Managing European Shorelines and
Sharing Information on Nearshore Areas

messina

INTEGRATING THE SHORELINE INTO SPATIAL POLICIES

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Community of Agglomeration for the Thau Basin
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The MESSINA initiative

The intensification of population migration towards the coast and increased frequency of coastal hazards due to global climate change have lead coastal managers at the local level to pay a particular attention to coastal dynamics and shoreline evolution. But in spite of major efforts invested and knowledge accumulated in the fields of shoreline management, lessons learned from European, national and regional initiatives have been so far poorly embedded in daily coastal management practices.

The MESSINA initiative - Managing European Shoreline and Sharing Information on Nearshore Areas - intends to partly bridge this gap by: (i) breaking "knowledge isolation" of some local authorities and institutions in Europe, (ii) raising their managerial and technical capabilities through a mutualisation of the experience accumulated by each of them, and (iii) upgrading existing shoreline management guidelines through an integration of the latest techniques and methods available in Europe.

The main products expected from MESSINA are:
(i) a "coastal manager toolkit" made of 4 practical guides ("Monitoring and modelling the shoreline", "Valuating the shoreline", "Engineering the shoreline", "Integrating the shoreline into spatial planning policies") and a demo CDROM featuring a GIS-based prototype of shoreline management planning,
(ii) a serie of 4 workshops in line with the topic of each practical guide, and
(iii) a web site giving a full online access to the project outputs and to a database of approximately 50 shoreline management case studies.

The overall objective of MESSINA is ultimately to maximize the benefits of future investments in coastline management and raise the public awareness about the need to manage the coastline in a sound and sustainable way.

MESSINA is proposed by a European consortium made of the French Geographic Institute (IGN), the National Institute of Coastal and Marine Management of the Dutch Ministry of Public Works (RIKZ), the Municipalities of Ystad (Sweden) and Rewal (Poland), the Community of Agglomeration for the Thau Basin including the city of Sète (France), the Isle of Wight Council (UK), the Province of Ragusa (Italy), the Swedish Geotechnical Institute (SGI) and the Universities of Messina, Naples (Italy), Barcelona (Spain), and Szczeczin (Poland).

The Practical Guide "***Integrating the shoreline into spatial policies***" provides a synthesis of the results of MESSINA partners' activity devoted to the prototyping of Coastal Geographic Information Systems (GIS) on three coastal sites in Europe. It is intended to help local stakeholders and coastal engineers willing to implement a coastal GIS dedicated to shoreline management with a set of methodologies, tools, best solutions described with their context, cost and limitations.

The Practical Guide ***Integrating the Shoreline into Spatial Policies***, as part of the ***MESSINA Coastal Toolkit***, will contain the following main chapters:

Section I – Introduction

Section II – Recommendations for GIS technologies dedicated to Shoreline Management

Section III – Guidelines for Coastal GIS integration

Section IV – Experiences on implementing coastal GIS

Section V – Conclusions

Glossary of terms and abbreviations

References

SECTION I - INTRODUCTION

This guideline has been prepared in the framework of the MESSINA project part-funded by the INTERREG III C West Zone programme. It aims at adapting the guidelines developed in the framework of EUROSION to the particular purposes of MESSINA. These guidelines should help regional authorities and local managers willing to make a major contribution to coastal erosion management and coastal information sharing for spatial planning policies.

The EUROSION study has reviewed a number of European experiences of shoreline management in which GIS played a particular role. Based on these experiences this study has formulated broad recommendations on the “ideal” specifications for GIS dedicated to coastline management. The objective of MESSINA is to take forward some of these recommendations and see how they can practically be implemented to answer the needs expressed by MESSINA partners. In turn, the outcomes of MESSINA are expected to be further developed and refined within other European regions.

EUROSION has particularly highlighted that the objectives which are assigned to an information system, hence its functions, are central for its sustainability and should be in line with demands formulated at the highest level of management (for example by the mayor). In too many cases, the design of information systems is technology driven and without an explicit design brief and support from the top management, this often results in the information system being abandoned after a few years of operation.

EUROSION has identified three generic objectives which are proposed to constitute the backbone of GIS dedicated to shoreline management. These are:
- The mapping of areas at risk of coastal erosion and coastal flooding
- The assessment of impact of human activities to shoreline stability
- The balance of costs and benefits associated with different shoreline management scenarios

These three generic aims are expected to reflect at least, if not all, the major part of shoreline management questions asked by decision-makers on a daily basis.

MESSINA agrees on this analysis and intends to translate this into practical achievements. However, while EUROSION provisions are expected to be applicable to any European region, MESSINA will complete EUROSION analysis by assessing the feasibility of their implementation and determining which site-specific factors influence the performance of the system. A high priority among these factors are the availability of local input data, the complexity of local coastal processes and local institutional arrangements.

The objective of these guidelines is to provide general advice on how to address the potential needs of geographical information for shoreline management at a local level, and how to render this geographical information not only useful but also

efficient for day-to-day problematic of shoreline management as well as projects, plans or programmes on coastal erosion processes.
MESSINA intends to build upon the recommendations of the EUROSION project in the field of shoreline information management. These recommendations can be summarized as follows:

- Investment decisions relating to shoreline management should be based on information which is not restricted to the investment area only, but on information which is made available for the entire coastal sediment cell. Experience gained from EUROSION study has indeed demonstrated that activities occurring along the same coastal sediment cell are likely to impact other parts of the cell, while activities which take place in different coastal sediment cells are not likely to interfere from a sediment budget point of view. The accurate delineation of coastal sediment cell boundaries is therefore a pre-requisite to any GIS-based decision-support information tools.

- GIS-based decision-support information tools in the fields of shoreline management should fulfil three main functions: (i) the mapping of coastal erosion and associated flood risk areas, (ii) the balance of cost and benefits of future investment decisions, and (iii) the assessment of potential environmental impact of investment decisions on adjacent areas. These core functions should in turn orient data collection and integration efforts.

- GIS-based information tools should be developed in partnership with the various local data providers. This is meant to avoid duplication of efforts, facilitate access to existing up-to-date data, and improve the updating processes. The willingness to design, develop and implement such tools should be manifested at the highest hierarchical level by all the participating institutions. Political leadership possibly from the regional authority, is a key pre-requisite.

Three potential sites were proposed for testing MESSINA GIS concepts and therefore concreting a prototype which will comply with the three above mentioned recommendations. All of which are in the process of developing a GIS competence to support decision-making. More particularly:

(i) The *Côte d'Albâtre* (French region of *Haute-Normandy*) where the regional council of Haute-Normandie and the departmental council of Seine-Maritime were planning to implement a coastal observatory. Among the goals assigned to this observatory are the monitoring of the coastline evolution and the assessment of areas at risk of coastal landslides which are of high importance.
(ii) The *City of Rewal* (Polish region of *Zachodniopomorskie*) on the Eastern part of the Szczecin Lagoon near Dziwnow has been hosting a GIS developed by the University of Szczecin for several years. This GIS features various layers mainly focused on topography and socio-economical aspects of the city. MESSINA intends to adapt this practice to the city of Rewal which is a partner of MESSINA.
(iii) The *Lido of Sète-Marseillan* ending at the Thau pond (French region of *Languedoc- Roussillon*) at which a project of environmental restoration including dune replenishing is planned. The Community of Agglomeration

for the Thau Basin is currently willing to develop GIS to manage and monitor the realization of the project once feasibility study phase is over.

How to use these Guidelines?

These guidelines are designed for use by coastal authorities and stakeholders, coastal managers, developers and practitioners.

Section II is hoped to be as non-technical as possible to interest coastal authorities' stakeholders, majors, policy makers. This consists in summarising EUROSION's main findings and recommendations to ensure clear dissemination of these concepts at local level, with simple illustrations.
Section II goes on to address the need for local/regional GIS tools and functions to handle coastal concerns linked to shoreline management. MESSINA is thus providing operational recommendations for the settings of local Geographical Information Systems

Section III intends to support coastal managers within coastal authorities wishing to implement local coastal information systems based on geographic data for specific concerns including spatial planning processes. Guidelines are provided for the project organization, requirement, system specification, implementation and maintenance, data collection and integration, mapping methods and dissemination of the results.

The policies, concepts and methodologies described in Section II and III have been used to design three different GIS applications. The implementation of these applications and some illustrated outputs are presented in Section IV.

Main operational recommendations extracted from the analysis of those three developed cases are summarized in the conclusive Section V.

SECTION II – RECOMMENDATIONS FOR GIS TECHNOLOGIES DEDICATED TO SHORELINE MANAGEMENT

List of Figures

Conducting spatial planning in coastal zones will often lead to the coastal authority negotiating conflicting interests from residents who want an improved lifestyle and tourist attractions who are concerned with inherent direct or taxation incomes as well as coastal hazards and possible damages.

Will my investment be exposed to coastal erosion hazards during its lifetime?
Will my investment have an impact on the coastal erosion processes?
Do the benefits generated by my investment (including the environmental benefits) exceed its costs (including environmental costs)?

To try answering these key questions, each European coastal authority should be able to benefit from the experience of others within a similar hazard context, constraints or socio-economic factors.
Based on the review of more than sixty case-studies around Europe, the EUROSION study held from 2002-2004 deduced concise recommendations. The benefits of which can be observed at regional and local levels.

Throughout the MESSINA project these recommendations have been disseminated, discussed and applied through the implementation of the three foundational GIS prototypes. These recommendations have been transferred from European level to become locally operational as on the whole they can be applied to help the development of coastal erosion management projects linked to spatial planning.

It is pedagogically proposed to detail the approach followed by MESSINA. Whatever the solutions adopted, the majority of spatial planning processes are linked to risk assessment studies, based on hazards and assets. These concepts and methods are fully detailed in Section III for the Coastal Management and developer.

The need for ‘in-house’ use of a local Geographic Information System, with specialist team devoted to data and tools manipulations, is becoming more apparent for Coastal Authorities. The predominant aims for in-house GIS are to establish owned maps and spatial planning project monitoring as well as to produce the associated documents and answer public requests for information.

The explanation of GIS concepts this section is kept intentionally as generic non technical as possible for the benefit of coastal authority stakeholders, majors, policy makers. However recommendations are in reference to existing cases, described either within MESSINA or EUROSION documents.

II.1 Lessons learnt from EUROSION project

A detailed summary of the key points ascertained from this review, which any coastal manager should keep in mind before undertaking a coastal erosion management project.

Lesson 1: Erosion types, occurrence and the human driver

> *Human influence, particularly urbanisation and economic activities, in the coastal zone has turned coastal erosion from a natural phenomenon into a problem of growing intensity. Adverse impacts of coastal erosion most frequently encountered in Europe can be grouped in three categories: (i) coastal flooding as a result of complete dune erosion, (ii) undermining of sea defence associated to foreshore erosion and coastal squeeze, and (iii) retreating cliffs, beaches and dunes causing loss of lands of economical and ecological values.*

Coastal erosion is a natural phenomenon, which has always existed and has contributed throughout history to shape European coastal landscapes. Coastal erosion, as well as soil erosion in water catchments, is the main process by which terrestrial sediment is delivered to coastal features and systems including beaches, dunes, reefs, mud flats, and marshes. These coastal features and systems in turn provide unique habitats and recreational zones as well as protect fresh water and absorb wave energy. However, the migration of people towards the coast, together with our ever growing interference in the coastal zone has attributed to intensifying the problem of coastal erosion.

Among the problems most commonly encountered in Europe are:

- The abrasion of dune systems occurring from a single storm event which may result in flooding of the surrounding area: case of Holland Coast (MESSINA, 2005), Hel peninsula, Sylt or Camargue (EUROSION, 2004).

Fig. II-1. Flooding Petite Camargue (source EUROSION)

Fig. II-2. Extent of the flooding in the lower part of the Rhône valley and the Camargue. Image acquired by SPOT 4 on 7 December 2003; source: http://www.spotimage.fr/

- The collapse of properties located on the top of cliffs and dunes as documented in the MESSINA case-studies of High-Normandy and Estela (MESSINA PG4, 2006)

Fig. II-3. Endangered houses in Criel s/Mer, High-Normandy, France (source EUROSION)

Fig. II-4. Properties and roads within a collapsing area - Criel s/Mer, High-Normandy, France (MESSINA)

- The undermining of sea flooding defences as a result of foreshore lowering, such as in Ystad (MESSINA PG3, 2006), Sables d'Olonne and Châtelaillon, or coastal marsh squeeze such in Elbe and Essex (EUROSION, 2004)

- The loss of land of economical value, such as the beaches of De Haan, Sylt, Mamaia (EUROSION, 2004) and Giardini Naxos (MESSINA PG4, 2006), the farming lands of Essex or land with ecological value such as the Scharhoern Island along the Elbe estuary (EUROSION, 2004).

