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Coastal Erosion Management

CONSCIENCE

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Guidelines on Beach Monitoring for Coastal Erosion

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Guidelines on Beach Monitoring for Coastal Erosion

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Table of Contents

1. Introduction 4
1.1. Our eroding beaches 4
1.2. Background to the guidelines 5
2. Framework for coastal erosion management 7
2.1. A management framework 7
2.2. Strategic and tactical objectives 7
2.3. Operational beach management 9
2.3.1. The state of the coast and option selection 10
2.3.2. Coastal State Indicators 11
2.3.3. Benchmarking, intervention and evaluation 13
3. Development of a monitoring programme 16
3.1. Why to monitor 16
3.2. What to monitor 16
3.3. How to monitor 17
3.4. When to monitor 19
3.5. How often and how far apart to monitor 20
3.6. How to manage your data 23
4. Summary monitoring guidance 25
5. References 27

1. Introduction

1.1. Our eroding beaches

Our beaches are assets, which perform many functions for us. For example, beaches:

1. provide protection against erosion and coastal flooding;
2. dissipate wave energy, thereby reducing the risk of failure of coastal defences;
3. provide recreational space, including access to the sea for recreation;
4. are the habitat, feeding ground or resting place of many species;
5. provide access to the sea for small fishing vessels;

Beaches are also crossed by the entrances to ports, harbours, rivers or estuaries and have been encroached upon by ports and towns (particularly to form promenades). They provide space for further potential developments in urbanised or industrial areas.

However, much of Europe's coastline is eroding and erosion threatens some of the values and functions of the coast. Coastal erosion is the process of wearing away material from a coastal profile and the net loss of material from the section (Marchand, 2010). A description of the processes involved in the erosion of sandy beaches and dunes and the methods that are used to model these processes has been provided by van Rijn (2010c), who has also supplied a similar report for gravel/shingle beaches and barriers (van Rijn, 2010b).

The Eurosion project[1] estimated that about 15,100 km of European coastline is retreating (out of a total of 101,000 km at the scale they used) and that about 15km^2 of land is lost each year (European Commission, 2004). The risk of direct losses through erosion are much less significant that the risk of loss through coastal flooding caused by the breaching of dunes, barrier beaches or coastal defences (European Commission, 2004, Hall *et al.,* 2006) but as breaching is caused by erosion, the study of erosion is relevant to both. Moreover, there is increased development pressure at the coastline (Nicholls et al, 2007). In an incomplete survey the Eurosion project (European Commission, 2004, Part II, Table 4) calculated that an additional 1,800km^2 of the 10km wide coastal buffer zone had become urbanised between 1975 and 1990. Moreover, the damming of rivers has reduced the volume of sediment reaching Europe's beaches, which increases the risk of erosions at a time when sea level is rising.

In response to this our coastlines are increasingly managed – some 7,600 km of coastline are protected by hard defences (European Commission, 2004, Part II, Table 2) while there has been an increase in beach management through the use of 'soft defences' over the last 20 years (Hanson et al, 2002, van Koningsveld and Lescinski, 2007).

Note, however, that coastal erosion only becomes a problem when there is no room to accommodate change, so coastal erosion is a problem for urbanised frontages but is not for many rural areas where the beach is backed by high ground. In some places coastal erosion is necessary for the preservation of some of the coast's functions. For example, the chalk cliffs of Dover or Beachy Head (UK) are highly prized for their stark white

[1] www.eurosion.org

appearance, which is maintained through continued erosion exposing fresh chalk. Beaches also play host to rare species of plants and animals that thrive in the changing environment of a mobile beach, but which tend to get pushed out by more common species when a beach is stabilised. Moreover, erosion of one stretch of coastline often provides the beach material that is vital in protecting a down-drift stretch of coastline.

Hard defences (or coastal structures) such as groynes, detached breakwaters, seawalls, revetments and artificial reefs are generally built to reduce beach erosion and maintain a minimum beach width for recreation. They are no remedy for structural sediment deficiencies due to sea level rise. Moreover, hard defences often have a negative effect on the down-drift coastline as they can prevent sediment reaching it. However, many linear defences, such as seawalls, which were constructed decades ago (sometimes over a century ago) continue to perform their primary function of coastal protection adequately. The performance of these defences is increasingly being seen in a broader context, looking at their effect on the sediment budget of the coastal cell.

Van Rijn (2010a) has summarised the mechanisms of coastal erosions and the natural variability in beach position about the long-term trend. This report also outlines methods for controlling erosion through the use of hard structures and by soft nourishment.

Soft defences are based on the nourishment of beaches with sediment that is similar to the natural sediment. Sand nourishment (Marchand, 2010) can occur as:
- dune reinforcement above dune toe level to reduce the probability of breaching;
- beach nourishment where sand is dumper as high as possible on the beach to compensate local erosion; and
- shoreface nourishment, where nearshore berms or mounds are constructed from dredged material to help break incoming waves and to act a supply of sediment to the beach (through natural onshore sediment transport).

Shingle (gravel) nourishment tends to occur relatively high up on the beach (as there is often a sand or rock substrate beneath the shingle).

Experience with sand nourishment on the Holland coast has shown that large scale erosion can be stopped by massive beach and shoreface nourishment over long periods of time (van Koningsveldt and Lescinski, 2007). The early schemes, such as Bournemouth in the UK, have now been through repeated cycles of beach nourishment and monitoring, so considerable experience has been gained with this method of beach management. An important lesson learnt is that regular high quality monitoring is necessary to manage the design and maintenance of each recharge and to plan ahead successfully for future recharges (SCOPAC, 2003).

This report provides guidelines on coastline monitoring for the management of coastal erosion. Different monitoring requirements may be needed to manage other problems, but these are not covered here.

1.2. Background to the guidelines

These guidelines on monitoring were developed as part of the EC-funded research project *Concepts and Science for Coastal Erosion Management* (commonly known as

CONSCIENCE). CONSCIENCE has defined and validated 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)[2]. The project has developed guidelines 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 (including the guidelines) can be found on the project website http://www.conscience-eu.net/.

