Concepts and Science for Coastal Erosion Management

Specific Targeted Research Project

Thematic priority: Forecasting and developing innovative policies for sustainability in the medium and long term

Coastal State Indicators at the CONSCIENCE Case Study Sites

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Task Leader José Jimenez

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Coastal State Indicators at the Conscience Case Study Sites

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Contents

1. Introduction

The Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management in Europe (2002) is explicit in the urgency and need for implementing ICZM for its coasts. A major principle set out in this Recommendation is that coastal zone management should be based on working with natural processes and respecting the carrying capacity of ecosystems, which will make human activities more environmentally friendly, socially responsible and economically sound in the long run. A major issue in many parts of European coasts is the problem of coastal erosion and associated risks. The scope and urgency of this problem was comprehensively studied and described by the *Eurosion* project.

The recently signed *Protocol on Integrated Coastal Zone Management in the Mediterranean* (2008) specifies among other topics that (sic) the Parties, with a view to preventing and mitigating the negative impact of coastal erosion more effectively will undertake to adopt the necessary measures to maintain or restore the natural capacity of the coast to adapt to changes, including those caused by the rise in sea levels. The Parties shall endeavour to anticipate the impacts of coastal erosion through the integrated management of activities, including adoption of special measures for coastal sediments and coastal works. The Parties undertake to share scientific data that may improve knowledge on the state, development and impacts of coastal erosion

Within this context, the European Union through the *Eurosion* project recommends four main elements to define a policy to combat coastal erosion:

- Increase coastal resilience by restoring the sediment balance and providing space for coastal processes.
- Incorporating coastal erosion costs and risks in existing planning and policy instruments.
- Make responses to coastal erosion accountable.
- Strengthening the knowledge base of coastal erosion management and planning.

However, these elements have not been formalized in a framework to be applicable by coastal managers nor their applicability to European coasts has been validated. To bridge this gap and to adapt such a strategy to the reality of European coasts, the European Union research project *Conscience* was launched with the main strategic objective of developing and testing concepts, guidelines and tools for the sustainable management of erosion along the European coastline, based on best available scientific knowledge and on existing practical experience.

Concepts and Science for Coastal Erosion Management (commonly known as CONSCIENCE) is an EC-funded research project being carried out by eight organisations, coordinated by Deltares (NL). The overall objective of CONSCIENCE is to define and validate through pilot applications a methodology to support the implementation of the concepts of coastal resilience, favourable sediment status, strategic sediment reservoirs and coastal sediment cells for the European coasts (European Commission, 2004)[1]. The project is developing a series of guidelines and tools in support of this approach to ensure that it can be effectively assimilated into a sustainable management strategy for erosion. More information on the project, the participants and the deliverables can be found on the project website http://www.conscience-eu.net/.

The project makes use of a decision-making framework for formulating a sustainable solution as a base methodology, the Frame of Reference (Figure 1).Characteristics of the Frame of Reference are the definition of clear objectives at strategic and tactical levels and an operational decision recipe involving four steps. At the highest level a strategic objective is formulated, determined by the long term vision about a desired development of the coast. This vision could be based on generic ideas about sustainable development and should ideally reflect the interdependency of the natural coastal and socioeconomic systems. At the next level one or more objectives are formulated describing in more detail what has to be achieved in order to comply with the strategic objective. As this implies the choice between different tactics, we call these the tactical objective(s). If for instance on a strategic level the objective is formulated as 'sustainable development of coastal values and functions', at the tactical level we have

[1] These concepts were originally derived by the EUROSION project: www.eurosion.org

to choose between different options, such as maintaining the coastline at its current position (i.e. not allowing erosion), or allowing a certain variability in coastline position.

