlikely that any scheme to stabilise the entrance channel and/or to increase available depths could be justified today, in terms of its commercial viability.

Present practice

The present system of maintaining depths along the approach route is by dredging almost every day of the year. Sand is dragged from the high points of the channel, where it crosses the outer sand bank system, and is deposited away from the channel. This system was adopted about 3 years ago, and the harbour master thinks that it is more effective than the old bucket dredger that it replaced. Nevertheless, ships have gone aground twice during the time of the COAST3D observations.

4.3 Dimensions of the problem within its context

Socio-economic dimensions

The CZM context of the problem

- to provide and maintain a deeper approach channel to Teignmouth harbour at a most cost effective way,

indicates the need to take account of many other interests as well. At Teignmouth, the planning authorities would probably insist that consideration should be given to the effects of any channel maintenance proposal on:

- the adjacent beach. The beach is an important resource for the town's holiday resort businesses, and must be maintained sandy, unpolluted and attractive.
- flooding. Flooding of low-lying parts of the town has occurred in the past, and remedial action has been taken. The risk of flooding must not be increased.
- safe disposal of sewage to sea. Sewage from Teignmouth and Shaldon is disposed of through a long sea outfall. The effectiveness of that outfall must not be reduced.

Physical dimensions

The cyclic movements of sandbars and -banks in the estuary mouth, appear to be a dominant physical feature in relation to characteristics of the navigation channel.
The time scale of a complete cycle is estimated to be approximately 40 months.

Beach characteristics representing its value for recreation are the typical beach width and average grainsize of coarse sands (0.4mm).

Risk of flooding is strongly related to typical peak discharges of the river Teign of 100 cumsecs during Autumn and Winter, and to extreme wave conditions.
The estuary has extensive intertidal mudflats with a typical width of 500 m at High Water, except at the entrance which is only 125 m wide.
Important feature is the sea wall.

Coastal management dimensions

The relevant context from a coastal management perspective, is covered by the Shoreline Management Plan (SMP) for Lyme Bay and South Devon (which includes the Teignmouth area). Any scheme for maintenance and deepening of the navigation channel will have to take account of the co-herent set of management objectives according to the SMP.
For the purpose of the COAST3D example case

- *to provide and maintain a deeper navigation channel*

it is assumed to focus on the following additional objectives according to the SMP :

- *To maintain bathing beach quality*
- *To protect the developed areas of Teignmouth and Shaldon*

The SMP does not mention an explicit objective related to sewage disposal.

The Shoreline Management Plan does indicate objectives.
Standards for normative parameters and dimensions of a potential scheme (so called design parameters or quantifiable coastal state indicators) will have to be developed during the (Strategic) Planning stage: the first step in the following process of determining the information need.

All the proposals studied over many years were eventually rejected because of cost.
Commercial viability of any scheme obviously appears to be normative.

4.4 Information need

Starting from the general objectives derived in 4.3, the coastal manager has to develop operational, quantitative objectives related to the specific problem: the general objective needs to be specified in terms of quantitative design parameters.
Once the design parameters are established, the next step is to seek information on the behaviour of the design parameters in past, present as well as future.

Considering the COAST3D-example-case at Teignmouth the available information on context and dimensions of the problem (4.2 and 4.3) indicates that –at this stage of analysis- no specific design parameters have been established yet.
For the sake of the example-case focussing on physical characteristcs only, the definition of the necessary design parameters will require information on the parameters and scales as mentioned under physical dimensions in 4.3.

4.5 Information strategy

In order to answer questions from its shareholders and from the planning authorities, the port authority would wish to commission certain studies, possibly including field measurements, data analysis, and modelling. The optimal strategy to obtain the required information is depending on boundary conditions related to available resources (time, money, expert knowledge and tools).

Available tools
Available expert knowledge and available CZM tools determine the actual strategy to follow. Each technical CZM tool as described in 2.2, may contribute to the example case of Teignmouth. For each tool the potential contribution will be illustrated in the following subsections, based on COAST3D experience and – results

Collation of background information

Dimensions and cyclic behaviour of the sandbars in the estuary mouth so far have been documented on the basis of some scattered historic echo-sounding information and qualitative information from photographs by the harbour master. Any additional information sources need attention.
Historic time series of waves and discharge data of the river Teign are essential to establish design parameters related to flood protection. The same accounts for historic data on beach characteristics to establish beach recreation parameters.

Monitoring

Information on actual rates of morphodynamic change may be derived from bathymetric monitoring; a traditional method is echo sounding by boat, resulting in data with a specified spatial and temporal density. A method offering continuous and synoptic information on sandbank and beach characteristics is an ARGUS video-system. (cf. appendix 2).
Hydrodynamic boundary conditions may be derived from a range of possible wave- and current instruments. Synoptic wave information is provided by e.g. an X-band radar system (cf. appendix 2).

To determine the optimum numbers and optimum positions of various monitoring instruments, the use of models is advised (see below).

Measurements Time- or space specific information on hydrodynamic or morphodynamic characteristics may require specific measurements. Considering the navigation channel and features of the beach, examples are (cf. appendix 2) :
observations of current gradients inside and around the channel, bed characteristics in the channel, wave gradients onto the beach etc.

Modelling Analysis of the temporal and spatial behaviour of the area of interest may strongly benefit from the use of models. Basic requirement: the model is able to reproduce the defined characteristic parameters at a satisfying level of accuracy. In any case, models used in only a diagnostic mode are helpful instruments for interpretation purposes.
Considering the typical 3D character of phenomena related to the case of deepening and maintaining a navigation channel, coastal area models seem most appropriate (cf. Appendix 1).

Interpretation The analysis and interpretation of monitoring- and measurement data and of model results is supported by several statistical techniques. To facilitate an objective interpretation and comparison of results from different model concepts statistical indices have been applied. The actual development of new, and use of existing objective model performance indices and testing on such a broad range of models is a distinct result of the COAST3D project and a promising step in model evaluation. The so-called Brier-Skill index proved to be particularly promising.

Considerations on priorities

Apart from the availability of tools and knowledge a decison on an information strategy is depending on available resources; time and money.

Boundary conditions: Time and money Since the proposal in the Teignmouth case study would be rather speculative, it is likely that the port authority would have only a limited budget available for these studies. The port authority would therefore be seeking best value for money from the studies. Also, it is likely that there would be only a limited time available for the studies: typically this could be as little as 6-9 months, but possibly the port authority could be persuaded to extend this to about 18 months.
These practical boundary conditions lead to the following considerations with regard to the setting of priorities.

In general it is important to have indications of the relative value versus the relative cost of the different tools or of different combinations of tools. However, presenting indications in general terms is hardly possible as the different considerations most often are very case-specific.
Nevertheless, regarding the relative value of monitoring - and measuerment data in combination with modelling, the following considerations seem of importance:

- minimum requirements to drive an hydrodynamic or morphodynamic model are data on bathymetry and on boundary conditions on flow and waves (preferrably from measurements, otherwise from a regional model)
- minimum instrumentation for calibration of the present state-of-art models in a complex environment like Teignmouth, involve
  a wave buoy offshore, a tide gauge in open sea, 2 current meters inshore, and a wind gauge;
- improvement of calibration results may be achieved by adding
  additional two current meters offshore and a tide gauge in the estuary;
- maximum calibration results require addition of
  an inshore wave gauge, two more current meters inshore, measurements of sediment sizes (esp. in region of interest) and of bedforms (roughness).

5. GUIDELINES ON CZM COMMUNICATION PROCESS

5.1 Introduction

Application of the guidelines on a systematic CZM information analysis illustrated in the previous chapters, involves a frequent communication between CZ managers and specialists at different levels. The success of the information analysis is strongly depending on the quality of the communication process. Based on experience of the COAST3D project, some general guidelines on this CZM communication process may be derived.

Coastal managers can call upon specialists during different phases of the information analysis and for different purposes: for system state descriptions, intervention development, impact assessment or reduction of uncertainties. Required specialist knowledge may be gathered through studies or developed in research projects. Thus, the most challenging objective of the research project COAST3D -from a coastal manager's point of view- has been the goal: 'to deliver validated modelling tools, and methodologies for their use, in a form suitable for coastal management'. A challenging objective in the sense that -although applied research programs are often granted based on practical relevance- only a few of previous research projects on coastal behaviour have actually attempted to translate the gained knowledge into coastal management guidelines, and often with limited success. The EU demonstration projects on Integrated Coastal Zone Management ICZM (EU,1999), for example, have signalled this problem and identified some of the causes: (-) the lack of consideration/contact with potential customers for the research results and an assessment of their needs at an early stage; (-) an unwillingness among academics to consider practical and workable approaches in applying science to 'simple' situations.

