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

Assessment of Data Needs for Coastal State Indicators

Date	**May 2010**
Deliverable number	**D 10**
Revision status	final
Task Leader	James Sutherland

CONSCIENCE is co-funded by the European Community Sixth Framework Programme for European Research and Technological Development (2002-2006) Start date March 2007, duration 3 Years		
Document Dissemination Level		
PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Co-ordinator: Deltares, the Netherlands
Project Contract No: 044122
Project website: www.conscience-eu.net

Assessment of Data Needs for Coastal State Indicators

Deliverable:	**D 10**
Project:	**Concepts and Science for Coastal Erosion Management**
EC Contract:	**044122**

Document Information

Title:	Assessment of data needs for coastal state indicators
Lead Author:	James Sutherland (HR Wallingford)
Client:	Commission of the European Communities Research Directorate-General
Contract No.:	044122
Reference:	CONSCIENCE Deliverable D10. This report also constitutes HR Wallingford Technical Note CBS0330/02

Document History

Date	Version	Author	Reviewed by	Notes
13/07/09	R0-r1	J Sutherland	Field site managers	Initial outline (revision 1).
01/09/09	R0-r2	J Sutherland	as above	Pevensey details altered
10/09/09	R0-r3	J Sutherland	as above	Hel and Insch details added
24/09/09	R0-r4	J Sutherland	as above	Black Sea & summary added.
25/09/09	R0-r5	J A Jiménez	as above	Costa Brava added.
29/10/09	R0-r6	J. Sutherland	as above	NL added
18/01/10	R1-r0	J Sutherland	M. Marchand & managers	Extra detail added to NL case. Release 1.
05/05/10	R2-r0	J Sutherland	M. Marchand & managers	Revision to include feedback from final meeting.
21/05/10	R3-r0	J Sutherland	M. Marchand	Executive summary added

Prepared --

Approved --

Authorised --

Acknowledgement
The work described in this report was supported by the Commission of the European Communities under Contract number 044122, Concepts and Science for Coastal Erosion, CONSCIENCE

Executive Summary

Coastal State Indicators (CSIs) are parameters that quantitatively describe the dynamic-state and evolutionary trends of a coastal system. CSIs have been derived at six contrasting sites in the EU to assist coastal managers to manage coastal erosion. There are regular measurements and use of the coastal state indicators at three of the sites considered (Holland coast, Costa Brava Bays and Pevensey Bay). At all three sites extensive studies into the behaviour of the beach (such as its response to storms) have been undertaken, which led to the choice of appropriate coastal state indicators, the setting of threshold values for intervention and the choice of a means of intervening. At the other three sites, the relevant coastal state indicators are starting to be derived, but are not routinely used by the coastal managers.

The different pilot sites have demonstrated how tactical objectives at different scales and for different purposes (recreation as well as coastal erosion) can be implemented using coastal state indicators. However, this requires a policy framework that sets strategic and tactical objectives for coastal erosion, as the coastal state indicators are used to assess how well objectives are being met. In countries where there is an effective policy framework this tends to be at a national level.

At their best, coastal state indicators integrate site-specific knowledge and study results with repeated measured data to provide coastal managers with information that they can act on to manage their beaches in an adaptive manner.

Contents

Tables

Figures

1 Introduction

1.1 CONSCIENCE and the Frame of Reference

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/.

A sustainable solution for coastal erosion problems should be based on an understanding of the sediment dynamics, framed in a policy context with explicit objectives and an institutional environment in which each stakeholder has a clear role. The CONSCIENCE project has adopted the Frame of Reference (van Koningsveld and Mulder, 2004, van Koningsveld and Lescinski, 2007) as a decision-making framework for formulating a sustainable solution. The Frame of Reference approach is illustrated in 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 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.

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

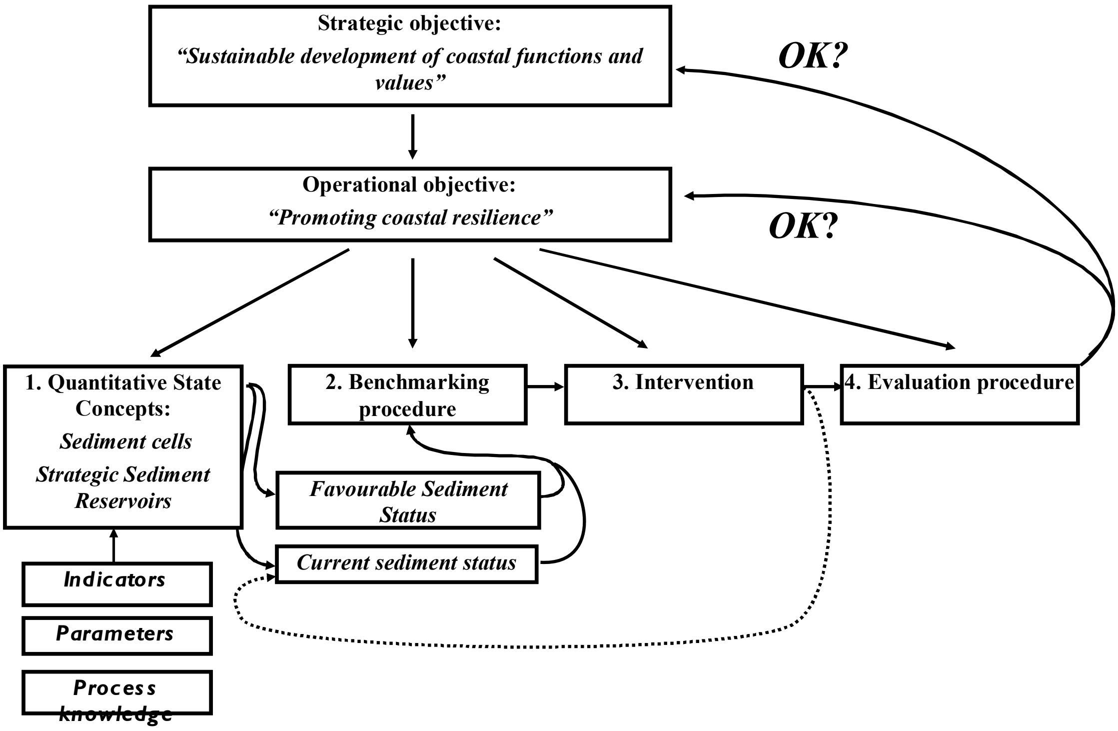


Figure 1 Frame of Reference decision making framework

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. This report assesses the data needed to calculate the values of the Coastal State Indicators that have been used at the field pilot sites of CONSCIENCE. Section 1.2 describes the role of the strategic and tactical objectives in the Frame of Reference. The operational decision-making recipe is described in Section 1.3, while the Pilot sites the CSIs were applied at are described in Section 1.4. Sections 2 to 7 describe the data needs for the CSIs used at each Pilot Site. Section 8 contains a discussion of the information from Sections 2 to 7.

1.2 *Strategic and Tactical Objectives*

At the strategic level we have to answer questions regarding the values and functions of our coast. For instance, many coasts contain valuable ecosystems, sometimes explicitly protected through national or European legislation (e.g. Natura 2000). But at the same time these coasts are used for recreation, housing, groundwater extraction, agriculture etc. In case the hinterland is low lying, the coast also can have a protection function against flooding from sea. Coastal erosion can threaten one or more of these values and functions. But before deciding to control erosion, it is advisable first to analyse the relation between coastal dynamics and the functions of the coast. For instance, a dynamic and sometimes eroding coastline is less of a problem in the absence of residential areas. Seasonal beach erosion may not be a problem for recreation, if it only happens during the winter storms. In other instances, it may be essential not to tolerate any coastal erosion in case this would lead to significant coastal flooding of residential areas.

In practice, it appears very difficult to set realistic and unambiguous objectives for coastal erosion management. This already became apparent from the analysis of 60 case studies done by the EUROSION project, which concluded that very few case studies had clearly defined their objectives for coastal erosion management [European Commission, 2004]. Developing strategic and tactical objectives should be part of a broader ICZM policy. Using the principles of ICZM is the best way to guarantee a sustainable development policy for coastal erosion, which has the support of all relevant stakeholders.

At the strategic level, objectives are often linked to key policy principles, such as safety and sustainable development. From a strategic objective it does not directly become clear how to deal with coastal erosion. Therefore, a tactical objective is needed that determines if coastal erosion needs to be controlled or not. For instance, in the UK, the Department for the Environment, Food and Rural Affairs (Defra) has defined the following possible tactical objectives for coastal erosion management (SMP guidance reference):

- Hold the line: maintain or upgrade the level of protection provided by defences.
- Advance the line: build new defences seaward of the existing defence line.
- Managed realignment: allowing retreat of the shoreline, with management to control or limit movement
- No active intervention: a decision not to invest in providing or maintaining defences.

1.2.1 Time and space scales for tactical objectives

It is important to realise that objectives can be made for different time horizons. For instance, providing safety against erosion and flooding due to a storm has a typical time horizon of days: the coast should be strong enough to withstand a storm at any day of the year (and especially during the stormy seasons). On the other side of the spectrum we may find a time horizon of decades to centuries, particularly if we would like to manage coastal erosion in view of sea level rise and climate change. For each of these temporal scales there is an associated spatial scale: for every day safety we need to zoom in to the condition of the coast up to metres or hundreds of metres. For adaptation to sea level rise we define the coastal cell at the scale of tens to hundreds of kilometres. By way of example take a look at the three different scales for management of the Dutch coast in Section 2, which has resulted in the use of a separate CSI for each of the three scales considered.