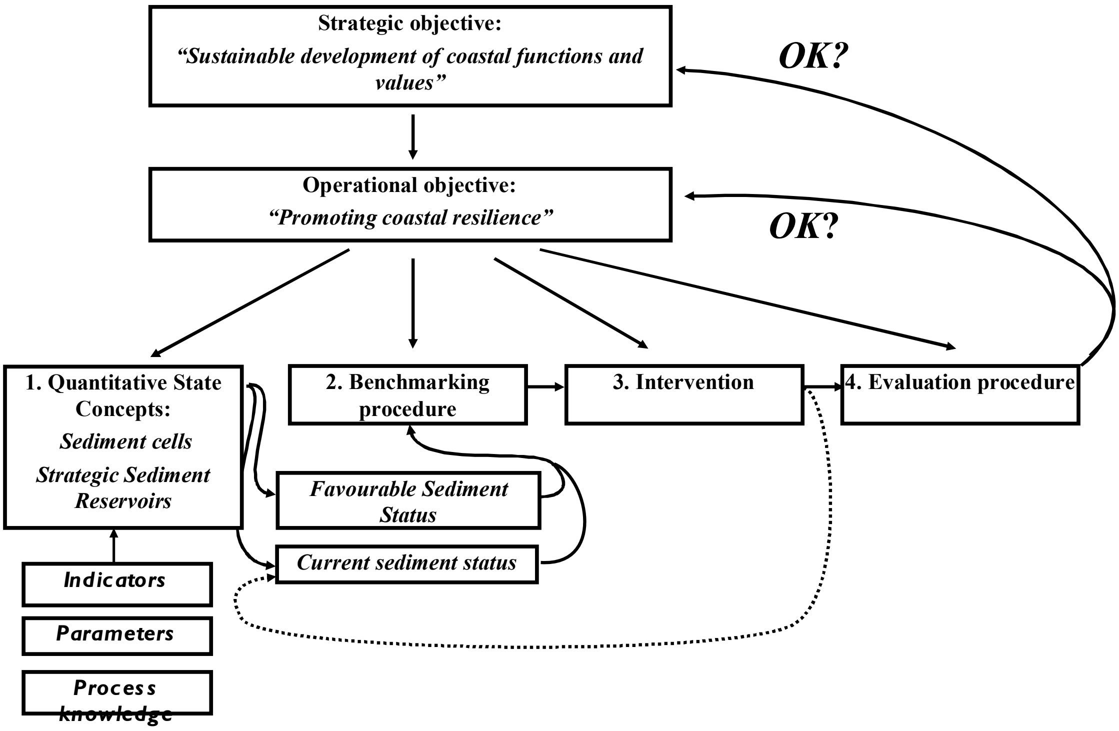

Figure 1 Frame of Reference decision making framework

Once this tactical objective has been defined, the actual management process regarding interventions can be formulated through an operational decision recipe with four steps:

1. *Quantitative state concept:* a means of quantifying the problem in hand. Coastal State Indicators (CSIs), which are specific parameters that play a role in decision making, are relevant at this stage of the process.
2. *Benchmarking process:* a means of assessing whether or not action is required. CSIs are compared to a threshold value at this stage.
3. *Intervention procedure:* A detailed definition of what action is required if the benchmark values are exceeded.
4. *Evaluation procedure:* Impact assessment of the action taken. If the action

was not successful it may be necessary to revise the strategic/operational objectives (hence the feedback loops in Figure 1).

The frame of reference approach relies on the use of Coastal State Indicators to quantify the state of the coast and, in this sense; they are the basic tool to analyze the problem at a given site. This report corresponds to deliverable D17 where we present the selected Coastal State Indicators that have been used at the field pilot sites of CONSCIENCE (Figure 2). This report is complemented with report D10 where the required measurements for each indicator at their application in the benchmarking procedure are detailed for each site.

2. Coastal State Indicators

In general terms, an indicator can be defined as a sign that relays a complex message in a simple and useful manner. Following this, Coastal State Indicators (CSI) can be defined *as a reduced set of parameters* (the sign or signs) *that can simply, adequately and quantitatively describe the dynamic-state and evolutionary trends of a coastal system* (relaying a complex message in a simple and useful manner).

The indicators should provide three main functions: simplification, quantification and communication. In this sense, they are becoming an essential part of the communication process between scientists and managers and a way to reduce the risk of failure of such a process.

When we focus on environmental indicators, and CSI's can be considered as specific environmental indicators, their major functions are:

- to assess the condition of the environment
- to monitor trends in conditions over time
- to compare across situations
- to provide an early warning signal of changes in the environment
- to diagnose the cause of an environmental problem