Against this background, governmental agencies -end users participating within the COAST3D project- from the onset of COAST3D have continuously stimulated modellers and experimenters to demonstrate the usefulness of their tools for CZM. Contrary to the conclusions of (EU,1999), this process has identified as a basic problem: (-) the formulation by coastal managers of questions that unambiguously lead to answers covering the actual information need.

The opposing views suggest that the translation of specialist knowledge to coastal management is a non-trivial problem. Finding a methodology to handle this problem has become a major challenge for COAST3D. The methodology for formulation of the information need described in Chapter 2 describes only part of the problem. Another aspect is the improvement of the communication between specialists and end users.

5.2 A knowledge management problem

Coastal managers often feel that it is difficult to apply the results of research or studies to policy formulation and practical management. The fact that researchers feel that on a scientific level they *have* made significant progress suggests that the translation of results may be a knowledge management problem. What do we mean by the term knowledge management?

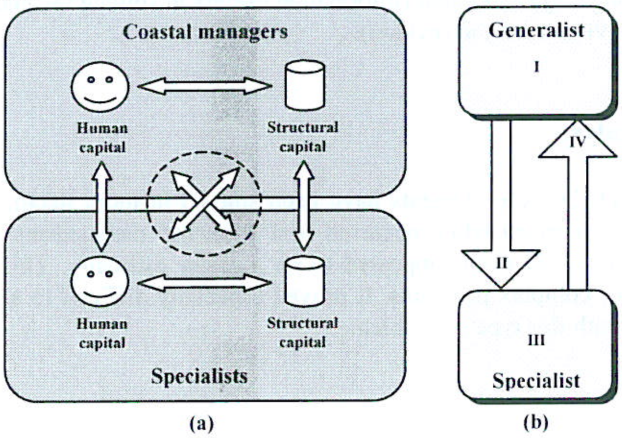

Figure 5.2.1: (a) Information flows between coastal managers and technical specialists.
(b) Analysis molecule of generalist-specialist interaction

POLANYI (1966) identified two different forms of knowledge capital: '*tacit knowledge*' and '*explicit knowledge*', the former being knowledge that is in a person's mind (human capital), the latter being some form of knowledge that has been made explicit (structural capital), e.g. theories and models. Knowledge conversion may then take place between similar and different forms of knowledge capital (see Fig. 5.2.1.a).This yields four conversion types: human-human (socialisation), human-structural (externalisation), structural-human (internalisation) and structural-structural (combination) (cf. NONAKA AND TAKEUCHI, (1995)). Recall the example mentioned in Section 2.1 to illustrate. For a specialist in coastal behaviour, structural capital might be a set of equations or a model that better describes bar-behaviour under currents and waves (information about reality). For a coastal manager, structural capital might be a decision recipe for the design of shore nourishments (information for reality). The former knowledge capital may be used to improve the latter. In practice such benefits of specialist knowledge are often not or hardly recognised.

5.3 Framework for communication

Let us investigate knowledge transfer between coastal managers and specialists in more generic terms. Coastal managers have a continuous need for information on the system under their control. The general objective of CZM is to prevent and mitigate this problem. Questions, expressing the information required by the coastal manager, may identify problems to be solved by one or more specialists. These in turn may need to involve other specialists to help solve sub-problems, etc. Each problem solver operates within a context provided by the problem owner. The answers to the posed questions, apparently, do not always help to solve the end users problem.

In the framework for communication the coastal manager, as an end user of specialist knowledge, will by definition be a 'generalist' dealing with the system on a more aggregated level than the 'specialist'. The information transfer (both *up* and *down*) between these two takes place by communication of questions and answers. Separating the communication of assignments and of results, knowledge transfer between generalists and specialists is divided into four elements (see Fig.5.2.1b):

(I) the problem and its owner at the higher level of aggregation,
(II) the downward communication of a request for information,
(III) the (sub)problem to be studied by the specialist, and
(IV) the upward communication of the answer to the generalist.

A mismatch between the elements IV and I, in other words when the specialist answer does not provide the information required to solve the generalist problem, is regarded to be symptomatic for the 'gap' between generalists and specialists. This gap may in turn be caused by mismatches between I and II (the question does not match the problem), II and III (the study conducted does not match the question) and III and IV (the answer given does not match the objective of the study). In the interaction between generalists and specialists, the four elements form a chain. Each mismatch carries over into the following elements where it may trigger other mismatches. Mismatches may occur on one or more of three levels of information: *content* (description of the wrong thing), *form* (description of the right thing but in the wrong way) and *intent* (information useless in solving the end user's problem) (cf. (VANKONINGSVELD *et al.*, in review)).

5.4 Problem analysis

During COAST3D these elements have been studied in more detail, to better understand where and when mismatches occurred and by what mechanisms. Matching specialist knowledge with CZM needs appeared to be a major difficulty. This seemed to be more problematic for complex problems. It proved especially difficult to ask the right questions when dealing with this type of problem.

A general definition of 'problem type' may illustrate this. PERROW (1967) developed such a definition by focussing attention on information and technology. He proposed to discern two aspects in problems and the technology used to solve them: (1) the number of exceptions and (2) the degree of definition of the procedures available to respond to these exceptions. The first aspect is called 'task variability', the second 'problem analysability' (see Fig. 5.4.1). The problems of asking the right questions appeared to correlate especially with 'ill-defined' problems.

Problem analysability	*Task variability*: **Some exceptions**	*Task variability*: **Mostly exceptions**
Well defined	*Routine* 1	2 *Technique*
Ill defined	3 *Handwork*	4 *Non-routine*

Figure 5.4.1. Technology classification (PERROW, 1967)

What goes wrong and why? Coastal managers, as consumers of specialist advice, usually require information on aspects of coastal behaviour that they do not yet fully understand (information about reality) and on ways to deal with this (information for reality) (cf. Fig 2.1.3 – end user's state of knowledge).

Although coastal managers may have a clear view of reasons why they need specific information *(intent)*, a vision of the required *content* and *form* usually is much more vague. Because the requirements for an end product are not known accurately beforehand, specialists contracted to deliver the results, consequently find room for interpretation. On the one hand this flexibility supports the innovative process. On the other hand it involves a risk of results that mismatch the end users needs in terms of content, form and ultimately intent.

However vague the vision of a coastal manager may seem, it is based on a sort of tacit knowledge of the system. The tacit knowledge on 'ill-defined' problems includes technical and cognitive elements. The technical elements include e.g. concrete know-how, crafts, and skills; the cognitive elements focus on so-called mental models (JOHNSON-LAIRD, 1983), in which human beings create working models of the world by making and manipulating analogies in their minds (realities and visions, 'what is' and 'what ought to be'). In the COAST3D project it was observed that specialists, when given flexibility, are inclined to give (technical) information on *how*, *what* was done. It proved much harder to get (cognitive) information on *when* to do *what*. Externalisation of (tacit) mental models in a kind of mobilisation process is assumed to be a key factor in creating new knowledge (NONAKA and TAKEUCHI, 1995). The communication process should be focussed on this aspect. To enable practical implementation of this notion, the concepts of 'hypothesis networks' and 'pilot applications' have been developed for generalists and specialists respectively.

5.5 Hypothesis networks vs. questions

In 'ill-defined' problems (PERROW, 1967), as often addressed in end-user oriented (coastal) research projects, it appears hard -if not impossible- to formulate questions that unambiguously lead to cognitive information in terms useful for coastal managers. Converting 'tacit' knowledge on 'ill-defined' problems into questions (see Fig.5.5.1), potentially crucial information apparently remains implicit. As POLANYI (1966) put it: "We can know more than we can tell". An important lesson learned in the COAST3D project was that it is hard to ask questions about what you do not (yet) know.