1.2.2 Objectives at the CONSCIENCE pilot sites

Table 1 shows different strategic and tactical objectives which were found in the 6 CONSCIENCE pilot sites. Note that in some cases these objectives were not officially laid down in policy documents.

Table 1 Strategic and tactical objectives for the CONSCIENCE pilot sites

Site	Strategic objectives	Tactical objectives
The Holland coast (NL)	Safety, sustainable values & functions	Hold the line, preserve dune strength and coastal foundation
Hel Peninsula (Poland)	Preserve the peninsula	Maintain beach width Prevent breaching
Danube Delta (Romania)	Sustainable coastal development	Reduce coastal erosion
Costa Brava (Spain)	Maintain recreational carrying capacity Enhance safety of infrastructure	Maintain beach configuration
Inch Beach (Ireland)	Promote sustainable tourism	Prevent damages to infrastructure
Pevensey Bay (UK)	Sustainable risk management	Hold the line

Note, however, that even when a tactical objective has been set, it may be possible to implement it in a number of different ways. For example, holding the line at the barrier beach at Pevensey, for example, is undertaken using beach nourishment, recycling and reprofiling, (Sutherland and Thomas, 2010) but it could have been undertaken by installing hard defences, such as a seawall, groynes or offshore reefs. The choice of the form of intervention can be made after the selection of the tactical objective and before the operational decision making recipe is implemented, or it can be made as part of the operational decision making recipe.

In the UK the tactical objective is set by the Shoreline Management Plan, SMP (Defra 2006) but the means of implementing the tactical objective (the scheme) is decided using a more-detailed cost-benefit analysis in a separate strategy study. The operational decision making recipe can then be used for implementing the chosen scheme and only the CSIs relevant for that scheme need to be monitored. However, if the form of intervention is left to the operational decision making recipe then the CSIs needed for all schemes under consideration need to be monitored.

It seems that in practice, it is normal for the scheme to be chosen before the operational decision making recipe. An additional stage could be added to the Frame of Reference, between the operational objective and the decision-making recipe in such cases.

1.3 Operational decision-making recipe

The operational decision-making recipe relies on the use of Coastal State Indicators to quantify the state of the coast. The relevant CSI(s) and the thresholds values at which some intervention should take place are derived using knowledge of the key physical processes that govern coastal erosion and measured or modelled parameters that characterise the forcing (such as waves and water levels) and the resistance (such as soil characteristics and dune/barrier cross-section). The characteristics of CSIs are given in Section 1.3.1 while the benchmarking, intervention and evaluation stages are discussed in section 1.3.2.

1.3.1 Coastal State Indicators

The definition implicitly assumed by EC research project COASTVIEW for Coastal State Indicators (CSIs) was – "a reduced set of parameters that can simply, adequately and quantitatively describe the dynamic-state and evolutionary trends of a coastal system (relay a complex message in a simple and useful manner)" (van Koningsveld et al 2005).

CSI's 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

CONSCIENCE has developed the use of Coastal State Indicators in coastal erosion management and tested their application at a number of pilot sites, described in Section 1.4. This report is concerned only with the CSIs used at the Pilot Sites and does not assert that these are the only suitable CSIs that could be used or developed for coastal erosion.

1.3.2 Benchmarking, intervention and evaluation

The benchmarking, intervention and evaluation stages of the Frame of Reference are similar to a typical asset management cycle, such as PAS 55 (BSI, 2004). Completing the benchmarking, intervention and evaluation stages of the decision-making recipe should provide an organization with a purpose-made set of processes, tools and performance measures that will enable it to achieve an optimum approach to managing its assets – in this case a beach.

1.4 Pilot Sites

The six pilot sites used in CONSCIENCE are:

1. Dutch Coast (between Den Helder and Cadzand) (NL)
2. Hel Peninsula, Gulf of Gdansk (Poland)
3. Black Sea coastal zone of the Danube Delta (Romania)
4. Costa Brava Bays, Mediterranean coast (Spain)
5. Pevensey Bay, English Channel coast (UK)
6. Inch Beach, Kerry Atlantic coast (Ireland)

Their locations are shown in Figure 2, while descriptions of the sites and the problems to be addressed there can be found on the web-site (http://www.conscience-eu.net/). Contact details for the Pilot Site leaders can be found in Table 2.

The pilot sites have been used to test the applicability of the management concepts and models being developed in the project. Moreover, each participant has been working with the local end user at their Pilot Site, which has ensured that the practical advice of the local end users has been incorporated into the development and application of the concepts and tools.

This report is an assessment of the data needed to use the Coastal State Indicators that have been tested at the CONSCIENCE pilot sites. Further information on the data collected at the Pilot Sites can be found in CONSCIENCE Deliverable D16, *Data set inventory for field pilot sites*. The results from this report have informed the development of CONSCIENCE deliverable D15 *Guidelines on Monitoring*.

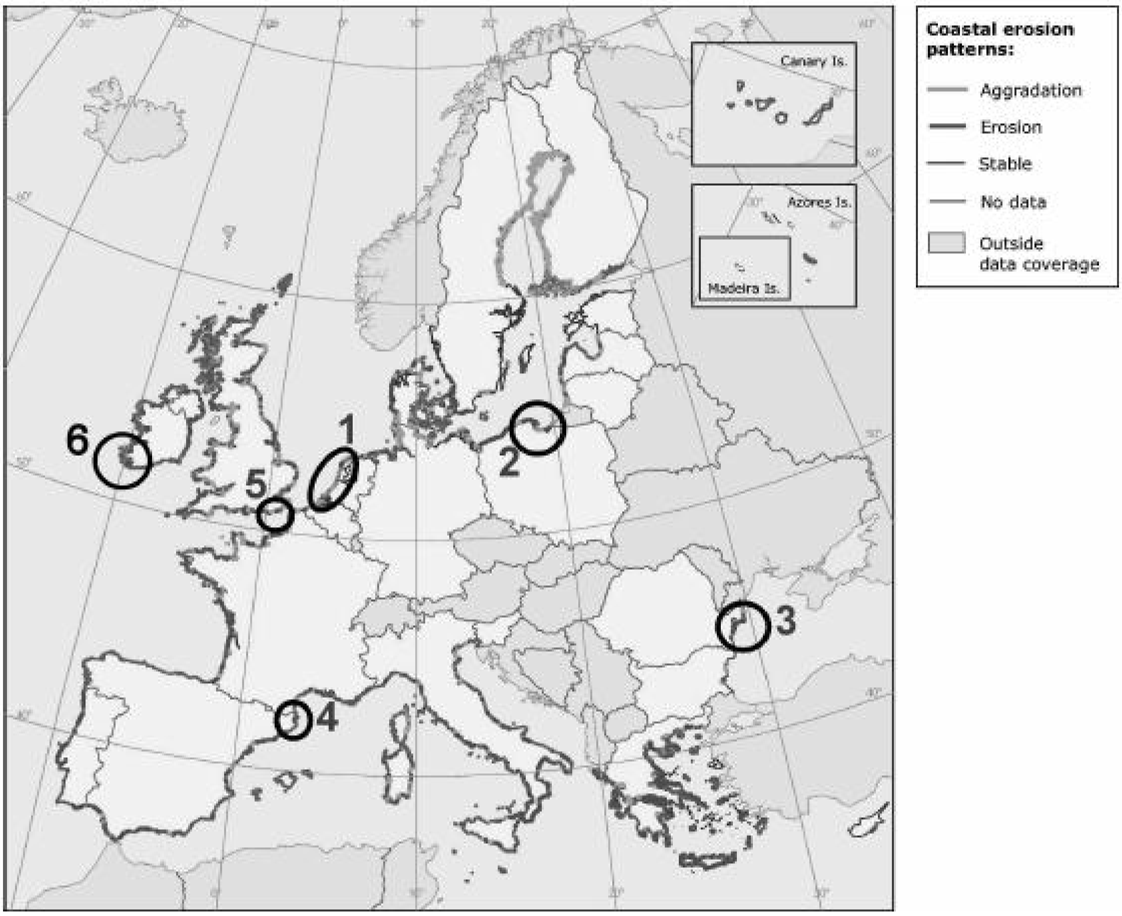


Figure 2 Pilot sites

Table 2 Contact details of the pilot site leaders

Pilot Site	Leader	Email address
Dutch Coast	Jan Mulder	Jan.Mulder@deltares.nl
Hel Peninsula	Wojciech Sulisz	sulisz@ibwpan.gda.pl
Black Sea coastal zone	Adrian Stanica	astanica@geoecomar.ro
Costa Brava Bays	Jose Jiménez	Jose.Jimenez@upc.edu
Pevensey Bay, UK	James Sutherland	J.Sutherland@hrwallingford.co.uk
Inch Beach	Jeremy Gault	J.Gault@ucc.ie

2 CSIs at the Dutch coast

2.1 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 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.

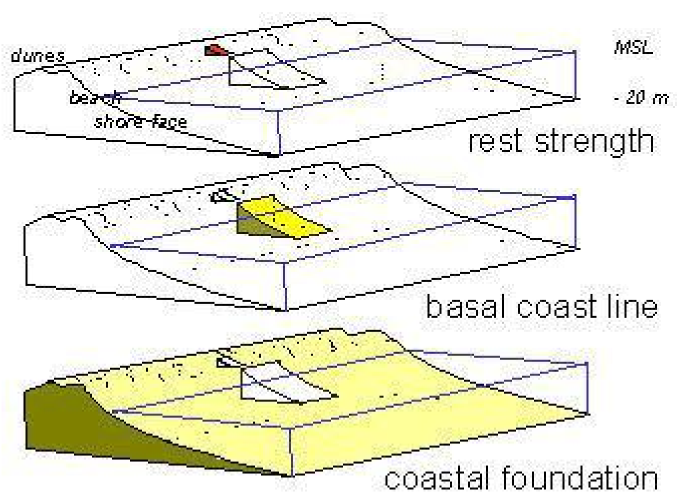


Figure 3 Three different tactical management objectives.