- to anticipate future conditions and trends

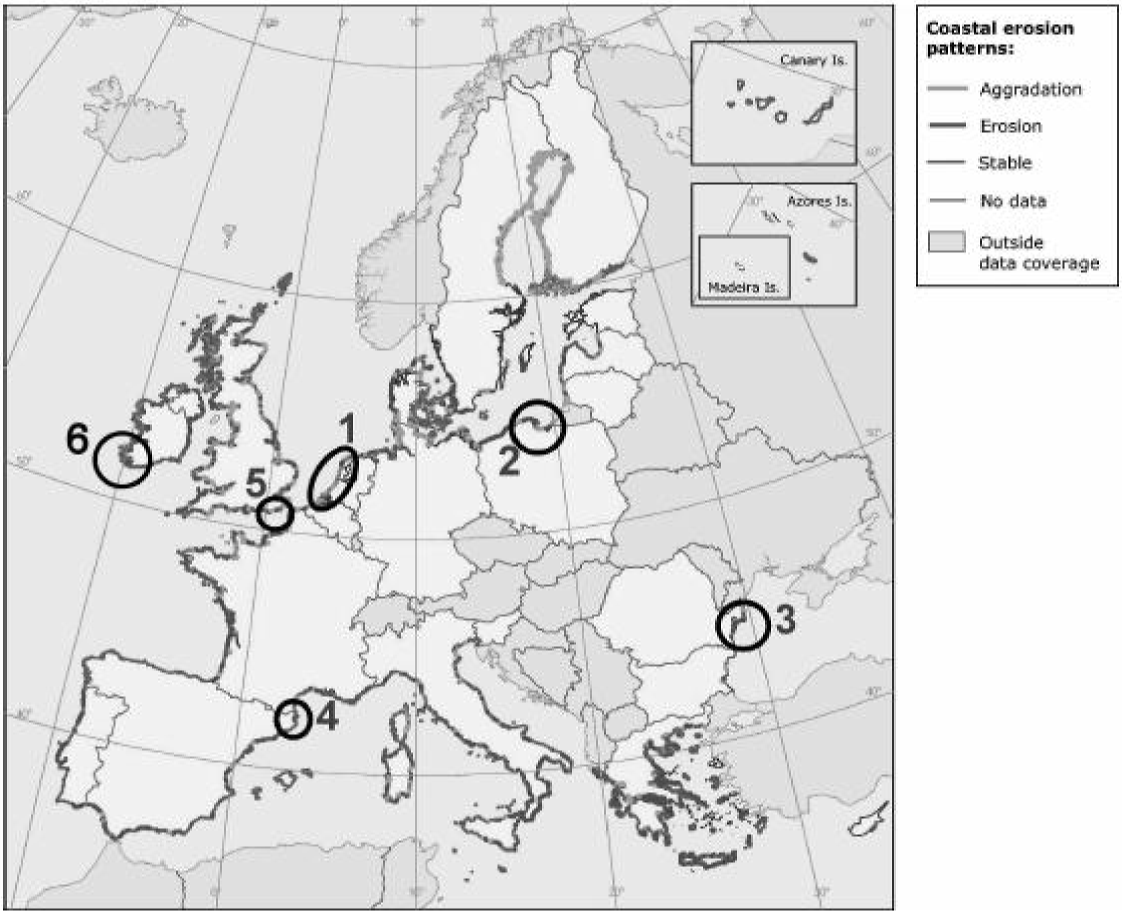

Figure 2. Conscience Pilot sites

Following previous works in the development of environmental indicators it is possible to identify some basic criteria that CSI's must fulfil to be useful and consistent.

- ***Be relevant***.

It must be demonstrated that the proposed indicator is conceptually linked to the coastal function of concern. This link has to be of "first-order", i.e. it is not only a matter that a variable takes part in the process but that it is significantly contributing to it. This requires a scale analysis, in which key variables/processes/responses are selected according to the significance of their role in the coastal function at the proper scale.

- ***Be easily measured***.

The indicator should be straightforward and relatively inexpensive to be measured. This also includes requirements such as meeting data quality objectives (whatever they are) and being consistent with the process/variable of interest, e.g. it makes no sense to determine beach width with a precision of mm, since this precision does not imply a better characterisation of the system response.

- ***Be sensitive to stresses on the system***.

The indicator should be responsive to stresses on the system. Applied to ecological indicators, the ideal situation would be an indicator that is sensitive to stresses due to human actions while having limited and documented sensitivity to natural variation.

When this is applied to CSI's, it has a series of implications. Thus, one of the intrinsic characteristics of the coastal zone (and for any environmental issue in general) is that it is a highly dynamic system, and, in consequence, it will be necessary to "live" with it, i.e. any selected indicator will have a "natural-induced" source of variation and a "human-induced" one. The key point will be the identification and isolation of each component from gathered data.

- ***Have a known response to disturbances, anthropogenic stresses, and changes over time***.

The indicator should have a well-documented reaction to both natural disturbance and to anthropogenic stresses on the system. This means that any variable or characteristic of the system can only be used as an indicator provided that there is a scientifically sound pattern of response. In other words, to simplify a system we need to know which are the elements of the system and how do these react to stress.

For CSI's this is not a major constraint, since there is a sound knowledge about their response (in time and space) to stresses (natural and anthropogenic ones).

- ***Be anticipatory***.

A change in the indicator should be measurable before substantial change in the targeted objective occurs. This implies the selection or definition of a threshold which serves as a "warning signal" to indicates the changes.