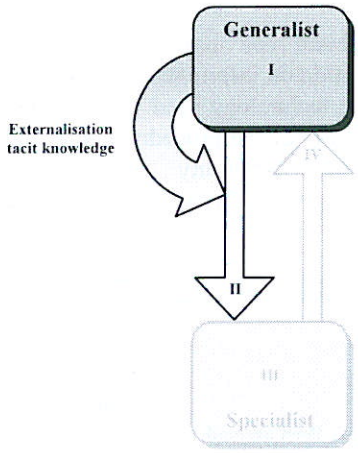

Figure 5.5.1: How to formulate a question that matches the problem?

The concept of 'hypothesis networks' does not attempt to formulate questions on what is *not* known; instead it aims to formulate a coherent network of hypotheses reflecting what *is* known (and what is assumed, e.g. to overcome uncertainties). A proposed procedure is to interview e.g. coastal managers in order to 'externalise' the end user's mental models. The resulting hypotheses on how the system works and how it should be managed may then be falsified or sharpened by either study or research. The most detailed level of the hypothesis network may incorporate hypotheses requiring fundamental research. Instead of going through the cumbersome process of formulating questions about parts of the otherwise tacit mental model of the coastal manager, the specialist is confronted with the explicit mental model. Hypothesis networks may then be used in support of asking the right questions and asking these questions in the right way.

5.6 Pilot applications vs. answers

Specialists now can direct their creative potential directly to falsifying or sharpening one or more of the presented hypotheses (easier internalisation). It seems wise for specialists to select a hypothesis that is both within their range of capabilities and broadly expressed as important by the end users. More detailed studies may be needed to do the job but the end users are firstly interested in what the researcher can contribute to their mental model. Only then will he be interested in the (un)certainty of this improvement. This is reflected in the quote: 'I don't need your models, I need solutions to my problems' mentioned in Section 1.3. When the results of a specialist study or research project succeed in falsifying or sharpening one or more of the hypotheses in the hypothesis network, we state that those results *match the needs of the coastal zone manager* who can identify with that particular network. Needless to say that some hypotheses are more important than others. Establishing the order of relevance, however, is far from trivial.

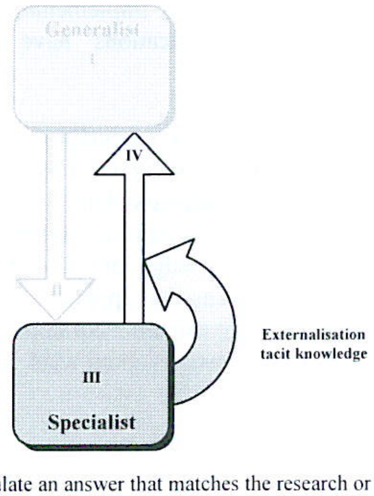

Figure 5.6.1: How to formulate an answer that matches the research or study?

The problem now is how to get the specialists to externalise their mental models of how the system works (see Fig.5.6.1). We found the implementation of pilot cases to be a promising methodology. Considering a specified pilot case appeared to be the only way for specialists to demonstrate how state-of-the-art knowledge can be applied in a practical situations. This has several advantages. The 'snapshot' of what e.g. a model can do (see Fig.5.6.2), first of all helps modellers to show how a model study should be set up and how the results can be usefully interpreted. Secondly it will identify the (un)certainties in the model predictions. This helps the modellers to identify strengths and weaknesses in their models and suggest future improvements. Last but certainly not least, it helps the coastal managers to see how the model can improve their understanding of the system (easier internalisation – see Section 5.2) (WALSTRA and VANKONINGSVELD, 2001).

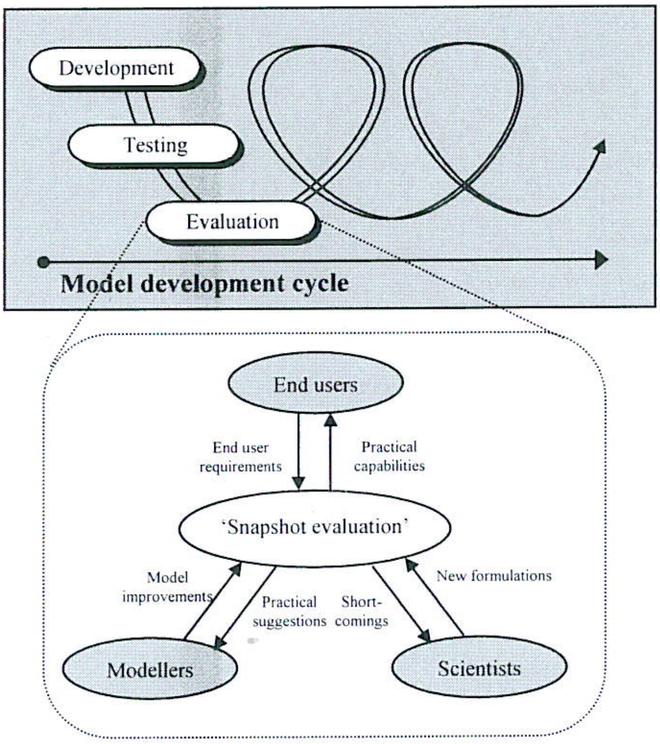

Figure 5.6.2: Evaluation and end user oriented model development

In an ideal situation, a prediction of some of the relevant aspects of a case should be made at the beginning of a study or research project, with the means then available, including estimated (un)certainties. At the end of the project a similar prediction should be made with the hopefully improved means. The achieved reduction of the uncertainties (or possibly their improved estimation) could be a measure of the project's success. On top of that, the pilot case may be a significant, and not to be underestimated, binding and structuring factor within the project (combination – see Section 5.2)(cf. DEVRIEND and VANKONINGSVELD, 2000). Projects structured around problems are expected to produce 'end user results', whereas projects structured around disciplines are bound to produce 'scientific results'.

6. SUMMARY, DISCUSSION AND CONCLUSIONS

The COAST3D objective to deliver tools and methodologies in a form suitable for coastal management has had distinct impact.

information analysis

First of all by creating a notion of the necessity to consider explicitly the information need of the coastal zone manager. The result of this notion has been the development of a methodical approach to CZM information analysis. Guidelines to this approach illustrated by applications on two cases, represent a framework to CZ managers for decisions on when to use, what type of tools. Indications on how to use the tools are illustrated in the appendices for the different tools applied during COAST3D.

communication process

Secondly, the notion of an existing gap between (science driven) research and (problem driven) coastal zone management, has initiated a change in the way of thinking on this subject. A frequent communication between CZ managers and specialists at different levels, appears a primary condition to enable a systematic information analysis. Some general guidelines on this CZM communication process have resulted from this notion.

The presented guidelines illustrate the potential role of specialists and researchers at different levels, in the process of CZM. The success of the role seems to depend on a threesome factors.

willingness

As a first factor is required a willingness to co-operate. The problem oriented information need of coastal zone managers and science driven interests of researchers –at least at first sight- very often may not comply. Bridging this gap requires co-operation of all participants in the process.

open atmosphere

A second factor of success appears the creation of an open atmosphere for discussions. In the communication approach based on CZM hypothesis networks and pilot applications by researchers, the rate of success will depend on the ability and willingness of a 'vulnerable' attitude of the participants. On one hand, coastal zone managers are invited to express explicitly what -they think- they know and how they feel - intuitively or from experience- on certain problems. On the other hand, specialists and researchers are invited to indicate explicitly the current state-of-art of their tools. An open and 'safe' atmosphere , if necessary including agreements on confidentiality of results, seems vital for the interaction process.

flexible planning

A third factor is the flexibility of the project planning and organisation. Coexistance in one project, of problem driven- and science driven approaches may combine advantages of both; the first essential to bridge the gap between coastal science and coastal management, the latter essential for progress on the longer term. Research results may be translated directly to end user requirements, analysis of the performance of different tools in pilot applications may provide important clues for new research approaches. Both activities however, ask for a flexible project planning enabling researchers to devote time to both.