These guidelines on monitoring draw particularly on the following CONSCIENCE deliverables:

- D1: Inventory of coastal monitoring methods and overview of predictive models for coastal evolution.
- D10: Assessment of data needs for coastal state indicators.
- D14: Coastal sediment management tools.
- D16: Data set inventory for field pilot sites.

They are all available from http://www.conscience-eu.net/documents and can be used to supplement the material in the following sections of these guidelines.

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

2. Framework for coastal erosion management

2.1. A management framework

A sustainable solution to coastal erosion problems should be based on an understanding of the sediment dynamics, but it will be carried out within a policy framework that may set explicit objectives and in an institutional environment where stakeholders have different roles. 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, as this makes it clear where data are key to informing coastal management decisions.

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 level involving four steps.

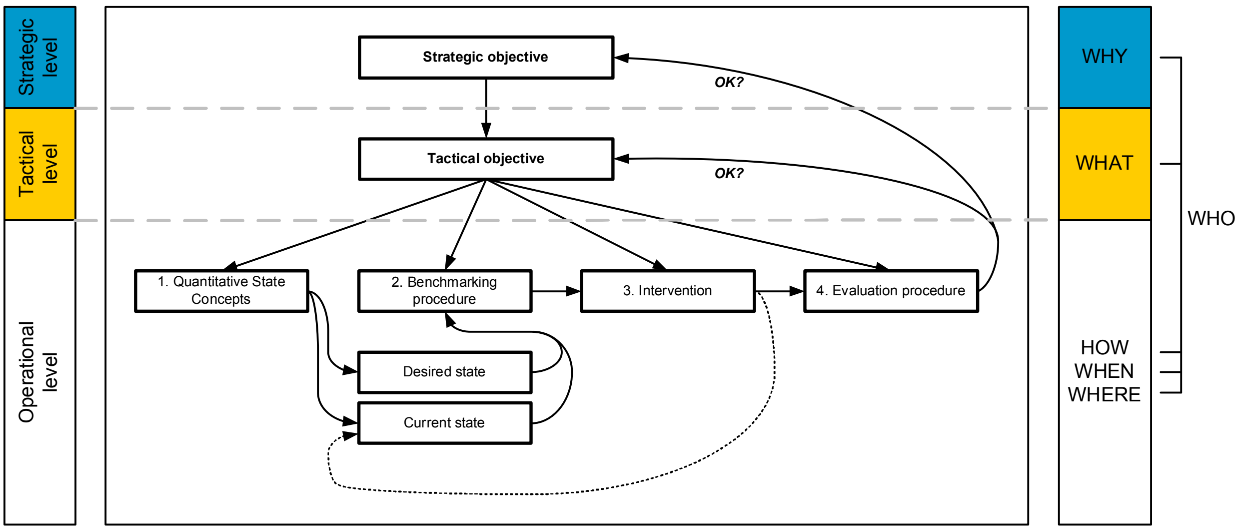

Figure 1 Generic frame of reference

2.2. Strategic and tactical objectives

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 tactical objectives are formulated describing what has to be achieved in order to comply with the strategic objective. 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.

Table 1 shows different strategic and tactical objectives which were found in the 6 CONSCIENCE pilot sites (Sutherland, 2010b). Strategic objectives are set by governments at a national level in some countries but not in others, where strategy is decided at a local level. 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

It is important to realise that tactical objectives can be made for different time horizons, as in the Netherlands, as illustrated in Figure 2. 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. On the other side of the spectrum we may find a time horizon of decades to centuries, particularly for managing 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 at scales of metres to hundreds of metres. For adaptation to sea level rise we consider littoral sediment cells at the scale of tens to hundreds of kilometres.

The choice of a tactical objective will influence the development of a beach monitoring programme. However, there may be different ways of implementing a tactical objective, for example by using different combinations of hard and soft defences, and the choice of how to implement a tactical objective will also influence beach monitoring, as discussed in the next section.

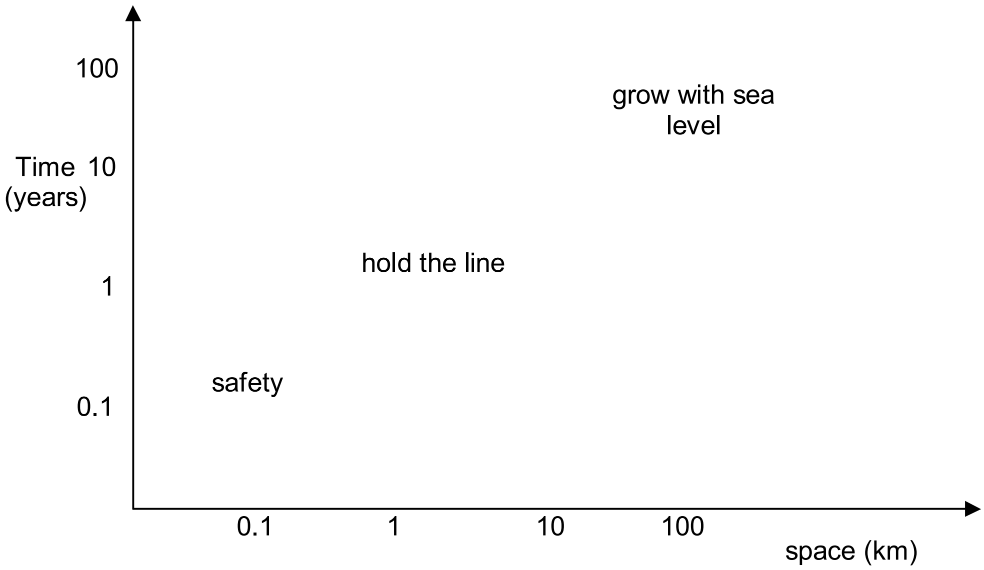

Figure 2 Time and space scales for different tactical objectives

2.3. Operational beach management

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 is an important step at the operational level.

