Concepts and Science for Coastal Erosion Management

Specific Targeted Research Project

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

Coastal Sediment Management Tools

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Executive Summary

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 computer languages.

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. GISs can input and export in different data formats, can undertake spatial analysis, conduct spatial queries and model three-dimensional surfaces (although this is not always as well developed as in specialist DTM software). GISs are being developed for the particular requirements of data having both temporal and spatial variations, which is important for beach management.

The experience of the pilot sites within the EC-funded research project 'Concepts and Science for Coastal Erosion Management', CONSCIENCE[1], 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 could 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 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 coastal management tools 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.

[1] http://www.conscience-eu.net/

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1. Introduction

1.1. Background and report contents

Concepts and Science for Coastal Erosion Management (commonly known as CONSCIENCE) is an EC-funded research project carried out by eight organisations, coordinated by Deltares (NL). The overall objective of CONSCIENCE was 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)[2]. The project has developed 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/.

This report is a review of the types of sediment management tools that are in use. These tools have been characterised into the following categories in Section 2 of this report:

- Beach level data analysis;
- Shoreline data analysis;
- Sediment budget analysis;
- Coastal system mapping,

The experience of using sediment management tools at the six CONSCIENCE field sites is presented in Section 3, with an emphasis on tools used to derive coastal state indicators (CSIs) as discussed in Section 1.2. A discussion and conclusions are given in Section 4.

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 1, while descriptions of the sites and the problems to be addressed there can be found on the web-site (http://www.conscience-eu.net/).

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

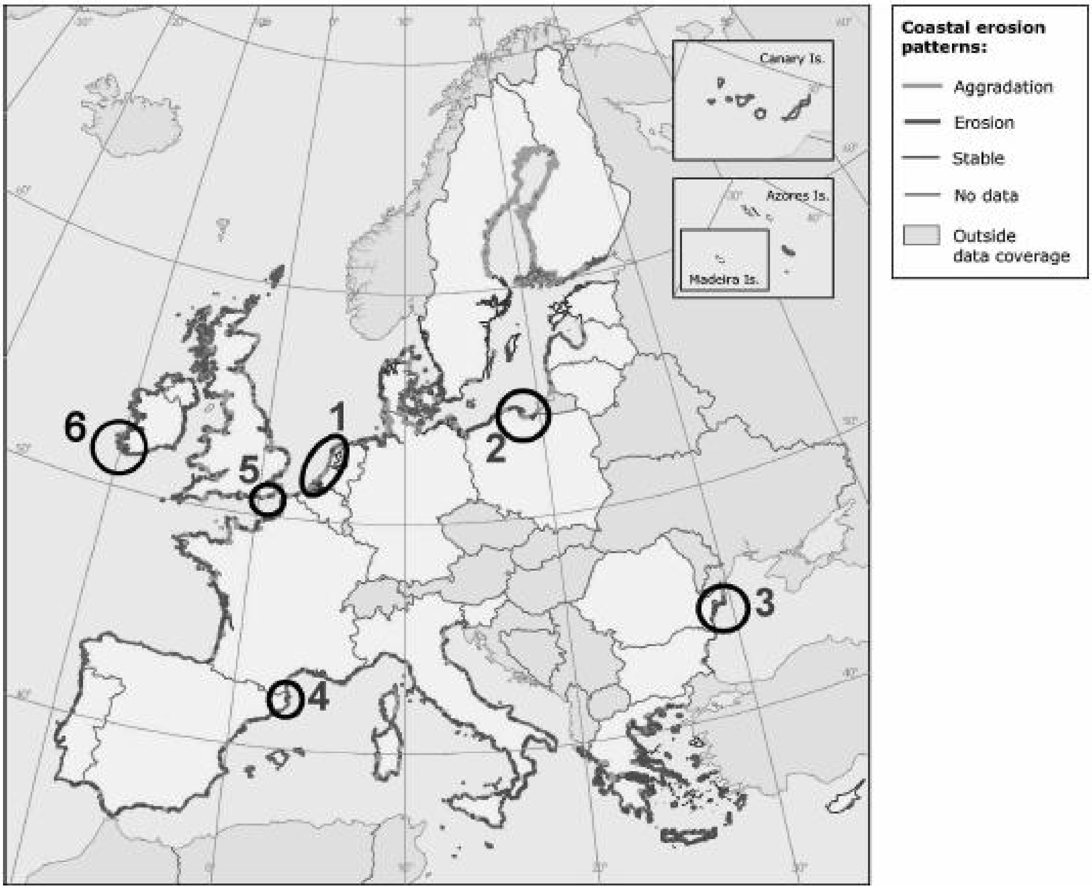


Figure 1 Field sites in CONSCIENCE

1.2. Coastal State Indicators

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 CONSCIENCE deliverable D10 'Assessment of Data Needs for Coastal State Indicators', which is available from the web-site (http://www.conscience-eu.net/).

This paper looks at the coastal state indicators (CSIs) used in the management of coastal erosion at six contrasting sites that cover a range of coastal types, hydrodynamic conditions and management systems. Indicators have been used in many fields, including coastal zone management, (Martí et al 2007, van Koningsveld *et al.*, 2005) to assess progress in implementing a policy. Indicators are used to enable scientific knowledge to be communicated to decision makers. They are not simply data. There have been many definitions of 'indicator' and here the definition of coastal state indicator (CSI) used in the CoastView project (van Koningsveld *et al.,* 2005) has been adopted:

Coastal State Indicators are 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)."

Under this definition, 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. Coastal state indicators are used to assist the coastal manager to implement a policy (or to assess how effective an implementation has been).

2. Review of coastal sediment management tools

The tools listed in this section are examples of tools used for sediment or beach management that are in use generally.

2.1. Beach level data analysis

Improving our understanding of beach and nearshore seabed evolution often involves the collection of very large amounts of data. This inevitably covers large areas, and necessitates frequent and repeated surveys. GIS is commonly used by coastal managers to manage, display and analyse coastal, estuarine and riverine data. It is an ideal tool to deal with the spatial variability of the data. However most landforms within these environments also experience temporal variation, and this makes time trend analysis an important requisite if coastal landform evolution is to be understood. However, GIS techniques have not traditionally been able to calculate the change in values over time; and instead a simple but perhaps misleading technique has been used. (This is where a Digital Terrain Model (DTM) created for a given survey is subtracted from an earlier one). The net result of this calculation is purely the difference in levels between two "snapshots" of bathymetries or beaches in time. It gives no indication of the variation of the levels between these two snapshots, and yet is often misinterpreted to illustrate the time trend of the data.

One way to avoid this problem is to extract the levels for each DTM at each individual cell, plot them in a graph and perform a linear regression analysis on them. Clearly this is very time-consuming, particularly since many DTM's consist of over 10,000 data cells; also this method does not indicate the spatial distribution of the time trends. New trend analysis tools, such as HR Wallingford's Trend Analysis and Management Tool (TrendAMaT, Kemp and Brampton, 2007), are starting to combine time trend analysis with the GIS spatial distribution and to show the changes in bed-level (or any other parameter) both spatially and temporally. This provides new information on coastal landform evolution, as shown in Figure 2. GIS tools use colours to map the trends they have calculated for tens of thousands of individual data points across the area of interest. This indicates the areas of high variability. Such tools are being designed for use by for coastal practitioners and provide a time-saving, analytical means of processing datasets of ever increasing size.

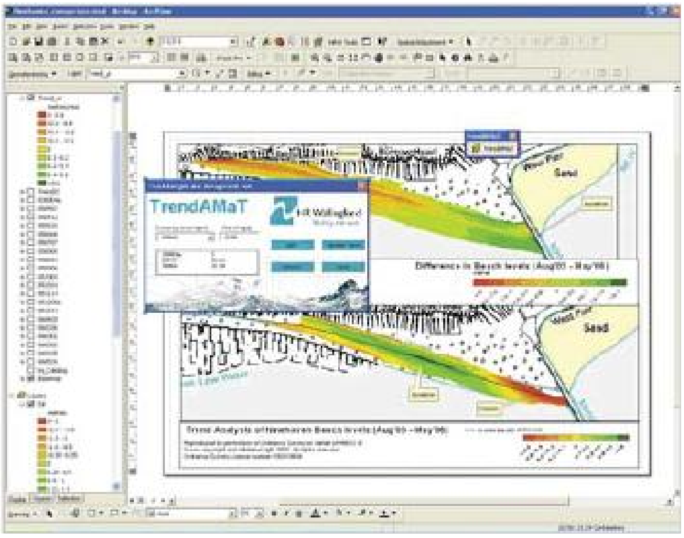


Figure 2 Beach level trend analysis within a GIS

Other packages, such as HR Wallingford's Beach Data Analysis System (BDAS) Halcrow's Shoreline and Nearshore Data System (SANDS) and Deltares' Universal Coastal Intelligence Toolkit (UCIT, van Koningsveld et al, 2004) can be used to analyse repeated measurements of cross-shore beach profiles. Statistical analysis of repeated measurements of the same profile can be used to establish the profile's variability and to predict likely maximum or minimum levels. They may also be used for trend analysis, whether of the elevation at a particular position, profile position at a chosen elevation or cross-sectional area under a profile.

Of the above packages only UCIT (van Koningsveld et al, 2004) was designed to integrate measurement data and model results to calculate coastal state indicators, thereby linking the measurements and the scientific knowledge to the strategic and tactical management objectives (see also Sutherland, 2010).

2.2. Shoreline data analysis

The analysis of historic shorelines within a GIS can be undertaken in a similar way to the analysis of beach level data. Shoreline positions can be digitised from a variety of sources, such as historic and recent maps or charts, digital orthophotos, satellite imagery, or by extracting a contour from a Digital Terrain Model (DTM). Different features may be mapped, according to the data available. Examples include high water level, low water level or cliff edge position from maps, but can also include proxy shorelines such as the vegetation line.