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Appendix I

Appendix 1 TOOLS USED IN COAST3D: MODELS

Name	Brief description	Guidelines on how to use	Examples of results for Egmond and/or Teignmouth
COASTAL PROFILE MODELS Coastal profile models are used to predict the cross-shore variation in hydrodynamics and/or morphodynamics. Can also be used to predict changes in beach profile. Many different models have been developed, some of which were available to the COAST3D Project			
UNIBEST – TC (WL|Delft)	Actually a suite of five sub-models used together to predict changes in beach profile for given wind, wave and tidal current conditions. Basically a 1DH model, although some sub-models are quasi-2DH Models the cross-shore distribution of wave heights and water levels, the vertical distribution of velocities and suspended concentrations, and the cross-shore distribution of suspended sediment transport and bed load transport.	Typically models the beach/seabed profile from about 1 or 2 km offshore to the limit of mean wave set-up. Detailed swash-zone processes are not included. The model needs as input the following information: *Existing beach/seabed profile* *Sediment sizes* d_{50}, d_{90} *Bed roughness under waves alone, and currents alone* *Water level, depth-averaged tidal velocities, and wind speed and direction at fixed location* *Wave height/period and direction at offshore boundary* Water levels, tidal currents and wave conditions are required at regular times, e.g. hourly	At Egmond. offshore boundary was 5km offshore, and wave decay to seaward side of bars was over predicted. Inshore, the cross-shore distribution of wave heights gave reasonable agreement with measurements, and wave directions at the shoreline were very accurate. However, at some locations, alongshore and cross-shore velocities showed some significant deviations from measured data. The model predicted quite well the overall erosion suffered during a major storm, but could not predict the measured accretion during less severe wave conditions. The predicted profiles during the main campaign showed that the model was capable of giving a relatively accurate prediction of the morphological behaviour of the outer bar, but the inner bar and especially the beach could not be modelled satisfactorily. Model not used at Teignmouth

COSMOS-2D (HR Wallingford)	Used to predict changes in beach profile for given wave and tidal current conditions. Classified as a 2DV model (two dimensions in the vertical plane) Models the cross-shore distribution of wave heights and water levels, the vertical distribution of currents and sediment transport, and resulting changes in beach and nearshore morphology. It can also be used to model the distribution of long-shore sediment transport rates across the profile.	Typically models the beach profile from about 1km offshore to the limit of mean wave set-up. Detailed swash-zone processes are not included. The model needs as input the following information: *Existing beach/seabed profile* *Significant wave height, wave period and wave direction at the offshore boundary* *Water levels at the offshore boundary* *Alongshore tidal or wind-induced current strength* Wave and tide information is required at regular times, e.g. at hourly intervals. Currents are calculated from these. In addition, information is required on *sediment size and bed roughness height* (normally assumed constant over the modelled profile). Can be run for very many days. Runs of several years are possible (e.g. the model runs 5 years of inputs in about 4 hours), but the resulting bed evolution should be treated sceptically, as COSMOS is a storm-response model, and does not include the processes that are important on time-scales of years.	At Egmond, the model gave very good prediction of the wave decay through breaking over the two bars, but over-predicted the wave breaking-induced alongshore currents. The model gave reasonably good agreement with measured beach changes during storms, generally predicting the trend correctly, although not always with the correct magnitude. In common with all other models tested at Egmond, the model could not predict the beach accretion associated with lesser wave conditions. Processes which become more important under these conditions, such as wave asymmetry, infra-gravity wave motion, and porous flows are only roughly approximated or omitted in COSMOS-2D. Further development needed to reproduce accretion events. Not used at Teignmouth, because situation is too 3-dimensional.
BEACH2D (Liverpool University)	Used to predict hydrodynamics on a beach. Classified as a 2DV model (two dimensions in vertical plane) Models the cross-shore distribution of wave development, surface set-up/set-down, and the vertical distribution of velocities.	Typically models the beach profile from about 1-2km offshore to the point of maximum wave run-up. The model needs as input the following information: *Existing beach/seabed profile* *Significant wave height and peak wave period at the offshore boundary* *Water levels* Wave/water level data is required at regular intervals, e.g. hourly Effects of random waves are reproduced by dividing wave height distribution (assumes a Rayleigh distribution) into classes, and weighting the results of separate model runs for each class	At Egmond, the model gave good agreement for wave heights: wave breaking caused by both the outer and inner bars, and wave re-formation after breaking were well predicted. Good agreement was also obtained for velocity distributions at times when the tidal currents were not significant. The effects of strong tidal currents are not included in the model. This model was not used at Teignmouth, because of 3D effects at the beach.

BEACH1D (Liverpool University)	Used to predict the hydrodynamics on a beach and changes in beach profile Classified as a 1DH model (one dimension in the horizontal plane) Models the wave heights, water levels, cross-shore, depth-averaged sediment transport, and the resulting changes in bed elevation.	Typically models the beach profile from about 1-2km offshore to the point of maximum wave run-up. The model needs as input the following information: *Existing beach/seabed profile* *Significant wave height and period at offshore boundary* *Sediment size* The beach profile in the model is updated every 3 hours	At Egmond, the measured and predicted beach profiles agreed quite well regarding the overall erosive trend during the storm event, although there were some discrepancies in the details. For the accretionary event, the predicted trend was erosive, as with all the other beach profile models tested at Egmond during the COAST3D project.
CROSMOR (Utrecht University)	A model used to predict the hydrodynamics and nearshore morphological changes along a beach/seabed profile. Models the cross-shore distribution of wave heights, periods and currents, and associated sand transport, and calculates the resulting changes in morphology, based on a probabilistic approach.	Typically models the beach profile from about 1km offshore to the point of maximum wave run-up (but detailed swash-zone processes are not included) The model needs as input the following information: *Initial beach/seabed profile* *Sediment sizes* d_{50}, d_{90} *Bed roughness under waves alone, and currents alone* *Water level* *Significant wave height, peak wave period, and incident wave direction, at offshore boundary* *Alongshore current and wind velocities* Water levels, velocities and wave conditions are required at regular times, e.g. hourly Effects of random waves are reproduced by dividing wave height distribution into (typically) six classes, and weighting the results of six model runs.	At Egmond, during the pilot campaign, the model gave good representation of wave breaking at high water, but not enough breaking at low water. Alongshore velocities were well predicted at times, but at some locations were too small at certain stages of the tide. Cross-shore velocities showed reasonable agreement with measured data, and consequent bed evolution was also in good agreement with observations. Model not used at Teignmouth
Alongshore Current Model (Utrecht)	A one-dimensional model (1DH) used to predict alongshore currents. The model is based on a depth-integrated and time-averaged balance between breaking waves (including surface rollers), wind, and alongshore pressure gradient on the one hand, and bottom friction and lateral mixing on the	The offshore boundary of the model is taken just outside the wave breaking zone. The model needs as input the following information: *Wave conditions (height/period/direction) at the offshore boundary.* *Alongshore pressure gradient (derived from water level data along the coast).*	Model was tested against field data from the main campaign at Egmond. Offshore boundary was chosen at the seaward side of the inner bar. Good agreement was observed for the cross-shore distribution of mean alongshore currents. The results showed that the inclusion of the effects of surface rollers improved the accuracy of the model.

	other. Models the cross-shore distribution of mean alongshore currents	*Wind speed/direction* *Bed roughness*	
COASTAL AREA MODELS Coastal Area Models are used to predict the distribution of waves, and/or currents, and/or sediment transport over the whole of a study area, (i.e. in both the cross-shore and the alongshore directions) Can also be used to predict changes in seabed/beach morphology. Many different models have been developed, some of which were available to the COAST3D Project			
PISCES-Telemac (HR Wallingford)	A combination of models used to predict changes in the seabed bathymetry in the study area, and hence changes in plan shape of beaches and morphological features. Classified as a 2DH model (two dimensions in the horizontal plane). Models the areal distribution of water levels and depth-averaged currents (TELEMAC), waves (FDWAVE), and depth-averaged sediment transport (SANDFLOW), and calculates the resultant bed evolution .	Typically models a few kilometres of coastline, extending two to five kilometres offshore. However, model is usually "nested" in a hydrodynamic model covering a much larger area, to ensure that changed hydrodynamics in the study area are not reflected back into the study area at the (inner) model boundaries. The TELEMAC model, developed by EDF-LNH, uses an unstructured grid of triangular elements, enabling very detailed modelling of the area of interest whilst keeping imposed boundary conditions suitably distant by using larger elements. The model combination needs as input the following information: *Existing bathymetry* *Water level at one cross-shore boundary* *Tidal and/or wind-induced currents at all other boundaries (typically a shore-parallel boundary, and a second cross-shore boundary)* *Wave height, period and direction at shore-parallel boundary.*	At Teignmouth, for the pilot campaign, the model gave good agreement for water level and current distributions. Not only was the complex large-scale pattern of currents well predicted, but smaller scale eddies at the edge of the jet emerging from the river mouth were also reasonably well reproduced. For the main campaign, the model again gave good overall agreement with the measured velocities. Deviations from the measurements are mainly caused by the presence of gyres and errors in wave prediction. Default values were used for many parameters, and the model gave satisfactory results even in this complex coastal area. The morphological changes over a 14-day period, including a storm and spring and neap tides, were modelled. These gave good agreement with the changes observed between bathymetric surveys at the start and end of this period, for the migration of the sand banks to the North of the shipping channel in both the positions and magnitudes of accretion and erosion patterns. Agreement was also obtained