Operational beach management is largely a matter for coastal practitioners and experts. In the frame of reference approach a beach management programme can be formulated through an operational decision recipe with four steps (as shown in Figure 1):

1. *Quantitative state concept:* The first element of the decision making process is to perform an analysis of the current state of the coast, including its behaviour, land use, functions and the different options that are proposed for implementing the chosen tactical objective. This stage has also been referred to as option selection (Sutherland and Thomas, 2010) as at the end of it the behaviour of the coast should be understood and the method of managing it should have been chosen.
2. *Benchmarking process:* a means of assessing whether or not action is required.
3. *Intervention procedure:* A detailed definition of what action is required if the benchmark values are exceeded.
4. *Evaluation procedure:* An 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).

2.3.1. The state of the coast and option selection

Developing an understanding of the state of the coast and selecting an option to implement the tactical objective are important steps in deciding how to manage a beach. A picture must be built up of the geology and geomorphology of the area and the main mechanisms of coastal erosion should be determined. Monitoring data is vital in developing a picture of the way a beach is evolving. Data helps in developing an understanding of trends and the variation around a trend. A review of different methods of monitoring beaches, covering a range of time and space scales was provided by Sutherland (2010a) which also provides an overview of the models and other tools used to predict beach evolution. The storm response element of this review for non-cohesive beaches is covered in considerably more detail by van Rijn (2010b, 2010c). The erosion and management of soft cliffs is described in Lee and Clarke (2002) while the effect of the erosion of cohesive shore platforms on beaches is described in Royal Haskoning et al (2007).

Data on forcing conditions – winds, waves, tides and surges – are also important in understanding what caused the changes in a beach topography and bathymetry.

When an understanding of the behaviour and likely future evolution of a beach has been determined, different options for managing the beach can be considered. This is likely to balance cost and effectiveness within the context of current policy. If there is a drive to work with nature then it is more likely that the selected option will be based on soft techniques such as nourishment and re-cycling, possibly with planning restrictions to allow space for natural variability in the position of the coastline. Options that rely on sediment and allow space for it to move are described as resilient.

The selection of an option to implement the tactical objective(s) leads to the definition of a desired state of the beach. For example:

- If a beach and dune system is to prevent breaching due to a storm, then the cross-sectional area of the dune above the storm surge water level must be sufficient to withstand a storm of the chosen severity (TAW, 2002). An example for the north Holland coast is given by van Koningsveld and Lescinski (2007).
- If a shingle (gravel) barrier beach is used to hold the line then its position must be known. An example for the Sussex (UK) coast is given in Sutherland and Thomas (2010).
- If a beach is used to prevent damage to a promenade then a minimum beach width is needed to prevent overtopping or structural failure. An example for the Costa Brava coast is given in Valdemoro and Jiménez (2006).

However, the process of determining the desired state of the beach is not straightforward as it requires:

- Process understanding to determine the main mechanisms of erosion and their potential consequences, such as structural damage, permanent loss of land and / or flooding.
- Parameterised formulae, numerical or physical models to predict the response of a system;
- Data on local forcing so that a site-specific response may be determined.

- Data on local beach topography / bathymetry for calibration and / or validation of the models.
- A desired level of safety, which is often expressed as a return period (the average duration between storms of that severity). For example the barrier beach at Pevensey (UK) should withstand a storm with a return period of 400 years, while the dunes of north Holland should withstand a storm with a return period of 10,000 years.

2.3.2. Coastal State Indicators

Considerable modelling may be required to determine a desired state, which can be described using a coastal state indicator (CSI). A coastal state indicator is a measurable parameter that defines the desired state of the coast in order to meet a tactical objective. For example, the CSI for a sand dune that is meant to prevent breaching during a storm with a chosen return period is the residual strength of the dune, defined as the minimum acceptable area under a cross-shore profile above the associated storm surge level, as shown in Figure 3. For more details of this example see TAW (2002) and Sutherland (2010b).

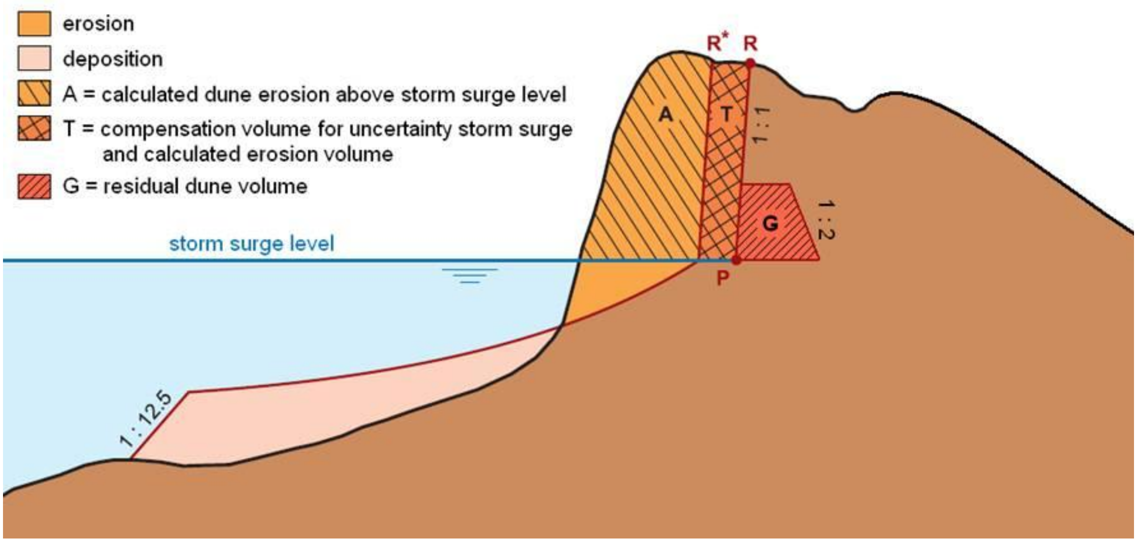

Figure 4 Cross section of coastal profile defining erosion and deposition during design conditions, and the resulting residual dune strength (TAW, 2002)

Coastal State Indicators should:

- be relevant – there must be a direct conceptual link between the CSI and the coastal function of concern;
- be measurable – ideally using a range of different technologies from the cheap and simple to the expensive and complicated in order that the indicator may be applied in a range of situations with different monitoring policies;
- have a known response to disturbances – that is scientifically based and so reproducible;
- be anticipatory – so that an indicator can be used to prompt action when the indicator reaches a scientifically-derived threshold value;

- be integrative – by combining data and knowledge of processes across the appropriate time-scale and spatial-scale to provide information that is useful to the coastal manager in implementing a policy.