Shoreline positions may be converted into shoreline changes by defining a baseline, generating orthogonal transects at set intervals, locating the shoreline position on a transect and calculating the change in position. Rates of change are then determined using regression analysis. The significance of the calculated rates of change depends on the signal to noise ratio. This can be improved by increasing the length of the series or by carefully selecting the data to be analysed. The former is limited by the length of the historic record. The latter can be improved by judicious choice of survey timing (HR Wallingford, 2008).

In the UK, for example, historical Ordnance Survey maps can be used to see how tidelines have changed over potentially more than 100 years. There are problems with the use of such data, particularly when different data sources are combined within the same analysis (Ruggiero et al, 2003) and it is important to understand the limitations of the data before an analysis is undertaken. Estimates of the total uncertainty in shoreline position are a combination of source uncertainty, interpretation uncertainty and natural short-term variability (Ruggiero et al., 2003). An analysis of the errors associated with using UK Ordnance Survey map data to calculate shoreline change can be found in HR Wallingford (2006) summarised by Sutherland et al (2008).

Long-term shoreline change rates can be determined using linear regression on cross-shore position versus time data. Douglas and Crowell (2000) have shown that simple regression is superior to end-point rate and complex statistical methods for calculating shoreline erosion rates. Genz et al. (2007) reviewed methods of fitting trend lines, including using end point rates, the average of rates, ordinary least squares (including variations such as jackknifing, re-weighted least squares, weighted least squares and weighted re-weighted least squares) and least absolute deviation (with and without weighting functions). Genz et al. recommended that weighted methods should be used if uncertainties are understood, but not otherwise. The ordinary least squares, re-weighted least squares, jackknifing and least absolute deviation methods were preferred (with weighting, if appropriate). If the uncertainties are unknown or not quantified then the least absolute deviation method should be preferred. Several of the favoured analysis methods are implemented in the USGS Digital Shoreline Analysis System (Thieler et al, 2008)

2.3. Sediment Budget Analysis

The cause of coastal erosions is an imbalance in the sediment budget of the coastline. On geological time scales, coastal evolution is governed by balance between sediment supply and sea level rise (Valentin, 1952) as illustrated in Figure 3. It is common practice to construct a sediment budget for a stretch of coast, to aid in developing an understanding of the cause of coastal erosion or accretion. A sediment budget is a representation of all sources, losses and stores of sediment within a specified area. These areas are sometimes known as cells, although this is not the same as a sediment cell, which contains all sources, pathways and sinks, in contrast to the specified area for a sediment budget, which normally does not.

Figure 3 Coastal evolution is a function of sediment supply and sea level rise

Potential gains and losses of sediment include the following, illustrated in schematic form in Figure 4:

- Qbs = supply of beach sediment caused by erosion of backshore feature, such as a cliff or dune system or potentially by Aeolian transport;
- Qbl = loss of beach sediment to backshore by Aeolian sediment transport or overwash (particularly if backshore is low-lying, including lagoons);
- Qrs = supply of beach sediment from a river;
- Qls = supply of beach sediment by longshore drift, which is likely to occur under different conditions at each longshore end of the sediment budget area;
- Qll = loss of sediment by longshore drift, which is likely to occur under different conditions at each longshore end of the sediment budget area;
- Qps = supply of sediment by erosion of shore platform. It has been estimated that about 2/3 of the supply of mobile beach sediment along the Holderness coastline (east of England) comes from the erosion of the shore platform, with only 1/3 of the supply coming from the cliff;
- Qos = supply of sediment to beach from offshore source;
- Qol = loss of sediment to deep water (often a sink);
- Qns = supply of beach sediment by nourishment (recharge) or recycling from outside region
- Qnl = loss of beach sediment by recycling out of region.

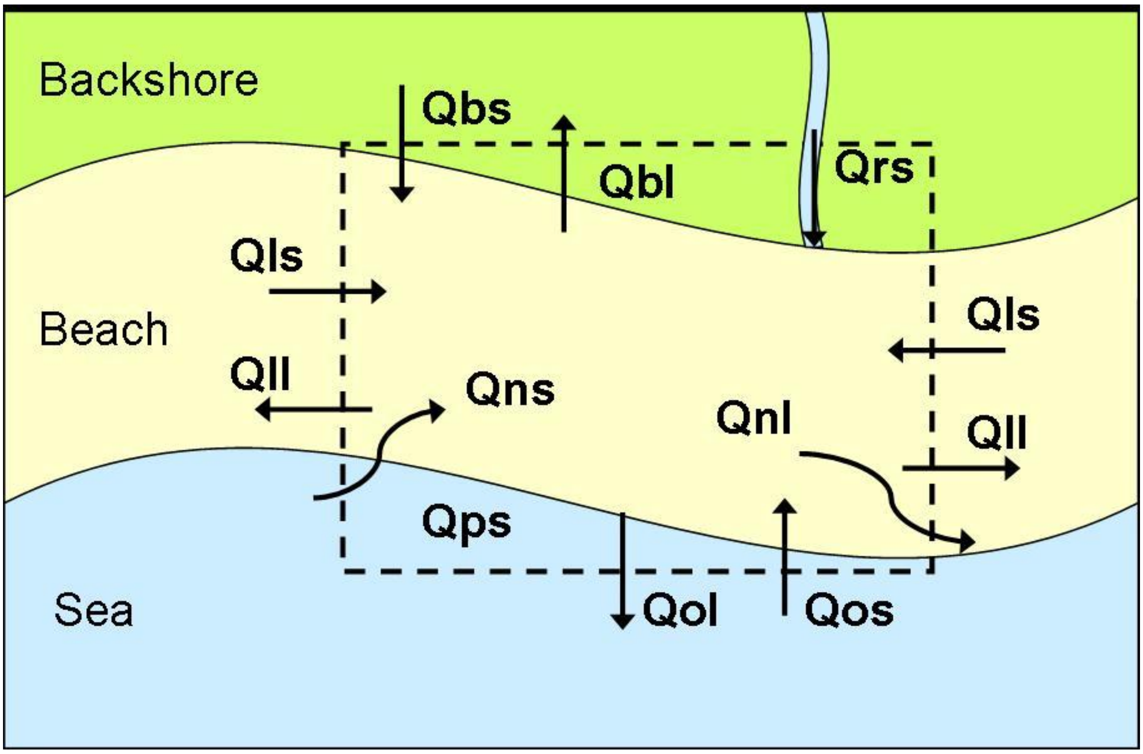


Figure 4 Illustration of a sediment budget

Typically these gains and losses are expressed as metres cubed of sediment per year, but rates of change may also be used.

The overall sediment budget is then:

$$Qbs - Qbl + Qrs + Qls - Qll + Qps + Qos - Qol + Qns - Qnl = \Delta V + R \qquad [1]$$

where:
ΔV = change in volume of beach material (positive being a gain in beach volume); and
R = residual (representing errors in budget).

The residual gives an indication about how well balanced the sediment budget is. The assumption that sediment is conserved implies a residual of zero, so it can be seen as measure of the net error in the other calculations. However, some of the terms in the sediment budget are more difficult to model than others.

For example, the mechanism of onshore sediment supply (perhaps from a nearby sandbank) to the shoreline is poorly understood, while the modelling of the losses of beach sediment into deep water is not robust. Mechanisms such as abrasion, which can lead to the creation of fine material that may be advected away from the beach are also difficult to quantify. In many cases, the supply of beach material from offshore, Qos, and the loss of beach material to offshore, Qol, are not modelled but are used to replace the residual on the right hand side. In other words the sediment balance may be represented as:

$$Qbs - Qbl + Qrs + Qls - Qll + Qps + Qns - Qnl - \Delta V = \Delta Qo \qquad [2]$$

where
ΔQo = nett sediment transfer to offshore = Qol - Qos
and only the terms on the left hand side are calculated.

Advice on the construction of sediment budgets can be found in a number of sources including Rosati and Kraus (1999, 2001). Some approaches, including Rosati and Kraus (1999, 2001) include relative sea level fall as a sediment source (the volume of sediment above sea level, or a datum related to sea level such as the depth of closure, increases) and treat relative sea level rise as a sink (the volume of sediment above sea level, or a datum related to sea level such as the depth of closure, decreases). Other approaches do not.

A series of linked sediment budgets can be an important part in managing sediment at a regional scale (perhaps that of the littoral sediment cell). They can be included in a GIS to indicate their spatial extent and to identify the areas of erosion against a background of a map or photograph which assists in identifying assets at risk from erosion.

2.4. Coastal System Mapping

Coastal system mapping provides a means of synthesising and formalising scientific understanding of how particular stretches of coast behave (French and Burningham, 2009, Whitehouse et al, 2009). Important sediment sources, stores and sinks are identified and the connectivity of coastal and estuary sub-systems is defined. The resulting maps provide an efficient means of encapsulating scientific understanding in a conceptual model of coastal system behaviour. This provides the basis for deciding the most appropriate spatial scale at which to undertake predictive morphodynamic modelling and aids the specification of model boundaries.

Coastal system mapping also provides a framework for the deployment of predictive models capable of simulating large-scale and long-term coastal morphodynamics. A proof of concept of this has been the coupling of an open coast model, SCAPE (Walkden and Hall, 2005), with an estuary model, ASMITA (Stive et al. 1998; van Goor et al. 2003) within the system mapping framework (Walkden and Rossington, 2009).

Coastal system mapping has been developed as a two-stage process. The first stage involves conceptualisation of the coastal system in terms of a set of discrete components and representation of the interactions between these components in diagrammatic form. The components come at two levels: larger scale features and smaller-scale elements (which make up the features). All are still at the level of landforms.

The second stage of the coastal system mapping process involves analysis of the network properties of the system diagram to derive quantitative summary statistics that provide measures of the relative abundance of features and elements and their interactions. Additional measures of system complexity provide a basis for comparing different maps (such as alternative conceptualisations of the same coastal location or comparisons of maps produced for different sections of coast).