2.2 *Name and description of Coastal State Indicators*

2.2.1 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).

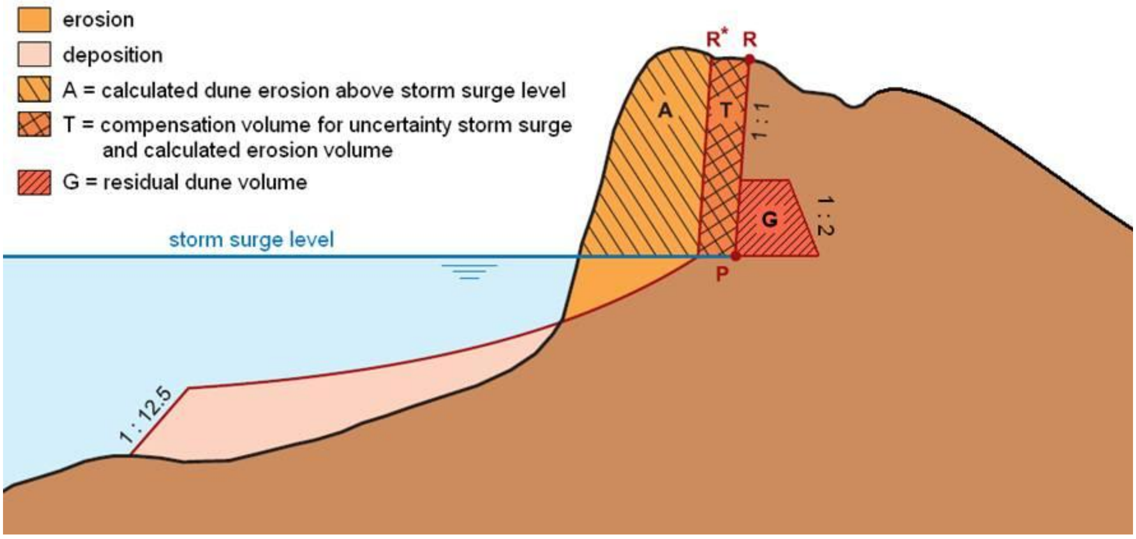


Figure 4 Cross section of coastal profile defining erosion and deposition during design conditions, and the resulting residual dune strength (TAW, 2002)

2.2.2 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.

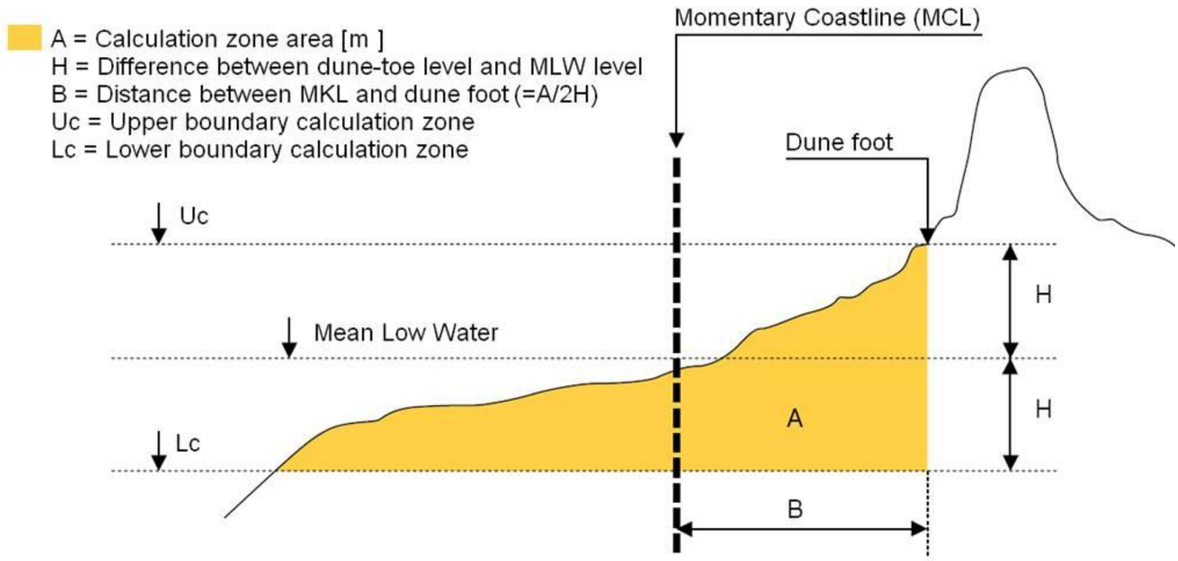


Figure 5 Definition sketch of Momentary Coast Line (TAW, 2002), which is based on the sediment reserve in the near shore zone

2.2.3 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.

2.3 Measurements used to derive CSIs

2.3.1 Safety against flooding

For the residual strength of the dunes two type of measurements are essential: the actual shape of the cross shore profile and the hydraulic design conditions which apply for a certain safety standard. The profiles are derived from the JARKUS database (see below). For large parts of the Dutch coast a safety standard of 1/10,000 exist. The corresponding hydraulic design condition is derived by extrapolating historical measured hydraulic conditions (i.e. water level, wave height and wave period) to the required probability. These hydraulic conditions are measured at the minus 20 m depth contour, so that the measurements are not significantly influenced by the existing nearshore bathymetry.

2.3.2 Maintain coastline position of 1990

The calculation of the MCL is based on data from the Dutch annual coastal monitoring programme JARKUS, which has been operational since 1963. JARKUS measures coastal depth profiles from the first dunes up to 1 km in a seaward direction, at alongshore intervals of 250m.

2.3.3 Preserve and improve coastal foundation

The area of the coastal foundation is measured by the JARKUS bathymetry soundings for the offshore part and by airborne Laser Altimetry for the dune part. For the sea level rise use is made of the National Monitoring Network Water as well as of future scenarios regarding accelerated sea level rise.

2.4 How often are the measurements made?

The JARKUS coastal depth profiles are measured each year. Less frequently the deeper part of the Dutch Coastal system is included in the echo sounding (for most areas a frequency of 5 years applies to these extended soundings). Measurements of the hydraulic conditions are gathered continuously. Every 5 years an update of the hydraulic boundary conditions is issued by the Ministry.

2.5 Minimum acceptable data needed for the CSIs

To test the residual strength every five year the coastal profile has to be measured with this frequency. To obtain reliable hydrodynamic boundary conditions the water level has to be measured continuously at several locations over a long time period.

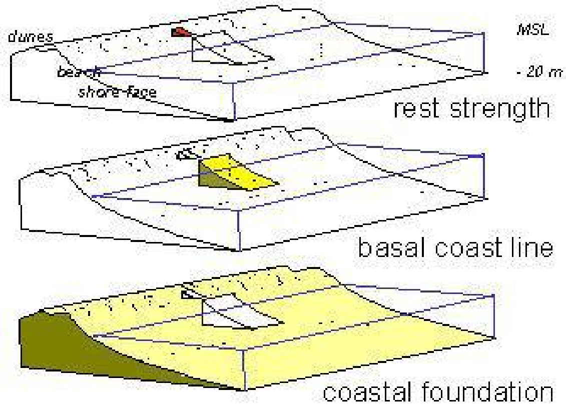
To verify the coastline position on a yearly basis, yearly measurements of (part of) the coastline profile have to be obtained. The spatial density depends on the spatial variability and the interest. For the Dutch coast, the variability is high as well as the interest (safety against flooding). Decreasing the frequency and density of the measurement leads to a decrease in insight in evolution of the coastline, the possibility to react and therefore increasing the risk.

The time-scale for preservation of the coastal foundation is considerably larger. The decrease in sediment reserve in deeper water does not result in an immediate effect on residual strength and user functions in the coastal zone. Therefore data is needed on a less frequent basis, but on a larger spatial scale (covering the complete coastal foundation).

In summary for testing the residual strength, continuous measurements are needed, for preservation of the coastline position measurement on a yearly base and for coastal foundations measurements on a timescale of years to decade.

Table 3 shows the required measurements, frequency and density for the tactical management objectives. The frequency and density depends on the coastal variability (the more uniform, the less measurements are needed) and the interest (the higher the risk, the larger the needed frequency and density). The values in this table are representative for the Dutch case (large variability and high interests).

Table 3 Required measurements, frequency and density for the tactical management objectives

TACTICAL MANAGEMENT OBJECTIVES	Test proceeding (CSI)	Needed measure-ments	Needed frequency	Needed density
	Every 5 year *residual strength* is verified	Hydrodynamic parameters	Continuously	? stations
		Profile (bathymetry) near shore zone	Every 5 year	Every 250m alongshore
	Every year the *BCL* position is verified	Profile (bathymetry) near shore zone	Annual	Every 250m alongshore
	Every several year the *sediment volume* in the coastal foundation is verified	Bathymetry of entire coastal foundation (including deeper water and dune area)	Every several year	20 meter grid

Evaluations of interventions (nourishments) are based on the yearly profile measurements. In order to get more insight in the detailed functioning of separate nourishments additional measurements in the area of the nourishments are carried out. Based on evaluation of nourishments, the nourishment designs can be improved.