The major functions of coastal state indicators 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, and 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. Table 2 shows the coastal state indicators used in the different pilot sites of the project (Sutherland, 2010b). It should be noted that these are not the only suitable CSIs that could be used or developed for coastal erosion.

Table 2 Grouped Coastal State Indicators

CSI	Quantity represented	Pilot Site
Dune strength	Standard of protection (SoP) 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 Beach
Coastal foundation	Growth with sea level rise	Dutch coast
Shoreface volume	Flood and coastal erosion risk	Hel Peninsula
Coastal slope	Flood and coastal erosion risk	Black Sea

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.

2.3.3. Benchmarking, intervention and evaluation

In the benchmarking procedure (Figure 1) the current state of the coast is compared with the desired state (defined by a coastal state indicator) after which the need for intervention is determined. The acceptable form(s) of intervention should have been set within the previous stage (section 2.3.1). When the intervention has been carried out its success should be evaluated.

Coastal state indicators are used to assist the coastal manager to implement a policy (or to assess how effective an implementation has been). The coastal manger does not need to understand the detailed processes of erosion or the modelling tools used to determine what parameter should be chosen as the coastal state indicator and what its threshold value should be. The coastal manager simply needs to be able to measure the coastal state indicator and know how to act when it falls below a threshold value. Coastal State Indicators are therefore an appropriate tool for bridging the gap between the science of coastal erosion and the implementation of a policy at a beach. Examples of how coastal state indicators can be used to implement tactical objective in the Netherland and UK are given below. Further details are provided in Sutherland (2010b).

2.3.3.1. Case study in the Netherlands

One of the tactical objectives in the Netherlands is to maintain the coastline position of 1990, called the basal coastline (BCL). Each year the position of the coastline is measured. This measurement is called the momentary coastline (MCL) and a linear trend is fitted to the last 10 values of the MCL. This trend is extrapolated forward to the next year to give the testing coastline (TCL) as shown in Figure 4. If the TCL crosses the BCL then sand nourishment is arranged to prevent the MCL crossing the BCL.

The effectiveness of this approach has been evaluated (van Koningsveld and Lescinski, 2007) and large scale sand nourishment has been shown to be effective in implementing the tactical objectives over a period of several years.

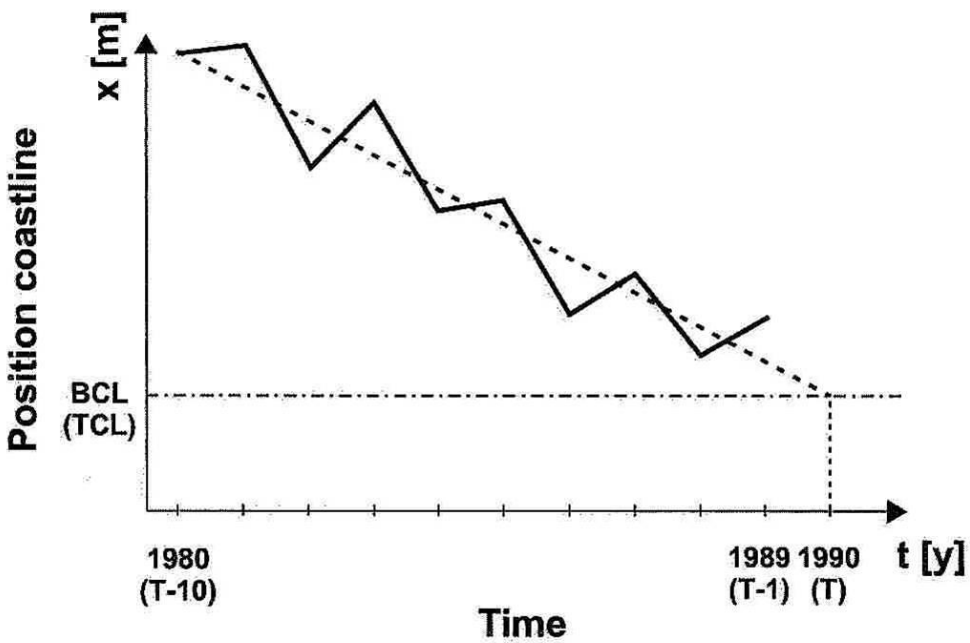

Figure 4 Definition of BCL (Basal Coast Line) and of TCL (Testing Coast Line) by linear extrapolation of a 10 year trend

2.3.3.2. Case study in the UK

At the shingle (gravel) barrier beach at Pevensey (East Sussex, UK) a full beach survey is undertaken every month, coinciding with the lowest spring tide of that period (Sutherland, 2010b, Sutherland and Thomas, 2010). Each survey is conducted using a GPS receiver mounted on a quad bike. Typically a length of beach will be surveyed from the top of beach crest at +6.0m to MLWS at -3.0m. 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. Coordinates from the quad-bike survey are entered into a DTM software package to create a 3D DEM of the barrier beach.

The backshore width (defined as the cross-shore distance between the +5m contour on the front and rear faces of the barrier beach) is used as the coastal state indicator to represent the standard of protection against a storm. This is extracted from the DEM at 52 locations along the beach. The coastal manager has three options if the backshore width is too low:

- ⇒ Beach nourishment (adding material from elsewhere),
- ⇒ recycling material from elsewhere on the beach and
- ⇒ reprofiling (moving material towards the top of the beach from lower down).

The process is evaluated the following month when the CSI is measured again.