Fig. II-5. High economical attracti-veness for the beach of Giardini Naxos, loosing sand, Sicily (source MESSINA)

Fig. II-6. Sand cliff erosion on the Island of Sylt, Germany (source EUROSION)

Lesson 2: Erosion origins, natural and human-induced

> *Coastal erosion results from a combination of various factors – both natural and human-induced – which has different time and space patterns and have different nature (continuous or incidental, reversible or non-reversible). In addition, uncertainties still remain about the interactions of the forcing agents, as well as on the significance of non-local causes of erosion.*

The various types of coastal geology determine the difference in resistance against erosion. While hard rock coasts hardly erode, soft cliffs and sedimentary coast are far less resilient. Subsequently, various natural factors - acting on different time and spatial scales - reshape the geologically formed coastal morphology. Furthermore human-induced factors are present in many cases and they operate on the morphological development of the coastal area as well. In addition, the dominant cause of coastal erosion may stay “hidden” for decades, if not centuries before scientiste finally recognise it and quantify its amplitude. This often corresponds to effects which are hardly noticeable on the short term but clearly obvious after decades, and causes which are non-local. River damming belongs to the latter category and evidence of its impact to erosional processes have been recently recognised and in a fewer number of cases, quantified and demonstrated. It is important to mention that this question of erosion induced by river damming is still subject to debate, as in the case of Rhone delta (France). In some other cases, such as Ebro (Spain), dam-induced sediment deficit has been well documented (EUROSION, 2004).

Natural factors influencing coastal erosion

Waves. Waves are generated by offshore and near-shore winds, which blow over the sea surface and transfer their energy to the water surface. As they move towards the shore, waves break and the turbulent energy released stirs up and moves the sediments deposited on the seabed. The wave energy is a function of the wave heights and the wave periods. As such the breaking wave is the mechanical cause of coastal erosion in most cases and in particular on open straight coasts of Ventnor (MESSINA PG2, 2006), South Holland and Ystad (MESSINA PG3, 2006), Estella and Giardini Naxos (MESSINA PG4, 2006).

Fig. II-7. Waves breaking

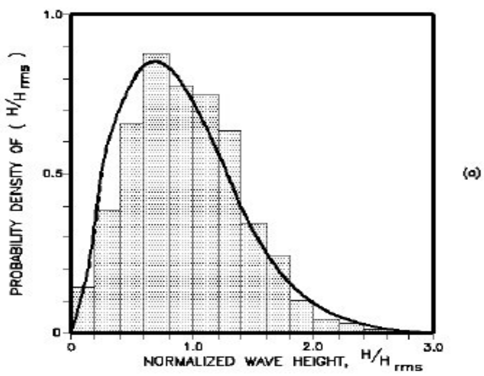


Fig. II-8. Normalized wave height within wave modelization process

Wind. Wind acts not just as a generator of waves but also as a factor of the landward movement of dunes (Aeolian erosion). Wind plays an important role in the dynamic of coastal dunes. By modifying the process of sand transportation and deposition (for example, by clearing or damaging the vegetation of dunes whose aerial part acts as a sediment trap), the sand can be dispersed in the air and the dunes progressively lost. This is particularly visible along some sandy coasts of South Holland and the southern Sweden, Ystad (MESSINA PG3, 2006), also those of Aquitaine or Chatelaillon in France.

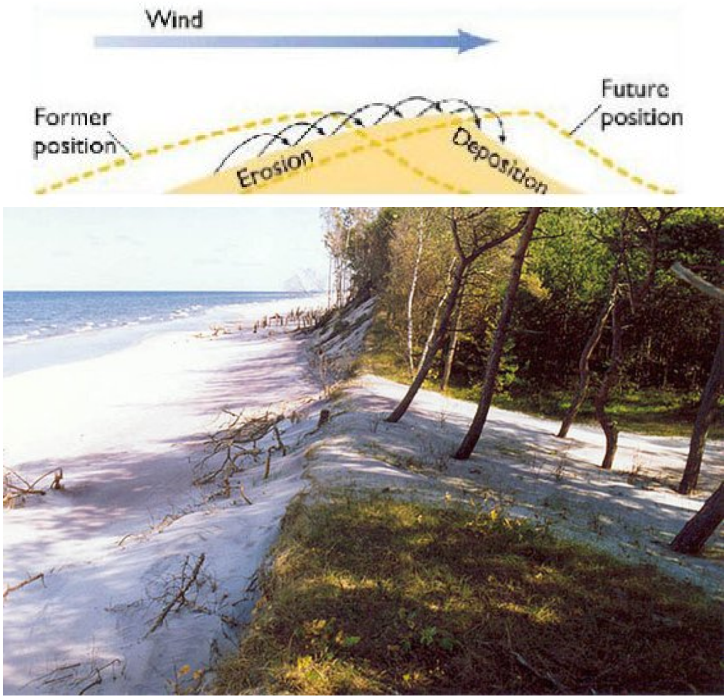
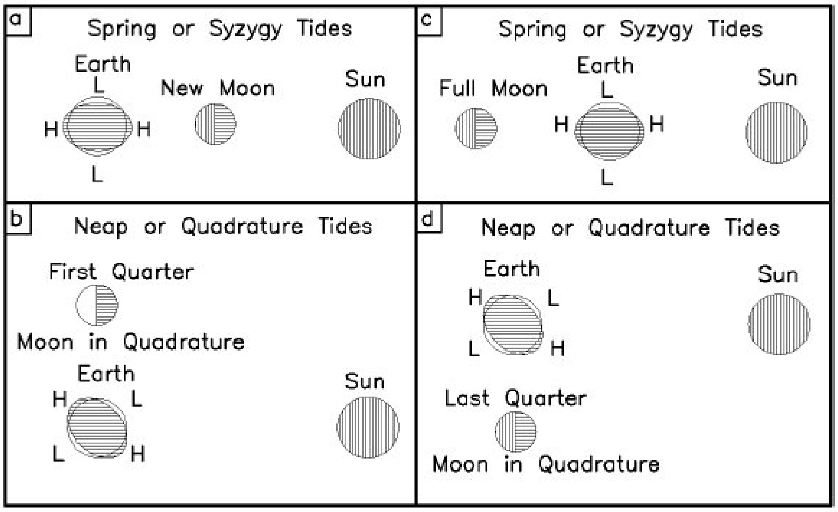


Fig. II-9. Wind impact on dune and illustration

Tides. Tides are the resulting rise and fall of water caused by the gravitational pull of the sun and moon. During high tides, the energy of the breaking waves is released higher on the foreshore or the cliff base (cliff undercutting). Macro-tidal coasts (i.e. coasts along which the tidal range exceeds 4 meters), all along the Atlantic sea are more sensitive to tide-induced water elevation than micro-tidal coasts (i.e. tidal range below 1 meter).

Fig. II-10. Spring and neap tides (Shalowitz, 1964)



Near-shore currents. Sediments scoured from the seabed are transported away from their original location by currents. In turn the sediment transport system defines the boundary of coastal sediment cells, i.e. relatively self-contained system within which (coarse) sediments stay. Currents are generated by the action of tides (ebb and flood currents), waves breaking at an oblique angle with the shore (long-shore currents), and the backwash of waves on the foreshore (rip currents). All these currents contribute to coastal erosion processes in Europe. By way of illustration, long-shore drift is responsible of removing outstanding volumes of sand in Estela beach. Erosion induced by cross-shore sediment transport is best illustrated with the cases of Sables d'Olonne. As for tidal currents, their impact on sediment transport is maximal at the inlets of tidal basins or within estuaries such as in the cases of the Wadden Sea, the Arcachon basin and the Western Scheldt. In some places, near-shore currents and associated sediment cells follow complex pathways as epitomised by the cases of Estela, or Falsterbo.

Fig. II-11. Falsterbo Måkläppen peninsula

(source SGI)

Fig. II-12. Illustration of Falsterbo

(source image MESSINA)

Storms. Storms result in raised water levels (known as storm surge) and highly energetic waves induced by extreme winds. Combined with high tides, storms may result in catastrophic damages such as along the North Sea in 1953. Beside damages to coastal infrastructure, storms cause beaches and dunes to retreat tenths of meters in a few hours, or may considerably undermine cliff stability. In the past 30 years, a significant number of cases have reported extreme historical storm events that severely damaged the coast. Illustrative examples include Holland (storm of 1976), Châtelaillon (1962, 1972, 1999), Estela (2000), High-Normandy (1978, 1984, 1988, 1990).

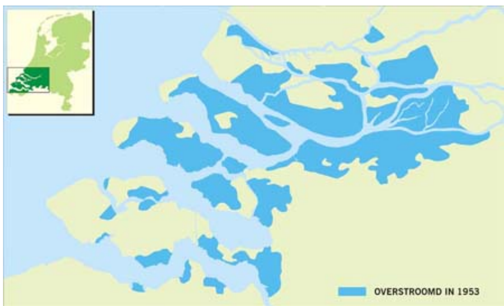


Fig. II-13. 1953 North Sea storm surge flooding Dutch areas

(source EUROSION, RIKZ)

Sea level rise. The profile of sedimentary coasts can be modelled as a parabolic function of the sediment size, the sea level, the wave heights and periods, and the tidal range. When the sea level rises, the whole parabola has to rise with it, which means that extra sand is needed to build up the profile. This sand is taken from the coast (Bruun rule). Though more severe in sheltered muddy areas (e.g. Essex estuaries), this phenomenon has been reported as a significant factor of coastal erosion in all regional seas: Atlantic Sea (e.g. Donegal, Rosslare), Mediterranean Sea (e.g. Petite Camargue), North Sea (e.g. Holland coast), Baltic Sea (e.g. Gulf of Riga (MESSINA PG4, 2006)), and Black Sea.

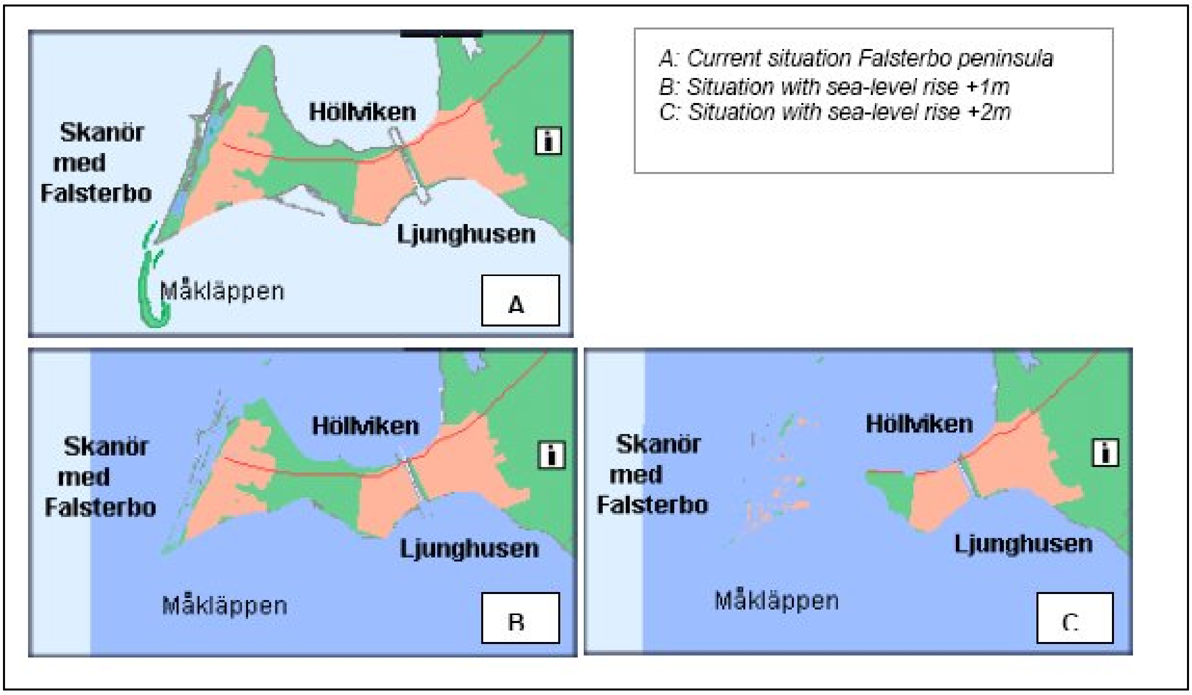
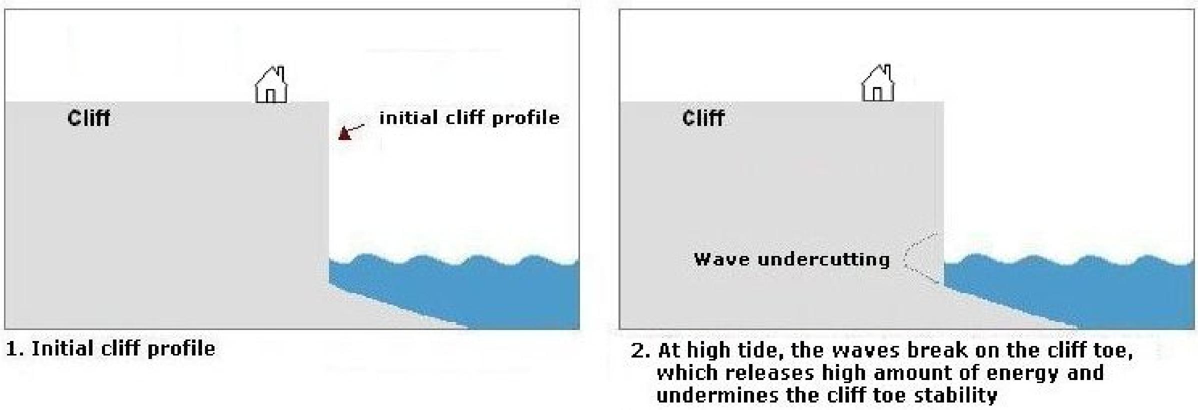


Fig. II-14. Sea level rise assessment of Falsterbo (source Lund University)

Slope processes. The term "slope processes" encompasses a wide range of land-sea interactions which eventually result in the collapse, slippage, or topple of coastal cliff blocks. These processes involve on the one hand terrestrial processes such as rainfall, water seepage and soil weathering (including alternating freeze/thaw periods), and on the other hand the undercutting of cliff base by waves. The cases of Criel-sur-Mer (High-Normandy), Sylt, Vale do Lobo are particularly relevant in that respect.