2.6 Procedure to determine threshold value of CSI

2.6.1 Safety against flooding

Every year the position of the erosion line and the presence of the residual dune volume behind this line are being tested in a procedure using a dune erosion model with hydrodynamic design conditions. If the residual dune volume appears to exceed the landward boundary of the coastal profile, interventions are needed to restore coastal safety. Several computer models are used to calculate the erosion line, such as DUROS (DUineROSie) and DUROSTA (DUineROSie-TijdsAfhankelijk). DUROS calculates the dune erosion of a dune profile assuming a closed sand balance in the cross-shore direction. The shape of the profile after a storm surge is assumed as known and is dependent on the fall velocity of the sediment and the height of the waves and maximum water level during the storm. DUROSTA is similar but shows the development of the profile during the storm in time. The hydraulic boundary conditions are issued and updated by the Ministry of Transport, Public Works and Water Management every 5 years. These conditions are derived from the National Monitoring Network Water which provides continuous information on water levels and significant wave heights from a large number of stations along the coast and from four offshore locations in the North Sea.

2.6.2 Maintain coastline position of 1990

With respect to the position and trend in momentary coast line the following procedure applies: As a standard of reference the Basal Coast Line (BCL), i.e. the position of the coast in 1990, has been defined for each coastal section of 250 m wide. The actual state of the coastline is based on the Testing Coast Line (TCL). The position of the TCL is determined, in a similar way as the BCL, by linear extrapolating the trend of coastline positions (MCL) of ten previous years (see Figure 6). The state of the system is compared with the reference state, i.e. by comparing the TCL position with the BCL position. This comparison provides an indication of the need for intervention.

The advantage to use the TCL instead of the MCL is that the decision for intervention is based on a ten year trend instead of the actual position of the coastline in a single year.

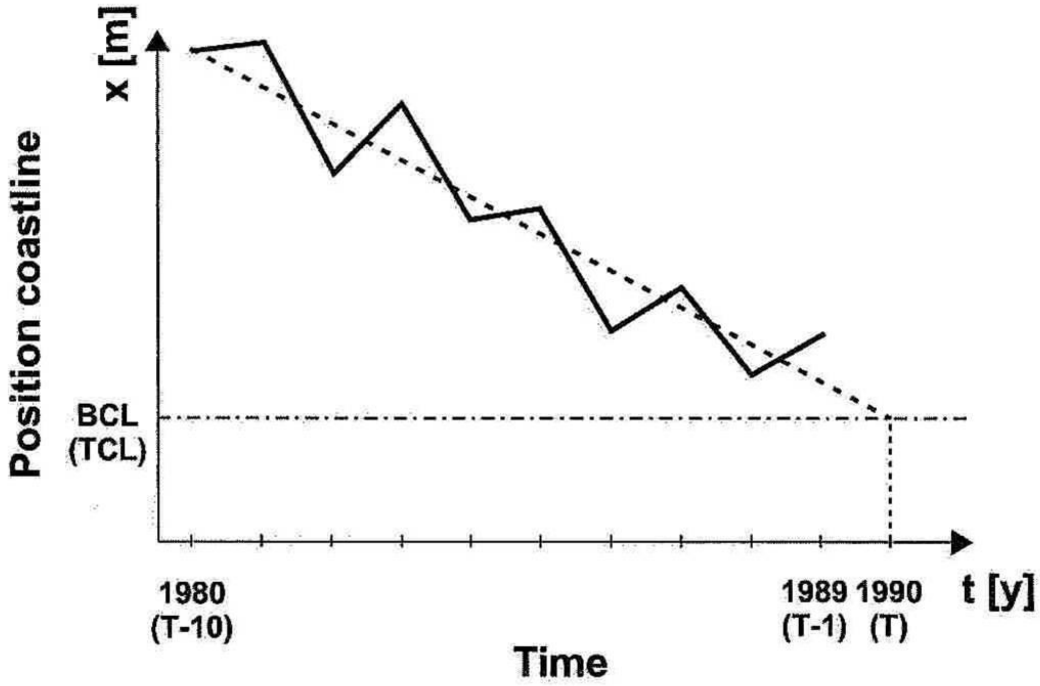


Figure 6 Definition of BCL (Basal Coast Line) and of TCL (Testing Coast Line) by linear extrapolation of a 10 year trend

2.6.3 Preserve and improve coastal foundation

The procedure for preservation of the sand volume in the coastal foundation is based on compensation of the yearly sand losses in the coastal foundation.

Geological information indicates that on a time scale of 50 – 200 years, the coastal foundation may be considered a closed system. Due to this fact, sea level rise has a major negative effect on the active sand volume of the coastal system. This sea level rise effect may be calculated as the product of the area of the active coastal system and the observed average sea level rise over the last century.

Other factors resulting in sand losses of the coastal foundation are sand mining, subsidence due to gas extraction and sediment redistribution towards the tidal basins as a result of major engineering works in the past (e.g. closure of the Zuiderzee in 1932).

The sum of all losses makes up the total of the required compensation.

3 CSIs at Hel peninsula

3.1 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.

3.2 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.

3.3 Measurements used to derive CSIs

73 cross-shore profiles are measured every 500 meters of the 36km long Hel Peninsula shoreline. The limits of the available cross-shore profiles are the shoreline and the maximum seaward measured depth. There are no precise limits. The lengths of the profiles are around 1 km, the maximum depths are around 10-12 m. Their lengths were selected (limited) to cover the same area in 2004 and 2008, when the measurements were conducted.

Also shoreline evolution for the period 2002-2008 was measured. The measurements of the shoreline position were collected by a man equipped with a GPS and data logger, who simply walked along the shoreline collecting the GPS data. The shoreline data are available for years 2002, 2003, 2004, 2005 and 2008. The position of the shoreline was measured at least every 500 m and cover 36 km of the Hel Peninsula shore.

Because the artificial nourishment activities are carried out every year, the desirable and minimum required frequency of measurements of the profiles and shoreline evolution is one year. The estimates of the beach volume are based on the 73 cross-shore profiles, the measurements of the profiles in 100 m spacing would increase the accuracy of the estimates of the sediment deficit along the shoreline. It would result in more efficient planning of the artificial nourishment activities.

3.4 Procedure to determine threshold value of CSI

The erosion of the Hel Peninsula shoreline results in the sediment deficit, which is indicated by the shoreface volume decrease. The threshold value of CSI would be the minimum volume of sand for beach nourishment that is cost-effective and economically justified.

4 CSIs at the Black Sea coast

4.1 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”.

Used CSIs:
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; and
4. coastal slope (from the shoreline to five and ten metres respectively).

4.2 Measurements used to derive CSI

CSIs have been derived from

- classical topographic surveys across 19 transverse profiles along the entire 34 kms long pilot site, plus one pilot area of seasonal detailed topographic measurements (see D16 for details). The 19 transverse profiles were measured annually for over two decades at the end of summer (end of August – first week of September) – until most of the landmarks were washed out by erosion during the recent period. Profile landmarks remained in the southern and northern sections of the coastal cell (including the detailed measurements pilot area in Sf. Gheorghe).
- Bathymetry profiles between 1.5 m and 15 m water depth on transverse profiles every 500 metres close to the river mouths (12 kms south of the Sulina mouth and 6 kms north of the Sf. Gheorghe mouth) and every 1 km in the central part. These measurements were made in 2002 and 2007.
- Coastline position along the entire littoral strip was measured with GPS (Sercell and SeeDucer) equipment mounted on an antenna fixed at the rear left side of a 4x4 car. The measurements were made during the trip by car along the berm crest (or as close as possible) from Sulina to Sf. Gheorghe.
- Volumes of dredged sands (navigation depth maintenance works along the Sulina Canal) – annual volumes of sands available since 1991.

4.3 How often are the measurements made?

All details regarding the types of measurements and periods of times when these were made are given in D16.

4.4 How often would you like the measurements to be made and why?

Morphological surveys should be carried out along 19 profiles and detailed measurements should be made in the pilot site established at Sf. Gheorghe, after a campaign of establishing a new landmark network along the entire coastal strip. The optimal frequency for undertaking surveys would be at least four times every year for all profiles in order to understand seasonal variations. The surveys should be undertaken every February, June, August - September and November – December.

Coastline position should be collected seasonally as well, so four times per year, continuously along the entire coastal strip. Bathymetry surveys should be undertaken between 1.5 and 15 m water depth or over the entire coastal cell. A transverse profile should be measured every 500 m, either 4 times per year (seasonally, as above) when artificial nourishment is undertaken (for monitoring the works) or once every two years where there is no intervention.

Seasonal LIDAR campaigns are also desirable – for the dune zone, emerged beach and submerged part up to 2 m water depth (max – due to turbidity).

ADP measurements of the coastal currents are also necessary – once per year.

4.5 What would be the minimum acceptable data needed for this CSI?

- After the presumed establishing of a new landmark network – one field campaign per year for the 19 profiles; seasonal measurements are needed in the detailed pilot site in Sf. Gheorghe.
- Coastline position – at least once every year, end of summer.
- Bathymetry surveys – once every five years.
- Annual LIDAR and ADP campaigns, which should be grouped in the same period with the classical topographical measurements on transverse profiles.
- The yearly data of dredged sand volumes is also essential.
- These measurements should be a critical minimum of data inputs in order to monitor the sediment dynamics both in case of no intervention as well as in the case of artificial nourishment.

5 CSIs at the Costa Brava coast

5.1 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).