		Wave/tide/current information is required at regular times, e.g. hourly intervals. In addition, information is required on *sediment size and bed roughness height* over the study area (although at present the model assumes these are constant over the modelled area). The model is normally run for only a few tidal cycles. Running the model for simulations on the timescales of years requires special techniques.	with localised changes further inshore on the lower beach. However, the predictions did not match the observed changes to the South of the shipping channel, because the fine-sand sediment size used throughout the model did not represent the much coarser grains found in the southern area PISCES was not used at Egmond – it was not thought to be necessary for a quasi-two-dimensional situation.
Delft3D-MOR (WL|Delft)	A suite of models used together to predict changes in the seabed bathymetry in the study area, and hence changes in plan shape of beaches and morphological features. Classified as 3D, but some modules used in 2DH mode. Models the areal and vertical distribution of water levels, currents, waves, sediment transport, and calculates the resultant bed evolution	Typically models a few kilometres of coastline, extending one or two kilometres offshore. However, model is usually "nested" in a hydrodynamic model covering a much larger area, to ensure that changed hydrodynamics in the study area are not reflected back into the study area at the (inner) model boundaries. All modules operate on a flow-grid which is a curvilinear grid, which allows for high resolution in the areas of interest against relatively low computational cost. The model needs as input the following information: *Existing bathymetry* *Water levels along all boundaries* *Wave height, period and direction at offshore boundary.* Wave/water level information is required at regular times, e.g. hourly intervals. In addition, information is required on *sediment size and bed roughness height* over the study area. (Spatially-varying sediment grain size and bed roughness height were applied for the Teignmouth case).	At Teignmouth, results have been for hydrodynamic modelling, using the Delft3D-FLOW and Delft3D-WAVE modules, in both cases taking the 2DH mode option. Both for the pilot and main campaigns the model gave good representation of the measured hydrodynamics. During the pilot campaign the largest deviations were observed during times at which horizontal eddies, induced by the outflow currents from the harbour entrance, were present. However the main trends of the two dominant eddies north and south of the outflow were predicted well. During the main campaign a significant storm occurred which was primarily used to evaluate the model. In general there was good agreement with the measurements. An extensive sensitivity analysis was carried out in which a great number of parameters was varied. A surprising result was that detailed wave simulation did not yield more accurate results. A preliminary conclusion is that inaccuracies in the predicted flow velocities can mainly be ascribed to errors in the wave predictions. Delft 3D over-estimates the wave effects under relatively low wave conditions. This may be improved by a site-specific calibration of the wave models (not yet carried out at Teignmouth)

LIMOS (CIIRC)	Last of a suite of models to predict beach topography changes for given wind, wave and current conditions. Classified as 2DH models Models the areal distribution of wave conditions (PROPS model), depth-averaged currents (CIRCO model), sediment transport changes in beach/seabed bathymetry (LIMOS model).	Typically models a few kilometres of coastline, extending one or two kilometres offshore. Does not reproduce detailed swash zone processes. Does not include tidal currents. The model needs as input the following information: *Initial bathymetry* *Water level and wind speed/direction at fixed location.* *Wave height/period/direction at offshore boundary* *Sediment size and bed roughness* The model has several tuning parameters (breaking wave parameters, eddy viscosity, and free parameters in sediment transport formulae). There is a version of the model which can be run as a coastal profile model. Model can be run for many days.	For the Egmond pilot campaign, modelling of wave breaking was found to be very dependent on the assumed breaking coefficient, and this coefficient also affects reproduction of wave set-up. Reproduction of alongshore current was not very good because the model does not include the effects of tidal currents. Probably for this reason, the model results for morphological change over the five days of the test conditions gradually diverged away from the measured bathymetry. For the Egmond main campaign, good fits of wave breaking and longshore currents can be obtained varying the tuning parameters. On the other hand, cross-shore velocities are poorly reproduced, because the model is depth-averaged. The model showed a trend to an excessive smoothing of the bars in the morphodynamic modelling. Only used to a very limited extent at Teignmouth, because if the model's inability to include the effects of tidal currents, which are very complex at this site..
2DPLAN Model (Liverpool)	A model used to predict bed level changes over the coastal area of interest. Classified as a 2DH model The model contains two modules. The hydrodynamic module solves the wave number vector and wave energy equations for the wave characteristics, and the fluid continuity and momentum equations for the currents, The morphodynamic module solves the sediment mass continuity equation for the bed level changes. Models the areal distribution of wave conditions, depth-averaged currents and	Typically models a few kilometres of coastline, extending one or two kilometres offshore. Does not reproduce detailed swash zone processes. The model needs as input the following information *Initial bathymetry* *Representative sediment characteristics* *Boundary water levels and depth-mean velocities* Running the model for more than a few tidal cycles requires special techniques	Not used at Egmond. Used at Teignmouth, but, in comparison with measurements from the pilot campaign, agreement on velocities was not good, possibly because model boundaries were too close inshore. (unlike some of the other models used at Teignmouth, this model is not nested within a larger area model) Results from Teignmouth main campaign showed the importance of wave-current interaction in the nearshore zone, especially in areas subject to strong tidal currents

	sediment transport rates, and bed level changes.		

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Appendix II

Appendix 2 TOOLS USED IN COAST3D: Measurement Equipment

Name	Brief description	Guidelines on how to use	Examples of results for Egmond and/or Teignmouth
Bathymetry/Topography			
Total Station Levelling	Method of surveying the beach and inter-tidal area, using a laser levelling system	Commercially available instrumentation, used extensively for ground surveys. For surveying the intertidal and supra-tidal beach, levels are usually measured along regularly spaced cross-shore transects, from a landward reference point down to about 1m below the low water mark (depending on wave conditions). Surveys are best carried out at about low water of high spring tides to give best coverage of beach. For beach monitoring purposes, permanent markers should be established to enable accurate re-location of transects, and the beach levels should be related to a standard datum.	Beach levels at Egmond have been regularly monitored for decades. At Teignmouth, beach levels were monitored each month at three transects for three years prior to the Coast3D measurement campaign
Differential Global Positioning System (DGPS)	Method of fixing absolute position (three co-ordinates), based on calculated distance from at least four geo-stationary satellites	Commercially available instrumentation. The method uses 2 DGPS receivers, one in fixed location (base station), the second being moved between each measurement. The base station needs to be very stable, and must be referenced in the local geodesic system with great accuracy. The second receiver can be stand-alone, or mounted on a mobile platform, e.g. cross-country vehicle. The accuracy of the horizontal co-ordinate is about +/- 20mm. Overall the vertical accuracy is about 50mm on relatively flat and smooth areas, rising to about 100mm on steep sloping faces of bars, and on areas with sediments that are less well consolidated. .	At Egmond, used on the WESP (by RWS) to measure cross-shore profiles At both Egmond and Teignmouth, the second receiver was mounted on a quad-bike (by UCa), allowing a very large area to be surveyed in a very short time. Surveys were carried out at about low water, to give repeat measurements of beach topography. At Egmond, 21 surveys were carried out, each covering an area of about 300 by 100 metres. Three surveys were carried out at Teignmouth during the main campaign, covering an area of about 900m (alongshore) by 50 to 150m (cross-shore), depending on the tidal range and wave activity (wave set-up)