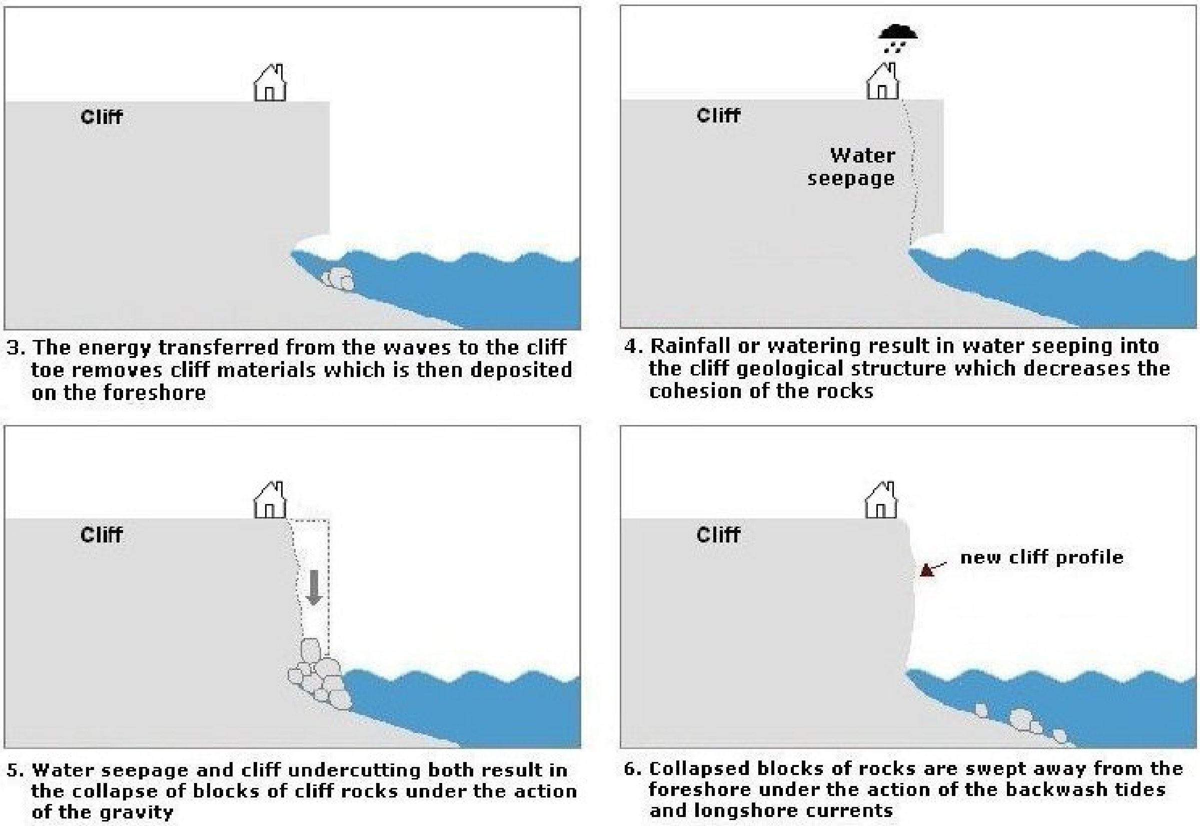


Fig. II-15. Coastal cliffs landslide principle (source EUROSION)

Fig. II-16. Cliff base undercut by waves (left) and rocks slide (right) (images MESSINA)

<u>Vertical land movements (compaction).</u> Vertical land movement – including isostatic rebound, tectonic movement, or sediment settlement – may have either a positive or negative impact on coastline evolution. If most of northern Europe has benefited in the past from a land uplift (e.g. Baltic sea, Ireland, Northern UK), this trend has stopped (with exception of the coast of Finland), such as in Donegal and Rosslare (Ireland), and even reversed (e.g. Humber estuary). Along these coasts, the sea level induced by climate change rises faster than the sea, which results in a positive relative sea level rise.

Figures II-17 summarise natural factors responsible for coastal erosion and highlight the time and space patterns within which these factors operate. Note that "distance" and "Time" reflect the extents within which the factor occurs and causes erosion.

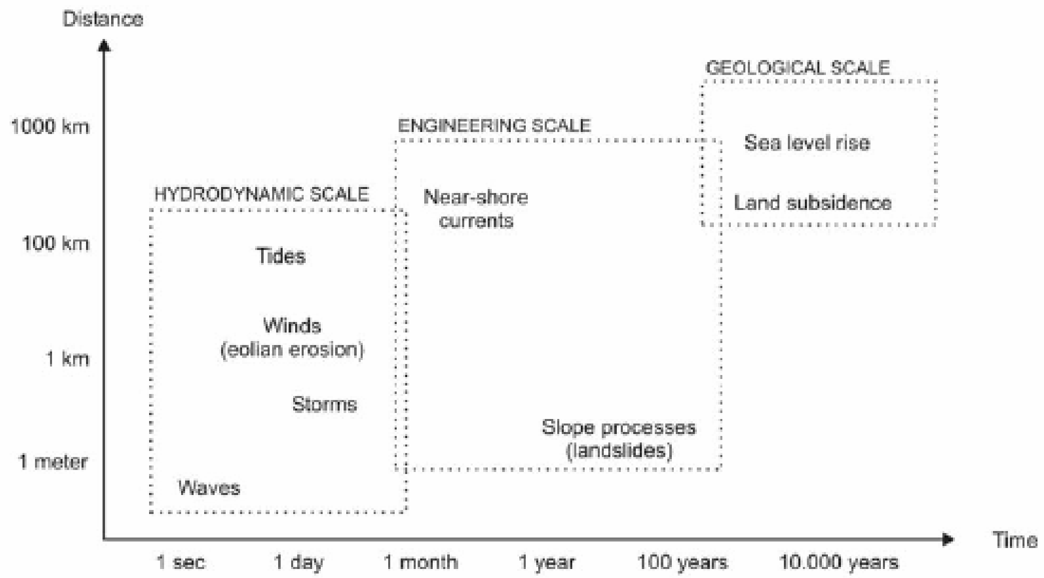


Fig. II-17. Time and space patterns of natural factors of coastal erosion

Human induced factors

<u>*Hard coastal defence.*</u> Hard coastal defence may be defined as the engineering of the waterfront by way of seawalls, dykes, breakwaters, jetties, or any hard and rock-armoured structures, which aims at protecting the construction or other assets landwards the coastline from the assault of the sea. Such structures modify coastal sediment transport patterns through 3 major processes:

(i) Trapping of sediment transported alongshore and a sediment deficit downdrift due to the fact that contrary to "natural" coastlines, hard structures do not provide sediment for the alongshore drift. Mainly by *harbour and marina protection structures* such as those of Vale do Lobo (Portugal), Ijmuiden - Holland case (Netherlands), Skanor – Falsterbo (Sweden), Messina (Italy) or by *groins* such as those of Ystad (Sweden), Jutland (Denmark), Estela (Portugal), Marina di Massa (Italy), and Hel Peninsula (Poland).

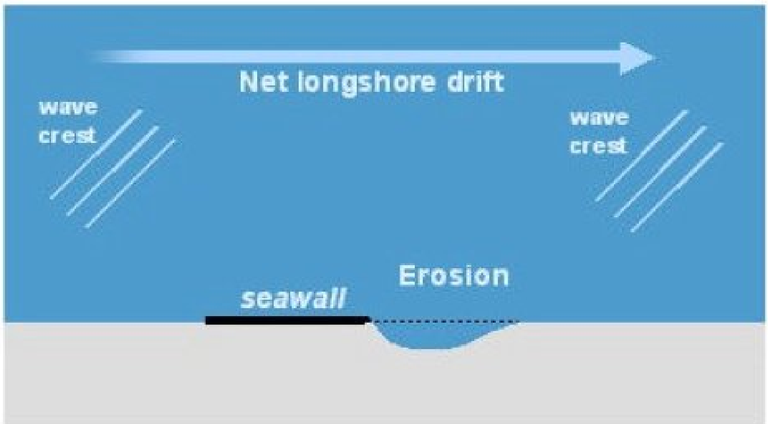
Fig. II-18. Coastal protection with excessive system of groins, Jutland, Denmark

(source EUROSION)

(ii) Incoming waves reflected by hard structures hamper energy dissipation and augment turbulence resulting in increased cross-shore erosion. This phenomenon has been paradoxically boosted along those coastal stretches where seawalls have been built precisely to counteract coastal erosion, and is best illustrated by the cases of Sables d'Olonne (France) (MIOSSEC, 1998)

Fig. II-19. Coastal hard structure impact: example of a seawall

(source EUROSION)



(iii) **Wave diffraction,** which is the alteration of the wave crest direction due to the vicinity of seaward structures (such as jetties or breakwaters). This alteration results in wave energy to be either diluted in some places (less impact on the coastline) or concentrated in some other places (more impact on the coastline and subsequent erosion).

Fig. II-20. Coastal hard structure impact: example of a jetty

(source EUROSION)

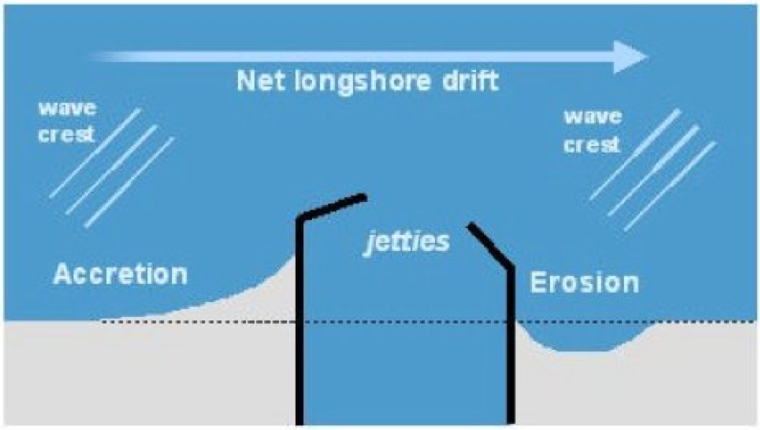
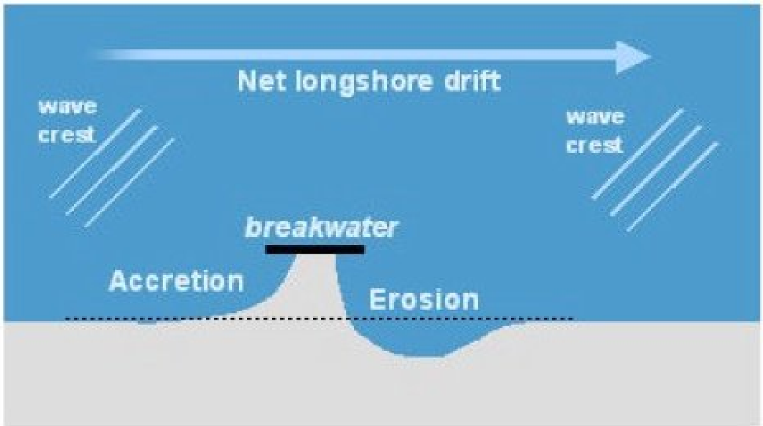
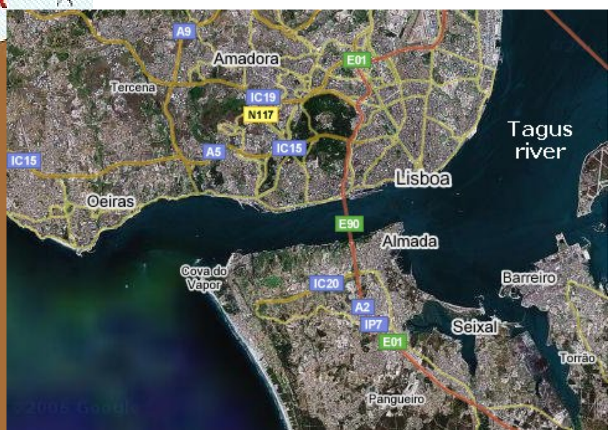


Fig. II-21. Coastal hard structure impact: example of a breakwater

(source EUROSION)



River water regulation works. The impact of water flow regulation works on coastal processes has been highlighted only recently probably such impacts become visible after several decades. Damming has intensively sealed water catchments locking up millions of cubic metres of sediments per year. For some southern European rivers (e.g. Ebro, Rhone), the annual volume of sediment discharge represents less than 10% of their level of 1950 (less than 5% for the Ebro) resulting in a considerable sediment deficit at the river mouth, and subsequent erosion in the sediment cell as illustrated by the cases of Ebro delta, Petite Camargue - Rhone delta (France) or Vagueira (Portugal).
Besides river damming, any activity which result in reducing the water flow or prevent river flooding (as a major generator of sediments in the water system) is expected to reduce the volume of sediments reaching the coast. This is best illustrated by the case of the Tagus which impact can still be felt at Cova do Vapor (Portugal).