5.2 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 7).

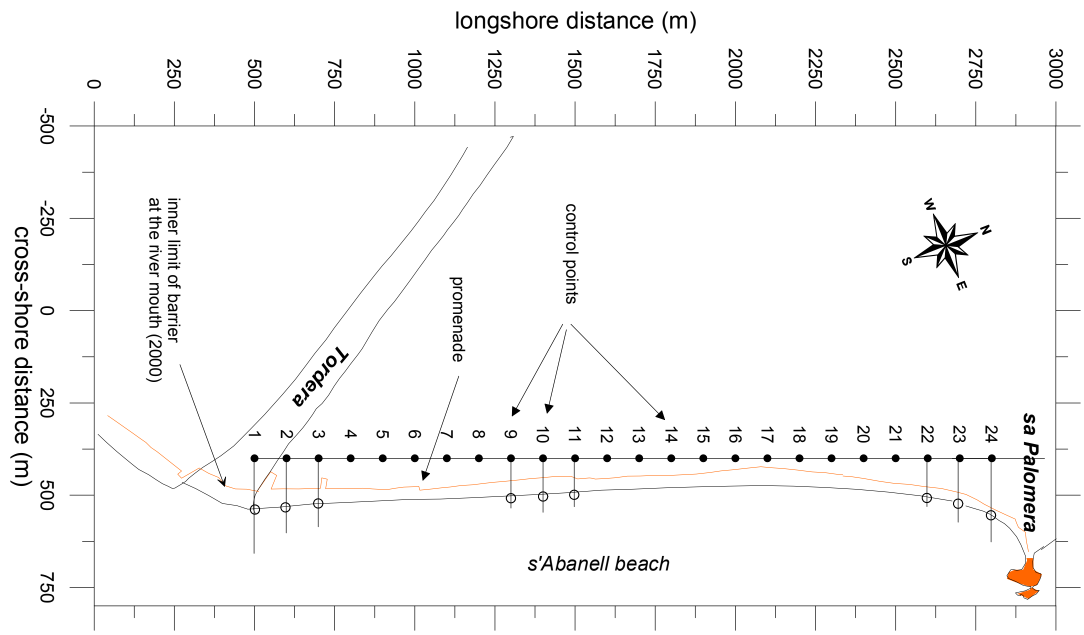


Figure 7 s'Abanell beach with control points to derive CSI values

5.3 Measurements used to derive CSIs

The measurements used to derive CSIs at the Costa Brava beaches are of two types: (i) aerial photographs and (ii) beach surveys.

The first type corresponds to previous beach configurations which are required to build up a database with beach width data over a period of decades to derive the shoreline evolution trend. These data have been obtained from the Institut Cartogràfic of Catalunya which actually produce a collection of orthorectified photographs (at 1:5000 scale) for the Catalonia coastline at a time span of about 2-4 years.

The second type corresponds to beach surveys done by DGPS at both beaches. This type of data is used to derive the shoreline position and, at the same time is also used to determine the subaerial beach volume and how the beach profile reacts to wave action. This is very important to calibrate/update modelling of beach processes and will be used for determining/updating the CSI thresholds.

5.4 Frequency of measurements

The shoreline and/or beach profile measurements are made every six months, to obtain a representative beach configuration prior to storm and summer seasons. This is because these beaches play two main functions: protection and recreation, each one associated with a different optimum beach configuration. Moreover, due to wave seasonality in the area, these two functions are played at different seasons of the year which are uncoupled.

Thus, if the main management target is recreation, the optimum beach configuration needs to be verified before the start of the bathing season, which in the NW Mediterranean coast starts at June. On the other hand, if the target is protection, we should be interested in having the optimum beach configuration at September, just at the beginning of the “normal” stormy season.

In order to make any decision on beach management (e.g. to nourish) we need to know in advance the expected configuration of the beach the next season as there is a time lag between detecting a problem and implementing a solution due to administrative reasons. A project has to be prepared, a call for tender has to be issued because it involves the use of public money and finally, the work has to be executed. Therefore, the measurements made have to be part of a database including long-term data (covering a period of several decades) permitting us to detect problems in advance.

To do this, beach width values have to be continuously incorporated in a database to update the shoreline evolution trend of the beach at a yearly basis. In addition to this, if significant storms impact on the beach inducing large morphological changes, beach profile surveys after the storm should also be done. These data will be very useful to improve the calibration of morphodynamic models used to determine/validate threshold values.

5.5 Procedure to determine threshold value of CSI

The threshold value for the beach width is determined for each beach as a function of the management targets: protection and recreation. Moreover, since the two beaches have a very different behaviour, the procedure to define them varies.

To define the threshold for *protection*, the following steps have to done:

- To define the design storm. Since we want the beach to protect the hinterland from the impact of a storm, we have to decide which the safety level we are assuming. This implies to have an extreme wave climate characteristic of the site and, to select a return period, T_R.
- Once the storm conditions have been selected, the next step consists of evaluating the storm-induced erosion, the *storm reach* (SR). To do this, we have employed a storm-induced beach profile erosion numerical model (Sbeach). The model is run using the selected storm as input together a beach profile of the area but assuming that has an infinite width. This is done because we are interested in estimating the maximum induced beach erosion in the case that no constraint exists.
- If this second step is done for several storm conditions obtained from the extreme wave climate, we can build up a probability distribution of storm-induced beach erosion. From here, once the manager decides the safety level, we can directly estimate the associated beach erosion.
- Define the time horizon for which the analysis is done. This means deciding when we want to check if the beach is properly providing the protection required. If we want to check it for actual conditions (i.e. today), we compare the calculated beach retreat (from modelling) with measured beach width. If we want to check for the near future (i.e. 1 or 5 years from now) we have to compare the calculated beach retreat with the expected beach width (actual measured beach width + evolution rate × time). In the first case we shall probably not have time enough to react whereas in the second case, we'll have time to decide what to do.
- In addition to this, we use the concept of minimum width that can be defined as the *minimum beach* (MB) that we should need after the storm impact. This could be fixed as the width required by trucks, bulldozers or any men to work in rebuilding infrastructures (~ 6 m). On the other hand, this can be used as a safety factor by assuming that after the impact of the storm, the remaining beach has to be wide enough to resist the impact of another storm of a given T_R.
- With this, the threshold value for the beach width. BW, with respect to the protection function is defined by (Figure 8)

$$\text{BW (t)} \leq \text{SR} + \text{MB}$$

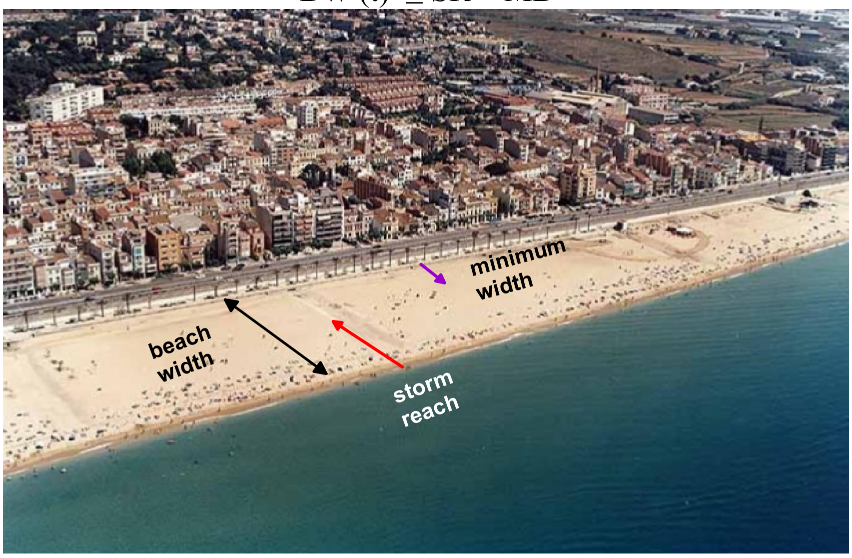


Figure 8 Variables to define the CSI threshold value for the beach regarding the protection function.

To define the threshold for *recreation*, the following steps have to be done (see Valdemoro and Jiménez, 2006):

- To define the time horizon for the analysis. This means deciding when we want to check if the beach is properly providing the recreation function. If we want to check it for actual conditions (i.e. today), we calculate the beach occupation rate (surface per user) from measured beach width. If we want to check for the near future (i.e. 1 or 5 years from now) we have to obtain the beach occupation rate with the expected beach width (actual measured- beach width + evolution rate × time). In the first case we shall probably not have time enough to react whereas in the second case, we'll have time to decide what to do.
- We have to define the saturation level for the beach that represents the limit of beach occupation and that once is exceeded, the beach recreation function will failure. In Mediterranean beaches of intensive use this limit is usually set to 4 m^2/user. However, this limit varies depending on the type of the beach. Thus, for high price tourism destinations, this value has to be increased since there is a direct relationship between the tourism quality and the required space on the beach.
- In addition to this, we use the concept of used beach width that can be defined as the *beach* width that users occupy whatever the beach total width is (Figure 9). For Mediterranean beaches this value is in the order of 35 m.
- With this, the threshold value for the beach width with respect to the recreation function is defined as a function of users' density of the beach by estimating the available beach surface as a function of the beach width (actual or predicted). As an example Figure 10 shows a conceptual model on how the available surface varies in an eroding beach assuming that the number of users is steady. Once the saturation level is fixed depending on the characteristics of the tourism destination, it is easy to estimate the beach width and the time of occurrence for exceeding the threshold level.