French and Burningham (2009) identified the features as: offshore, open coast, headland, bay, spit, cuspate foreland, inlet, tombolo, barrier island, island, estuary, river, updrift coast and downdrift coast. The elements are sea cliff, coastal dune, coastal lagoon, beach, shore platform, tidal flat, saltmarsh, channel, inlet-associated bank, headland-associated bank, offshore bank, beach ridge, offshore reef, seabed sand, seabed gravel, low ground and high ground. The elements also included the following management interventions to the sediment system: seawall, revetment, detached breakwater, long groyne or jetty, reclamation embankment, groyne, outlet, sediment recharge, sediment bypassing, sediment recycling, beach re-profiling and tide locking. An example of a system map is shown in Figure 5.

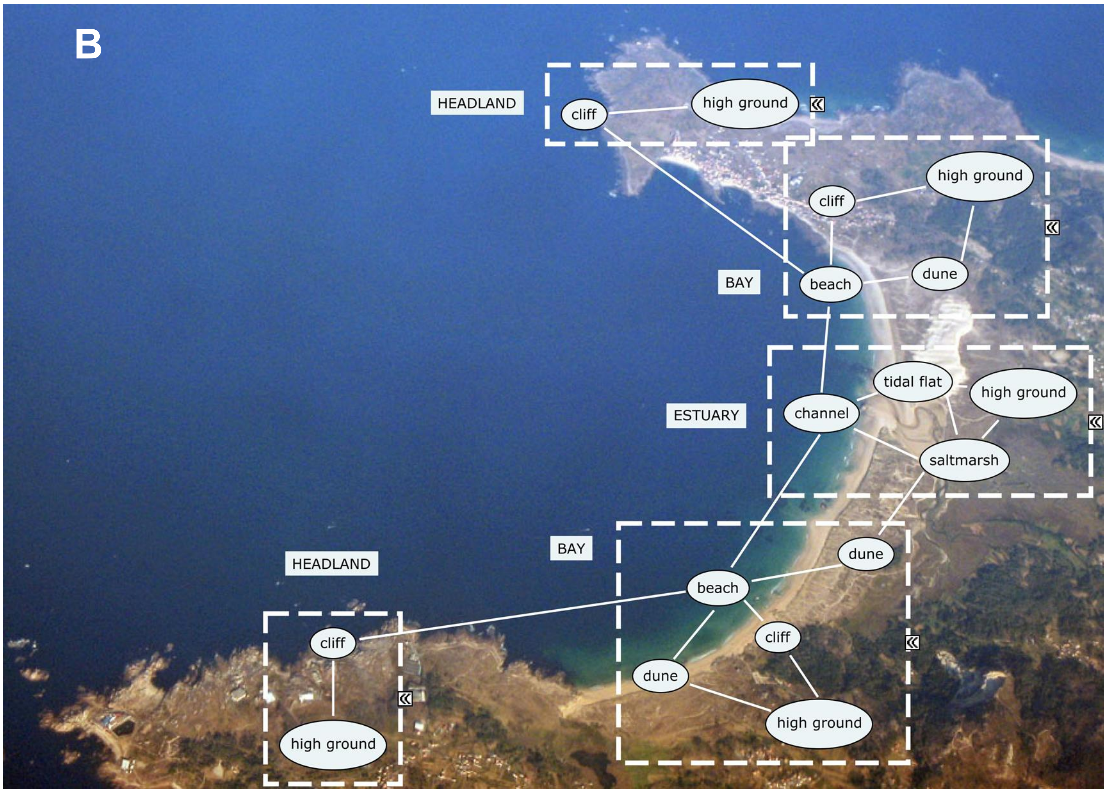


Figure 5 System map showing element-level connectivity with features superimposed

3. Experience of coastal sediment management tools at pilot sites

3.1. The Netherlands

Name of coastal sediment management tool used at pilot site:
WINKUST

Purpose of tool:
1) Determine coastal indicators (see Figures 6 and 7) and erosion rates

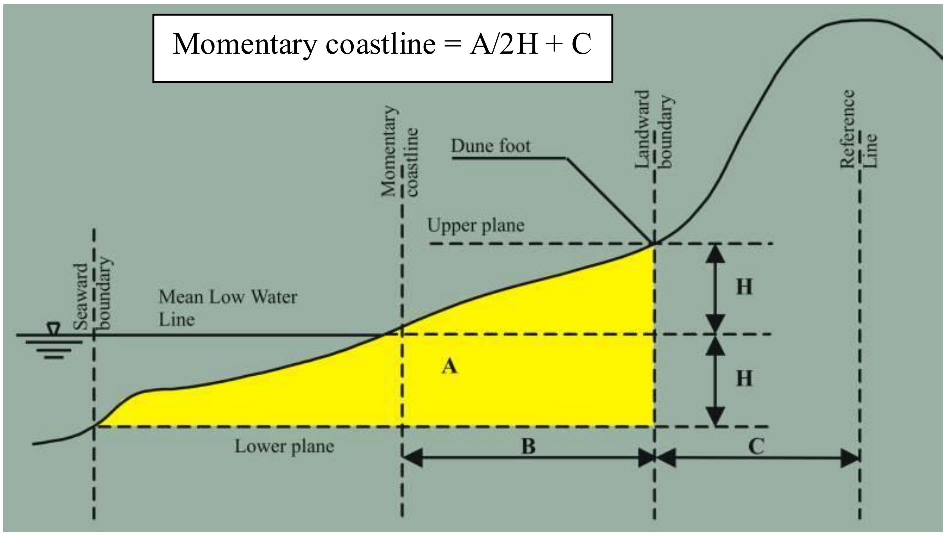


Figure 6 Calculation of momentary coastline

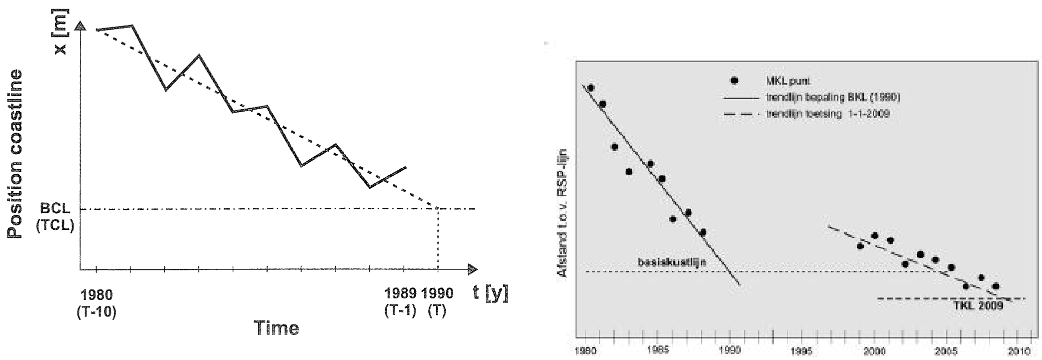


Figure 7 Calculation of testing coastline

2) Testing the water defence system (determine erosion contours under normative conditions , see Figure 8)

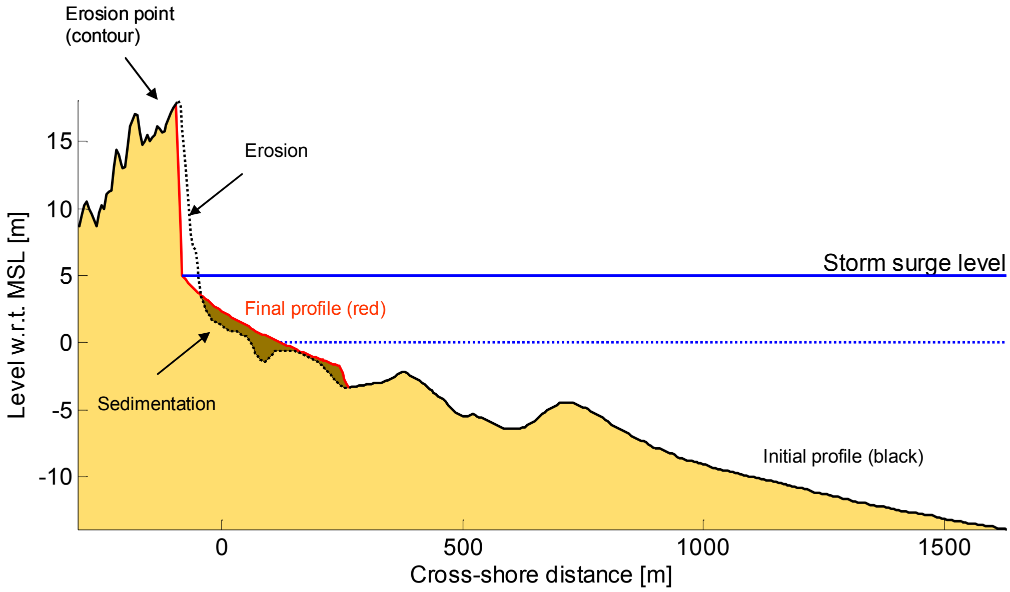


Figure 8 Calculation of erosion due to storm

Brief description of input data:
1) Coastal profiles (depth profiles) and landward boundary and seaward boundary
2) Coastal profiles (depth profiles) and Normative storm surge levels

Is tool developed in a GIS?
No for the deriviation of indicators, Yes for part of the visualisation (Morphgis)

What Coastal State Indicators are calculated:
1) Observed Erosion rates (sediment volumes)
Momentary Coastline (MCL)
Trend in position of Momentary Coastline
Testing Coastline (TCL) (extrapolation of trend)
2) Predicted Erosion
Erosion point ('afslaglijn' and 'afslagpunt')

How does your tool process data? (related to question above)
1) Data analysis (MCL) and 2) numerical model

Are CSIs compared to a threshold value? (If so, how?)
Yes, with Reference Coastline (BasisKustlijn – BKL) and safety standard.

How is information presented?
Coastal profiles, time graph of indicators .