(image above: GoogleMaps)

Fig. II-22. Impact of water flow regulation on Tagus river mouth in Copa do Vapor, Portugal

(source EUROSION)

Dredging. Dredging activities have intensified in the past 20 years for navigational purposes (the need to keep the shipping routes at an appropriate water depth), construction purposes (an increasing amount of construction aggregates comes from the seabed), and since the 1990's for beach and underwater nourishment.

Dredging may affect coastal processes by a variety of way:

(i) by removing from the foreshore materials (stones, pebbles), which protect the coast against erosion. By way of illustration, it is estimated that 50% of the total volume of the protective pebbles (3 millions cubic meters) has been extracted from the chalk cliff of High-Normandy (France) since the early 1900's.

(ii) by contributing to the sediment deficit in the coastal sediment cell, such as in the Humber estuary, the coast of Sussex (United Kingdom) for construction purpose (extraction of sand, gravel and shingle), the Western Scheldt (Netherlands) for navigational purposes, Cova do Vapor (Portugal) where sand has been dredged off the coast to supply materials for the beaches of Costa del Sol, or Marina di Ravenna – Lido Adriano (Italy) where dredging from river beds took place.

(iii) By modifying the water depth, which in turn result in wave refraction and change of alongshore drift, as illustrated by the Wadden Sea (Netherlands).

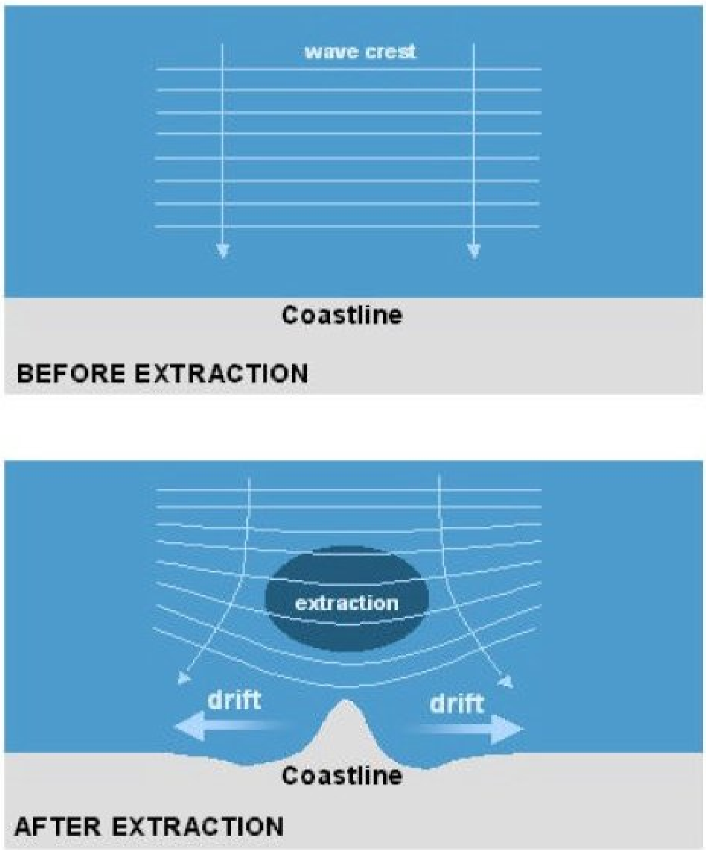


Fig. II-23. Impacts of dredging and sediment extraction activities on the nearest shoreline

(source EUROSION)

Vegetation clearing. A significant number of cases have highlighted the positive role of vegetation to increase the resistance to erosion - e.g. Aquitaine (France) and the Baltic States: Gulf of Riga (Latvia), Klaipeda (Lithuania), Tallinn (Estonia). Additionally, changes of land use and land cover patterns, which tend to reduce the vegetation cover on the top of cliffs may increase infiltration of water and undermine the cliff stability. This is best illustrated by the examples of the golf courses of Estela (Portugal).

Fig. II-24. Reduction of vegetation on top of cliffs increasing water infiltration thus more eroded cliff. (photo foreground)

(source MESSINA)

Gas mining or water extraction. A few examples illustrate the effect of gas mining or water extraction on land subsidence (Wadden Sea - Netherlands). Although this phenomenon seems to have a limited geographical scope in Europe, its effects are irreversible and can be quite significant. In Marina di Ravenna – Lido Adriano (Italy) the land has subsided nearly a meter over last 50 years, causing a major sediment deficit and an increased retreat of the coastline.

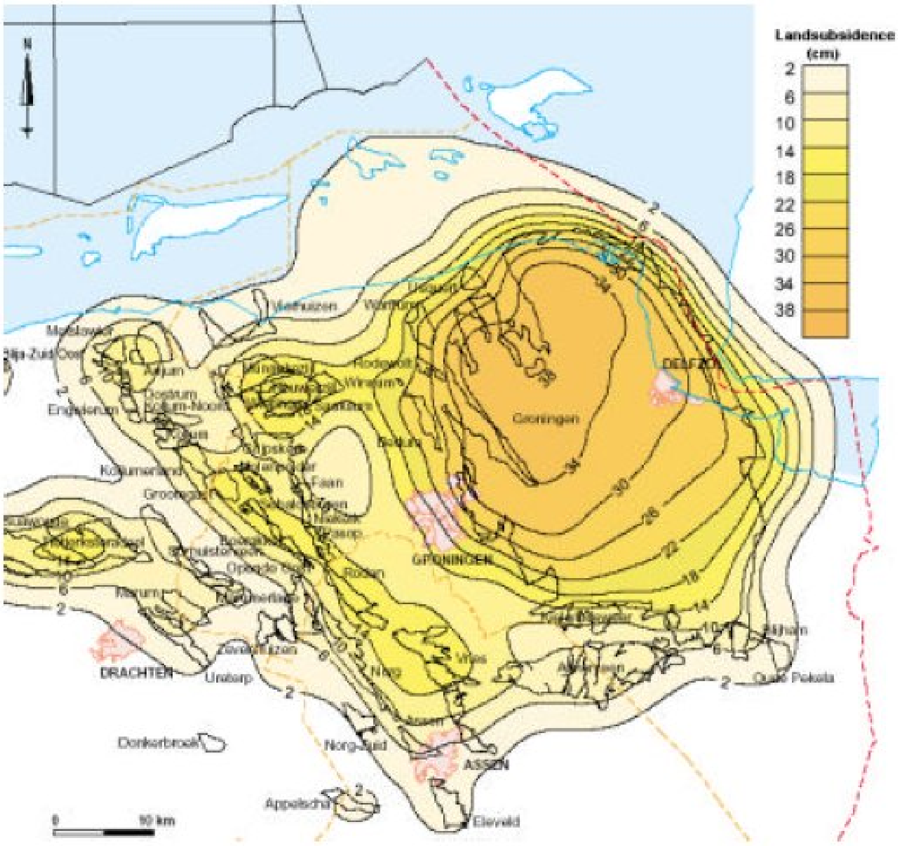


Fig. II-25. Land subsidence in the northern provinces of the Netherlands and Wadden Sea due to gas mining

(source EUROSION)

Ship-induced waves. The side impacts of wave_energy created_by shipping, and especially with large fast ferries has resulted in increased coastal erosion. This has been recorded in case studies of the Gulf of Riga (Latvia) or the Tallinn bay (Estonia).

Figures II-26 summarises human-induced factors responsible for coastal erosion and highlight the time and space patterns within which these factors operate.

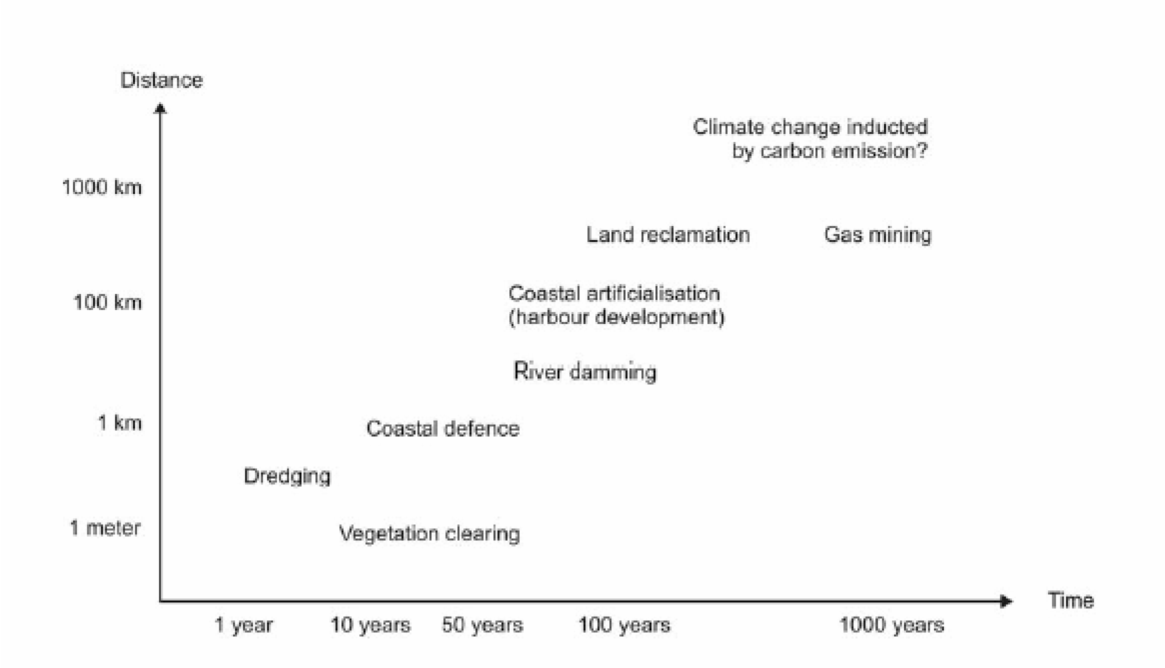


Fig. II-26. Time and space patterns of human induced factors of coastal erosion.

Lesson 3: Environmental Impact Assessment and coastal erosion

Coastal erosion induced by human activities has surpassed in Europe coastal erosion driven by natural factors. Human-induced coastal erosion mainly proceeds from the cumulative and indirect impacts of small and medium size projects, as well as from river damming. However, little attention is being paid to these impacts by project developers, Environmental Impact Assessment (EIA) practitioners and competent authorities.

With the exception of harbour authorities, geo-morphological changes along the coast are not being paid the attention they deserve by the promoters of projects that impact coastal processes. The poor number of Environmental Impact Assessment (EIA) reports that address coastal sediment processes as a serious environmental impact, largely reflects this. It has to be mentioned however, that EIA reports are still very difficult to obtain even after the administrative authorities in charge of project consent have approved them. The opinions expressed here are mainly based on discussions with partners and experts who met during MESSINA validation workshops.

The relatively poor integration of coastal sediment transport and induced morphological changes in EIA procedures may be explained by the fact that, except in the case of major projects, such as the extension of big harbours, coastal erosion cannot be attributed directly to one single coastal development project (see *lesson 2*). The impacts of small and medium size projects are instead cumulative with the impact of other developments, which tends to dilute the responsibility of each individual project for coastal erosion.

This is confirmed by the low numbers of small and medium-size projects along the coast which are required to conduct an EIA by the competent authorities during the "screening" phase (i.e. less than 10% of the total number of projects along the Holland coast). Even in cases where an EIA is required, the impact on coastal sediment processes may not be retained during the "scoping" phase as part of the environmental concerns to be covered by the EIA (EUROSION PART5.4, 2004)

The European Directive 2001/42/EC on Strategic Environmental Assessment (SEA) became effective at the level of Member States in 2004. The SEA directive recognises the importance of taking a wide-ranging perspective when addressing the cumulative impact of piecemeal developments and could be used to address in relation to coastal erosion and flooding issues. This is particularly relevant to management within water catchments areas and coastal and near shore coastal zones. Here knock-on effects, including exacerbation of erosion trends and risk of flooding, as a result of reduced sediment availability may not be immediately apparent.

Lesson 4: Knowledge of erosion processes

Knowledge on the forcing agents of coastal erosion and their complex interaction tends to increase over time. However, this knowledge is fragmented and empirical as reflected by the many different types of models commonly used throughout Europe to anticipate coastal morphological changes.

Since the 1950's, major efforts have been undertaken to understand the behaviour of coastal systems and highlight the interactions between waves, wind, tides, foreshore profile, sediment transport and coastline evolution. These efforts have led to the development of models, which are now commonly used in coastal engineering design.
The understanding of coastal processes is still largely fragmented and empirical.
As a result of this fragmentation, different theories building upon different concepts, assumptions and approaches have been developed since the 1950's and have resulted in different models that are more or less compatible. This multiplicity of models can be explained by the complexity of the phenomena involved in coastal morphological changes and their interactions, which remain largely unexplained.

Because of their relevance for coastal erosion management, particular attention has been paid during the review of models simulating:

- elevation of water level induced by wind stress
- near-shore wave transformation including shoaling, refraction, reflection, diffraction
- response of dune profile to storms
- response of beach profile to sea level rise
- wave-foreshore interactions including wave breaking, run-up and overtopping
- sediment transport including alongshore and cross-shore transport of sand, mud and sand/mud mixture

The factors forcing the above mentioned phenomena – coastline geometry, wave heights and periods, wind speed and direction, astronomic tides, currents velocity, water depth, sea bottom roughness, bathymetry, foreshore profile and sediment size – are common to a majority of models, but the way these factors are combined varies from one model to another.