Figure 9 Distribution of beach users across a wide beach in Costa Brava (Valdemoro & Jiménez, 2006)

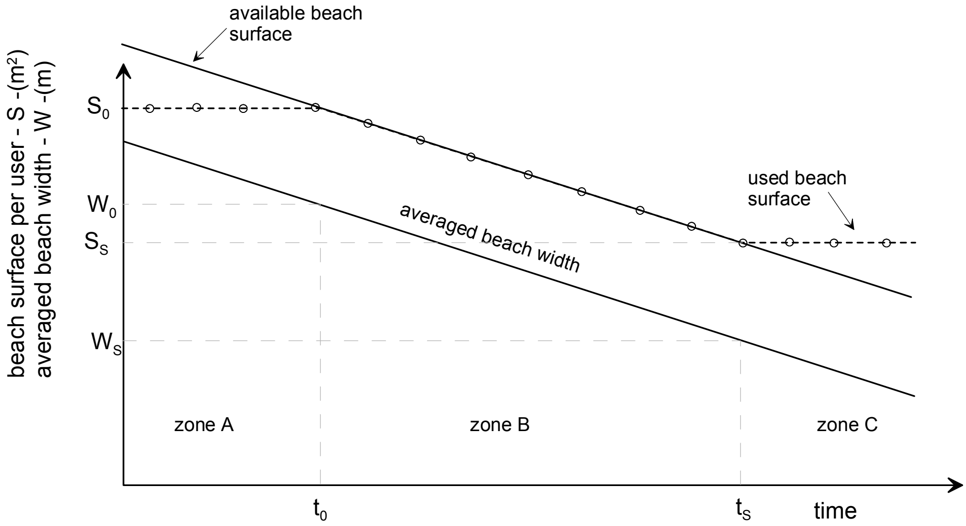


Figure 10 Relationship between beach width evolution in long-term eroding beaches and carrying capacity measured in terms of available and used surface per user (from Valdemoro and Jiménez, 2006)

Finally, it has to be stressed that all these variables and computations have to be done along the beach length without giving a beach-averaged value. This is especially important in protection because we need to know if there is any point along the beach that is likely not to properly protect 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 11).

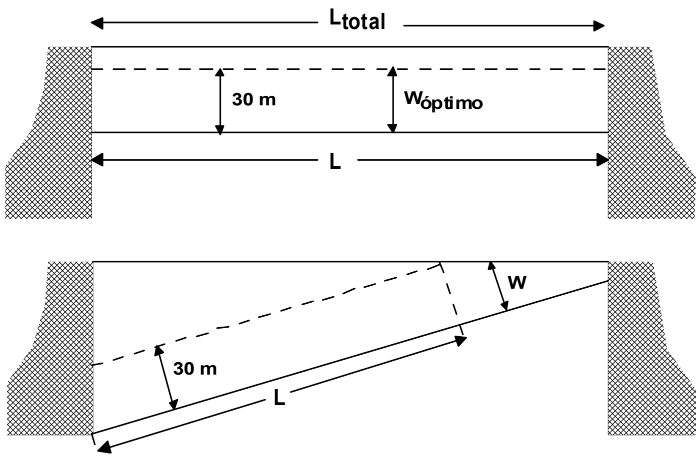


Figure 11 Two pocket beaches with the same surface but different configurations. Top: optimum configuration for a width threshold of 30 m with the entire beach properly playing the target function. Bottom: "bad" configuration for a width threshold of 30 m with the right side of the beach not properly playing the target function.

6 CSIs at Pevensey Bay

6.1 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.

6.2 Measurements used to derive CSIs

A series of 52 cross-shore profiles are measured at approximately 180m centres by the EA every four months using GPS stake-out surveys. Moreover, PCDL has introduced its own monitoring regime. A full beach survey is undertaken every month, coinciding with the lowest spring tide of that period. This is always around 06:00 for the Sussex coast. Each survey is conducted using a GPS receiver mounted on a quad bike. The bike is driven along beach contours at the position of changes in beach slope. Typically a length of beach will be surveyed from the top of beach crest at +6.0m to MLWS at -3.0m. Generally only the active beach is surveyed every month, static sections only being re-surveyed after significant wave events have occurred. The entire 9km long beach can be surveyed from the crest of the shingle ridge to the low water mark by a single person within a single tide in summer, but may take two tides in winter. Observations are obtained every one second, meaning that a typical long-shore resolution is 5m in most places, stretching to 10m on the flat, sandy lower foreshore. Spatial resolution cross-shore depends on beach geometry at the time, but tends to lie within 5m to 20m.

6.3 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.

Variations between the measured and target values of the three KPFs are used to identify the location and extent of works that may be required to meet the protection standard. If works identified as being necessary are not instigated and carried out in a timely manner, then PCDL would be subject to substantial financial penalties (although this has never happened).

6.4 Frequency of measurements

The EA measurements are made every four months, while PCDL measures every month. Increasing the frequency of measurements allows more of the shorter-term variability in the beach morphology to be captured. Deciding on the frequency of monitoring is a balance between the time and cost of additional measurements and the potential savings that an increase in information may bring.

PCDL's marginal cost for each additional survey is small as:

- each survey only takes 1 or 2 days to complete;
- equipment costs can be written off over several years;
- data processing is automated, so the extraction of the information required for beach management is quick.

The benefit PCDL receives from obtaining data every month (as opposed to the 3 times per year required by the EA) is that the information can be used to adapt the management plan to suit changing circumstances. For example the small-scale beach recycling operations can be based on one survey and checked against the next survey. Therefore, a more frequent set of measurements may allow a smaller margin of error to be built into the calculations as smaller deviations between successive surveys will be measured.

6.4.1 Desirable frequency of measurements

PCDL is happy to measure their CSIs 12 times per year as this assists them in managing the beach at a small cost. There seems to be little point in measuring more often as the percentage of working days spent surveying and interpreting results would increase and not all surveys could be on the lowest tides of the month – so the area surveyed would be more variable.

6.4.2 Acceptable minimum frequency of measurements

Beach nourishment from offshore sediment sources normally occurs as a single campaign in each year. In 2009 beach nourishment was undertaken in August, although in other years it has been as early as April or as late as October. Similarly nourishment by transporting shingle trapped against the southern harbour arm of Sovereign Harbour around the harbour by road lorry only occurs between October 1st and March 31st each winter (a restriction imposed by Eastbourne Borough Council).

The minimum acceptable data for this CSI would have to be enough to capture the effects of the nourishment schemes. The minimum requirement might be a set of measurements before the start of the nourishment campaign (say in August) and another after the bypassing of Sovereign Harbour and the worst of the winter storms (say in April). However, that would leave the shorter interval between surveys (4 months) during the relatively calm summer when lower cross-shore and longshore transport rates may be expected. The longer interval would be during the winter when the greatest variations in beach morphology normally occur. The minimum acceptable frequency of measurements should therefore be three times per year, which would allow the effects of the nourishment, bypassing and natural changes in morphology to be captured crudely at least.

6.5 Procedure to determine threshold value of CSI

The threshold value for the KPF cross-shore position of the +5m contour is the measured position in 2000.

The threshold value for the KPF beach width between front and rear +5m contours was determined from laboratory flume tests of erosion under severe conditions (HR Wallingford, 1995). Three representative cross-shore profiles representing the western, central and eastern areas of the barrier were modelled in a wave flume. The sand layer was moulded in impermeable concrete to represent the measured bathymetry out to 330m from the crest. The shingle was modelled using anthracite, a lightweight sediment, which had been scaled to reproduce permeability, the relative magnitude of the on-shore and off-shore motion and the threshold of motion.

Wave and water level conditions with joint return periods of 1, 5, 10, 100 and 250 years were modelled, as were conditions representing 250, 500 and 1000 year return periods including sea level rise in the water levels. Overwash occurred near the start of several tests, before the beach had had time to respond to the wave conditions. Landward recession of the crest was observed under most storm conditions. The severity of the recession was so great during some tests (with 250 and 500 year return periods) that the impermeable layer became exposed. This was considered to represent failure of the beach.

Nourished beach profiles with 20m wide crests were also modelled. Similar responses were observed to the representative profiles, although steeper beach slopes above still water level were observed, which was probably due to there being a greater depth of shingle in the nourished case. A crest width was chosen that withstood conditions with wave heights and water levels that had a joint probability return period of 400 years.

In addition the effect of various beach control structures on the plan-shape evolution of the beach was modelled using a laboratory wave basin model, as longshore drift alters the sediment budget and changes the volume of sediment available at any cross-section of the beach.

The threshold value for total beach volume as found by integrating the cross-sectional areas at each of the 52 profiles.

7 CSIs at Inch Strand, Kerry

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 is several years old).