3. Development of a monitoring programme

3.1. Why to monitor

Section 2 described a framework for coastal erosion management and showed how data played an important role in developing an understanding of the coastal system and then in the operational management of a beach. Bradbury (2010) offers the following reasons for collecting beach monitoring data:

1. understanding the past: both fluctuations and long-term trends are needed to understand beach evolution;
2. identification of present problems;
3. programming management intervention (see Section 2.3.3);
4. calibrating or validating physical and numerical models;
5. assessing the effectiveness of an intervention;
6. understanding the impacts of interventions;
7. ensuring compliance with consenting conditions;
8. providing evidence that required mitigation has been carried out.

However, collecting data costs time and money so data collection must be based on an understanding of risks (or the desire to develop this understanding). A beach monitoring programme may have different functions at different times or places:

- strategic monitoring designed to improve understanding of a coastal system, select management option and develop criteria for thresholds;
- operational monitoring to provide the data needed to calculate the chosen coastal state indicator(s) and compare them to their threshold values. Operational monitoring can also be used to assess the effectiveness of any intervention that resulted from the comparison between a coastal state indicator and its threshold value.

3.2. What to monitor

A decision must be taken as to what should be measured. In the CONSCIENCE project the monitoring data were used to calculate the coastal state indicators shown in Table 3 (Sutherland, 2010b). 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 inter-tidal beach at about Mean Low Water Springs. Three coastal state indicators 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. The coastal state indicators that are routinely used by coastal managers are identified in the last column of Table 3 and these are the most important as they are relied upon for beach management.

Table 3 Coastal State Indicators used at pilot sites

Coastal State Indicator	Measurement	Case Study	Used for management
Dune strength	Cross-shore topographic profile	Dutch coast	Yes
Momentary coastline	Cross-shore topographic profile	Dutch coast	Yes
Basal foundation	Cross-shore bathymetric profile	Dutch coast	Yes
Shoreface volume	Cross-shore bathymetric profiles	Hel peninsula	
Shoreline position	GPS following shoreline	Hel peninsula	
Shoreline position	GPS following berm	Black Sea	
Backshore width	Cross-shore topographic profile	Black Sea	
Dune zone width	Cross-shore topographic profile	Black Sea	
Dune zone height	Cross-shore topographic profile	Black Sea	
Coastal slope	Cross-shore bathymetric profile	Black Sea	
Beach width	Cross-shore topographic profile	Costa Brava	Yes
Total beach volume	Cross-shore topographic profile	Pevensey	Yes
Barrier width	Cross-shore topographic profile	Pevensey	Yes
Barrier crest position	Cross-shore topographic profile	Pevensey	Yes
Coastline position	Visual inspection	Inch Strand	

Three main forms of measurement are made:
1. the cross-sectional area of the beach or dune or barrier beach (within set vertical and / or horizontal limits);
2. the cross-shore position of a characteristic position on the beach or dune or barrier beach;
3. the shoreface volume or subtidal coastal slope.

Each form can be associated with tactical objectives at increasing typical space and time scales (see Figure 2). In most cases the third form of measurement is rarely, if ever, made but may play an important role in managing a beach to cope with long-term sea level rise. The appropriate form of measurement(s) to make should be decided locally, but may be influenced by the details of the measurements made at the CONSCIENCE pilot site, particularly those where the measurements are already routinely used in adaptive beach management.

3.3. How to monitor

Beach monitoring methods are summarised in Table 4, based on the descriptions in Sutherland (2010a). Some of these methods are quite cheap, while others require expensive equipment or are costly to operate, such as airborne methods. Each method has its advantages and disadvantages. It is therefore essential to establish what the data will be used for. A survey programme may, therefore, be based on a conceptual (or numerical) model of coastal hazards or risks (section 2.3.1). The level of risk may affect the spatial and temporal frequency of monitoring:

- Intensive monitoring of areas at high risk;
- Periodic monitoring of low risk areas.

Table 4 Coastal monitoring methods

Monitoring type	Explanation	Examples
Small scale		
Linear arrays of point sensors	Measurement of the depth of scour under all conditions	Tell Tail scour monitoring system
Underwater acoustic measurements of the seabed	An acoustic backscatter device can be used to detect the level of the seabed and give information about sediment in suspension in situations where the seabed and instrument are fully submerged.	Autonomous Sand Ripple Profiler (ASRP)
Measurements of emerged toe levels	There are a number of techniques that can be used to measure emerged coastal defence structure toe levels at a point every low tide.	Argus video system Counting the number of steps above the beach level at access points
Measurements of mixing depth	The seabed mixing depth is the maximum depth below the seabed where sediment motion occurs	Stack of numbered aluminium disks of known height
Medium scale		
Cross-shore profile surveys and topographic surveys	Beach profiles and topographic surveys are typically collected using a large range of methods	Theodolite Kinematic GPS (e.g. mounted on a quad bike) Laser scanning systems Repeated digital photography (Argus) X-band radar
Large-scale		
Mapping of tidelines or shorelines	The position of the shoreline or tidelines (i.e. location of some representation of high water level and low water level) is commonly marked on maps. Different editions of the same map series, sometimes stretching back more than 100 years, can be used to determine long term changes to the position of the shoreline.	Orthorectified aerial or satellite photos Topographic LIDAR Bathymetric LIDAR Synthetic Aperture Radar (SAR) Bathymetric surveys from ships

The selection of the appropriate method of monitoring will depend on how the data will be used and the budget available. The coastal state indicators in Table 3 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, while in cases where a high spatial density of measurements is needed and the environment is sensitive to disturbance (such as the Dutch dune system) a survey can be conducted using topographic LIDAR. 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. A detailed survey by low-flying (and therefore most accurate) topographic LIDAR could be used to remove the limitations of longshore and cross-shore profiles but requires considerable additional resources to set up ground control points, collect and analyse the large dataset and convert the DEM generated into coastal state indicators to assist with coastal management.

Methods exist at a range of budget levels to measure the basic parameters of cross-shore profiles, shoreline position and shoreface volume. The choice of how to monitor will depend on local budgets, the availability of equipment and the availability and training of staff (whether internal or contractors) for measuring and analysing the required data.