Finally the MCL results are visualised (GIS) in yearly 'Coastline Book' (in Dutch Kustlijnkaartenboek www.kustlijnkaarten.nl) as shown in Figure 9.

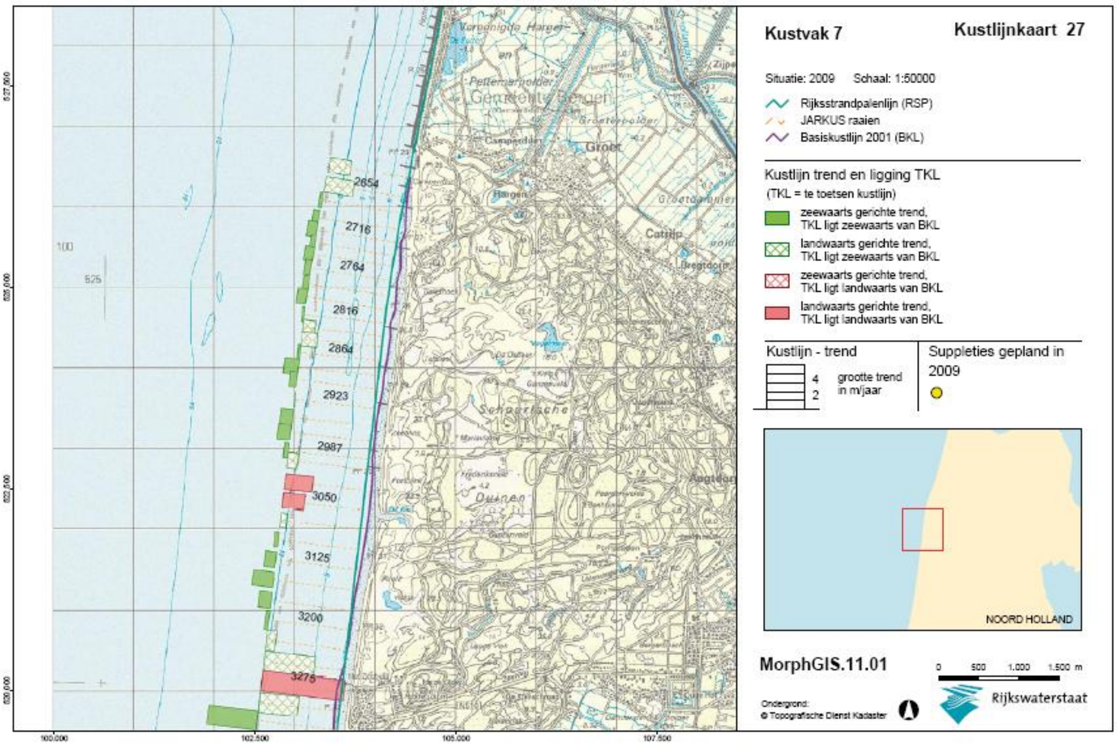


Figure 9 Visualisation of indicators along Dutch coast

How often is this tool run at your pilot site?
1) Once a year for MCL
2) Once every five year for defence system

Who normally runs it?
1) Ministry of Transport, Public Works and Watermanagement for MCL

2) District Water Board for defence system

How is the data used?
1) To determine nourishment scheme (yearly)
2) To test water defence (every 5 years tested whether safety standards are fulfilled)

3.2. Pevensey Bay

Name of coastal sediment management tool used at pilot site: LSS, a DTM software written by McCarthy Taylor Systems Ltd (http://www.dtmsoftware.com).

Purpose of tool:
Processes GPS x,y,z survey data

Brief description of input data:
Beach surveys are completed using Trimble R8 GNSS receiver mounted on an ATV. Data is collected at 1 second intervals as the ATV is driven over the beach at low water, generally following contour lines.

Is tool developed in a GIS? Yes / No
Yes. GIS modelling and volumetric calculations are generally considered to be less robust than those written by LSS. Output results are incorporated into GIS for analysis and display.

What Coastal State Indicators are calculated:
1. Position of 5m contour at front and rear of embankment
2. Section volumes for 53 discrete areas
3. Overall volume of 9km long embankment

How does your tool process data? (related to question above)
Builds 3D model of beach surface then extracts position of 5m contour(s) and calculates volumes to defined boundaries for each required area

Are CSIs compared to a threshold value? (If so, how?)
Yes. Pevensey CSIs were fixed relative to surveys undertaken in June 1999, reinforced by improvement works in some vulnerable areas. All three CSIs identified above are then checked to tolerances based on a maximum 5m crest recession

How is information presented?
Usually in tabular form, as beach volumes are most compared output, as shown in Figure 10. This survey was made during a stormy period so indicates shortage of material updrift (in west) and hence initiated recycling from east to west. The table consists of a rolling 12 month survey period and identifies shortfalls by cells turning pink, calculating minimum amounts of sediment that need to be delivered.

PEVENSEY COASTAL DEFENCE LIMITED
Monthly Report - November 2009

APPENDIX C

Quad Bike Survey Results
19th + 20th November 2009

Above	Calculations for 5m Crest Recession by Volume																	
0 ABMS	Min KPF	KPF	2008 Dec	2009 Jan	2009 Feb	2009 Mar	2009 Apr	2009 May	2009 Jun	2009 July	2009 August	2009 Sept	2009 Oct	2009 Nov	Allowed Recession	Current KPF cu.m	%	Min Vol Reqd.
569	10,000	11,236	10,019	10,909	8,427	8,500	10,012	10,012	10,004	9,636	22,075	18,796	17,352	11,642	10,112	406	3.6	
570		29,392	20,029	22,477	20,195	19,345	20,999	20,999	21,328	20,462	24,224	23,952	24,168	21,547	22,192	-7,845	-26.7	645
571	34,000	35,373	34,038	34,017	35,099	34,930	34,862	34,862	34,711	34,342	34,688	34,665	33,999	33,554	31,602	-1,818	-5.1	
572		42,840	40,733	40,634	40,191	39,277	39,383	39,383	39,032	39,178	39,563	39,509	39,892	41,984	39,424	-855	-2.0	
573	34,000	36,774	32,287	31,759	30,915	30,907	32,412	32,412	32,540	31,881	32,082	31,835	31,193	30,263	33,271	-6,511	-17.7	3,007
		155,615	137,106	139,796	134,827	132,960	137,668	137,668	137,615	135,500	152,633	148,756	146,604	138,990		-16,624		
574	34,527	36,812	34,240	34,167	33,141	32,791	34,330	34,330	34,422	34,082	34,057	34,195	33,588	33,739	33,958	-3,073	-8.3	219
575	43,195	43,719	39,769	39,765	38,989	38,545	40,082	40,082	39,907	39,648	39,674	39,681	39,513	39,794	40,287	-3,925	-9.0	493
576	22,990	27,266	28,492	26,073	27,089	27,072	26,804	26,804	26,515	26,215	26,529	26,745	26,230	27,435	24,217	169	0.6	
577	21,048	21,623	22,589	20,987	21,996	21,204	21,370	21,370	21,658	21,320	21,408	21,818	21,973	18,848	18,887	-2,775	-12.8	39
578		37,435	36,013	35,915	35,633	35,859	35,984	35,984	35,707	35,582	35,827	35,753	35,832	36,174	34,516	-1,261	-3.4	
579	25,973	26,928	25,516	25,649	25,476	25,573	25,664	25,664	25,434	24,920	25,132	25,183	24,719	24,938	23,641	-1,991	-7.4	
580	29,238	32,687	31,373	31,344	31,862	31,795	32,147	32,147	31,959	31,568	32,125	32,152	31,808	32,061	29,245	-626	-1.9	
581		49,427	49,573	49,368	48,906	48,501	48,712	48,712	48,707	48,040	48,464	48,994	48,530	48,461	45,975	-966	-2.0	
582		38,200	38,493	38,698	39,003	38,779	39,007	39,007	38,657	38,442	38,961	38,849	38,676	38,384	35,129	184	0.5	
583		17,145	18,500	16,834	17,200	17,613	17,999	17,999	17,339	16,962	17,351	17,185	16,851	18,345	14,759	1,201	7.0	
584	35,906	41,205	41,917	41,713	42,199	41,390	41,436	41,436	41,545	41,401	41,781	41,860	41,643	38,006	37,106	-3,199	-7.8	
585		27,549	26,721	27,023	28,493	28,904	28,801	28,801	28,862	28,754	28,940	29,013	28,642	29,692	24,070	2,144	7.8	
		399,996	393,195	387,535	389,986	388,026	392,337	392,337	390,712	386,935	390,249	391,429	388,004	385,876				

Figure 10 Output Volumes Table (part) for Pevensey

How often is this tool run at your pilot site?

A full beach survey is completed every month. Occasionally two per month during winter storms

Who normally runs it?

Project manager

How is the data used?

Output volumes are used to identify;

1. where beach crest widths are narrow and require reprofiling to return drawn-down sediments to the top of the beach.
2. zones of erosion and accretion so that recycling can be initiated to reinforce depleted areas with shingle sourced from accreting sectors
3. overall losses so that target amounts for annual beach recharge can be calculated.

3.3. Inch Strand, Dingle Bay

Name of coastal sediment management tool used at pilot site:
Models - Wave modelling with MIKE21, Erosion processes nearshore (LITPACK)
GPS Surveys

Purpose of tool:
Compare the actual impact of storm conditions on coastline position with model predictions.
Measure the position of the coast in response to storms / changes in topography using a series of beach profiles.

Brief description of input data:
Bathymetry (derived from charts), Wave parameters (from local deployments and national wave grid), sediment type (CMRC laser granulometry), tide (from tide-tables and corrected for atmospheric conditions).

Is tool developed in a GIS? Yes / No
Not developed in, but can be easily incorporated within a GIS.

What Coastal State Indicators are calculated:
Coastal Position is determined and was compared with the expected position produced from the models and historical maps.