Echo Sounder Surveys	Method of surveying the seabed, using a standard maritime echo sounder	Data logged at 10Hz gives a reading every 0.2m at a ship speed of 2m/s (speed depends on sea-state). A 208Hz echo sounder has a quoted accuracy of 0.5% of indicated depth (minimum error 25mm). Final result depends on sea-state, technology for heave-compensation, skill of surveyor and sophistication of post-processing. Frequent (twice-daily) bar checks of the echo sounder are required	Bathymetric charts were produced for Teignmouth at a scale of 1:2500 based on parallel track lines 25m apart, plus cross-check lines perpendicular to these. A zig-zag line in the estuary channel gave the estuary channel form. The area covered was approximately 1.5km x 1km, plus part of the estuary.
Seabed characteristics/Bedform			
Van Veen Grab	A method of obtaining samples of subtidal sea bed material either for visual analysis or for quantitative particle size distribution analysis.	Deployed by hand over side of survey vessel. The primed grab is triggered when it hits the seabed, taking a shallow "bite" of the surficial sediment.	At Teignmouth the grab retrieved a range of fine sand, gravelly and shelly material, and stones. Stones can jam open the jaws of the grab, necessitating a repeat deployment.
Roxann System	An acoustic system used to produce a map of the nearshore and offshore zones of the study area, showing the size classification of the seabed sediments. The system works by comparing acoustic returns from the seabed at a number of different frequencies.	The system is mounted on a survey vessel, and needs an experienced specialist operator, both to make the survey and to interpret the results. An adequate number of bed samples must be taken to visually calibrate the system for site-specific conditions. Based on these point samples, the seabed composition can then be mapped in detail over the entire survey area.	Not used at Egmond. At Teignmouth, the system was installed on the survey vessel Sir Claude Inglis (HR). One survey was carried out, before the pilot campaign. For calibration purposes, 50 grab samples of the seabed were taken on a grid covering the survey area.
Digital Side-Scan Sonar	An acoustic system designed to map the bedforms in the offshore and nearshore zones. Mounted on a survey platform (e.g. survey vessel or the WESP), can be used to build up a geo-corrected mosaic image displaying the bedforms throughout a study area.	Very portable, and can be mounted on a survey platform in a few hours. Tracklines need to be spaced at a small interval (typically 50 metres) to enable an accurate mosaic to be assembled. Residual sediment transport directions can be deduced in locations where asymmetric bedforms occur. The accuracy of positioning during recording was a few centimetres in Egmond (due to mounting on WESP ad very accurate DGPS system) and a few metres at Teignmouth (system was towed and less accurate DGPS system)	For the COAST3D project, the system was supplied/operated by Mag. At Egmond, the system was mounted on the WESP, which provided an ideal platform to work in very shallow waters. The system was able to resolve bed features over the entire recording width (2x45m). A complete mapping of the experimental area was carried out towards the end of the main measurement campaign. At Teignmouth, the system was installed on the survey vessel "Sir Claude Inglis". A complete mapping of the experimental area was carried out approximately midway through the main campaign.

Water levels/Waves			
Pressure Transducer	A device for measuring total pressure. Pressure transducers are suitable for mean water depth at any depth within the instrument's range. They are only suitable for measuring waves in water shallower than about 10m, due to excessive oscillatory pressure attenuation effects, with short period waves being lost at shallower depths.	In use for many years, and now a standard, commercially available, instrument. Needs to be mounted on a suitable platform, e.g. structure, frame, tethered buoy etc. Accuracy of wave measurement depends on water depth and wave period. Attenuation corrections must be applied.	Used extensively at both Egmond and Teignmouth. Not suitable for use at depths > ??m, due to excessive attenuation effects. Data recovery rate was 90 to 100% Accuracy for depth is 1 to 2%. Transducers on free-standing frames may not represent the water depth accurately if the frame settles into the seabed due to scour action. Accuracy for wave-height is 10-15% for waves of period 6s in depth of 5m. Wave energy at frequencies higher than 0.4Hz is not detected by most commercially available instruments.
Wave Pole	A pole or pile driven into the seabed, and extending above the highest water level. Used as a mounting for a pressure transducer to measure water level, wave height and wave period		Five wave poles were installed by RWS at Egmond (independently of the COAST3D project), at water depths varying from about 4.7 to 0.1 metres below mean sea level. The results indicated the cross-shore variation of wave heights. No wave poles were installed at Teignmouth.
Directional Wave Buoy	A surface buoy for measuring offshore wave conditions, including wave height, period and direction. Uses several accelerometers to measure the vertical motion of the buoy, and its tilt angle and direction. The resulting signals are radioed to a shore receiving station for processing and storage.	Has been in use for many years, and is now a 'standard' instrument, typically deployed for a period of at least 12 months, with measurements every three hours. Needs a minimum water depth of about 8 metres in which to operate, and also needs a ship with fairly heavy lifting gear to deploy and recover. Not accurate for wave periods shorter than about 2 seconds, or longer than about 30 seconds. Being deployed some distance offshore, has disadvantage that also records waves that propagate from the coast, usually not relevant for coastal problems.	At Egmond, a directional waverider buoy was deployed by RWS offshore in a water depth of 15.7 metres (below mean tide level), remaining on location for several months, from the start of the pilot campaign until after the end of the main campaign. Measurements were taken every hour At Teignmouth, a directional waverider buoy was deployed offshore at a depth of about 9 metres below mean tide level. Deployment was for the duration of the main measurement campaign (about 6 weeks), with wave measurements taken every hour.

Wave Recording System (WRS)	The Wave Recording System is an array of 6 pressure transducers used to derive the wave height, period and directional spectra in the nearshore zone. It is especially valuable at sites where reflected waves are expected (e.g. from a seawall or a steep beach).	The 6 pressure transducers are deployed by divers in a triangular configuration on the seabed. Signals from the transducers are carried up to a surface buoy, and transmitted to base by GSM radio. Alternatively the data can be stored at the buoy, and downloaded from a boat. This is a research-level system developed by UPl, that has had trials at several UK coastal sites.	At Egmond, the wave recording system was deployed in the nearshore zone, at a location where the water depth was 6 metres. Unfortunately the onshore migration of the bar system during the main measurement campaign covered the WRS in 1.5 metres of sand, and no data was obtained. At Teignmouth, the WRS was deployed in about 8 metres of water, at the offshore boundary of the experimental area. Data was obtained at hourly intervals throughout the main measurement campaign
Inshore Wave Climate Monitor (IWCM)	The IWCM is an array of five electrical resistance wave staffs used to derive wave height, period and directional spectra in the inter-tidal zone.	The 5 wave staffs are driven into the beach in a triangular array, and are connected to a central data storage/battery power unit. Data recovery can be carried out weekly using a notebook PC. Wave staffs are fairly widely available, but the overall system has been specially developed by UPl.	At Egmond, the system was deployed during the main measurement campaign, at a location close to mean low water springs. However movement of the nearshore sand bars meant that the staffs were now in a deep trough, and could not be accessed for data retrieval. At Teignmouth, the system was deployed at East Pole Sand near the low water mark, and data was obtained at hourly intervals throughout the main campaign.
X-band Radar	A system for the remote sensing of wave direction and wavelength. Based on interpretation of the 'noise' in the radar return signal, generated by reflections off ripples on the sea surface.	Uses a conventional maritime radar antenna, which needs to be mounted about 10 metres above sea level. Requires a wind speed of a couple of metres per second to generate the wave field required for the system to operate General patterns of wave direction, wavelength, wave refraction/diffraction etc. can be viewed on a conventional display screen. However quantitative information requires digitisation and storage of the images, and analysis using special software only recently developed by POL. Further developments may include the derivation of wave height from the signal, and the use of linear wave theory in an inverse mode to obtain bathymetry.	At Egmond, the X-band radar system operated for about a month during the main measurement campaign, recording a sequence of 64 images at 2.25 second intervals every hour. The antenna was mounted on top of the Relay Station at the back of the beach, and data was obtained over a semi-circular area of the nearshore zone, with a radius of about 1.8km. The locations of the bars were easily discerned, as indicated by wave breaking. At Teignmouth, the antenna was mounted on the roof of Teignmouth Pier, and the system was operational for most of the main measurement campaign.
Velocities			