3.4. When to monitor

Monitoring should be carried out regularly so that a consistent set of results can be compared. A seasonal trend in both the mean and standard deviation of the beach level has been measured at some locations. An example from the toe of a seawall in Lincolnshire (eastern England) is shown in Figure 5 (Sutherland et al, 2007). These trends will affect the beach monitoring programme. If the intention is to determine the best long-term trend in beach levels, the measurements should be taken when the standard deviation in the residual beach levels is at its lowest as this is when the signal-to-noise ratio will be at its highest. In other words the beach should be monitored in or around August (at least in Lincolnshire) when the variability in the beach level is at it's lowest. These surveys should also be conducted during calm weather, advice which has been given for a long time (e.g. Ordnance Survey, 1882). At that time, however, the beach level will be close to its highest, so it is unlikely that any particularly low beach levels will be recorded.

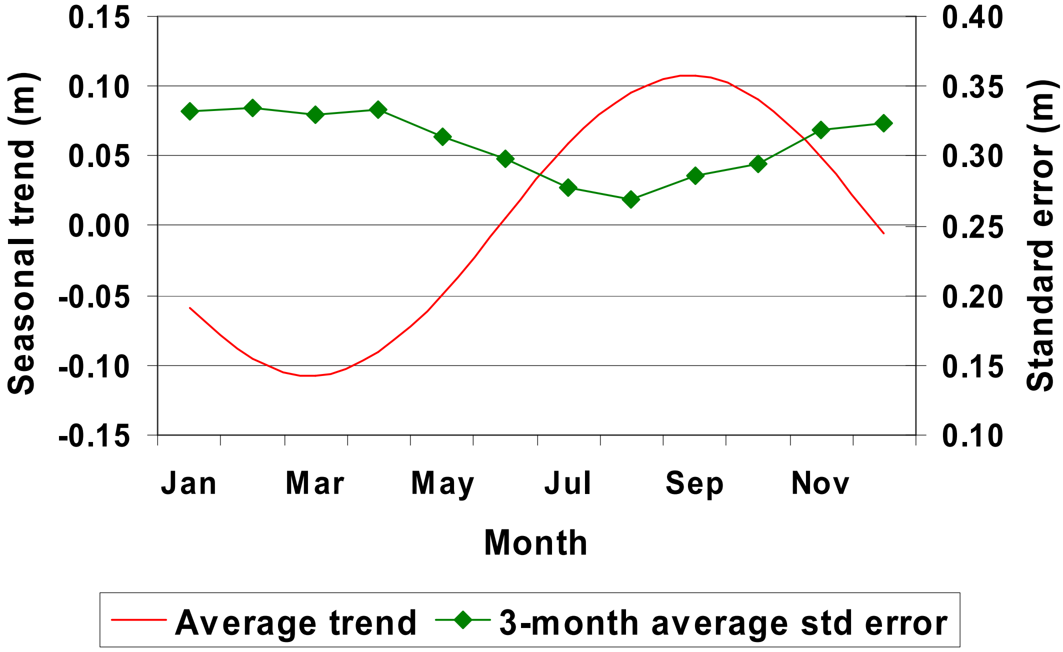

Figure 5 Seasonal trend and standard error in beach level in front of a seawall

Therefore, if the intention is to detect extreme low beach levels then surveys should be undertaken when mean beach levels are low and the standard deviation in the residual beach levels is at its highest. In other words beach levels should be monitored in or around March (in Lincolnshire). Moreover, it may be desirable to measure as soon after a storm as possible to detect the lowest beach levels.

Note, however, that the relative timing of the seasonal trend will vary from place to place. For example, Zhang et al. (2002) analysed a detailed dataset of 588 high water line positions collected at Duck, North Carolina, USA between 1996 and 1999. They showed that the standard deviation of the high water line position was a minimum in June and July. They concluded that beach surveys that are to be used to predict long-term trends in shoreline position should be performed in June and July between spring and neap tides and should not be performed immediately after a storm. It is more common to measure beach topography at spring tides, when the greatest extent of beach becomes exposed.

3.5. How often and how far apart to monitor

There were noticeable differences in the spatial distances between the locations of consecutive coastal state indicator measurements and in the temporal separation between measurements, when comparing the different case studies within CONSCIENCE, as shown in Table 5. This indicates that no single solution is ideal and that each survey programme should be devised to suit local needs.

Table 5 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 coastal state indicator 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 (se Section 2.3.3.1). 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 (Sutherland et al, 2007). 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 6 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.

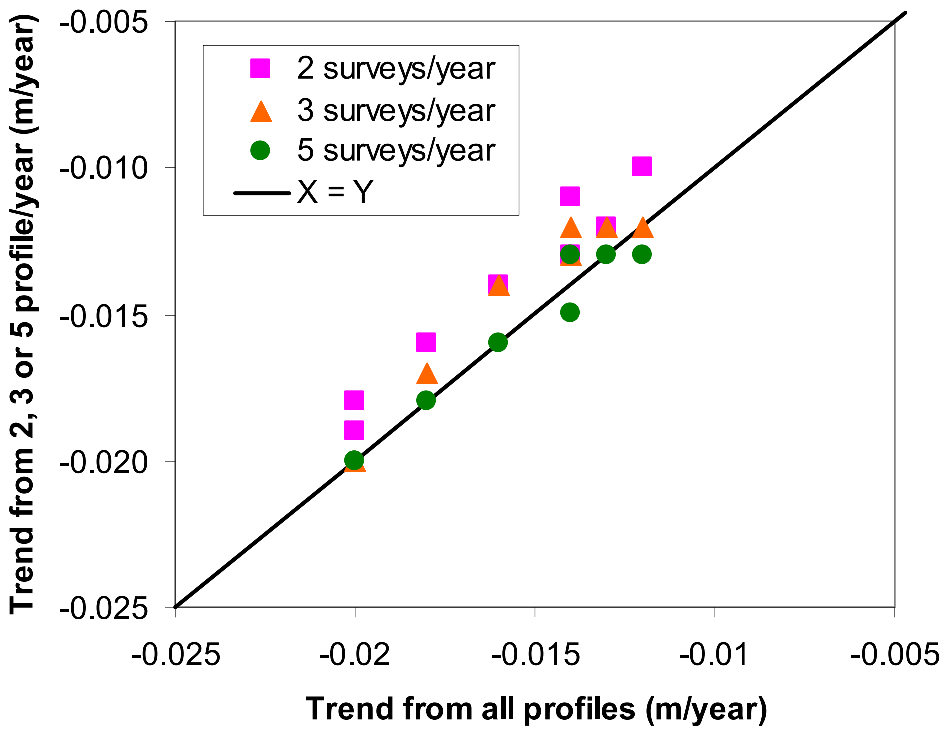

Figure 6 Percentage changes in the standard deviation in beach level from 2, 3 and 5 surveys per year