- ***Be integrative***.

The full suite of indicators provides a measure of the key gradients across the analysed system (change in the system state in time and space). Moreover they must allow to be aggregated to generate an issue-oriented indicator.

In coastal issues this is not only a criteria to be fulfilled by indicators but the common way of approaching to coastal processes. Thus, the issue of temporal and spatial integration of coastal processes and responses has been largely identified as a key task in analysing coastal dynamics at scales useful for coastal management purposes.

The Coastal State Indicators used at the pilot sites and the required measurement are listed in Table 1, where CS stands for cross-shore. Nine (out of 15) were typically calculated from cross-shore profiles, which had a maximum extent from the rear of the dune (or gravel barrier) to the lowest part of the intertidal beach at about Mean Low Water Springs. Three CSIs required regular bathymetric profiles to be collected from shallow water out to between -10m and -20m. Two were collected by moving a GPS system along the shoreline (one by vehicle along the berm crest, the other by foot along the shoreline) while the last was generally obtained through visual inspection.

Table 1 Coastal State Indicators used at pilot sites

CSI	Measurement	Case Study
Dune strength	CS topographic profile	Dutch coast
Momentary coastline	CS topographic profile	Dutch coast

Basal foundation	CS bathymetric profile	Dutch coast
Shoreface volume	CS bathymetric profiles	Hel peninsula
Shoreline position	GPS following shoreline	Hel peninsula
Shoreline position	GPS following berm	Black Sea
Backshore width	CS topographic profile	Black Sea
Dune zone width	CS topographic profile	Black Sea
Dune zone height	CS topographic profile	Black Sea
Coastal slope	CS bathymetric profile	Black Sea
Beach width	CS topographic profile	Costa Brava
Total beach volume	CS topographic profile	Pevensey
Barrier width	CS topographic profile	Pevensey
Barrier crest position	CS topographic profile	Pevensey
Coastline position	Visual inspection	Inch Strand

Table 2 shows the Coastal State Indicators grouped according to similarity in the quantity represented. The first six all represent the standard of protection offered by the dune or barrier system against breaching during a severe storm.

Table 2 Grouped Coastal State Indicators

CSI	Quantity represented	Case Study
Dune strength	Standard of protection for storm	Dutch coast
Barrier width	Standard of protection for storm	Pevensey
Total barrier volume	Standard of protection for storm	Pevensey
Backshore width	Standard of protection for storm	Black Sea
dune zone width	Standard of protection for storm	Black Sea
dune zone height	Standard of protection for storm	Black Sea
Momentary coastline	Position & boundary condition for SoP	Dutch coast
Beach width	Boundary condition for SoP of hard defence	Costa Brava
Barrier crest position	Position	Pevensey
Shoreline position	Position	Black Sea

Shoreline position	Position	Hel peninsula
Coastline position	Perception of safety	Inch Strand
Basal foundation	Flood and coastal erosion risk	Dutch coast
Shoreface volume	Flood and coastal erosion risk	Hel peninsula
coastal slope	Flood and coastal erosion risk	Black Sea

The following six represent the location of the shoreline in all cases, but for some (Dutch momentary coastline and Costa Brava beach width) the CSI is based on a direct (NL) or surrogate (ES) measure of beach volume. This means it is not only a measure of position but also of the boundary condition for the standard of protection for storm. The greater the beach volume the greater the amount of energy will be dissipated before the incident waves reach the dune or seawall. There is no equivalent measure for the Pevensey barrier crest position, which says nothing about the beach volume from the barrier toe seawards. If the underlying sand beach were to erode, this would allow higher waves to reach the barrier and increase its probability of breaching. This is acknowledged, but not measured as part of the beach management system. The management system at Pevensey therefore does not take into account the long-term effects of sea level rise.

The final three CSIs (basal foundation, shoreface volume and coastal slope) are measures of the sand volume in the subtidal shoreface. The coastal slope can be seen as a surrogate for the sand volume in the subtidal shoreface, but is also an indicator of the relative risk of inundation and the potential rapidity of shoreline retreat, since low-sloping coastal regions can retreat faster than steeper regions when sea level rises.

The basal foundation and shoreface volume are direct measures of the sand volume in the subtidal shoreface. This assists in the derivation of an overall sediment budget and in the assessment of losses from shoreface nourishment. The sand volume in the subtidal shoreface acts as a large-scale, long-term boundary condition for the CSIs that are measured on the intertidal beach and dune/barrier systems. The subtidal beach act to filter the incoming wave field through depth-limited wave breaking and bottom friction. A decrease in a CSI such as the basal foundation or shoreface volume will lead to higher waves propagating further up the beach and potentially causing more erosion and increasing the risk of a dune or barrier system being breached.