In practice, a significant number of simple empirical and semi-empirical models (e.g. the Bruun rule or the CERC equation – see Section III) are being developed with acceptable results for a limited number of situations (e.g. for open straight coasts, mild slope shoreline, estuaries, negligible diffraction and reflection phenomenon, etc.); the same models present major limitations which make their application to other situations invalid. Alternatively, robust theories such as the Bijker transport theory (1971) exist and cover a wider range of situations but require considerable field measurements and computation resources.

The operational consequence of this broad range of models is that coastal engineers never really know in advance which model will fit into their specific situation.

In general further improvements are needed to existing models in order to adhere to the prevailing conditions in specific case studies.

Experience also shows that the repetition of existing models may be unreliable, as coastline response to engineered mitigation solutions may not conform to model predictions. This should be factored in any future feasibility studies so as to ensure that what is proposed is fit for its purpose.

Lesson 5: Local management action in broader perspective

> *Past measures to manage coastal erosion have generally been designed from a local perspective: they have ignored the influence of non-local forcing agents and have disregarded the sediment transport processes within the larger coastal system. As a consequence, they have locally aggravated coastal erosion problems, and have triggered new erosion problems in other places. They still influence the design of present measures.*

Historically, many hard constructions were built to stop local erosion in order to protect the assets at risk. Although an effective solution on the short term, the longer-term effectiveness is mostly unsatisfactory. In front of many seawalls, boulevards and revetments, the beach erodes as a result of wave reflection. This in turn destabilizes the constructions.

Maintenance is costly and some constructions have proved to be unequal to the powerful natural processes and have broken down. This has promoted costly reconstructions of coastal defences or the building of new (additional) constructions.

In other cases the building of groynes and breakwaters has resulted in a shift of erosion to neighbouring areas and created the need for further protection of the assets at risk. This resulted in a domino effect of hard constructions, for example in Hel Peninsula (Poland) where over time a complete groyne field was created over a distance of 12 km.

In many cases the groynes did not completely prevent erosion. Today, some coastal defence structures that have been inherited from past management strategies are still “active” as the seawalls of Playa Gross (Spain, built in 1900), Chatelaillon (France, 1925), De Haan (Belgium, 1930), or the vegetated dunes of Western Jutland (Denmark) stabilized in the 1900’s, and they keep on interacting, positively or negatively, with sediment processes.

The traditional local perspective of coastal erosion management is illustrated by the poor number of Environmental Impact Assessment (EIA) reports that address coastal sediment processes as a serious environmental impact (*lesson 3*).

An exception to the picture described above can be found in some of the cases. A nice example is **Marinella di Sarzana** (Italy), where neighbouring communities successfully cooperated on a combined river and coastal zone management, resulting in an integrated project proposal, which is evaluated through the Environmental Impact Assessment procedures.

Fig. II-27. Marinella de Sarzana, Liguria, Italy (MESSINA, 2004-2006)

Lesson 6: The coastal sediment cell

> *As an attempt to better respond locally to non-local causes of coastal erosion and to anticipate the impact of erosion management measures, a number of cases mainly in Northern Europe have built their coastal erosion management strategies upon the concept of "sediment cell" as well as on a better understanding of sediment transport patterns within this sediment cell. Such approaches require a strong cooperation between regions, which share a same sediment cell.*

In understanding the causes and extent of coastal erosion, the introduction of the concept of the "coastal sediment cell" undeniably constitutes a major breakthrough, as it helps to delineate the geographical boundaries of investigations for erosion causes and impact of erosion mitigation measures (e.g. High-Normandy, Isle of Wight, Holland coast, Wadden sea). A coastal sediment cell can be defined as a length of coastline and associated near-shore areas where movement of sediments are largely self-contained. In practice, this means that measures taken within a specific sediment cell may have an impact of other sections of the same sediment cell but will not impact adjacent cells.

From the "coastal sediment cell" perspective, a loss of sediment is less favourable than redistribution within the coastal system. Less sediment within the system restricts the ability of the coastline to adapt to changing circumstances. Furthermore, hard constructions like harbour-moles or breakwaters block (some part of) the natural sediment transport. Some sediment is "imprisoned" by the constructions and is not freely available in the natural process. The same effects occur when stabilizing cliffs and thus preventing the natural input of sediments from cliff erosion.

Therefore, fixing of sediments (due to hard constructions) is less favourable than using measures that disturb the natural process to a lesser extent or measures which even make use of the natural processes, for example beach- and foreshore nourishments. The latter choice is called "working with nature".

Building upon the concept of coastal sediment cells it can be concluded that adopting the following three key management principles for the coastline should be adopted as verified in the cases of High-Normandy, Isle of Wight and Holland Coast:

1. Maintain the total amount of sediment (in motion or dormant) within the coastal system
2. When taking measures, try to work with natural processes or leave natural processes as undisturbed as possible
3. If no other options available, use hard constructions to keep sediments in its position

The concept of sediment cells does however present major limitations due to its time dependence: sediment processes within a specific sediment cell cannot be totally “self contained” and transfer of sediments among adjacent cells may finally become non-negotiable after a long period. Moreover, the concept of sediment cell is restricted to processes occurring along the shoreline and does not include land-based causes of coastal erosion such as reduction of river sediments or modification of river outflows and estuary water levels as observed in the Gulf of Riga. These limitations must lead, such as Essex, to find the adequate geographical size of the sediment cell.

Lesson 7: No miracle solutions, but learning through experience

> *Experience has shown that, at the present time, there is no miracle solution to counteract the adverse effects of coastal erosion. Best results have been achieved by combining different types of coastal defence including hard and soft solutions, taking advantage of their respective benefits though mitigating their respective drawbacks.*

From the observation that coastal erosion results from a combination of various natural and human-induced factors (*lesson 2*) it is not surprising that miracle solutions to counteract the adverse effects do not exist. Nevertheless, the general principle of "working with nature" was proposed as a starting point in the search for a cost-effective measure (*lesson 6).*

However, this observation also undeniably assumes that the idea that soft engineering solutions are preferable to hard ones. This is backed by a number of considerations derived from experience:

- Even well tried soft solutions that have aroused a tremendous enthusiasm in the past 10 years, have been subject to serious setbacks. Such setbacks have been caused by inappropriate nourishment scheme designs, induced by poor understanding of the sediment processes (technical setback), difficult access to sand reserves which induces higher costs (financial setback), or unexpected adverse effects on the natural system and principally the benthic fauna (environmental setback).

  The MESSINA Practical Guide "*Engineering the Shoreline*" (MESSINA PG4, 2006) objectively describes the case-study on Maronti Bay, on Ischia Island (Italy), where beach nourishment was unsuccessful because no preliminary study on the particularities of the bay was ordered. The sand has gone as quickly as the thousands of euros invested.

  The sourcing of sand reserves in the Mediterranean Sea is the main topic of the project BEACHMED-e[1], INTERREG project; due to such cases as Sitges (Spain) where dredged sand supplied as nourishment has caused irreversible damage to sea grass communities (Posidonia).

- Soft solutions, due to their particularity of working with nature, are found to be effective only in a medium to long-term perspective, i.e. when coastal erosion does not constitute a risk in a short-term perspective (5 to 10 years). Their impact does slow down coastline retreat but does not stop it. The long term positive effect of soft solutions may be optimised by hard structures making it possible to tackle an erosion problem efficiently but have a limited lifetime (in general no more than 10 years).

  This has been particularly well documented by EUROSION project in the cases of:

[1] http://www.beachmed.it/

Petite Camargue (France) where the presence of previously condemned hard structures turned out to provide sufficient viability for a soft defence such as dune restoration wind screens to operate.

De Haan (Belgium), where a seawall provides safety to social and economical assets though beach nourishment with a sub-tidal feeder berm provides long term stability to the surrounding dunes.

Western Jutland (Denmark) where the uses of detached breakwaters significantly reduce the expenses related to beach nourishments.

In addition, most of the cases of United Kingdom which already benefit from Shoreline management plans (SMP) combine different types of techniques.

Lesson 8: The setting of clear objectives, towards accountability

> *Assignment of clear and measurable objectives to coastal erosion management solutions - expressed for example in terms of accepted level of risk, tolerated loss of land, or beach/dune carrying capacity - optimises their long-term cost-effectiveness and their social acceptability. This has been facilitated by the decrease of costs related to monitoring tools.*

In most of the case studies reviewed by MESSINA, coastline retreat is a phenomenon observed for more than a hundred years. In a few cases, such as the Isle of Wight (United Kingdom), evidence exists that people have struggled against coastline retreat for thousands of years. In addition and though they get older, some coastal defence structures inherited from past management strategies are still “active” and they keep on interacting, positively or negatively, with sediment processes, as mentioned in *lesson 5*.

In other cases, hard and soft solutions implemented had a lifetime that did not exceed a few months; such as the timber groins of Rosslare (Ireland). This highlights the need for adequate monitoring of solutions throughout the lifespan of coastal erosion management projects since these solutions may not reach the efficiency targeted, or on the contrary, may continue to interact with other elements even beyond their initially planned life span.
Commonly used monitoring techniques are described within their best context of application within the Practical Guide "*Monitoring and Modelling the Shoreline*" (MESSINA PG2, 2006)

Experience has also revealed that coastal erosion management solutions which have defined, clear objectives and regular monitoring programmes could also detect more quickly any discrepancy between the expected coastline response and effective coastline response. They are also in a position to decide corrective actions which in turn save a significant amount of money in the long run as illustrated by the cases of Western coast of Jutland (Denmark) or Playa Gross (Spain).

It is however important to notice that regular monitoring programmes are still an exception in Europe and are not the general rule. There is in particular a significant gap between northern and southern Europe in the systematic use of coastline monitoring techniques as part of shoreline management policy. Such countries as the

UK, the Netherlands and German Landers have generalized the regular use of LIDAR, ship borne surveys or locally apply ARGUS video systems, though other countries as Portugal, Greece, or even France implement coastline monitoring techniques only at certain locations and generally restricted, as experimental research projects (MESSINA PG2, 2006) (MESSINA CASE-STUDY STRATEGIC MONITORING PROGRAMME, 2006).

Lesson 9: Multi-functional design and acceptability

Multi-functional technical designs, i.e. which fulfils social and economical functions in addition to coastal protection, are more easily accepted by local population and more viable economically.

The perception of risk by local populations influences considerably the design of coastal defence solutions. A commonly spread idea among communities residing within areas at risk is that hard engineering provides better protection against coastal erosion and associated risk of coastal flooding. This belief, which may be founded at in the short-but term but not necessarily in the long run, has been observed in a number of European sites.

For similar reasons, it is only recently that sand nourishment schemes, which constitute since 1992 the backbone of the Dutch policy of coastal defence along the Holland coast, have been receiving a large support from local population. This support is largely due to the positive side effects of sand nourishment on recreational activities associated with beach extension, and protection of fresh water lens induced by consolidation of dunes.
This is also largely confirmed by a majority of sites throughout Europe which opted for beach nourishment – such as Giardini Naxos, Marina di Massa (Italy), Can Picafort, Mar Menor (Spain), Mamaia (Romania), De Haan, Zeebrugge (Belgium), Sylt (Germany), Hyllingebjerg (Denmark), Hel Peninsula (Poland), Chatelaillon (France), or Vale do Lobo (Portugal).
In some Mediterranean cases, tourism opportunities induced by beach nourishment has become a local necessity even if those areas which do not particularly suffer from coastal erosion, which in some cases led to illegally mined sand such as in the case Dolos Kiti (Greece).

Beyond beach nourishment schemes whose implementation has been boosted in the past 5 years other technical designs have made it possible to combine coastal defence with social, economical, and ecological functions. This is best illustrated by the examples of the natural area of Koge Bay (Denmark), which has been reclaimed from the sea for nature, recreation and flood defence purposes, and Giardini Naxos (Sicily) where artificial reefs have been experimented both to absorb incoming wave energy and regenerate a marine biota. (MESSINA PG4, 2006)

Seeking multi-functional design is also driven by financial considerations. A number of examples exhibit significant costs of coastal defence. They range from a few thousands euros for localised protection such as wooden pile breakwaters or geotextiles as seen along Estela beach (Portugal, 20,000 Euros); to several millions euros as seen in the complete reshaping of a beach by combination of sand nourishment, rock armoured breakwaters, dune restoration, and design studies such as in Sète-Marseillan's lido (France, several tens millions Euros). In addition to these costs, is ongoing maintenance and monitoring as well as in the case of beach nourishment the cost for repeating nourishment actions regularly. Developing technical designs that fulfill different functions therefore increases the chances of finding co-funding partners for the long term.

Lesson 10: Cost - benefit analysis

Though critical for decision-making, the balance of coastal defence costs and their associated benefits is, in general, poorly addressed in Europe. This may lead to expenses, which are at the long run unacceptable for the society compared to the benefits.

The breakdown cost of coastal defence by funding partners is well reported in most cases, only few of them have documented its benefits appropriately.
Among those, the case of South Downs (United Kingdom) estimates that the 14 millions Euros of coastal defence at Shoreham and Lancing provide protection to 135 millions Euros of properties – including 1300 homes and 90 commercial premises – from the risk of coastal erosion and associated flooding within 100 years.
Along the North Norfolk (United Kingdom) coastal cliffs, the example of Happisburgh demonstrates on the contrary that the costs of cliff stabilization combined with detached breakwaters estimated to several million Euros – as proposed by the local authorities - largely exceeds the value of the 18 houses buildings and the road, which makes the project not easily financially viable.
Such assessments of cost and benefits tend to be systematically undertaken in the United Kingdom in shoreline management plans recommended by DEFRA who give the impetus for it.