How does your tool process data? (related to question above)
As this is an atypical CSI, the data produced is a series of positions which can then be processed either in a GIS to show position or post-processed in Surfer (for example) to assess changes in height (volume).

Are CSIs compared to a threshold value? (If so, how?)
Coastline position is compared to a historical position but not to any actual threshold value (this is a direct outcome of not conducting routine monitoring)

How is information presented?
The output from Mike 21 can be presented graphically (Figures 11, 12 and 13) but will also create the input data for LITPACK (Figure 14). Comparisons of shore line position have been simply presented using Excel / Grapher or within a GIS (Figure 15).

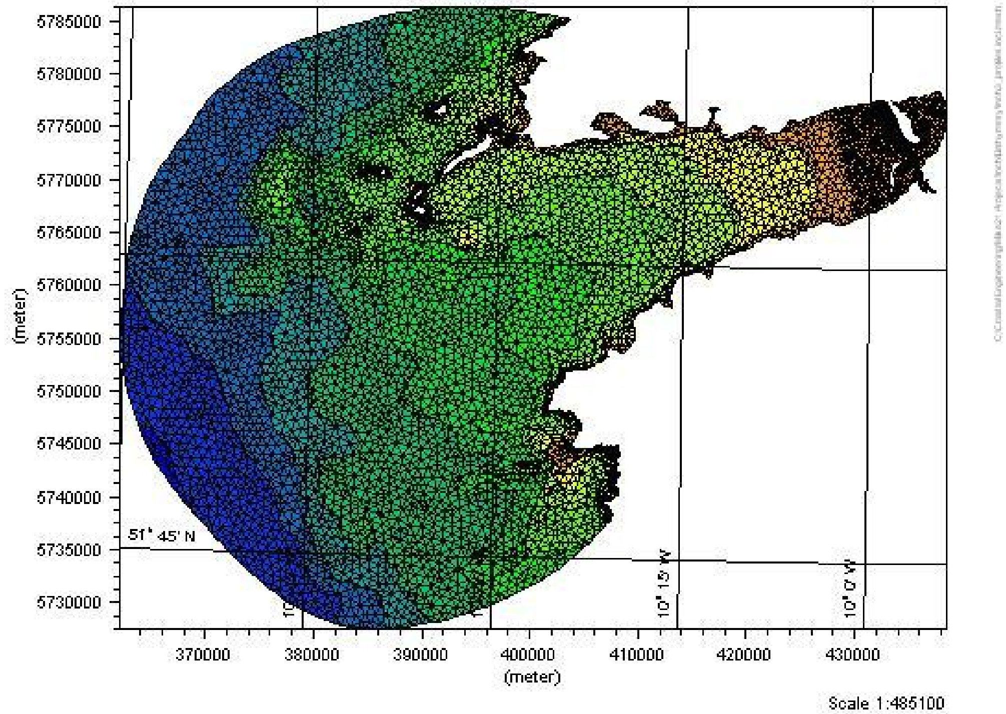


Figure 11 Mike 21 model area

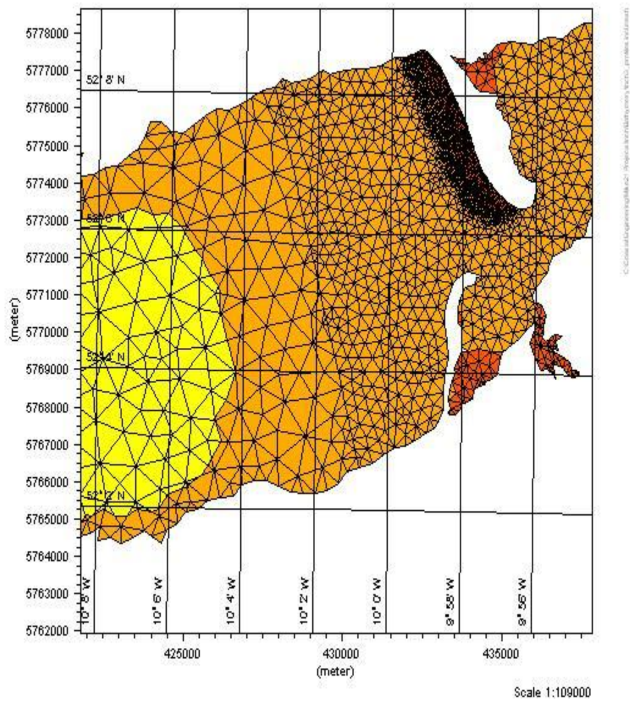


Figure 12 Mike 21 model grid near Inch strand

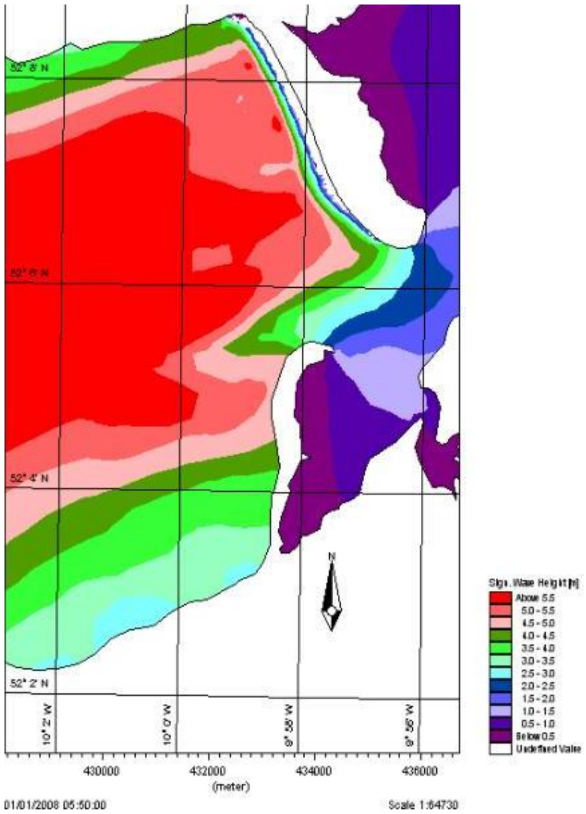


Figure 13 Mike 21 significant wave height

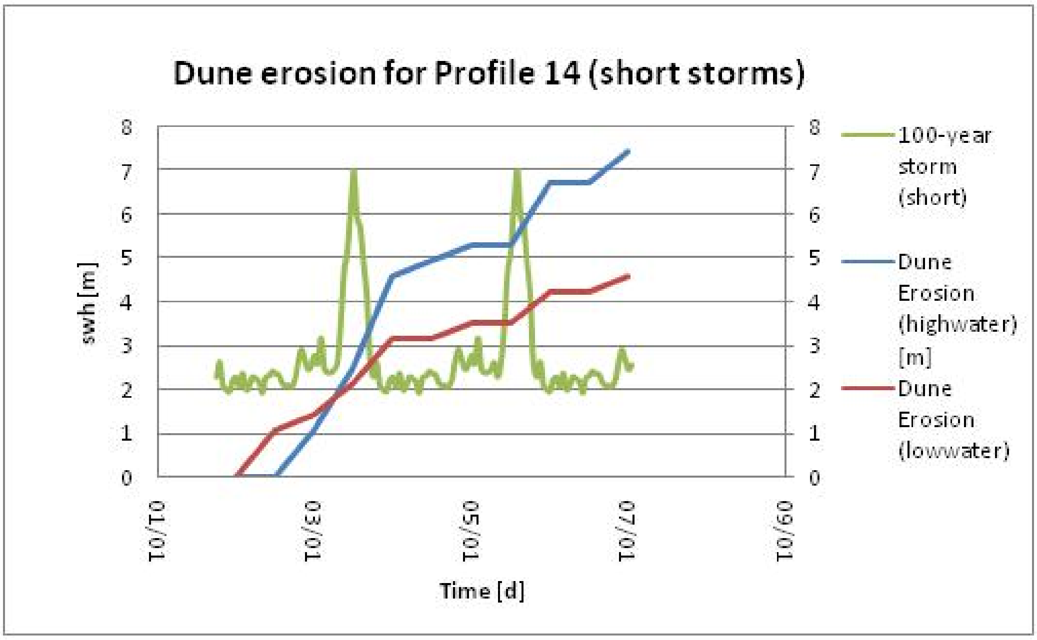


Figure 14 Dune erosion from Litpack model

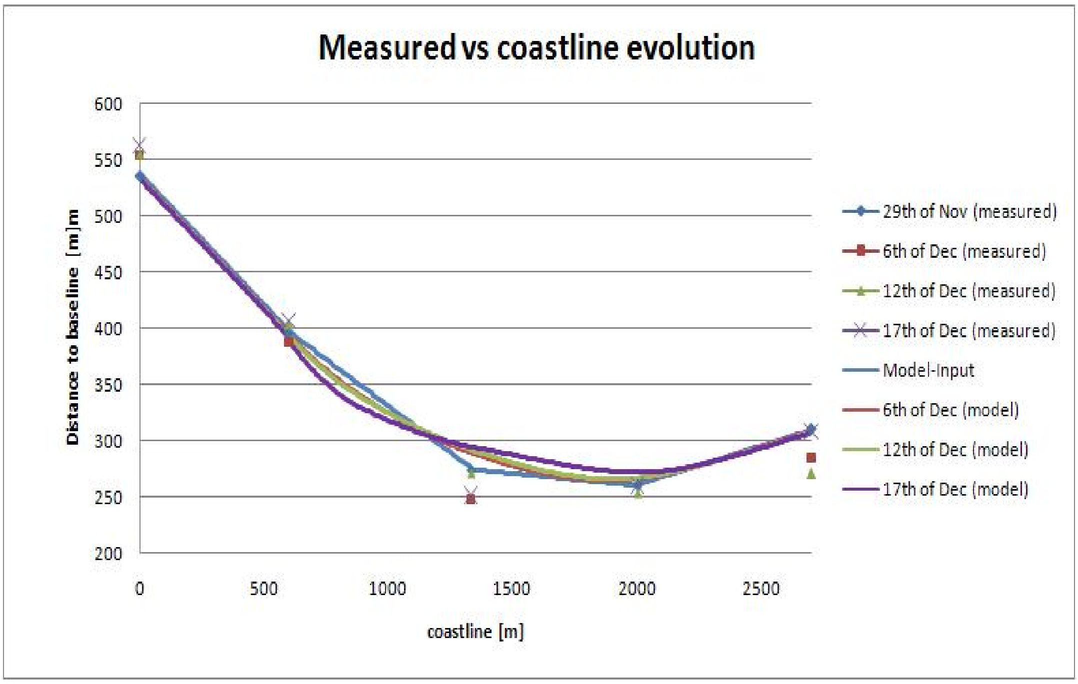


Figure 15 Measured and modelled coastline position

How often is this tool run at your pilot site?
The tool employed is only run as part of scientific projects and therefore the scheduling is of an ad-hoc nature. Whilst the managing authority do have the in-house capacity to conduct shore-line GPS surveys the resources required would have to be drawn from their limited operational budget or in competition with other departments for central funding.