There is a contrast between different sites in the way that the CSIs are derived and used. For example, in the Black Sea three different CSIs (backzone width, dune zone width and dune zone height) are all used to indicate the standard of protection offered by the beach/dune system against storm erosion. Similarly at the Hel peninsula beach width, beach height, dune width, maximum dune height, dune cross-section area and hinterland height have all been considered in the preliminary list of CSIs for storm damage. Along the Holland coast a single CSI (dune strength) is used for the same purpose, while at Pevensey another (barrier width) serves a similar function.

3. Coastal State Indicators at the Dutch site

3.1 Introduction

Coastal erosion is a common feature along the Dutch sandy shorelines. Since 1990 a policy has been adopted that aims at controlling structural erosion mainly through sand nourishments. Although this policy has proven to be successful to keep the coastline at its 1990 position, there is increased concern with regard to the fate of the strategic sediment reserves in deeper water, in view of sea level rise, new claims for sand mining and construction of new harbours. Coastal erosion management aims at a sustainable development of the Dutch coast. Three different tactical management objectives are used to reach this aim, each of them being relevant for different time and space scales:

1) Safety against flooding during storms (based on rest strength of the coast)
2) Maintain coastline position of 1990 (based on sediment reserve in near shore zone)
3) Preserve coastal foundation (based on sediment reserve including dune area and deeper water)

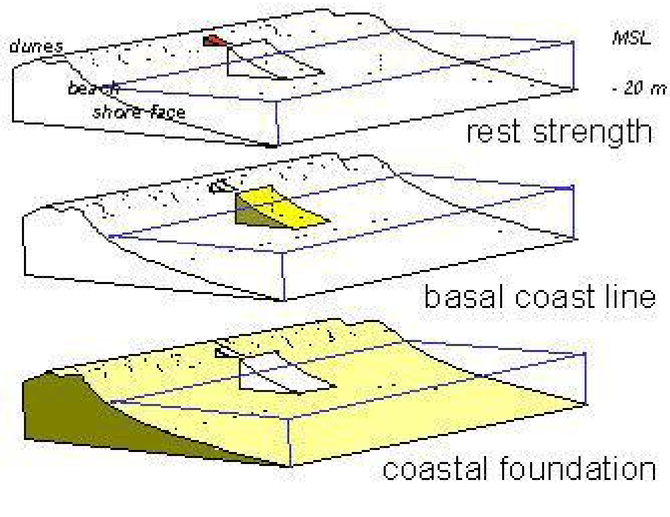

Figure 3 Three different tactical management objectives.

Figure 3 indicates the different spatial scales. The relevant time scales increase with increasing spatial scales, up to centuries for the coastal foundation. For each of these three objectives Coastal State Indicators are used as described below.

3.2 Name and description of Coastal State Indicators

Safety against flooding:

To guarantee safety against flooding, safety standards have been defined in the Flood Defence Act (1996): dunes must be able to withstand a storm event with a probability of exceedance of 1 in 10,000 years in the provinces of North- and South Holland. For coastal provinces with less economic value the probabilities are 1 in 4,000 and 1 in 2,000 years, respectively. The CSI used for the safety policy is to preserve the ***residual strength of the dunes***, defined as the minimal dune volume to withstand the design storm and its associated erosion line (Figure 4).