Electro-Magnetic Flow Meter	The EMF meter measures current strengths in two dimensions, by measuring the voltage generated by the conductor (water) flowing past two pairs of electro-magnetic poles.	The EMF meter has been in use for many years, and has become a "standard" instrument for measuring instantaneous current strengths in two directions, usually in the nearshore/intertidal zones. Usually employed to give velocities in the horizontal plane, it can also be aligned to give velocities in the vertical plane. The meter needs careful calibration, preferably both before and after an experimental campaign. Problems can sometimes occur with "zero-drift", although these can often be overcome at data analysis stage.	Used extensively at both Egmond and Teignmouth, usually in association with other instrumentation, e.g. tripods, CRIS etc. Practical working range for velocity is about 0.03 to 2.0m/s Inaccuracy is a maximum of about 15% for time-averaged velocities greater than about 0.5m/s, with significantly larger errors at lesser velocities. Errors in wave orbital velocities may also be about 15%. .
S4 Current Meter	A submerged, spherical instrument package available commercially, and used principally to measure instantaneous velocities in the nearshore and offshore zones. Similar in concept to an EMF meter, but with self-contained power source, data storage etc. Some versions of the S4 incorporate other instrumentation, e.g. pressure transducer (to measure wave heights/periods), salinometer, thermistor.	The S4 current meter has been in use for many years now, and has become a standard instrument for measuring current strengths and directions in the nearshore and offshore zones. Because of its size (300mm diameter) the S4 data may not be reliable in water depths of less than about 2 metres, and must be at least 1 metre below the water surface. The sphere and its sinker weights (or mounting frame) need to be deployed by boat with fairly heavy lifting gear (approx 400kg). It is necessary to retrieve the sphere in order to download the data. For example, using 10 minute burst sampling of average current speed at Teignmouth, S4s were deployed for a 27 day period. Calibration of the S4 is advisable before and after a measurement campaign.	A total of 9 S4 instruments was deployed at Egmond (by UCa and HR),, in water depths varying between about 1.1 and 5.5 metres below mean sea level, mostly giving good data recovery. Nine S4s were deployed at Teignmouth, 5 in the nearshore zone, and three in the intertidal zone. Those in the intertidal zone were mounted on specially built frames (UCa), measuring at a distance of about 0.65m above the seabed.
Acoustic Doppler Velocity Meter (ADV)	A device for measuring instantaneous currents, based on the Doppler shift in frequency of an acoustic signal due to the moving water.	A relatively new technique, but increasingly being used in coastal research. Gives instantaneous velocities and directions at the position of the sensor. Needs to be mounted on a suitable platform, e.g. structure, frame, or tethered buoy.	In the COAST3D experiments, ADV meters were attached to one or two maxi-tripods (e.g. by UU).
Acoustic Doppler Current Profiler	An acoustic system used to measure the vertical profile of horizontal velocities	A relatively new technique, but increasingly being used in coastal and estuary research. Usually mounted on a survey vessel with the transducer (e.g. 1500kHz) pointing downwards,	At Egmond, mounted in a frame on the seabed, in a water depth of about 5 metres. For various reasons, reliable data was only obtained for a period of about 9 days during the main campaign.

(ADCP)		allowing instantaneous measurements of the vertical profile at many locations in the study area. But can also be mounted on the seabed, with the transducer pointing upwards, to give a time series of vertical profiles at a fixed location. Current speeds can be measured at vertical intervals of typically 0.5m through the water column, but measurements cannot be made within the top 2m and the bottom 1.5m of the water column. The accuracy depends on height of cells and on averaging time.	At Teignmouth, two ADCPs were deployed, by HR. One was bottom mounted in a water depth of 8 metres. The other was installed on a survey vessel: on two occasions during the main campaign, continuous profiling of current speed and direction was undertaken whilst travelling all along the boundary of the study area, including across the harbour entrance. Each survey was repeated at approximately hourly intervals throughout the tidal period.
Float tracking	A standard technique for observing (tidal) flow patterns over an area. Analysis of float positions at given times enables near-surface tidal velocity and direction to be determined	HRW standard drogues (1x1m cruciform terylene panels) were deployed in the estuary mouth at Teignmouth. The centre of the drogues was set at either 1m or 3m below water surface. Surface floats attached to the panels were tracked by boat.	Three releases at Teignmouth during an ebbing spring tide showed how the flow from the estuary developed and interacted with the tidal flow outside the estuary.
Suspended Sediment Concentrations			
Pumped Sampling	A technique for obtaining samples of the water and suspended sediment, which are then analysed to determine suspended sediment concentration and size grading, and other relevant parameters	A standard technique which has been used by many organisations for very many years. At Teignmouth, 16mm nozzles were positioned at known heights above the bed (usually on a frame), connected by flexible tubing to a pump and filtration unit mounted in an inflatable boat. Samples were typically taken every 1 to 2 minutes, comprising 20 to 40 litres depending on sediment concentration. Each sample was pumped through a pre-weighed 40 micron nylon filter, which, together with a sample of the filtrate, was retained for analysis.	Direct samples for a flood tide on Spratt Sands gave maximum concentrations of suspended sand of 45 mg/l at 0.1m above bed, and 20mg/l at 0.5m above bed. The median size of the suspended material was 0.10 to 0.12mm.
Optical Backscatter System (OBS)	An instrument to measure suspended sediment concentrations, based on the proportion of light scattered by particles in suspension..	This system has been used for many years, and has become a "standard" method of determining instantaneous suspended sediment concentrations. Unlike the similar acoustic system, the optical system gives only a point measurement at the position of the sensor. The measured concentration is very sensitive to particle size, and detailed calibration is necessary	Used extensively at both Egmond and Teignmouth, in various combinations with other instrumentation, e.g. tripods, CRIS etc.

		against in-situ samples. If the background concentration (e.g. of silt) to be subtracted from the record is of the same order of magnitude as the sand concentration, the OBS sand concentrations will be rather inaccurate.	
Acoustic Backscatter System (ABS)	A multi-frequency acoustic backscattering system to provide high resolution vertical profiles of the concentration and median grain-size of suspended sediments along a (short) transect.	For the COAST3D project the system used three acoustic frequencies, and hence three transducers. The transducers were fixed to a bedframe, deployed either in the inter-tidal or nearshore zones. The system requires detailed acoustic and electronic calibration, and preferably some in-situ suspended sediment measurements. Typically, measurements can be made at a vertical spacing of 1 cm throughout a 1m transect above the bed.	The equipment was deployed throughout the Egmond pilot and main campaigns, and returned good data. Unfortunately in-situ pumped samples of the suspended sediment were not obtained, so the data could not be calibrated accurately. At Teignmouth the system was deployed by POL on the maxi-tripod on the inter-tidal portion of Spratt Sand, where it recorded suspended sediment concentrations simultaneously with an optical backscatter system. The system was calibrated against in-situ pumped samples over one ebb tide.
Morphodynamics/Sediment transport			
Fluorescent tracers	Sand dyed with a fluorescent paint is injected at a fixed location on the beach, and its movement is tracked at each low water to give an indication of the direction and rate of sand movement.	A fairly standard technique that has been in use for many years now. The sand to be dyed is taken from the beach being studied. Different colour dyes are available. The amount of sand injected is typically about 100kg (for each site/experiment), depending on the wave conditions. Generally, sand movement cannot be detected for periods longer than about 3-4 tidal cycles (again depending on wave/tide conditions)	Used at both Egmond and Teignmouth by UCa. During the main campaign in Teignmouth, several injections were carried out to quantify sediment transport within the swash zone. Due to high energy in this area, the dispersion of the dyed sand grains was very fast, and the moving layer was very thick. In these hydrodynamic conditions it is impossible to identify the edge of the fluorescent cloud to quantify a sediment transport rate. Four injections were carried out on the Egmond beach with 2 or 3 low tide detections, by night to locate the fluorescent sand grains with ultra-violet lights. Sediment movements were quantified (direction and rate) showing the longshore and cross-shore sand transport components integrated