This remains however an exception in other countries in spite of considerable expenses for coastal defence as illustrated by the Dutch coast where an average of 30 to 40 millions Euros are dedicated to beach- and foreshore nourishment each year, the case of Saintes-Marie-de-la-Mer (Petite Camargue - France) where more than 60 million Euros have been spent over the past 10 years for groins and dune regeneration, or the case of Portugal where 500 million have been invested in dune and seafront rehabilitation and hard defence since 1995 along coastal stretch lying from the harbour of Aveiro to the resort of Vagueira.

It cannot be denied however those local decisions are made on the basis of at least qualitative information on the benefits. Such a qualitative assessment of benefits is briefly reviewed in a number of cases:

- Safety of people and goods – mainly houses – addressed in all cases
- Reduction of extreme water levels thanks to sedimentation in the bed of estuaries and tidal basins (cases of Holderness, Humber, Wadden Sea)
- Better access to harbour facilities by dredging nourishment materials in navigational channels (Western Scheldt)

- Protection of fresh lens against salt water intrusion in fertile hinterlands (Aveiro, Holland)
- Revalorisation of the property market value induced by risk reduction (Playa Gross)
- Increase in beach frequentation induced by the foreshore extension (Sitges, Marina di Massa, Giardini Naxos), dry sand (Sables d'Olonne), or modification of plunging characteristics of breaking waves (Playa Gross)
- Rehabilitation of natural areas and associated biodiversity (Aquitaine, Koge Bay)
- Provision of shelters for fishermen's boats (Vagueira, Dolos Kiti)
- Absorption of nitrogen's by coastal marshes initially designed for coastal defence

Some approaches coexist to balance the multiple assets to consider while estimating cost-benefits for one coastal erosion solution or the other. Those methods are fully detailed with their inherent context of application in the MESSINA Practical Guide "*Valuing the Shoreline*" (MESSINA PG3, 2006)

II.2 Policy recommendations for local authorities

Generic policy options

As a generic approach of policy options, those defined by the UK Department for Environment, Food and Rural Affairs (DEFRA) suits and is shown in Figure II-28

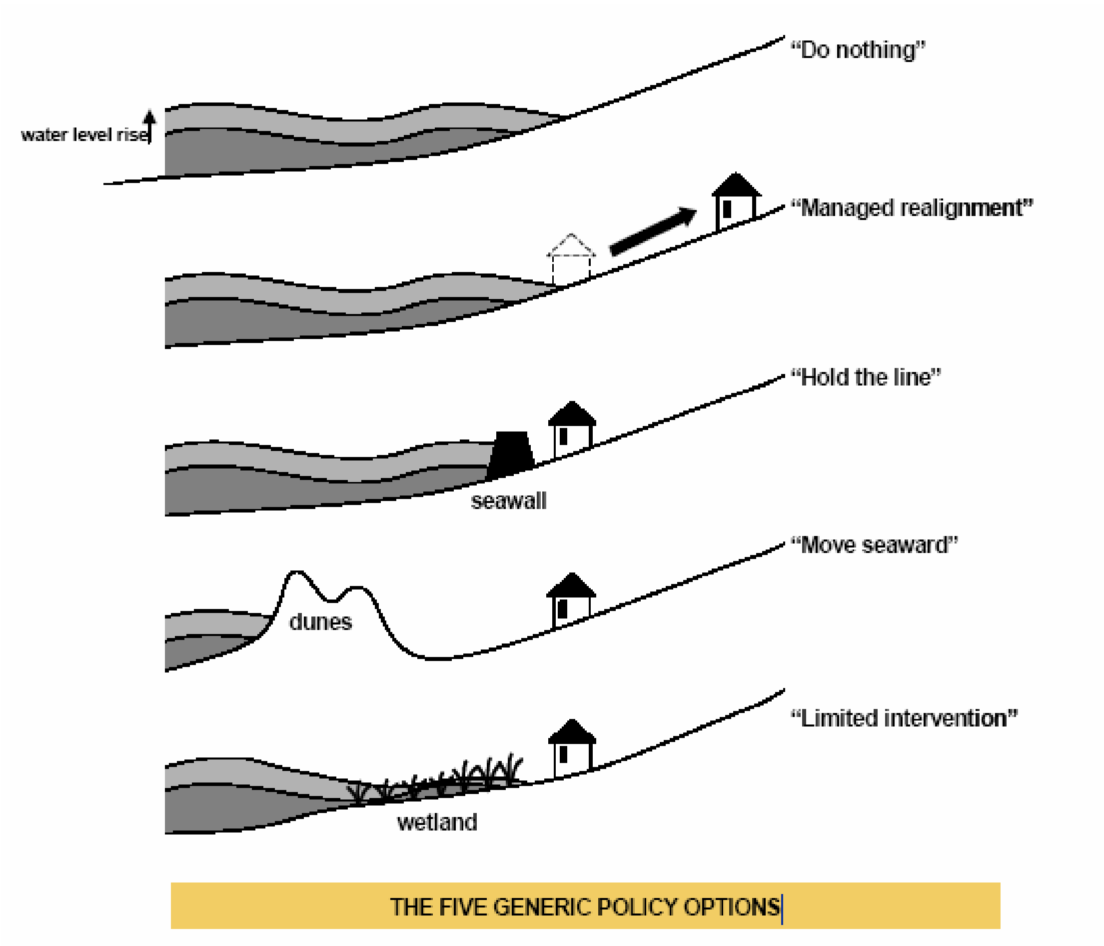


Fig. II-28. The five generic policy options

Do nothing
There is no investment in coastal defence assets or operations, i.e. no shoreline management activity.

Hold the line
Hold the existing defence line by maintaining or changing the standard of protection. This policy covers those situations where works are undertaken in front of the existing defences to improve or maintain the standard of protection provided by the existing defence line. Policies that involve operations to the rear of existing defences should be included under this policy where they form an integral part of maintaining the current coastal defence systems.

Move seaward
Advance the existing defence line by constructing new defences seaward of the original defences. This use of policy is limited to those management units where significant land reclamation is considered.

Managed realignment
Identifying a new line of defence and, where appropriate, constructing new defences landward of the original defences.

Limited intervention
Working with natural processes to reduce risks while allowing natural coastal change. This may range from measures that attempt to slow down rather than stop coastal erosion and cliff recessions (e.g. nourishments), to measures that address public safety issues (e.g. flood warning systems, dune and forest maintenance, building restriction in coastal strip).

Besides this, the distinction between the policy options is not always clear. Nourishment of a beach to compensate structural erosion can fit the policy option of 'limited intervention' as well as 'hold the line'.

Moreover in some case studies coastal defence policies decided at a national level have not yet been adopted, leaving the management of erosion problems to local and/or regional authorities.

A proactive approach is a policy of anticipating erosion processes. Technical measures or plans (management plans, flood warning systems etc.) are adopted to prevent erosion or minimize the expected effects of erosion. A reactive approach refers to the policy of performing coastal defence measures to reduce the effects of existing erosion processes. Another part of the strategy is to decide whether to use hard or soft measures to deal with erosion.

On the basis of the findings and the EUROSION vision four key recommendations were proposed that, once implemented as a package, will make coastal erosion problems and risks in Europe manageable.

Recommendation nr. 1

Increase coastal resilience by restoring the sediment balance and providing space for coastal processes

A more strategic approach to coastal erosion is needed for a sustainable development of vulnerable coastal zones and for the conservation of coastal biodiversity. In the light of climate change it is recommended that coastal resilience is enhanced by:

(a) restoring the sediment balance;

(b) allocating space necessary to accommodate natural erosion and coastal sediment processes and

(c) the designation of strategic sediment reservoirs.

In view of the importance of the availability of sediments and space for sediment transport (from rivers, along the shore and between coastal system and seabed) the concept of a 'favourable sediment status' is proposed for coastal systems. This concept can help form the basis for shoreline and water catchment management.
Favourable sediment status may be defined as the situation of 'coastal sediments' that will permit or facilitate meeting the objective of supporting coastal resilience in general and of preserving dynamic coastlines in particular.

Recommendation nr. 2

Internalise coastal erosion cost and risk in planning and investment decisions

The impact, cost and risk of human induced coastal erosion should be controlled through better internalisation of coastal erosion concerns in planning and investment decisions. Public responsibility for coastal erosion risk (through the taxation system) should be limited and an appropriate part of the risk should be transferred to direct beneficiaries and investors.
Environmental Assessment instruments should be applied to achieve this.
Risks should be monitored and mapped, evaluated and incorporated into planning and investment policies.

It is not proposed to create new instruments but instead recommend to incorporate coastal erosion concerns (especially risk assessment) into the implementation of existing instruments at all level of administration that are: (i) hazard and risk mapping assessment and spatial planning; (ii) financial instruments; (iii) Integrated Coastal Zone Management (ICZM).

Hazard and risk mapping

The need to map erosion hazards – whether storm related or gradual – has been recognised by a majority of stakeholders involved in coastal development. Various mapping methodologies have been developed in Europe but their relevance is restricted to specific coastal types: coastal cliff - based on photogrammetric techniques (e.g. High-Normandy), coastal dunes - based on storm profile models (e.g. Holland), beaches - based on sediment transport information (e.g. Sète-Marseillan), etc.

Most of the methodologies map the coastal erosion “hazard” (i.e. the probability or the extent of coastal erosion within a specific period of time regardless of the assets located along the coast). Thus strictly speaking coastal erosion risks, which include the value of vulnerable assets, are not fully assessed. To fill such a gap and facilitate exchange of experience and improvements, it is desirable to bring together the various existing approaches into one integrated methodology, which would operate for all types of risks associated with coastal erosion.

However at this stage, the transition from hazard mapping to risk mapping requires techniques for a valuation of coastal assets (subject of recommendation 4) well described in MESSINA Practical Guide "Valuing the Shoreline" (MESSINA PG3, 2006).
To support the full process of coastal erosion hazard mapping, MESSINA is proposing in Section III concrete guidelines for mapping coastal erosion hazard, coastal values and coastal associated risks.

Spatial planning

Planning and zoning is an effective means for local governments or administrations to divert development from areas at risk from erosion or flooding. By incorporating coastal erosion hazard and risk mapping into long-term local plans, local governments give developers advance notice of land use policies and the reason for those policies. In addition, where public safety is concerned, local governments can reduce the risk of claims from citizens when they regulate development on land prone to erosion or susceptible to flooding. If regulations are well-founded, authorities are more likely to be able to resist a claim for coastal erosion-related damage. Government and citizens are also better off if they can minimize the losses caused coastal erosion in their communities. The process of incorporating risk within spatial plans should constitute an important section of any Coastal Sediment Management Plan (see *recommendation 3 too*)

Financial instruments

Traditional funding mechanisms have to a large extent contributed towards the increase in the risk to life and property from coastal erosion by encouraging investments along the coast. To reverse the trend, it is felt that innovative funding mechanisms should be designed, in particular, to support the implementation of Coastal Sediment Management Plans. Particular arrangements may include:

➢ The design and implementation of financial compensation schemes, at the national level, in order to accommodate the resettlement of coastal populations at imminent risk from coastal erosion or flooding. Such schemes should be applicable to clearly identified areas at imminent risk of coastal erosion. This will help ensure a reasonable indemnification of private owners and investors while as the same time avoiding speculative development.

➢ A broader use of financial market instruments, in particular, insurance and bank sectors can be used to transfer the costs related to adverse consequences of coastal erosion from the community to the investors. This can be done either by offering insurance against damages to the insured property or extending the liability of parties responsible for schemes resulting in claims for damages caused by coastal erosion. Such insurance schemes do not exist currently in Europe, but may be conceived as extensions to existing mechanisms covering other natural hazards, including flooding.

Integrated Coastal Zone Management (ICZM)

Integrated Coastal Zone Management is not just an environmental policy. While the need to protect the functioning of natural ecosystems is a core aim of the strategy, ICZM also seeks to improve the economic and social well-being of coastal zones and help them develop their full potential as modern, vibrant communities. In the coastal zone, these environmental and socio-economic goals are intrinsically interconnected.
Important issues of Europe’s coastlines are:

- Badly planned tourist developments
- Decline of fishing industry
- Poorly conceived transport networks
- Increasing urbanization
- Erosion
- Pollution
- Habitat destruction

In September 2000 the European Commission adopted the document “Integrated Coastal Zone Management: a Strategy for Europe”. The EC Coastal Strategy highlights the importance of coastal zones, and also includes a proposal for European Parliament and Council Recommendations where eight principles of good coastal zone management have been identified:

- Take a wide-ranging view of inter-related problems (thematic and geographic) using a broad “holistic” perspective
- Use a long-term perspective; allow for unforeseen future developments
- Local specificity: base decisions on good data and information
- Try to work with natural processes
- Participatory planning: involve all stakeholders
- Support and involve all relevant administrative bodies
- Make use of a range of instruments (laws, plans, economic instruments, information campaigns, Local Agenda 21s, voluntary agreements, promotion of good practices, etc.)