They currently do not have any capacity to conduct modelling but have commissioned the University to carry this out on previous occasions. More recently their budgets have been dramatically slashed so it is difficult to see how any modelling will be done outside the pure research field. The County Council are wholly supportive in the work completed to date and have actively engaged with the project. However they are hamstrung by the lack of a national coastal management (or protection) policy and resources at the national and local level.

Who normally runs it?
HMRC – Hydraulics & Maritime Research Centre, UCC

How is the data used?
The data is not employed in routine management, as there is no beach management programme associated with the calculation of CSIs at this site – especially the types of CSI identified under CONSCIENCE at the other sites.

There is obviously an interest in simulation of differing storm conditions (1 in 100 year events) and this information has been made available to the Authority.

However the (wave gauge / wave modelling) data has been used by the County Council to confirm that the wave climate is in accordance with the design criteria for the coastal protection scheme at the northern end of the strand.

3.4. Hel Peninsula

Name of coastal sediment management tool used at pilot site:
Matlab, Excel

Purpose of tool:
To provide volume of sand estimation for artificial nourishment, sediment transport volumes, shoreline position changes

Brief description of input data:
Bathymetry of the nearshore and shoreline position, wind-wave climate, sediment characteristics

Is tool developed in a GIS? Yes / No
No

What Coastal State Indicators are calculated:
Nearshore beach volume

How does your tool process data? (related to question above)
calculates volume from the area of the available cross-shore profiles multiplied by the spacing of the profiles and summed over the entire shoreline

Are CSIs compared to a threshold value? (If so, how?)
No

How is information presented?
Graphs presenting bathymetry of the area and shoreline position

How often is this tool run at your pilot site?
Each time new data are available

Who normally runs it?
IBW PAN's scientists

How is the data used?
To monitor the effects of the sediment transport processes with respect to strategic and operational objectives

3.5. *Danube Delta coastline*

Name of coastal sediment management tool used at pilot site:
No dedicated sediment management tool is applied at the pilot site.
Shoreline positions are positioned on maps – and distances etc. are computed and stored with the Global Mapper software (developed by Global Mapper Software LLC).
Topography – morphological data are processed and stored as Microsoft Excel files.
The same applies to sedimentology data.
Nevertheless, for the last years there has been a national effort to develop a GIS based tool for the entire Romanian coast, effort still in progress.

Purpose of tool:
See above.

Brief description of input data:
The following types of data are collected – even though not yet centralised in a unitary coastal sediment management tool:

- shoreline position – GPS measurements with GPS Ceeducer sensor mounted on 4 x 4 vehicle, driven at constant speed along the berm crest.
- All morphological features – measured with traditional topographic tools (total station and topo gauge)
- Coastal slope – X,Y,Z data recorded with Ceeducer dual beam and incorporated GPS tool
- Sediment samples – sampled in plastic boxes from the top 2 cm layer.

Is tool developed in a GIS? No
Partially, Global Mapper software has this capability but the existing layers (only for shoreline positions) cannot be considered as a proper GIS.
Nevertheless, for the last years there has been a national effort to develop a GIS based tool for the entire Romanian coast – including also all data from the pilot site. While the efforts have been continuous, the GIS tool is not ready yet (due also to financial constraints from the last 15 months – caused by the severe economic downturn).

What Coastal State Indicators are calculated:

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

How does your tool process data? (related to question above)

Are CSIs compared to a threshold value? (If so, how?)

Coastal managers compare only the shoreline position with previous measured values. No threshold value has been established for the pilot site.

How is information presented?
Maps, graphs, tables, but with no standard format (yet).

How often is this tool run at your pilot site?
Generally once a year

Who normally runs it?
GeoEcoMar and the Grigore Antipa Marine Research Institute are institutions with specialised teams performing the before mentioned surveys.

How is the data used?
Collected and processed data as well as synthetic conclusions are delivered once a year to coastal managers (Danube Delta Biosphere Reserve and Romanian Waters National Authority). Conclusions regarding the state of the coast are also delivered on a yearly basis to the Ministry for the Environment.

Data collected during multiannual campaigns have been integrated in the major studies performed at a national scale to identify coastal dynamics, as well as to offer solutions against coastal erosion. These projects were funded by the Japanese Government (JICA – southern part of the coast) and the US Govt. (USTDA – Danube Delta coast).

3.6. Costa Brava Bays

Name of coastal sediment management tool used at pilot site:
DSAS, an analysis tool developed by USGS (Thieler et al 2005) to be run on ArcGIS 9.0x.
XLINES a excel based tool.

Purpose of tool:
DSAS: To estimate rates of displacement from a set of shorelines at selected control points along the coast.
XLINE: to project beach width at selected given points (using results from DSAS) to estimate the beach width variation and to compare against threshold values.

Brief description of input data:
Shorelines at different time steps as shown in Figure 16. Position of the inner limit of the beach –promenade or waterfront-.

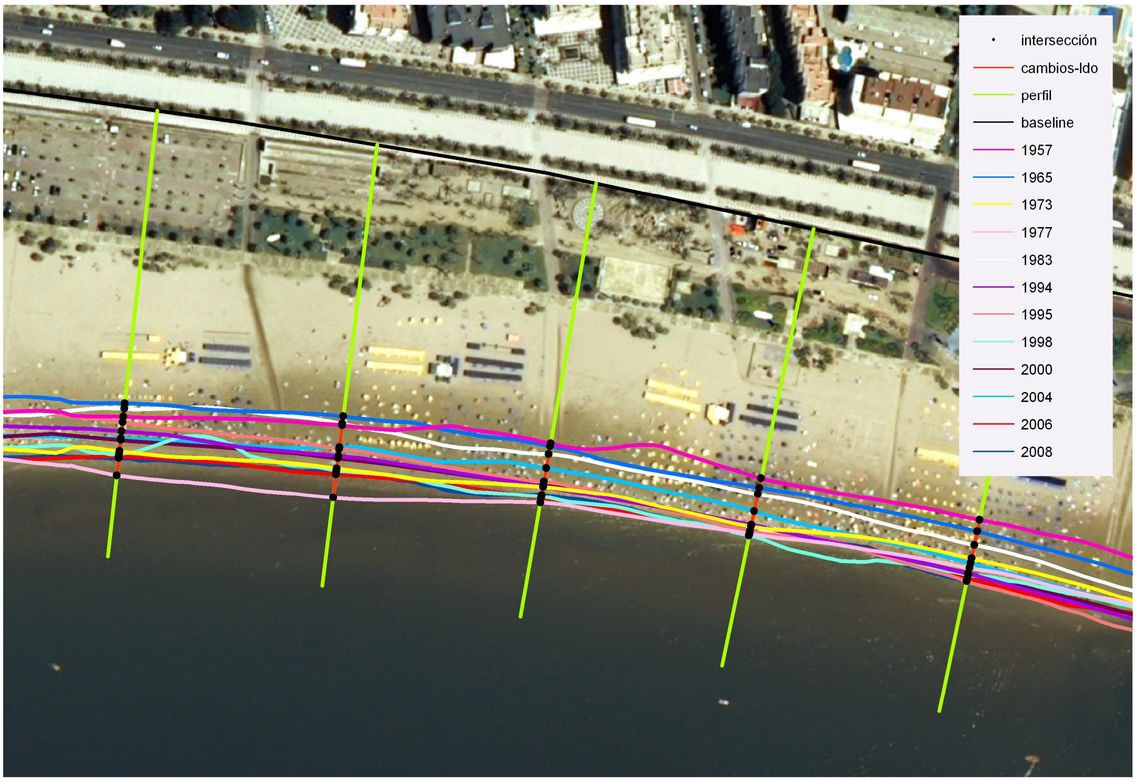
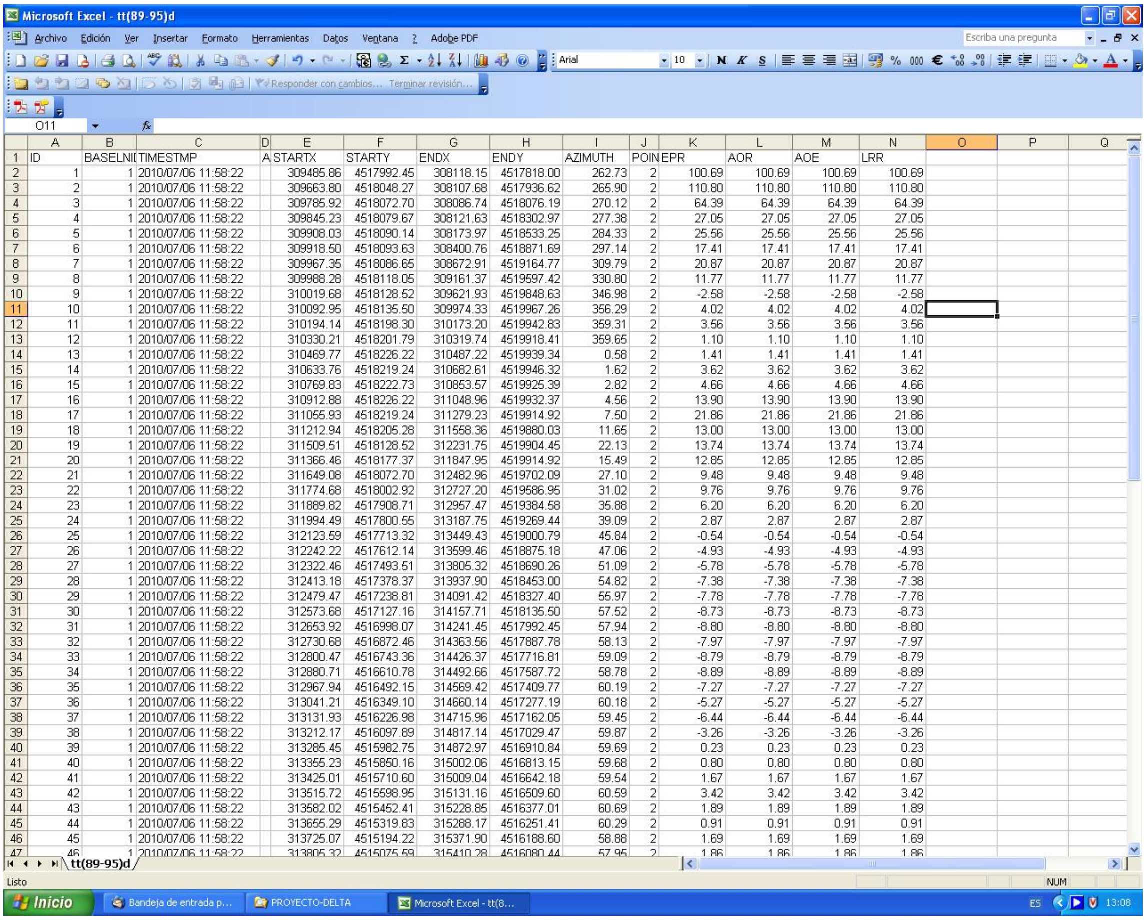