			over several tidal cycles.
Swash Morphodynamics	Rapid surveys employing a system of graduated rods are used to measure the evolution of the sea bed during the swash processes.	Graduated rods are placed in line along the cross-shore profile. A cylindrical ruler with a flat base is dropped over each rod in turn to measure the local bed level. The rods need to be well fixed on the beach, and their position accurately known. The method is operated by 2 people wearing wet suits. The complete measurement campaign lasts several hours, every rod in the swash zone typically being measured every 5 minutes, with an accuracy of about 5 to 10 mm. For safety reasons, measurement are not possible with wave breaker heights greater than about 1 metre. Essentially a research technique developed by UCa.	Used at both Egmond and Teignmouth by UCa. Fifteen experiments were realised on the two different sites. Nine experiments were conducted on the lower beach at Egmond, lasting for 2 to 9 hours, and 6 were conducted on the upper beach at Teignmouth, lasting between 5 and 8 hours. This experiment is manual, and requires the permanent presence of 2 experimenters for several consecutive hours, in all conditions of waves and weather.
Autonomous Sand Ripple Profiler	An acoustic system to scan ripple profiles, and to provide detailed data on bedform evolution. Measurements are made over a (short) transect.	The system is deployed in a bedframe, located either in the inter-tidal or nearshore zones. The ripple scanner requires software to extract and track the bed elevation over time. Minimum measurable variation in bed height is about 5mm A research technique being developed by POL.	This experimental equipment was deployed by POL on two occasions during the main measurement campaign at Egmond, for 5 hours and 29 hours respectively. The equipment was fixed to one of the Utrecht University maxi-tripods, in a water depth of 4.3 metres. Bed profiles were measured every few minutes along a transect length of 3.5 metres.. The system was also deployed in the inter-tidal zone at Teignmouth, on Spratt Sand which has very pronounced bed features. Data was obtained throughout the main measurement campaign, with measurements from a few hours before to a few hours after each high tide..
Tell-Tail Scour Monitor	An instrument to monitor the maximum depth of scour at a given location during a particular event, e.g. at a bridge pier during a major flood, or adjacent to a seawall during a major storm. Records movement of a vertical stack of "tails", that waggle when water flows past but not when buried in the beach or sea bed.	Four instruments placed on the beach using a mechanical digger. Initial level set to cover range of interest. Recorded bed level with 100mm resolution every 10mins over a vertical range of 0.8m. Instruments must be levelled to a local datum, and bed elevation measured at low tides.	The instruments at Teignmouth showed that the bed elevation changed during a single tidal immersion by up to 0.3m. Changes in bed elevation during the main campaign were at least 0.6m.

ARGUS Video System	The ARGUS system consists of several digital video cameras set up to view the beach and surf zone. The system is programmed to record images for a few minutes every hour during daylight.	For best results the cameras must be mounted high above the beach, at a location with a power supply and telephone line (for transmitting images to the office base). The images give very valuable information on daily changes in intertidal and beach morphology, and can also indicate long-term changes in near-shore bathymetry, e.g. bar location. The information primarily provides a qualitative view of the changing bed morphology, although techniques to process this into a quantitative measure of the bathymetry are being developed. ARGUS systems are only available through Oregon State University, USA.	At Egmond, the ARGUS system was mounted on a very tall mast (height 40m) located to the south of the experimental site. It was used primarily to monitor the position of the bar crests: comparison with the WESP surveys indicated that the ARGUS system gave a bar location accuracy of about 40 metres, depending on local wave heights and water depths. Therefore the system should typically be used to detect changes in bar position and patterns over several weeks, months and years: the system should not be used to monitor daily changes in bar position. Accurate information on offshore waves and water levels is essential for quantifying bar location. At Teignmouth, the ARGUS system was mounted on the top of The Ness, the headland at the southern end of the experimental site. It was used primarily to monitor changes in the bars, shoals and channels seaward of the entrance to Teignmouth Harbour. Five cameras were used at each site.
Instrument Carriers/Frames/Platforms			
Maxi-Tripod	A large frame placed on the seabed, providing a mounting platform for various measurement equipment. Designed for deployment mainly in the nearshore and offshore zones. Typical instrumentation includes: *pressure transducer to measure water levels, wave heights/periods* *one or more EMFs (or ADVs), for instantaneous current strength and direction at fixed elevation(s) above the seabed.* *One or more OBSs or an ABS, for instantaneous suspended concentration at fixed elevation(s)* *a compass* *a tilt-meter*	Different versions of the tripod/bedframe have been developed by different organisations, but have essentially the same purpose. The tripods have to be deployed and recovered either by ship or by an amphibious vehicle such as the WESP. Settling of the tripods, in combination with migrating and changing bedforms (and therefore variable bed levels) causes some problems for analysis of the data, since the exact height of the sensors above the bed is not monitored. Tripods typically work in a burst-sampling scheme: every hour a series of measurements starts for a period of 20 to 40 minutes. Servicing requirements vary according to design, but	For the COAST3D project, maxi-tripods/bedframes were deployed by UU, UCa, HR At Egmond, deployment of the maxi-tripods was carried out smoothly and rapidly by the WESP. Seven tripods were deployed to measure cross-shore gradients in wave- and flow-parameters. The tripods were located at seabed elevations ranging from about 1.4 to 5.8 metres below mean sea level. Measurements were taken every hour (?) during the five weeks of the main experimental campaign. At Teignmouth, six bedframes/maxi tripods were deployed by the survey vessel "Sir Claude Inglis". Three were deployed in the nearshore zone at water depths of about 2 to 6 metres below mean tide level, while a fourth was deployed in the intertidal zone,

	Also includes power supply and data storage equipment.	typically the tripod has to be recovered every 20-30 days for data downloading.	on Spratt Sand. Two were used to provide long-term monitoring of waves, tides, currents, suspended concentrations and temperature at the boundaries of the study area.
Mini-Tripods	A small tripod for deploying in the inter-tidal zone, equipped with basically the same instrumentation as the maxi-tripod, typically: *Pressure transducer, for waves, water levels* *One EMF (or ADV) for currents* *One OBS for suspended sediment concentration.* Also includes power supply and (limited) data storage.	Different versions have been developed by different organisations. Small enough to be deployed by hand, usually around the time of low water. Same problems as maxi-tripod in determining exact height of sensors, but can be checked visually at each low water.	For the COAST3D project, mini-tripods/beach frames were deployed by UU, UCa and UPI. At Egmond, ten mini-tripods were used in the inter-tidal zone. These tripods were deployed over nearly every high water, in a configuration and at locations which depended on the morphology at the time of deployment. At Teignmouth, eight mini-tripods were deployed in the inter-tidal zone. Again the exact locations depended on the local morphology at the time of deployment.
WESP	The WESP, a Dutch acronym for Water en Strand Profiler, is an approximately 15m high amphibious 3-wheel vehicle used primarily to carry out bathymetric surveys of the nearshore, intertidal, and beach zones. It can also be used to deploy and recover instrumented tripods, and to tow the CRIS instrumented sledge (q.v.).	The WESP is generally used to measure cross-shore transects from the top of the beach seawards to a water depth of about 6-7 metres (depending on wave conditions). A kinematic DGPS on the vehicle measures its position. The accuracy of the combined WESP/DGPS system is about 50 to 100mm for a flat or gradually sloping bed: for steeper profiles the accuracy is somewhat less. Developed and built by RWS, this is the only device of its kind in Europe. The COAST3D and KUST*2000 campaigns at Egmond were its first field trials, and it is still being evaluated.	At Egmond, cross-shore transects were measured with a spacing of 50 metres, in wave conditions up to 2 metres significant. Maximum bed slopes were about 6°, in which case the accuracy in the vertical was estimated to be about 100 to 200mm. Complete surveys of the experimental area were taken roughly every 2 days during the main measurement campaign. The WESP was not used at Teignmouth, partly because of the very considerable expense involved in transporting it from Egmond, and partly because of the very steep bed slopes near the harbour entrance.
CRIS	The CRIS (Coastal Research Instrumented Sledge) is designed to make detailed sediment transport measurements in the nearshore and intertidal zones. It is used in combination with the WESP (towing, power supply, data handling, water sampling). The sledge can be equipped with various instrumentation, including electro-magnetic flowmeters, optical	The CRIS was originally intended to be used to give quasi-synoptic measurements along a cross-shore transect. In reality though, the time interval between two consecutive measurements is too long, resulting in non-steady wave and tidal conditions. By mounting the instrumentation on the relatively open structure of the CRIS instead of the rather substantial WESP, 'undisturbed' measurements of	At Egmond, the total time at each location was about 40 minutes - about 20 minutes to settle into the sediment, and then about 20 minutes of measurements. Not used at Teignmouth.

	backscatter sensors etc.	sediment transport can be made. The CRIS was developed by UU/RWS specifically for the KUST*2000 campaign.	

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