The time between surveys (considering all coastal state indicators) is considerably less at Pevensey (1 month) than anywhere else (at least 6 months) and it is shorter than would appear necessary from Figure 6. 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.

3.6. How to manage your data

Coastal data monitoring programmes can collect large volumes of data over periods of years. Examples include the Dutch Jarkus database, the Channel Coastal Observatory in the UK. In order for this data to be of the greatest use to the coastal manager it is important that this data can be accessed, understood and relied upon. A data management system should be set up to store data and associated meta-data (information about the data) over its entire life-cycle from collection, through analysis and storage to retrieval and eventual replacement or archiving.

A number of general points should be followed to ensure that the data collected is of a uniform standard that is suitable to use in beach management. It is important to establish a reliable system of ground control points or permanent markers that can be used by all surveying groups, whatever technique they are using. The datum system to be used should be explicitly stated and a clear set of guidelines should be established for the surveys, including tolerances and national or international standards to be met (such as ISO or British Standards) and guidance on when to survey (with respect to the months, the spring-neap tidal cycle and the occurrence of storms).

Coastal data for sediment management can be stored and analysed in a range of software systems including proprietary Geographical Information Systems (GIS), digital terrain models (DTMs), Computer Aided Design (CAD) packages, spreadsheets, and simple bespoke databases built in languages ranging from Fortran to Matlab. Data management systems are discussed in more detail by Sutherland (2010c).

Spreadsheets have the advantages of simplicity and familiarity. Visualisation of time series or profile data is straightforward. However, they cannot handle large amounts of data nor can they display results against a geographical back-drop. The presentation of geographical data is straightforward in a CAD programme. Time series analysis is more difficult and their functionality is more limited than a bespoke database.

There is an increasing trend towards the use of GIS as a means of displaying results visually and within their geographical context. A GIS is a software package for the acquisition, storage, retrieval, manipulation and analysis of spatially referenced data. All GISs combine a database of the mapped data and a visualisation system for spatially-referenced data that can also display graphs and photographs. Some GIS tools have been developed specifically to manage beach data. These systems store and analyse beach data and can include other forms of data such as waves and water levels. The systems can be used to call predictive models, such as the extrapolation of shoreline position determined from regression analysis or a numerical model (Stripling and Panzeri, 2009) which can be used to schedule beach management activities. GISs are being developed for the particular requirements of data having both temporal and spatial variations.

Bradbury (2010) highlighted the following specifications for a suitable GIS for beach management:

- *"data input and export formats are rarely an issue as most systems can read most data vector and raster formats*
- *spatial analysis functions based on vector data are widespread*
- *database operations and ability to conduct spatial queries differentiates a GIS from conventional databases*
- *three dimensional surface modelling may be widely used for analysis of survey data. DTM modules do not always form a standard part of the GIS and vary considerably in the style of operation and output possible. This element is particularly important as it is likely to be used for further analysis such as contouring, slope analysis and volume estimation (eg volume above some threshold such as MHWS) or for visualisation purposes."*

This may involve building links between the GIS and external software and numerical models (e,g, Stripling and Panzeri, 2009). It may also be necessary to develop completely new functions tailored to a particular application, such as the calculation of Coastal State Indicators. Many GIS products allow the user to build menus and icons for complex bespoke operations, providing a seamless join with the main system. This functionality now allows for the development of a GIS-based coastal management tool capable of calculating site-specific coastal state indicators and presenting the results in a visual manner, super-imposed on a map or photographic background.

However, none of the systems used in the CONSCIENCE project go that far. The Dutch system was originally designed as a Matlab toolbox (van Koningsveld et al., 2004) and only the outputs are displayed visually in a GIS. At Pevensey the results are displayed as a table of numbers (colour coded if there is a shortfall in sediment volume). In this case the results are used by an expert local manager who has a detailed knowledge of the location so does not require the results to be presented against a map background to determine the required programme of intervention. Should the results need to be communicated more widely (to people who do not know the location and its profile lines so well) then mapping the results onto their appropriate locations would undoubtedly assist others in interpreting the results.

The experience of the CONSCIENCE pilot sites indicates that local systems, coded within a variety of software packages, are sufficient to calculate coastal state indicators for use in coastal management. In some cases more than one tool is used to store and process data then to calculate and present coastal state indicators. This is unnecessary and could lead to problems caused by human error in the transfer of data between tools.

Tools for calculating coastal state indicators can be constructed within a GIS, which can store measured data, process it to produce the required outputs (which may well be a coastal state indicator) and to present the results visually against a background of a map or photograph. GISs can also be used for the calculation of sediment budgets (Rosati and Kraus, 2001), shoreline retreat rates (Thieler *et al.* 2008) and changes in beach profiles or bathymetry (Kemp and Brampton, 2007). Moreover they can be used to call predictive models of waves and sediment transport (Stripling and Panzeri, 2009) and to present the results.

GISs have been developed to undertake data storage, analysis and presentation for the major beach management methods in common use, from the small-scale adaptive beach management based on coastal state indicators through to the derivation of large-scale long-term sediment budgets for strategic planning. The trend towards using GIS as the basis for coastal management software is likely to continue and some integration and consolidation into a limited number of leading packages is likely. Such systems will need to be set up for each site they are applied at and this will continue to require expert attention.