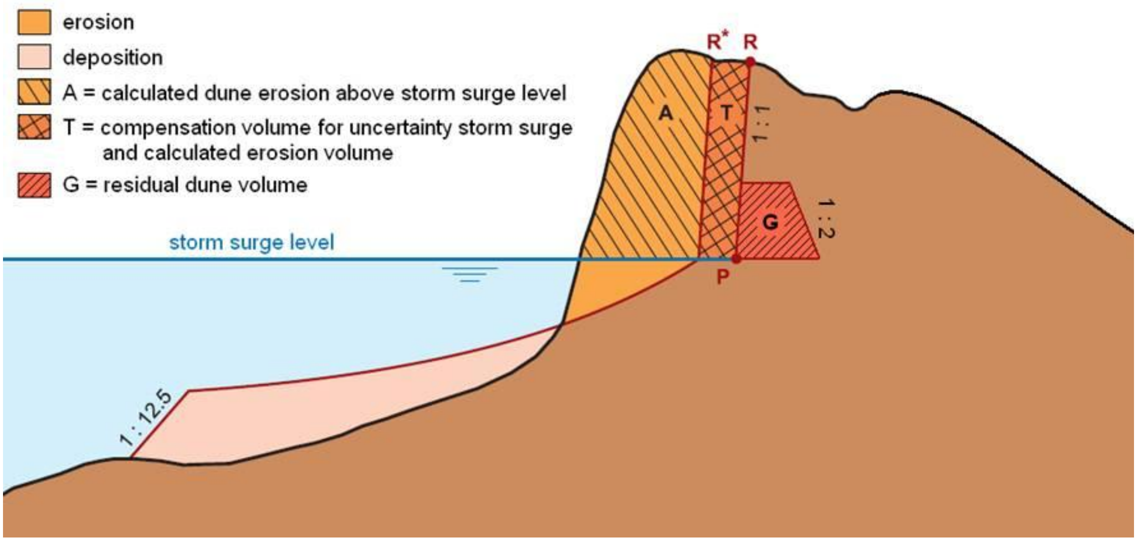

Figure 4 Cross section of coastal profile defining erosion and deposition during design conditions, and the resulting residual dune strength (TAW, 2002)

Maintain coastline position of 1990

To maintain the coastline position, the ***Momentary Coastline (MCL)*** has been developed as CSI, defining the coastline position as a function of the volume of sand in the near shore zone (see Figure 5). In case the MCL exceeds the Basal Coast Line (BCL) a nourishment is considered. Maintaining the coastline position guarantees that the preconditions for safety (and other user functions) are preserved in a sustainable manner.

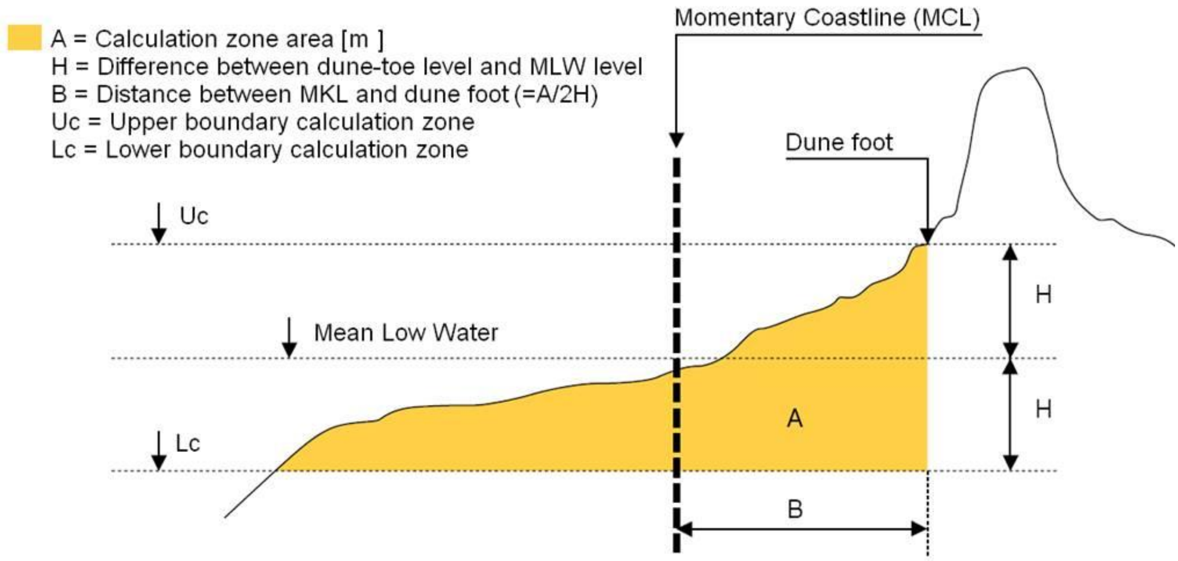

Figure 5 Definition sketch of Momentary Coast Line (TAW, 2002), which is based on the sediment reserve in the near shore zone

Preserve and improve coastal foundation

The coastal foundation consists of the area between the inner dunes and the -20 m depth contour. Considering that sea level rise causes morphological changes at greater depth, the preservation of the coastal foundation requires an additional sand nourishment. The CSI used is the ***volume*** calculated as the product of the total surface of the coastal foundation and the annual sea level rise.

4. Coastal State Indicators at the Hel peninsula (PL site)

4.1 Introduction

The Polish field site is the Hel Peninsula, which is a sandy strip of land located in the North of Poland between Gdansk Bay and Baltic Sea. The root of Hel Peninsula is situated at Wladyslawowo harbour. The coastal zone is managed by the Maritime Office in Gdynia. The main activities related with erosion of the beach are artificial nourishments.