Figure 16 Calculation of rate of displacement at different control points along a beach (coloured lines correspond to different shorelines) by DSAS in ArcGIS 9.0x environment.

Is tool developed in a GIS? Yes / No
Yes. DSAS is a tool for ArcGIS 9.0x.

What Coastal State Indicators are calculated:
Projected beach width.

How does your tool process data? (related to question above)
From a continuously updated shoreline database, rates of displacement are calculated at different (selected) locations along the beach, as shown in Figure 17. For each location and using the actual width as the initial condition, the projected beach width is calculated at selected time horizons.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	ID	BASELNI	TIMESTMP	A	STARTX	STARTY	ENDX	ENDY	AZIMUTH	POIN	EPR	AOR	AOE	LRR
2	1	1	2010/07/06 11:58:22		309485.86	4517992.45	308118.15	4517818.00	262.73	2	100.69	100.69	100.69	100.69
3	2	1	2010/07/06 11:58:22		309663.80	4518048.27	308107.68	4517936.62	265.90	2	110.80	110.80	110.80	110.80
4	3	1	2010/07/06 11:58:22		309785.92	4518072.70	308086.74	4518076.19	270.12	2	64.39	64.39	64.39	64.39
5	4	1	2010/07/06 11:58:22		309845.23	4518079.67	308121.63	4518302.97	277.38	2	27.05	27.05	27.05	27.05
6	5	1	2010/07/06 11:58:22		309908.03	4518090.14	308173.97	4518533.25	284.33	2	25.56	25.56	25.56	25.56
7	6	1	2010/07/06 11:58:22		309918.50	4518093.63	308400.76	4518871.69	297.14	2	17.41	17.41	17.41	17.41
8	7	1	2010/07/06 11:58:22		309967.35	4518086.65	308672.91	4519164.77	309.79	2	20.87	20.87	20.87	20.87
9	8	1	2010/07/06 11:58:22		309988.28	4518118.05	309161.37	4519597.42	330.80	2	11.77	11.77	11.77	11.77
10	9	1	2010/07/06 11:58:22		310019.68	4518128.52	309621.93	4519848.63	346.98	2	-2.58	-2.58	-2.58	-2.58
11	10	1	2010/07/06 11:58:22		310092.95	4518135.50	309974.33	4519967.26	356.29	2	4.02	4.02	4.02	4.02
12	11	1	2010/07/06 11:58:22		310194.14	4518198.30	310173.20	4519942.83	359.31	2	3.56	3.56	3.56	3.56
13	12	1	2010/07/06 11:58:22		310330.21	4518201.79	310319.74	4519918.41	359.65	2	1.10	1.10	1.10	1.10
14	13	1	2010/07/06 11:58:22		310469.77	4518226.22	310487.22	4519939.34	0.58	2	1.41	1.41	1.41	1.41
15	14	1	2010/07/06 11:58:22		310633.76	4518219.24	310682.61	4519946.32	1.62	2	3.62	3.62	3.62	3.62
16	15	1	2010/07/06 11:58:22		310769.83	4518222.73	310853.57	4519925.39	2.82	2	4.66	4.66	4.66	4.66
17	16	1	2010/07/06 11:58:22		310912.88	4518226.22	311048.96	4519932.37	4.56	2	13.90	13.90	13.90	13.90
18	17	1	2010/07/06 11:58:22		311055.93	4518219.24	311279.23	4519914.92	7.50	2	21.86	21.86	21.86	21.86
19	18	1	2010/07/06 11:58:22		311212.94	4518205.28	311558.36	4519880.03	11.65	2	13.00	13.00	13.00	13.00
20	19	1	2010/07/06 11:58:22		311509.51	4518128.52	312231.75	4519904.45	22.13	2	13.74	13.74	13.74	13.74
21	20	1	2010/07/06 11:58:22		311366.46	4518177.37	311847.95	4519914.92	15.49	2	12.85	12.85	12.85	12.85
22	21	1	2010/07/06 11:58:22		311649.08	4518072.70	312482.96	4519702.09	27.10	2	9.48	9.48	9.48	9.48
23	22	1	2010/07/06 11:58:22		311774.68	4518002.92	312727.20	4519586.95	31.02	2	9.76	9.76	9.76	9.76
24	23	1	2010/07/06 11:58:22		311889.82	4517908.71	312957.47	4519384.58	35.88	2	6.20	6.20	6.20	6.20
25	24	1	2010/07/06 11:58:22		311994.49	4517800.55	313187.75	4519269.44	39.09	2	2.87	2.87	2.87	2.87
26	25	1	2010/07/06 11:58:22		312123.59	4517713.32	313449.43	4519000.79	45.84	2	-0.54	-0.54	-0.54	-0.54
27	26	1	2010/07/06 11:58:22		312242.22	4517612.14	313599.46	4518875.18	47.06	2	-4.93	-4.93	-4.93	-4.93
28	27	1	2010/07/06 11:58:22		312322.46	4517493.51	313805.32	4518690.26	51.09	2	-5.78	-5.78	-5.78	-5.78
29	28	1	2010/07/06 11:58:22		312413.18	4517378.37	313937.90	4518453.00	54.82	2	-7.38	-7.38	-7.38	-7.38
30	29	1	2010/07/06 11:58:22		312479.47	4517238.81	314091.42	4518327.40	55.97	2	-7.78	-7.78	-7.78	-7.78
31	30	1	2010/07/06 11:58:22		312573.68	4517127.16	314157.71	4518135.50	57.52	2	-8.73	-8.73	-8.73	-8.73
32	31	1	2010/07/06 11:58:22		312653.92	4516998.07	314241.45	4517992.45	57.94	2	-8.80	-8.80	-8.80	-8.80
33	32	1	2010/07/06 11:58:22		312730.68	4516872.46	314363.56	4517887.78	58.13	2	-7.97	-7.97	-7.97	-7.97
34	33	1	2010/07/06 11:58:22		312800.47	4516743.36	314426.37	4517716.81	59.09	2	-8.79	-8.79	-8.79	-8.79
35	34	1	2010/07/06 11:58:22		312880.71	4516610.78	314492.66	4517587.72	58.78	2	-8.89	-8.89	-8.89	-8.89
36	35	1	2010/07/06 11:58:22		312967.94	4516492.15	314569.42	4517409.77	60.19	2	-7.27	-7.27	-7.27	-7.27
37	36	1	2010/07/06 11:58:22		313041.21	4516349.10	314660.14	4517277.19	60.18	2	-5.27	-5.27	-5.27	-5.27
38	37	1	2010/07/06 11:58:22		313131.93	4516226.98	314715.96	4517162.05	59.45	2	-6.44	-6.44	-6.44	-6.44
39	38	1	2010/07/06 11:58:22		313212.17	4516097.89	314817.14	4517029.47	59.87	2	-3.26	-3.26	-3.26	-3.26
40	39	1	2010/07/06 11:58:22		313285.45	4515982.75	314872.97	4516910.84	59.69	2	0.23	0.23	0.23	0.23
41	40	1	2010/07/06 11:58:22		313355.23	4515850.16	315002.06	4516813.15	59.68	2	0.80	0.80	0.80	0.80
42	41	1	2010/07/06 11:58:22		313425.01	4515710.60	315009.04	4516642.18	59.54	2	1.67	1.67	1.67	1.67
43	42	1	2010/07/06 11:58:22		313515.72	4515598.95	315131.16	4516509.60	60.59	2	3.42	3.42	3.42	3.42
44	43	1	2010/07/06 11:58:22		313582.02	4515452.41	315228.85	4516377.01	60.69	2	1.89	1.89	1.89	1.89
45	44	1	2010/07/06 11:58:22		313655.29	4515319.83	315288.17	4516251.41	60.29	2	0.91	0.91	0.91	0.91
46	45	1	2010/07/06 11:58:22		313725.07	4515194.22	315371.90	4516188.60	58.88	2	1.69	1.69	1.69	1.69
47	46	1	2010/07/06 11:58:22		313805.32	4515075.59	315410.28	4516080.44	57.95	2	1.86	1.86	1.86	1.86

Figure 17 Results of the application of DSAS. Rate of displacement (calculated by different methods) at different control points along a beach)

Are CSIs compared to a threshold value? (If so, how?)
Yes. Projected beach width at the different locations are compared against threshold widths for protection and recreation function, as shown inn Figure 18. In the first case, it is compared against the beach width to be eroded by a storm associated to a given probability

(return period). In the second case, it is compared against the optimum width from a recreational standpoint (associated to a given density of use).