Therefore to summarise:

- The indicator is coastline position.
- The coastline position was determined using a DGPS (but this was done as part of CONSCIENCE and not as part of any routine monitoring programme).
- Routine measurement is not routinely conducted.
- Measurements should be conducted at least twice a year and ideally once a season so that the annual fluctuations in coastline position can determined. This is necessary in order to place the contemporary position in a historical context and equally importantly to establish a baseline from which an accurate quantitative assessment of any change can be made. In addition attempts should be made to assess the coastline position immediately before and after storm events – as erosion (and recovery) in this area has been largely associated with storm events.
- Measurements should be made using a high end differential global positioning system (DGPS) and these surveys should be conducted by the local authority using an agreed code of practice. This should be strictly adhered to in order to ensure the integrity of the survey and the data and enable subsequent analysis. Data and meta-data standards should be observed and if possible the output should be placed in a Geographical Information System which would act both as library and an effective tool for illustrating and measuring changes in coastline position. Alternatively the coastline position could be recorded using aerial photography which if properly conducted will give an accurate measurement of the coastline position. However it would not provide any indication of the elevation of the dune system so perhaps the best option would be a combination of regular over-flights backed up with topographic surveys.
- The minimal acceptable data for this CSI would be an accurate position of the coastline on an annual scale.
- The threshold value is difficult to determine as, for example, in the case of Rosbeigh a breach of the dune system has resulted in a dramatic increase in public interest (distress). At Inch a large scale movement (10s of metres) of the dunes or damage to the existing coastal protection would result in some local action to stabilise the coastline. Therefore rather than being data driven it is driven by visual inspection and determination of change or perception of change and the threshold is usually reached after a major storm or series of storms. Although various models were applied during the course of CONSCIENCE, the local authority does not routinely employ models.

8 Summary

8.1 Summary of Pilot Sites

The six pilot sites in CONSCIENCE cover a range of coastal types, hydrodynamic conditions and management styles, which can be summarised as:

1. Holland coast: dune system preventing flooding of low-lying hinterland. Regular and systematic measurements at low frequency (once per year) to measure dune strength, momentary coastline and coastal foundation. Uses extrapolation of trend fitted to past 10 years data to predict in advance when the thresholds of the CSIs will be breached. Overwhelming economic case for preventing breaching of dune system (in most places the only form of sea defence) and long tradition of communal management of water issues.
2. Hel Peninsula: sand spit. Beach profile surveys have been performed out to 15m depth during most, but not all, recent years. Regular sand nourishment is undertaken, but profiles were not measured in every year that nourishment occurred. No tradition of systematic monitoring.
3. Black Sea coastline: low lying sandy beaches. Regular surveys of 19 profiles over 34kms (until landmarks lost to erosion) so low frequency (annual) and high separation between profiles. More detailed surveys near river mouths (where higher rates of coastal change may be expected).
4. Costa Brava coast: semi-enclosed erosive beach and pocket shoreline-oscillating beach. Shorelines extracted from aerial photographs collected over decades plus beach profile surveys during the last three years to determine CSIs (beach width). Semi-enclosed beach presents serious problems related to storm-induced erosion with several infrastructures being damaged. Emergency nourishments have been done but the supplied sediment has been rapidly removed. The pocket beach does not present problems related to sediment loss but sediment redistribution within the bay. Some beach configurations prevent the proper use and exploitation of the beach from the recreational standpoint, which can be easily solved by artificial sediment redistribution (backpassing).
5. Pevensey Bay: shingle (gravel) barrier beach preventing flooding of low-lying hinterland. Beach surveyed 12 times per year to determine CSIs. Beach actively managed through nourishment, local recycling within the barrier beach and re-profiling. Strong economic case for preventing breaching of barrier beach (in most places the only form of sea defence) so responsibility lies with Environment Agency. Regular monitoring on a regional scale has been established since 2000.
6. Inch Strand, Kerry: rock coastline of bay with sand spit. No routine surveys of coastal topography or bathymetry. Periodic aerial surveys (at spacing of years). Reactive response to erosion events that threaten or damage assets or lives. Visual inspection may prompt a more thorough investigation. Surveys made for specific projects.

8.2 Coastal State Indicators used

The Coastal State Indicators used at the pilot sites are listed in Table 4, 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 4 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

The Coastal State Indicators could be measured in different ways. Those that required cross-shore topographic information were normally measured using a GPS system along fixed transects. Other measurement systems, such as the traditional theodolite, could be used where there was, for example, a lower budget. In the Pevensey case the information was obtained by cross-shore transects using a GPS system for the Environment Agency and by mounting a GPS system on a quad bike and driving along breaks in the profile (which is similar to driving along contours). In the Black Sea case the shoreline position was measured by driving a GPS system along the berm crest, while in other locations (e.g. the Netherlands) this was determined from cross-shore topographic profiles.

The advantage of taking longshore measurements (Black Sea and Hel Peninsula shoreline position and Pevensey crest position) is that a continuous longshore profile of the desired quantity is obtained. The disadvantage is that there is a lower cross-shore resolution in the data than is provided by a typical cross-shore beach profile. The latter rely on there being smooth variations between profiles, so that the measured profiles may be treated as representative. In this case if there are no weak transects we may reasonably assume that there will be no weak points between transects. The same assumption is relied on for the calculation of total volumes by multiplying the measured cross-sectional area of a transect by the distance between 2 transects.

The Coastal State Indicators have been grouped according to similarity in the quantity represented in Table 5. The first six all represent the standard of protection offered by the dune or barrier system against breaching during a severe storm. Details can be found in Sections 2, 4 and 6.

Table 5 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 middle group of 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. For example, Pilkey and Davis (1987) associate gentler substrate slopes with higher rates of barrier transgression. Coastal slope has also been used as measure of flood and coastal erosion risk in the USGS Coastal Vulnerability Index (e.g. Thieler and Hammar-Klose, 2000a, b).

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 acts 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.

At both the Holland coast and at Pevensey Bay there are strong economic, social and environmental cases for preventing breaching. Added to this there is a national policy and central organisations tasked with overseeing this policy in both countries. Extensive studies have been undertaken in both countries to understand the key physical mechanisms responsible for erosion and the hydrodynamic climate (particularly extremes) that drives erosion. These studies have allowed the identification of the most appropriate CSIs and appropriate thresholds for them.

The economic argument and the tradition of central policy-setting and organisations are not so strong in Romania and Poland. Less effort has been undertaken to understand the processes involved and to narrow down the range of possible CSIs to the most appropriate one.

8.3 Frequency of measurement

There are noticeable differences in the spatial distances between the locations of consecutive CSI measurements and in the temporal separation between measurements, when comparing the different case studies, as shown in Table 6.

Table 6 Coastal State Indicators grouped by time and space separations

CSI	Spatial separation	Time between measurements	Case Study
Dune strength	250 m	5 years	Dutch coast
Barrier width	180 m	1 month	Pevensey
Total barrier volume	180 m	1 month	Pevensey
Backshore width	Mean 1.75 km	1 year	Black Sea
dune zone width	Mean 1.75 km	1 year	Black Sea
dune zone height	Mean 1.75 km	1 year	Black Sea
Momentary coastline	250 m	1 year	Dutch coast
Beach width	100 m	6 months	Costa Brava
Barrier crest position	180 m	1 month	Pevensey
Shoreline position	Few m	4 to 5 years	Black Sea

Shoreline position	≤ 500 m	1 year	Hel peninsula
Coastline position	Irregular	Event-driven	Inch Strand
Basal foundation	250m	Several years	Dutch coast
Shoreface volume	500m	4 years	Hel peninsula
coastal slope	Mean 1.75km	4 to 5 years	Black Sea

The first group of 6 represent the standard of protection against storms and vary in spatial and temporal scale. Longer timescales between measurements can be allowed when there is a sufficient buffer in the CSI to allow for shorter-term variability in the profile, or where there is a lower risk of damage to assets, people or the environment. It is perhaps surprising that the longest time between measurements occurs in the Dutch coast where the potential loss caused by a breach is greatest. However, it should be recognised that:

- considerable effort has gone in to understanding the erosion processes and hydrodynamic forcing along this stretch of coastline,
- the design condition has a 10,000 year return period, which is much larger than at other sites (for example, 400 years at Pevensey); and
- the momentary coastline (which limits the wave heights that can reach the dunes) is measured and nourished if necessary on an annual basis.

The spatial separation is smaller at the Dutch coast, Costa Brava and Pevensey than at the Black Sea coastline, which reflects the importance of, and potential risks to, these sites. In the case of Costa Brava and Pevensey beaches it is also a reflection of the relatively short longshore extent of these beaches, which means that such a detailed survey can be made within a single day.

Many surveys are conducted at about the same time each year. This gives a measure of the inter-annual trend, masked by the intra-annual variability. The Dutch get around this by creating a training coast line by fitting a linear trend to the latest 10 measurements of the momentary coastline and extrapolating forwards to the next year. This isolates the linear trend and shows the variation about it. This process does not give any indication of seasonal variations, however, which can be obtained from regular measurements at least twice a year.

The effect of collecting different numbers of surveys per year has been illustrated using the results from beach profile measurements made at approximately monthly intervals along a stretch of the Lincolnshire coastline (in eastern England) between 1960 and 1990 (HR Wallingford, 2008). A least-squares best-fit linear trend was fitted to time series of elevation at a point to give the rate of beach level change and the standard deviation in beach levels about this trend.

Figure 12 shows the calculated trend in level (m/year increase or decrease in level) from 2, 3 and 5 surveys per year plotted against the calculated trend in level from all surveys. The results from 5 surveys per year were the closest to those from all surveys, being on average 3% different. The trends from 3 surveys per year were on average 6% different from the trend from all surveys, while the trends from using 2 surveys per year were on average 11% different. The standard deviation of beach level was on average 6% different from 2 surveys per year compared to all the surveys.

The results indicated that the accuracy decreased with the number of surveys per year. The differences in trend and standard deviation could be approximately halved by increasing the number of surveys from 2 to 3 per year at that location. However, even with only two surveys per year the rate of change of beach level and the standard deviation in beach level about this trend were only 11% and 6% different from using all (usually 12) surveys per year. Although these results are site-specific and will vary with location and duration of the time series, the results indicate that surveying twice per year is likely to be sufficient.