4.2 Name and description of Coastal State Indicators

Threshold values for a required level of shore safety for T = 100 years have been proposed. These values can be considered as preliminary Coastal State Indicators for the Peninsula. The values include beach width, beach height, dune width, maximum dune height, dune cross-section area and hinterland height.

The Coastal State Indicators proposed in the present approach is the ***nearshore beach volume***. It is calculated from the area of the available cross-shore profiles multiplied by the spacing of the profiles and summed over the entire shoreline.

5. Coastal State Indicators at the Danube delta (RO site)

5.1 Introduction

The Black Sea pilot site is located along the Danube Delta coast, between the Danube mouths of Sulina and Sf. Gheorghe (NW Black Sea, Romania). The coastal cell is actually delimited by the Sulina jetties (north) and Sahalin spit island (south – south of the Sf. Gheorghe mouth). This coastal strip consists of low lying sandy beaches, typical for deltaic environments. Its specificity lies in the fact that it is part of the Danube Delta Biosphere Reserve (UNESCO and RAMSAR site), a nature reserve. The managers of the Danube Delta coast relate to the Romanian Ministry for the Environment and are the Danube Delta Biosphere Reserve Administration, as well as the National Administration "Romanian Waters".

5.2 Name and description of Coastal State Indicators

1. ***shoreline position***;
2. ***backshore width:*** cross-shore distance between the berm crest and the offshore limit of the dune zone;
3. ***dune zone length and height***;
4. ***coastal slope:*** from the shoreline to five and ten metres respectively.

6. Coastal State Indicators at Costa Brava beaches (ES site)

6.1 Introduction

The Costa Brava field site is situated on the NE Spanish Mediterranean coast. It comprises two beaches that can be considered as representative of most of the sandy beaches of the area: (i) a semi-enclosed one, s'Abanell beach, and (ii) a pocket beach, Lloret de Mar. As in the rest of Spain, the legal competence for Coastal Management relies on the Spanish Central Government (Ministry of Environment, Rural & Marine Affairs) who is the one with the duties and rights on protecting the Spanish coast. However, part of the duties and rights for beach management, those related to beach exploitation and use, are on the hands of the municipalities (Blanes and Lloret de Mar respectively).

6.2 Name and description of Coastal State Indicators

The CSI selected for the Costa Brava beaches is the ***beach width***. This does not refer to a unique value for the whole beach but to a detailed knowledge of how this width varies along the beach.

These width values are calculated along the beach at a spacing of 100 m and are defined as the distance between the actual shoreline and the promenade or the border between the beach and the hinterland (in the Southern part of the s'Abanell beach where a camp site exists) (see Figure 6).

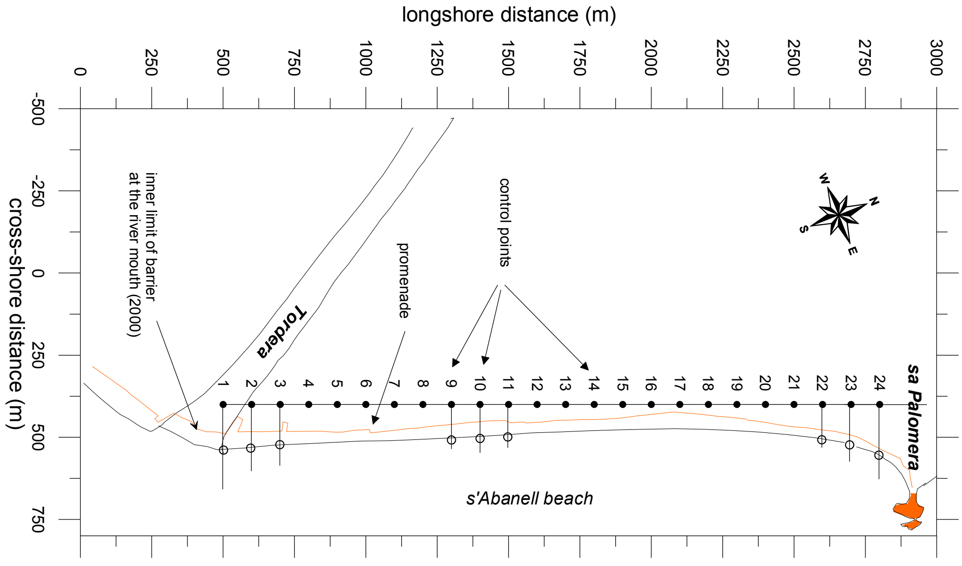

Figure 6 s'Abanell beach with control points to derive CSI values

These variables and computations have to be evaluated along the beach without giving a beach-averaged value. This is especially important for protection issues because we need to know if there is any point along the beach that is not properly protecting the hinterland. This is also the case of pocket beaches where without any sediment loss, the way of playing a given function –protection and recreation- can be significantly altered as a function of the beach configuration (Figure 7).