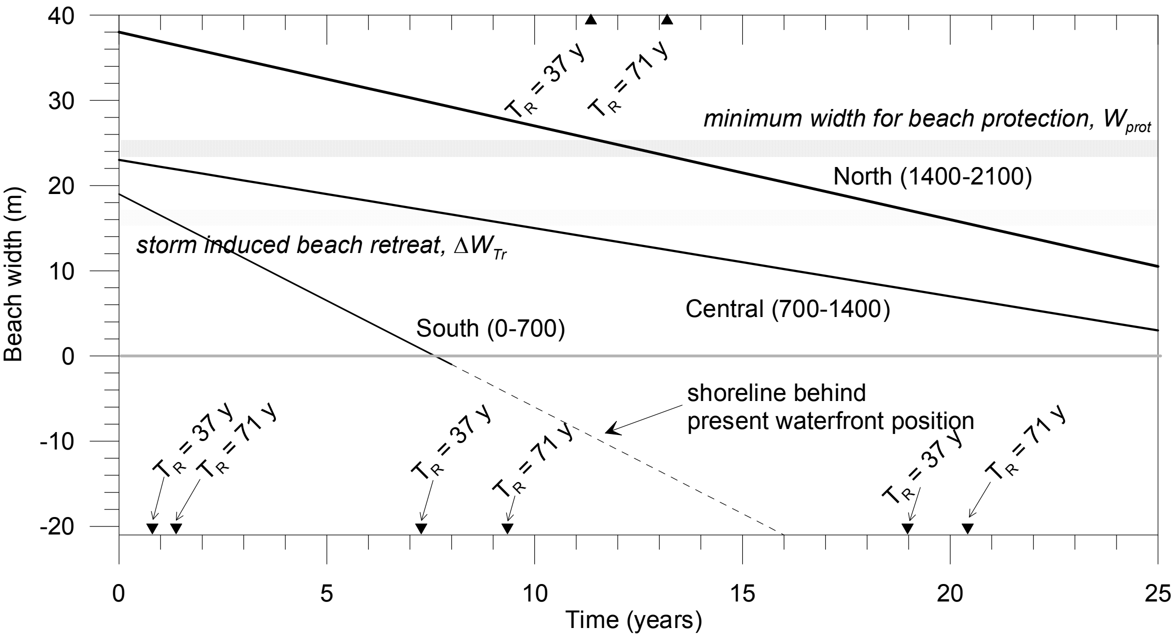
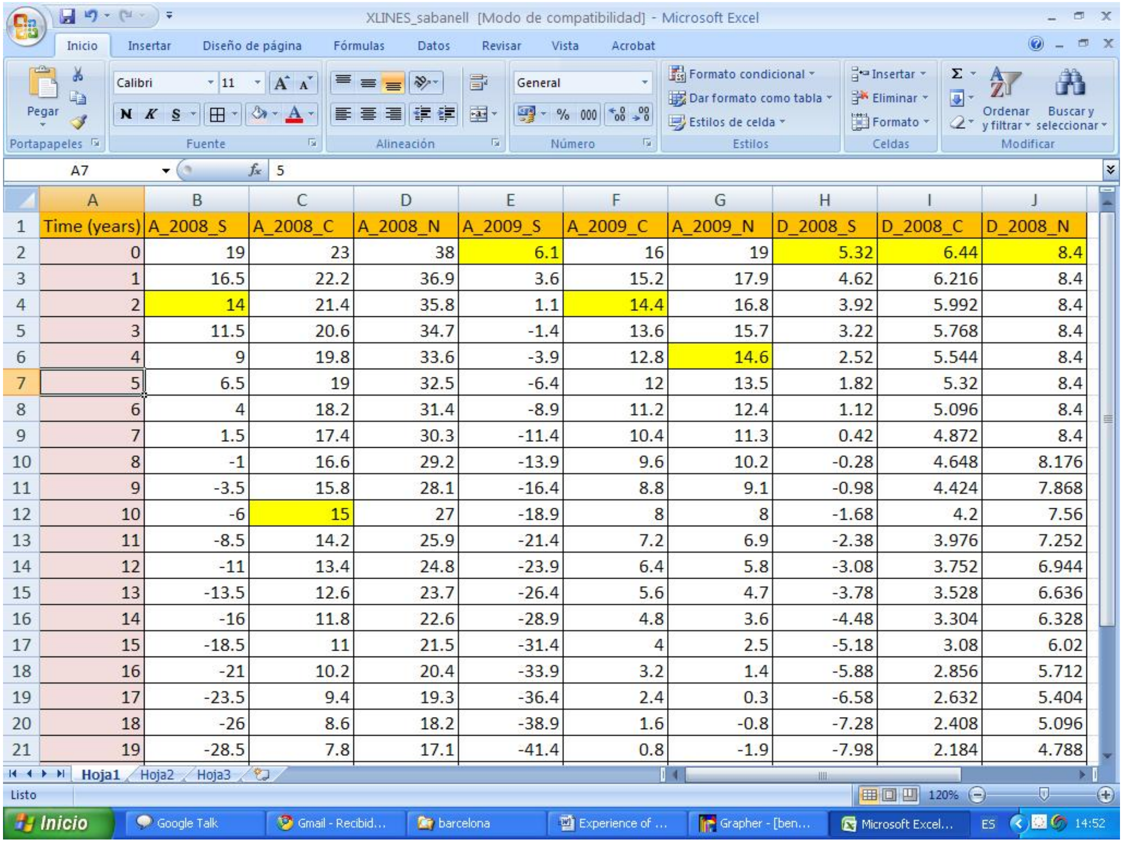


Figure 18 Projected beach width at different time horizons for different initial values and comparison against minimum beach width for protection against storm impacts.

How is information presented?
Information is presented in tabular form and usually is managed through Excel for additional calculations and Grapher (Golden Software) for publishing.
DSAS gives different rates of displacement (depending on the selected method) in columns for each control point along the coast (rows) (Fig. 17).
XLINES gives projected shoreline at given locations and rates of displacement (columns) at projection times (rows) (Fig 19).



	A	B	C	D	E	F	G	H	I	J
1	Time (years)	A_2008_S	A_2008_C	A_2008_N	A_2009_S	A_2009_C	A_2009_N	D_2008_S	D_2008_C	D_2008_N
2	0	19	23	38	6.1	16	19	5.32	6.44	8.4
3	1	16.5	22.2	36.9	3.6	15.2	17.9	4.62	6.216	8.4
4	2	14	21.4	35.8	1.1	14.4	16.8	3.92	5.992	8.4
5	3	11.5	20.6	34.7	-1.4	13.6	15.7	3.22	5.768	8.4
6	4	9	19.8	33.6	-3.9	12.8	14.6	2.52	5.544	8.4
7	5	6.5	19	32.5	-6.4	12	13.5	1.82	5.32	8.4
8	6	4	18.2	31.4	-8.9	11.2	12.4	1.12	5.096	8.4
9	7	1.5	17.4	30.3	-11.4	10.4	11.3	0.42	4.872	8.4
10	8	-1	16.6	29.2	-13.9	9.6	10.2	-0.28	4.648	8.176
11	9	-3.5	15.8	28.1	-16.4	8.8	9.1	-0.98	4.424	7.868
12	10	-6	15	27	-18.9	8	8	-1.68	4.2	7.56
13	11	-8.5	14.2	25.9	-21.4	7.2	6.9	-2.38	3.976	7.252
14	12	-11	13.4	24.8	-23.9	6.4	5.8	-3.08	3.752	6.944
15	13	-13.5	12.6	23.7	-26.4	5.6	4.7	-3.78	3.528	6.636
16	14	-16	11.8	22.6	-28.9	4.8	3.6	-4.48	3.304	6.328
17	15	-18.5	11	21.5	-31.4	4	2.5	-5.18	3.08	6.02
18	16	-21	10.2	20.4	-33.9	3.2	1.4	-5.88	2.856	5.712
19	17	-23.5	9.4	19.3	-36.4	2.4	0.3	-6.58	2.632	5.404
20	18	-26	8.6	18.2	-38.9	1.6	-0.8	-7.28	2.408	5.096
21	19	-28.5	7.8	17.1	-41.4	0.8	-1.9	-7.98	2.184	4.788

Figure 19 Results of the application of XLINES. Projected beach widths at different control points along a beach for different initial shorelines for different time horizons

How often is this tool run at your pilot site?
At least yearly (one shoreline per year). Occasionally if additional data (e.g. from topographic surveys) are available, they are included in the database and analyzed.

Who normally runs it?
Project officer.

How is the data used?
Projected beach widths are used to identify:

1. Zones along the beach vulnerable to the impact of storms. In these locations, the beach width will be narrow than the beach to be eroded by a given storm and it will imply that promenade or the back of the beach will be directly exposed to wave action.
2. Zones along the beach where density of users will increase above a given level at a given time. In these locations, the beach recreational carrying capacity will decrease.

4. Discussion and conclusions

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.

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 reviewed in this report 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 (perhaps in a similar way to Figure 9) 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 (Section 3 and Sutherland, 2010) 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.

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