Since then the European Parliament and Council Recommendation on ICZM (2002) promotes the implementation of those principles as the backbone for future developments along the coast. The ICZM Recommendation does not replace Environmental Assessment instruments but can be used in combination with them to identify mitigation solutions which are innovative, cost-effective, and socially acceptable. Wherever ICZM plans are implemented, Coastal Sediment Management Plans shall be considered as part of it.

In principle, each of the five generic policy options can incorporate the concept of ICZM. This concept puts erosion in the perspective of other issues in the coastal zone. For instance, habitat protection and water quality recovery are other issues that could use ICZM as a tool.

When it comes to legislation specifically covering ICZM, at present no European country has developed explicit legal instruments. ICZM has too, therefore, be covered through existing legal means. Predominant national instruments are Planning and/or Building Acts. This is not surprising given the fact that the implementation of ICZM will always require planning decisions. However, the lack of environmental legislation that needs to be consulted will not always ensure that biodiversity and environmental issues will necessarily be covered in any ICZM planning applications. The legislation pertaining to ICZM is all recent, having been passed in the last decade.

Recommendation nr. 3

Make responses to coastal erosion accountable

Coastal erosion management should move away from piecemeal solutions to a planned approach based upon accountability principles. These would help optimise investment costs against values at risk, increase the social acceptability of actions and keep options open for the future. According to EUROSION vision, "an accountable coastal erosion management”:

- has explicit objectives for a defined timescale;
- defines clear responsibilities at the various levels of administration;
- is based upon an understanding of the sediment balance and long term trends;
- does not compromise safety, important environmental values and natural resources;
- is based on a cost-benefit assessment;
- is supported by an appropriate budget for both investments and maintenance as well as for a financial mechanism to locally accommodate erosion or its impacts;
- is implemented by technical measures that have proved to be fit for purpose;
- includes a programme to monitor developments and effectiveness of measures;
- determines the duty to publicly report on all above aspects.

If insufficient measures are taken to make shoreline management accountable, costs to society will continue to increase and to become less sustainable. There is also a risk that coastlines will become less resilient to erosion.

Content of Coastal Sediment Management Plans (CSMP)

The shore and sediment management planning process should:

➢ Determine the ‘undisturbed’ and ‘present’ sediment conditions within coastal sediment cells in terms of:

  - Natural and present sediment budget including quantification of sediments supplied by sediment sources (e.g. rivers, cliffs, shoals), transported by currents and fixed by sediment sinks;
  - Composition, size and distribution of sediment particles in the nearshore and foreshore (sedimentology);
  - Composition and distribution of sediment-dwelling in fauna (benthic);
  - Geology and geomorphology of the coastline;
  - Past and present coastline positions;

- Coastal bathymetry and elevation;
- Water levels including wave regime, astronomic tides, extreme water levels and historical trends of sea level rise;
- Past and present land cover;
- Major infrastructure impeding sediment transport (e.g. dams, harbour, jetties, seawall).

➢ Review the effects of climate change on coast and fluvial flooding, urban drainage systems and sewer flooding and on coastal erosion. Consideration should be given to the effects if nothing is done to combat global warming;

➢ Map coastal erosion hazards and risks for different time horizons – e.g. 25, 50 and 100 years – with and without coastal defence measures and for different scenarios of sea level rise. Wherever coastal erosion may result in coastal flooding, coastal erosion mapping shall be extended to coastal flooding mapping.

➢ Assess the assets located within areas prone to coastal erosion and erosion-induced coastal flooding. This assessment shall be based upon data on:

- Population;
- Land market value;
- Economic registered activities;
- Areas of high ecological value;
- Cultural heritage including for example archaeological sites, designated buildings, historic battlefields and other remarkable sites.

➢ Define the objectives of the CSMP in terms of target thresholds for meeting the conditions of a ‘favourable sediment status’ within the coastal sediment cell. These objectives may be best described using a combination of 4 generic policy options:

- ***Hold the line***, by maintaining or increasing the standard of protection leaving the location of the coastline unaltered. This may include supplementing the sediment budget to achieve a ‘dynamic equilibrium’ of coastal processes;
- ***Move seaward***, by constructing new defences seaward of the original defences. In the context of the sediment management this may include beach nourishment;
- ***Managed realignment*** by allowing a landward movement of the shoreline position with some form of management intervention, on both flood and erosion prone frontages. This may or may not include a identifying a pre-defined landward defence position. This approach may or may not require the use of additional sediment supplies to augment the sediment released during the realignment process;
- ***No active intervention*****,** by making no investment in shoreline management i.e. allowing natural processes to ‘take their course’.

➢ Propose measures to meet the conditions of ‘favourable sediment status‘ as defined above. These measures may combine a wide range of instrument including:

- The designation of strategic sediment reservoirs as a key instrument to restore coastal resilience by supplying sediments where needed and providing space for coastal processes. Note the reservoir may come from an adjacent cell, offshore or could be related to management in the catchment;
- The modification of spatial planning documents to reflect the designation of strategic sediment reservoirs and the results of risk and hazard mapping;
- The designation of types of activities types which shall be subject to an Environmental Assessment procedure (EIA or SEA) focusing on coastal erosion processes within the coastal sediment cell;
- The introduction of regional and local regulations to mitigation the potential impact of human activities on coastal erosion processes. This may include for example building regulations, but also restriction of dredging activities during certain periods and for certain areas, or specific requirements for designing, constructing or decommissioning dams. For more information, the reader may refer to the document titled [EUR-5.4];
- The planning of coastal defence actions combining hard and soft engineering works such as beach nourishment, dune rehabilitation, breakwaters, seawalls, etc.

➢ Assess the costs and benefits of implementing the measures proposed in the Coastal Sediment Management Plan. Particular attention should be paid to external costs (i.e. the costs of environmental damages) and environmental benefits, which should be balanced with the “do nothing” scenario (i.e. the costs and benefits of not implementing the CSMP).

➢ Specify the financing plan. The Coastal Sediment Management Plan should clarify the sources of funding for its implementation. Particular attention should be paid to the funding mechanisms proposed to accommodate the policy option involving “managed realignment”.

➢ Establish monitoring procedures to ensure that the implementation of proposed measures meets the objectives assigned to the Coastal Sediment Management Plan and in particular contribute to meet the conditions of favourable sediment status within the coastal sediment cell. The monitoring procedures should also include mechanisms to detect discrepancies between realisations and objectives and to trigger corrective actions if needed.

Responsibilities for elaborating and implementing the Coastal Sediment Management Plans

Responsibilities for elaborating and implementing Coastal Sediment Management Plans (CSMP) should be devolved to **regional authorities** whose coastline is entirely or partly included in a single coastal sediment cell. When more than one region is concerned by a specific sediment cell, interregional arrangements should be established to elaborate CSMP.

Beside regional authorities sharing the same coastal sediment cell, the preparation of CSMP should involve the participation of a wide range of stakeholders including:

(i) the national authority (authorities) in charge of coastal erosion and coastal flooding related issues;
(ii) the national authority in charge of the environment;
(iii) representatives of coastal municipalities;
(iv) river district authorities;
(v) harbour authorities;
(vi) representatives of tourism industry;
(vii) representative of fisheries and aquaculture companies;
(viii) representatives of environmental interest groups;
(ix) representatives of academic and research institutions;
(x) representatives of coastal engineering companies;
(xi) the national authority in charge of public works;
(xii) the national authority in charge of housing;
(xiii) the national authority in charge of maritime transport;
(xiv) the national authority in charge of tourism;
(xv) the national authority in charge of rural affairs and aquaculture;
(xvi) the national insurance supervisory authority;
(xvii) the national federation(s) of insurance companies;

By undertaking this responsibility those authorities shall ensure that shoreline management is made fully compliant with the above principles of accountability. CSMP should be established for 5 to 10 years, be subject to a SEA, and periodically evaluated and revised.

Recommendation nr. 4

Strengthen the knowledge base of coastal erosion management and planning

The knowledge base of coastal erosion management and planning should be strengthened through the development of information governance strategies. These should be the starting point with information on ‘best practice’ (including learning from failures), for a proactive approach to data and information management and for an institutional leadership at the regional level.

The uncoordinated approaches to information provision and as a consequence the often inadequate bases upon which decisions have been made in the past are highlighted in EUROSION Finding 5 (EUROSION, 2004)

Finding 5: on information management

In spite of the availability of tremendous amount of data, information gaps continue to exist. Practices of coastal information management – from raw data acquisition to aggregated information dissemination - suffer from major shortcomings, which result in inadequate decisions. Surprisingly, sharing and dissemination of coastal data, information, knowledge and experiences are hardly ever considered by regional and local stakeholders. The use of a better knowledge base when coastal development is proposed provides an opportunity, which could help reduce technical and environmental costs of human activities (including measures for coastal erosion mitigation) and could help anticipate future trends and risks.

As a response to these major shortcomings the strategic fourth recommendation proposes a proactive approach to coastal data and information management in Europe. This approach aims at promoting the institutional leadership of regional authorities to provide the impetus for facilitating accessibility to existing data sources, advising on future production of information and knowledge, and spreading best practice in the fields of shoreline management.

Information lies at the heart of good decision making. At each level identifying the need and collecting and collating relevant information helps communication and the understanding of the issues and their possible solutions. In addition by feeding experience and information upwards lessons can be shared with others.

At the same time wider contextual understanding (disseminated from above through national and/or European data sets or by aggregation of local information) helps ensure local action takes full account of legislative requirements, is appropriate to the situation and does not compromise adjacent areas or interests.

Development of operational research on assessing the value attached to the coastline

We have highlighted the operational gaps in assessing the social, ecological and economical value of the coastline. In the future, particular attention should be given to the development of techniques, which enable a cartographic representation of the cumulated social, ecological and economical values of the coastal zones. In turn, cartographic representation of values facilitating the transition from coastal erosion hazard maps to coastal erosion risk maps, and supporting the implementation of cost-benefit assessment studies should be made.

Operational research on identifying and assessing values should build upon:

- Commonly-used data on population, land cover, land market values, infrastructure, registered economic activities, areas of high ecological values and cultural heritage sites;
- GIS techniques, thus facilitating integration with other activities and in particular coastal hazard mapping;
- Existing research on coastal valuation techniques, in particular those techniques which recognise the carrier, production, regulation and information functions of the coast.

Elaboration at the level of coastal regions

At regional to local scales, production, processing, storage, update, exchange and dissemination of relevant information on coastal erosion processes and coastline management should be considered as key prerequisites to ensure successful shoreline management operations. Regional authorities should play a lead role in creating the adequate institutional and technical conditions for such activities to take place, and their benefits maximised.
This should be achieved through the elaboration and implementation by regional authorities of a strategy on “**coastal information governance**”. This strategy should

not be restricted to coastline management, but extended to the broader context of integrated coastal zone management, wherever such approaches exist.
These regional information strategies should build upon the following principles:

- *Principle 1*: a lead authority working in partnership with a wide range of local to national stakeholders;
- *Principle 2* : a commitment to share relevant information (or data);
- *Principle 3:* use a well-documented web-based information system using internationally recognised standards;
- *Principle 4:* institutions retain responsibility for their own data including quality, timeliness and for its dissemination;
- *Principle 5:* the information system should be based on relevant and reliable data;
- *Principle 6:* adequate training;
- *Principle 7:* cost sharing by all partners;
- *Principle 8* : the system is reviewed periodically;
- *Principle 9:* regular review of the strategy realisation and performance

Coastal information governance strategies shall be supported in particular by the implementation of local information systems the general function of which should be to support the elaboration of Coastal Sediment Management Plans, and more specifically the characterization of undisturbed and present sediment conditions, the elaboration of coastal erosion hazard and risk mapping, the implementation of cost-benefits analysis and the support to environmental impact studies focussing on coastal erosion processes.
Tentative specifications for such local information systems, developed in (EUROSION PART5, 2004) have been followed for the implementation of MESSINA GIS prototypes.

II.3 Role of Geographic Information Systems (GIS)

While development and implementation of integrated coastal management policies is now established and internationally recognised ideal, the tools and methodologies for such goals are still under development. It is clear, however, that for any management of the coast to be effective, it is necessary for the policies to be based on informed decision-making.

This in turn requires ready access to appropriate, reliable and timely data and information, in suitable form for the task at hand. Since much of this information and data is likely to have a spatial component, GIS have obvious relevance to this task, and have a potential to contribute to coastal management in a number of ways.

These include:

- The ability to handle much larger databases and to integrate and synthesize data from a much wider range of relevant criteria than might be achieved by manual methods. This means that more balanced and co-ordinated coastal management strategies may be developed for considerably longer lengths of shoreline, spanning administrative divisions and even national borders where required (think of trans-border coastal sediment cells).

- Encouragement for the development and use of standards for coastal data definition, collection and storage, which promotes compatibility and interoperability of data and processing techniques between projects and departments. This as well ensures consistency of approach at any one site over time.

- The use of a shared database (especially if access is provided via data network), also facilitates the updating of records, and the provision of a common set of data to the many different (local) departments or offices that might typically be involved in management of a single stretch of coast.

- As well as providing efficient data storage and retrieval facilities, GIS also offers the ability to model, test and compare alternative management scenarios, before a proposed strategy or management option is imposed on the real world.

As with any new scientific methodology or emergent technology, successful take-up and implementation of GIS is as dependent on awareness and other human factors as it is on purely technical issues.