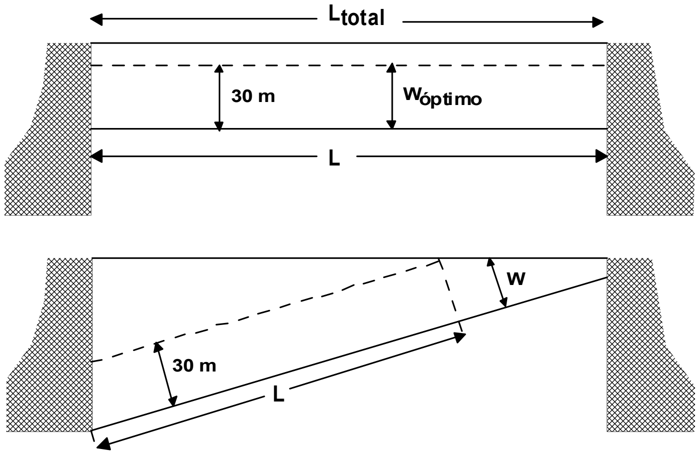

Figure 7 Two pocket beaches with the same surface but different configurations. Top: optimum configuration for a width threshold of 30 m with the entire beach properly playing the target function. Bottom: "bad" configuration for a width threshold of 30 m with the right side of the beach not properly playing the target function.

7. Coastal State Indicators at Pevensey Bay (UK site)

7.1 Introduction

The Pevensey Bay field site is situated on the English Channel coast of East Sussex between Eastbourne and Bexhill-on-Sea. The beach is managed for the Environment Agency (EA) by Pevensey Coastal Defence Limited (PCDL) as described by Sutherland and Thomas (2010). The service PCDL provides to the EA is monitored using Key Physical Features (KPFs) which is the local name for Coastal State Indicators.

7.2 Name and description of Coastal State Indicators

The Coastal State Indicators (CSIs) used at Pevensey are the following Key Physical Features:

1. ***total beach volume***;
2. ***cross-shore distance between the +5m contour at both the front and rear of the defences***;
3. ***cross-shore position of the +5m contour at the front face of the defence***.

Beach volumes from the EA profiles are derived from sectional areas measured above the 0m contour multiplied by each linear interval, which is typically around 180m. Coordinates from the PCDL quad-bike surveys are loaded into LSS, a DTM software written by McCarthy Taylor Systems Ltd (http://www.dtmsoftware.com). This is used to create a full 3D model of the beach. Volumes are extracted to mimic beach sections defined by each of the 52 profiles, and the observed 5m contour is compared to its design counterpart. The total beach volume is only allowed to fall by 2% (40,000m^3) from its target total volume.

The +5m contours at front and rear were chosen to represent the cross-shore position of the shingle ridge as it was sufficiently high to represent the steep shingle rather than the underlying sand beach, without being above the measured elevation of the crest of the barrier beach at any point. Protection standards are defined by a minimum width between the front and rear positions of the +5m contour. Typical front and rear slopes of the barrier are known from the profile measurements so the minimum width between the front and rear +5m contours acts as a surrogate for the cross-sectional area of the barrier.

The position of the front contour is allowed to vary from its target value by - 5m (i.e. crest recession of up to 5m is permitted at any profile) as it was recognised that the position of a contour line will vary in time due to cross-shore and longshore sediment transport.

8. Coastal State Indicators at Inch Strand (IR site)

8.1 Introduction

Inch and Rosbehy Strands, Dingle Bay, Kerry comprise large barrier-dune systems linked to dissipative shorefaces and a high energy tidal delta system. Inch is c. 5.5 km in length, orientated N-S and receives direct Atlantic swell waves from the west to the shoreface. The dunes systems reach up to 30m in height and comprise a complex of transverse and active parabolic dunes.

Analysis of existing data suggests that Inch only suffers large scale erosions (100's of metres) during extreme conditions. The main issue from the management standpoint is protection of infrastructure / safety of life and it would appear that the problem is being addressed.

8.2 Name and description of Coastal State Indicators

The major indicator applicable to this area is ***coastline position***, as this is what the general public, local authority and politicians use to measure the "stability" of this area. However there is no routine measurement of the position of the coastline position or indeed any other parameter on the coastline – level, slope etc). Therefore when change is reported it tends to be subjective and any quantitative assessment can only be made by conducting a one-off survey and comparing it with the latest aerial photography (which are several years old).