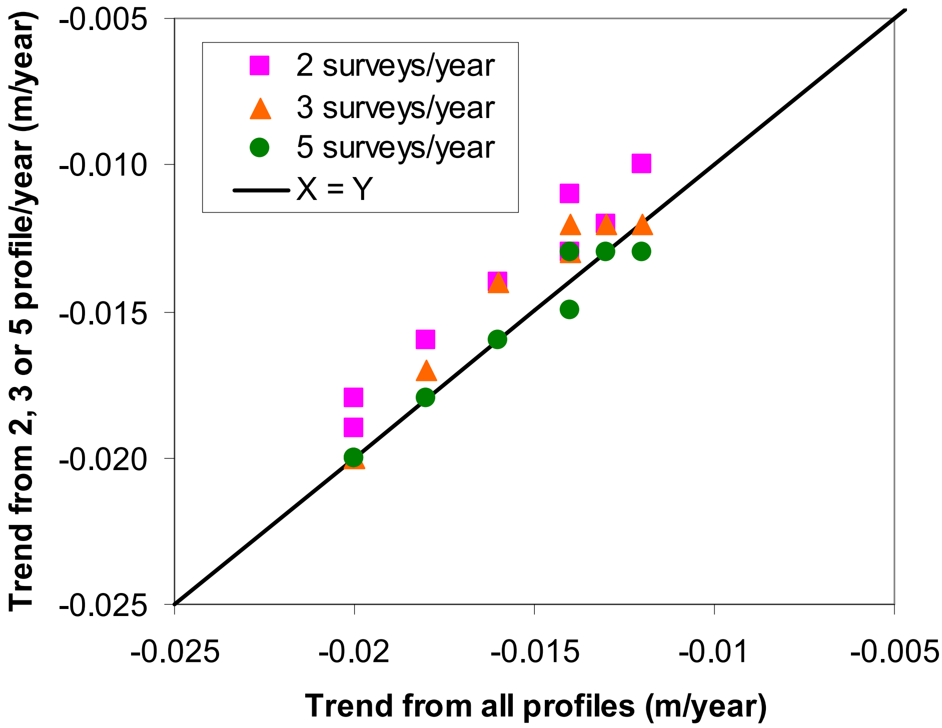


Figure 12 Percentage changes in the standard deviation in beach level from 2, 3 and 5 surveys per year

The time between surveys (considering all CSIs) is considerably less at Pevensey (1 month) than anywhere else (at least 6 months) and it is shorter than would appear necessary from Figure 12. However, in this case the marginal cost of each extra set of measurements is low (at about 1 to 2 person days per survey, plus marginal equipment costs) and the beach is actively managed (unlike in the Lincolnshire case). The additional measurements provide a quick means of assessing the previous intervention and of assessing where the next intervention should occur.

9 Discussion

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.

At both the Holland coast and at Pevensey Bay there are strong economic, social and environmental cases for preventing breaching. Added to this there is a national policy and central organisations tasked with overseeing this policy in both countries. Extensive studies have been undertaken in both countries to understand the key physical mechanisms responsible for erosion and the hydrodynamic climate (particularly extremes) that drives erosion. These studies have allowed the identification of the most appropriate CSIs and appropriate thresholds for them. For example, the three coastal state indicators used along the Holland coast are each linked to a separate tactical objective with a different scale:

- dune strength is used to assess safety against flooding;
- momentary coastline is used to maintain the 1990 coastline position; and
- coastal foundation is used to raise the coastal zone above the base of wave action with sea level rise.

At the Costa Brava Bays the coastal state indicator ‘beach width’ takes into account tactical objectives for storm protection and recreation (Valdemoro and Jiménez, 2006) showing how different functions of the beach can be combined in a single CSI.

The economic argument and the tradition of central policy-setting and organisations are not so strong in, for example, Romania and Poland, where less historic effort has been undertaken to understand the processes involved and to narrow down the range of possible CSIs to the most appropriate one. In Ireland action is commonly taken only when there is visible damage or there is a perception, based on observation, that there is a large enough risk to assets or human life to cause action to be taken.

10 Conclusions

Coastal state indicators have been derived at each of six contrasting sites along the EU's coastline in order to assist coastal managers to manage coastal erosion. There are regular measurements and use of the coastal state indicators at three of the sites considered (Holland coast, Costa Brava Bays and Pevensey Bay). At all three sites extensive studies into the behaviour of the beach (such as its response to storms) have been undertaken, which led to the choice of appropriate coastal state indicators, the setting of threshold values for intervention and the choice of a means of intervening.

At the other three sites, there are fewer routine surveys and fewer quantitative studies of the response of the beaches have been undertaken. The relevant coastal state indicators are starting to be derived, but have not been fully developed to link policy to response through the use of thresholds. Coastal state indicators are not routinely used by the coastal managers at these sites.

This experience suggests that the effective use of coastal state indicators for coastal erosion requires there to be knowledge of the state and behaviour of a coastal system to be able to identify the relevant coastal state indicator to meet the tactical objective set by policy makers. There will often be more than one option for implementing a tactical objective and the choice of option will influence the choice of coastal state indicator. This process relies on site-specific studies to define the best option, the relevant coastal state indicators and appropriate thresholds that should prompt intervention.

However, this requires a policy framework that sets strategic and tactical objectives for coastal erosion, as the coastal state indicators are used to assess how well objectives are being met. In countries where there is an effective policy framework this tends to be at a national level. The setting of operational and tactical objectives for coastal management is a pre-requisite for the implementation stage that uses coastal state indicators.

The successful application of coastal state indicators in the management of coastal erosion requires

- a management policy, which defines the strategic objective;
- a tactical objective that determines whether coastal erosion needs to be controlled, or not;
- knowledge of the state of the coastal system and understanding of the key processes of erosion and accretion;
- coastal state indicators that link the knowledge of erosion processes to the tactical objective;
- locally determined threshold values for the coastal state indicators;
- routine monitoring, to calculate values of the coastal state indicators;
- a range of measures for intervening, should a threshold value be crossed; and
- periodic assessment of the implementation and of the tactical and strategic objectives.

The different pilot sites have demonstrated how tactical objectives at different scales and for different purposes (recreation as well as coastal erosion) can be implemented using coastal state indicators. At their best, coastal state indicators integrate site-specific knowledge and study results with repeated measured data to provide coastal managers with information that they can act on to manage their beaches in an adaptive manner.

References

BSI (2004). PAS 55-1:2003. *Asset Management. Specification for the optimised management of physical infrastructure assets*. British Standards Institution, London.

Defra, 2006. *Shoreline management plan guidance (2 volumes).* Department for Environment, Food and Rural Affairs. Internet: http://www.defra.gov.uk/ (page accessed 16 March 2010).

European Commission, 2004. *Living with coastal erosion in Europe – sediment and space for sustainability.* Luxembourg: Office for Official Publications of the European Communities. 40pp, ISBN 92-894-7496-3.

HR Wallingford, 2008. *Understanding the lowering of beaches in front of coastal defence structures, Stage 2 Technical note 3*. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, R&D Project Record FD1927/PR3. Available from http://sciencesearch.defra.gov.uk/

Marchand, M., 2008. The CONSCIENCE project: bridging the knowledge gap for sustainable coastline management. Proceeding of *LITTORAL '08*, Venice, Italy.

Pilkey, O. H., and Davis, T. W., 1987. An analysis of coastal recession models: North Carolina coast. In: D. Nummedal, O.H. Pilkey and J.D. Howard (Editors), *Sea-level Fluctuation and Coastal Evolution*. SEPM (Society for Sedimentary Geology) Special Publication No. 41, Tulsa, Oklahoma, p. 59-68.

Sutherland, J., Brampton, A.H., Obhrai, C., Dunn, S. and Whitehouse, R.J.S., 2008. *Understanding the lowering of beaches in front of coastal defence structures, stage 2.* Joint Defra/EA Flood and Coastal Erosion Risk Management R&D programme, R&D Technical Report FD1927/TR. Available from http://sciencesearch.defra.gov.uk/

Sutherland, J. and Thomas, I., 2010. The management of Pevensey shingle barrier. Submitted to *Ocean and Coastal Management*, Elsevier.

Technische Adviescommissie voor de Waterkeringen (Technical Advisory committee for Flood Defence), 2002. *Leidraad Zandige Kust* (Guide on Sandy Coast). ISBN 90-369-5541-6

Thieler, E.R., and Hammar-Klose, E.S., 2000a. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Pacific Coast.* U.S. Geological Survey, Open-File Report 00-178, 1 sheet. Available online at: http://pubs.usgs.gov/of/of00-178/

Thieler, E.R., and Hammar-Klose, E.S., 2000b. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Gulf of Mexico Coast*. U.S. Geological Survey, Open-File Report 00-179, 1 sheet. Available online at: http://pubs.usgs.gov/of/of00-179/

Valdemoro, H.I. and Jiménez, J.A., 2006. The influence of shoreline dynamics on the use and exploitation of Mediterranean tourist beaches. *Coastal Management* 34: 405-423.

van Koningsveld, M. and Mulder, J.P.M., 2004. Sustainable coastal policy developments in the Netherlands. A systematic approach revealed. *Journal of Coastal Research*, 20(2) 375-385.

van Koningsveld, M. and Lescinski, J. 2007. Decadal scale performance of coastal maintenance in the Netherlands. *Shore and Beach*, 75(1) 1 – 17.

van Koningsveld, M., Davidson, M.A. and Huntley, D.A., 2005. Matching science with coastal management needs: the search for appropriate Coastal State Indicators. *Journal of Coastal Research,* 21(3) 399 – 411.