4. Summary monitoring guidance

There are a number of reasons for monitoring a beach, as data will help to understand the past, identify present problems, program management intervention, calibrating or validating physical and numerical models, assess the effectiveness of an intervention, understand the impacts of interventions, ensure compliance with consenting conditions and provide evidence that required mitigation has been carried out (Bradbury, 2010).

The key points for monitoring guidance include:

- Establish what the data is to be used for. A wide range of data could be used in coastal management, including data on wind, waves, tides, beach sediment, offshore bathymetry, coastal profiles, geomorphological features, coastal defences, beach nourishment or recycling. All will cost money to collect and that cost should be justified.
- Beach topography is commonly measured to provide information on the cross-sectional area of the beach or dune or barrier beach (within set vertical and / or horizontal limits) and on cross-sectional area of the beach or dune or barrier beach (within set vertical and / or horizontal limits). A measurement of the shoreface volume or subtidal coastal slope may also be important for considering the effects of sea level rise.
- Establish a reliable system of ground control points or permanent markers that can be used by all surveying groups, whatever technique they are using;
- Explicitly state the datum system to be used;
- Establish a clear set of guidelines for the surveys, including tolerances and national or international standards to be met (such as ISO or British Standards) and guidance on when to survey (with respect to the months, the spring-neap tidal cycle and the occurrence of storms) and where to survey;
- Develop a data management system that will allow the data to be stored, accessed, analysed and represented. There is a growing trend towards using GIS for this, although this is not a necessary requirement.

Experience within the CONSCIENCE project has shown that there are a range of successful monitoring programmes that assist beach management through the use of coastal state indicators. 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. The beach monitoring programmes at these locations reflect the needs of the coastal managers through an appropriate choice of coastal state indicator and threshold values.

5. References

Bradbury, A., 2010. Monitoring of Beaches. Chapter 5 of The Beach Management Manual. CIRIA Manual C685.

European Commission, 2004. *Living with coastal erosion in Europe – Sediment and space for sustainability.* Luxembourg office for official publications of the European Commission. ISBN 92-894-7496-3.

Hall, J.H., Sayers, P.B., Walkden, M.J.A. and M. Panzeri, 2006. Impacts of climate change on coastal flood risk in England and Wales: 2030 – 2100. *Phil. Trans. R. Soc. A.* 364: 1027 – 1049.

Hanson, H., Brampton, A., Capobianco, M., Dette, H.H., Hamm, L., Laustrup, C., Lechuga, A. and R. Spanhoff, 2002. Beach nourishment projects, practices and objectives – a European overview. *Coastal Engineering* 47(2): 81 – 111.

Kemp, J. A. and Brampton, A.H. (2007). The development of a time trend analysis tool for GIS and its application in the assessment of Nash Bank, South Wales. *Journal of Hydroinformatics. Vol 9 No 3 pp 193–201.*

Lee, E.M. and Clark, A.R., 2002. *Investigation and management of soft rock cliffs.* Thomas Telford, London, pp 382.

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

Marchand, M. (Ed.) 2010. *Concepts and Science for Coastal Erosion Management. Concise report for policymakers.* Deltares, Delft.
At http://www.conscience-eu.net/documents/concise-report-final.pdf
See also http://www.conscience-eu.net/guidelines/index.htm

Ordnance Survey, 1882. *OS 307 Instructions to Surveyors*. Ordnance Survey, Southampton, UK.

Royal Haskoning, British Geological Survey, University of Sussex and Newcastle University, 2007. Understanding and predicting beach morphological change associated with the erosion of cohesive shore platforms. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Technical Report FD1926/TR. Available from:
http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD1926_6523_TRP.pdf

Rosati, J. and Kraus, N.C., 2001. Sediment Budget Analysis System (SBAS): upgrade for regional applications. ERDC/CHL CHETN-XIV-3 pp13. US Army Engineer

Research and Development Centre, Vicksburg, MS. Internet: http://chl.wes.army.mil/library/publications/chetn

SCOPAC (2003) South Downs Sediment Transport Study. http://stream.port.ac.uk/environment/scopac5/index.htm

Stripling, S. and Panzeri, M.C. "Modelling shoreline evolution to enhance flood risk assessment" *Proceedings of the ICE - Maritime Engineering*, Volume 162, Issue 3, September 2009, pp 137 –144.

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., 2010a. Inventory of coastal monitoring methods and overview of predictive models for coastal evolution. CONSCIENCE Deliverable D1 at http://www.conscience-eu.net/documents

Sutherland, J., 2010b. Assessment of data needs for coastal state indicators. CONSCIENCE Deliverable D10 at http://www.conscience-eu.net/documents

Sutherland, J., 2010c. Coastal sediment management tools. CONSCIENCE Deliverable D14 at http://www.conscience-eu.net/documents

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., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan, Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278. See also http://woodshole.er.usgs.gov/project-pages/DSAS/version4/index.html.

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

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., Stive, M.J.F. and Mulder, J.P.M., 2004. *Balancing research efforts and management needs. A challenge for coastal engineering.* In Proceedings of the 29th Int Conf Coastal Engineering, pp 2985 – 2997.

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.

van Rijn, 2010a. Coastal erosion control based on the concept of sediment cells. CONSCIENCE Deliverable D13a at http://www.conscience-eu.net/documents/deliverable13a-controlling.pdf

van Rijn, 2010b. Modelling erosion of gravel/shingle beaches and barriers. CONSCIENCE deliverable D13b at http://www.conscience-eu.net/documents/deliverable13b-modelling.pdf

van Rijn, 2010c. Modelling erosion of sandy beach and dune erosion. CONSCIENCE deliverable D13c at http://www.conscience-eu.net/documents/deliverable13c-modelling.pdf

Zhang, K., Huang, W., Douglas, B.C. and Leatherman, S., 2002. Shoreline position variability and long-term trend analysis. *Shore and Beach* 70(2) 31 – 35.