Definition of an information system

Within the defined framework, an information system is defined as “a set of technological, human, organisational, financial, and information resources organized in such a way to produce, archive, retrieve, modify, process, combine, represent, exchange and/or disseminate information with a view to reach the objectives the system is designed for”.

For geographical purposes, this broad definition has been restricted as follows:
“a set of technological, human, organisational, financial, and information resources organized in such a way to improve archiving, retrieval, representation, exchange and dissemination of information produced by institutions involved in shoreline management and on a specific area”.

Components of a local Geographic Information System

i) The stakeholders

The leading institution which endorses the overall responsibility for implementing, promoting, administrating and maintaining the Geographic Information System can be either a regional, county, or municipality council, or the local representation of a national administration. In any case, the leading institution has an executive mandate and is accountable for its actions towards the public. Note that even in case the leading institution delegates the implementation and maintenance to a third-party institution (e.g. an NGO or a private company), it still remains the responsible party.

Data providers and users, i.e. institutions willing to share part of their information capital with other institutions, and as a counterpart, being granted an access to information from these other institutions shall also be considered as stakeholders.

ii) The equipment

Hardware and software, i.e. the set of interconnected computers and other devices (e.g. CD players) - together with their operating applications - which provide the technological infrastructure for archiving, retrieving, representing, exchanging and disseminating information (as such an internet based application suits)

iii) The documentation

The documentation is mainly composed of:
- the technical specifications of the application which, for instance, are part of the documentation made of the prototype specifications that describe the features shared and used in the framework of the Geographic Information System;
- the user handbook
- the manual of procedures for setting up and maintaining the local GIS.

General Implementation principles for local GIS

As mentioned above, political, institutional and organisational arrangements appear to be the most critical factors when designing and implementing an information system. These arrangements should express the willingness of a group of stakeholders to put their information resources on a common platform, and therefore guaranty its sustainability. In a sense, these arrangements define a “coastal information governance strategy” which will set the institutional basis for the design and implementation of local information systems. The minimum requirements to be fulfilled by such coastal information governance can be expressed as a number of principles:

- Principle 1: The strategy of the coastal information governance is established under the lead of the regional authority, in partnership with a wide range of local to national stakeholders operating along the coast, and as a part of the implementation of the European recommendation on ICZM at the regional level.

- Principle 2: The commitment to share information (or data) relevant for coastline management has to be expressed by, and endorsed, at the highest hierarchical level within each partner institutions.

- Principle 3: Partner institutions agree to make their data – or part of them - available to other partner institutions.

- Principle 4: Information or data made available are managed through a well-documented information system. The architecture of the information system is based upon internationally recognised standards in order to increase its inter-operability with other information systems.

- Principle 5: Each institution is fully responsible for the data it produces. It includes responsibility for the quality, the update, and the dissemination.

- Principle 6: Data featured by the information system are as comprehensive as possible and covers physical, policy, social, economical and technical aspects of coastal erosion and coastline management, and are interoperable.

- Principle 7: The personnel of the partner institutions is adequately trained to the use of the information system

- Principle 8: All the partners share the cost of information system design, implementation and maintenance.

- Principle 10: The performance of the information system is reviewed each year.

These principles should lead to the signature of a "Memorandum of Understanding" among the various stakeholders willing to become member of this platform (EUROSION PART5.8, 2004).

As mentioned earlier, the various stakeholders met during the pilot studies agreed that regardless of the information to be produced, this information should be necessarily derived from a set of basic data which best describe coastal erosion processes from different aspects (e.g. physical environment, legal and policy framework, socio-economic profile, technical operations). Necessary and recommended data sets are described in the Section III.

Operational Recommendations - Best practices

Adopt a project-wise approach for the design, implementation, and maintenance of the local GIS

The design and implementation of a local information system compliant with the provision of the coastal information governance strategy should follow a project approach, which include:

- Establishment of a Steering Group (or Board of Stakeholders)
- Recruitment of a GIS or Information System project manager
- Definition of a clear implementation plan
- Regular reports to the Steering Group

Through communication and interviewing, several best practices for implementing information systems could be extracted. Most problems in the implementation phase are related to the gap between technology, user demands and policy, non-defined scopes and targets, and lack of monitoring and evaluation.

The recommendations from best practices below are intended to be in the ‘back of the minds’ of managers that are halfway on the ladder between data supply and information needs, but may be useful for any other dealing with the supply of information towards any user.

Good practices for setting up a local Geographic Information System are:

Define purpose and scope. Well-defined project purpose and scope both rest on a solid understanding of the underlying program or policy. Together, they represent deliberate decisions about what part of the program the project should address and what realistically can be achieved given the resources available. Ideally, the selected purpose and scope not only attack current problems, but also lay a foundation or build capacity to deal with future ones.

Choose a well-skilled and respected project leader. The project leader is a critical success factor in regional / local information projects and GIS. Choose a person who is able to span the psychological and political distance between regional and local governments; has a good understanding of local operations; enjoys the confidence and support of top-level executives; is an excellent communicator; is a resourceful manager of people, time, and money; and is flexible and willing to seize opportunities.

Recruit the right project team. Assemble a team of both national/regional and local staff who collectively have strength in three areas: management, technology, and policy. Without individuals capable of handling project management functions (time lines, work plans, budgets, recruiting) you run the risk of poor coordination, and wasted time and effort. If a project lacks adequately skilled technology personnel, it is likely that deadlines will be missed and applications may fail or contain crucial flaws. Teams that do not include well-informed program and policy staff, especially those engaged in direct service functions, are likely to miss the boat on substantive service goals.

Sell the project to decision makers. At the beginning of the project, develop a shared vision that identifies tangible benefits and shows how investments of regional or local resources can achieve them. This vision (used consistently in important project documents and events) communicates to decision makers important information about why the project is being undertaken, what the expected goals are, and how the realization of these goals will benefit their stakeholders.

Communicate often and clearly with stakeholders. Good communication practices ensure that all stakeholders (both those actively involved and those who will eventually be affected) are continuously and adequately informed about project goals and progress. This is not a one size-fits-all endeavour. The techniques selected should be based on the particulars of the project and specific needs of each audience: what information do they need? How much detail? How often? Through what medium?

Adopt tools and techniques that can manage complexity. These projects require tools to manage people, time, relationships, partnerships, ideas, conflicts, resources, information, and processes. Project managers need a range of techniques and the insight to use them in the right context to manage multiple streams of formal and informal communication and activity. Successful techniques are usually based on a keen understanding of the project's goals and common sense adaptation of both traditional and newly popular management tools.

Finance creatively. A local information system effort will likely be financed by a package of resources that includes cash appropriations, grant, in-kind resources (public and private), and a lot of redeployed human effort. Creative financing entails not only the usual budget management skills, but the ability to convince others to contribute resources, to identify and capitalize on grant opportunities, to "leverage" resources, and to balance the constraints and rules that multiple funding sources can impose on a project plan.

Look for existing models. Any project can benefit from a systematic review of similar efforts in other places. Since private and public sector organizations in this country and others often conduct similar programs, there are nearly always models from which to learn. Academic researchers and non profit organizations may also have solved a problem, or at least developed part of the solution. There is a lot to learn from success stories and even more to be learned from cases where things didn't always go as planned.

Understand and improve processes before you apply technology. A system which successfully supports both the service delivery role of local governments and the information requirements of the state usually results from a clear understanding of the dependencies and requirements which govern the business processes that link them together. Project teams often find that a significant amount of the improvement they expect from a new system actually comes from understanding and improving these processes before they apply any technology.

Match the technology to the job. Before choosing a technical approach, give full consideration to the work processes and overall business context in which a state-local system must operate. Consider user capabilities and the organizational and staffing limitations of the agencies that will be implementing, using, and maintaining the system to deliver services. Conduct technical awareness activities such as literature reviews, searches on the World Wide Web, vendor presentations, or attendance at technology exhibitions and conferences. Prototyping is an excellent, relatively low-cost way to test the "fit" between a technology and the environment in which it must work.

Use industry standard technology. Industry standards exist for almost every type of hardware, software, and communications technology, including such things as data organization and access (e.g. database structure, query languages), data sharing (e.g. Electronic Data Interchange, encryption), networking services (e.g. data communications, network management, e-mail), and document imaging (e.g. scanning, imaging, work flow). Standards enable interoperability and electronic messaging among system components. They also offer vendor independence and scalability when you use a common standard, you will be able to choose among different products that adhere to the standard and will be able to scale up to larger systems when the need arises.

Adopt and abide by data standards. Data standards usually include an agreed upon definition of the meaning of a term and an agreed upon format for how the term will be represented in the system. Standard data definitions and formats organized in a common data dictionary are an essential prerequisite for effective information sharing among government organizations and between the government and private firms. They provide a common language for information sharing, help ensure that the data sets will be described accurately, facilitate automation, allow for both central and distributed storage of data, and support electronic information exchange.

Integrate with related processes and practices. In most cases, local GIS projects are focused on standard business processes such as issuing a license, determining eligibility for a benefit, or recording a property transaction or vital record. However, these business processes are conducted throughout the state in very non-standard environments. Projects therefore need to focus on both the business process and the ability of individual organizations to adopt an information system to support that process. Tools such as data dictionaries and process and workflow analysis help identify ways that different organizations can and should participate. Organizations unable to implement a sophisticated automated system in the short term can begin by focusing simply on the new or improved business process. An organization that needs to retain its reliance on paper processing can still improve its performance and consistency by adopting the set of standard data definitions that are built into the computerized system. In this way, each organization can begin to integrate the useful elements of the new system into its own environment, within its own operational and resource constraints.

Use prototypes to ensure understanding and agreement about design. The philosophy behind prototyping is that system development is more effective when customers are partners in the design process. Prototyping allows for the building of the system to begin much earlier in the development process, and allows customers to see and influence the system as it is being built. The prototype makes tangible all the ideas that both designers and customers usually try to communicate to one another in words. The prototype makes it possible for both to see and understand the needs, functionality, and limitations of the design and to alter it as needed.

Choose a capable pilot site. Many system implementations are initiated with pilot tests that bring the system into the field to evaluate and refine design, performance, and integration with other systems and activities. The pilot site is a critical organisation - one that is willing to undergo on-the-spot evaluation and identify and work on the inevitable problems that pilots are created to uncover and resolve. A capable pilot site must be representative of local conditions, have the organizational capacity and leadership commitment to carry out the pilot, and be geographically accessible for easy interaction among designers and users.

Make the best use of the market. Technical expertise to support the implementation of a new networking technology, a new database engine, or a more intuitive graphical user interface is not the exclusive knowledge of government officials. Depending on resources and the needs of the project, outsourcing portions of the work to technical specialists can be an effective way to get the job done. Well-managed outsourcing allows the government staff to focus on those issues that demand their specialized knowledge and experience while relying on other experts to do the technical work.

Train thoroughly. The process of adopting a new system can be made much less difficult by offering well-designed, user-oriented training sessions and reference materials. User training needs to demonstrate not only how the system works, but how it fits into the larger work picture. It also needs to take place at the right time and be offered by methods that take into account the different ways that people learn.

Support users. The time period surrounding implementation is a critical one for user support. Offering immediate, appropriate support at this point in time will relieve anxiety and will encourage willing and effective users. But there are always new users and most systems continue to add or change features throughout their life cycle. User support needs to be continually updated and continuously available through such methods as a formal help desk, newsletters, online help features, and lists of frequently asked questions.

Review and evaluate performance. A formal evaluation tells how well the system supports the purpose and goals of the project. A comprehensive evaluation is attractive to funders, policy makers, and taxpayers alike by answering questions such as: how well does the system meet customer needs? How well does it contribute to integrated service delivery or other service system goals; how well does it meet time-savings, streamlining, and other operational improvement and user effectiveness goals; and how well does the system meet cost-savings or revenue goals? The answers to these questions lead to decisions about changes, improvements, refinements, and lessons for future initiatives.

It is important to stress that behind a step-wise approach such as demonstrated in the manual of procedures for setting up a local GIS, there are several ideas and best practices that form the fundamental logic to a successful information system. Not only has the sequential elimination of site-specific non-relevant steps within these guidelines proved the benefits of a generic approach. Each information system project requires a somewhat different mix of these ideas and good practices to guide it to a successful conclusion. Even though the step-wise kind of thinking is useful and important for managing activities, it should be urged to think of these practices, not only as steps, but as ongoing areas of attention that exist throughout a project. The level of intensity that any one practice commands at any point in time will vary, but will not disappear (See Figure II-29 below).

The Section III of this Practical Guideline details for Coastal Managers each task mentioned hereinabove to implement the Coastal Geographical Information System: objective, methodology, human resource, financial resource, expected output, and validation.

- The *objective* part explain shortly the main(s) objective(s) of the action/tasks.
- The *methodology* details the process which will lead to the realization of the objective. In this part, it is sometime mentioned that the methodology can be adapted to the local specificities and/or to the leading organization’s usual process.
- The *human resources* part gives a general idea of the number of staff/day necessaries to execute each task. The effective number of staff/ days of the different tasks may vary a lot from one case to another. Each leading organization will have to take into account the specificities of its site, to adapt those figures and get them closer to the reality.
- The *financial resources* part gives an overview of the different costs that have to be taken into account for each task. The leading organization should use

these indications to estimate the costs (taking into account its local specific context).

- The *expected output* part describes each task's main(s) output(s).
- The *validation part* describes the validation process (which can also be adapted if it is relevant)

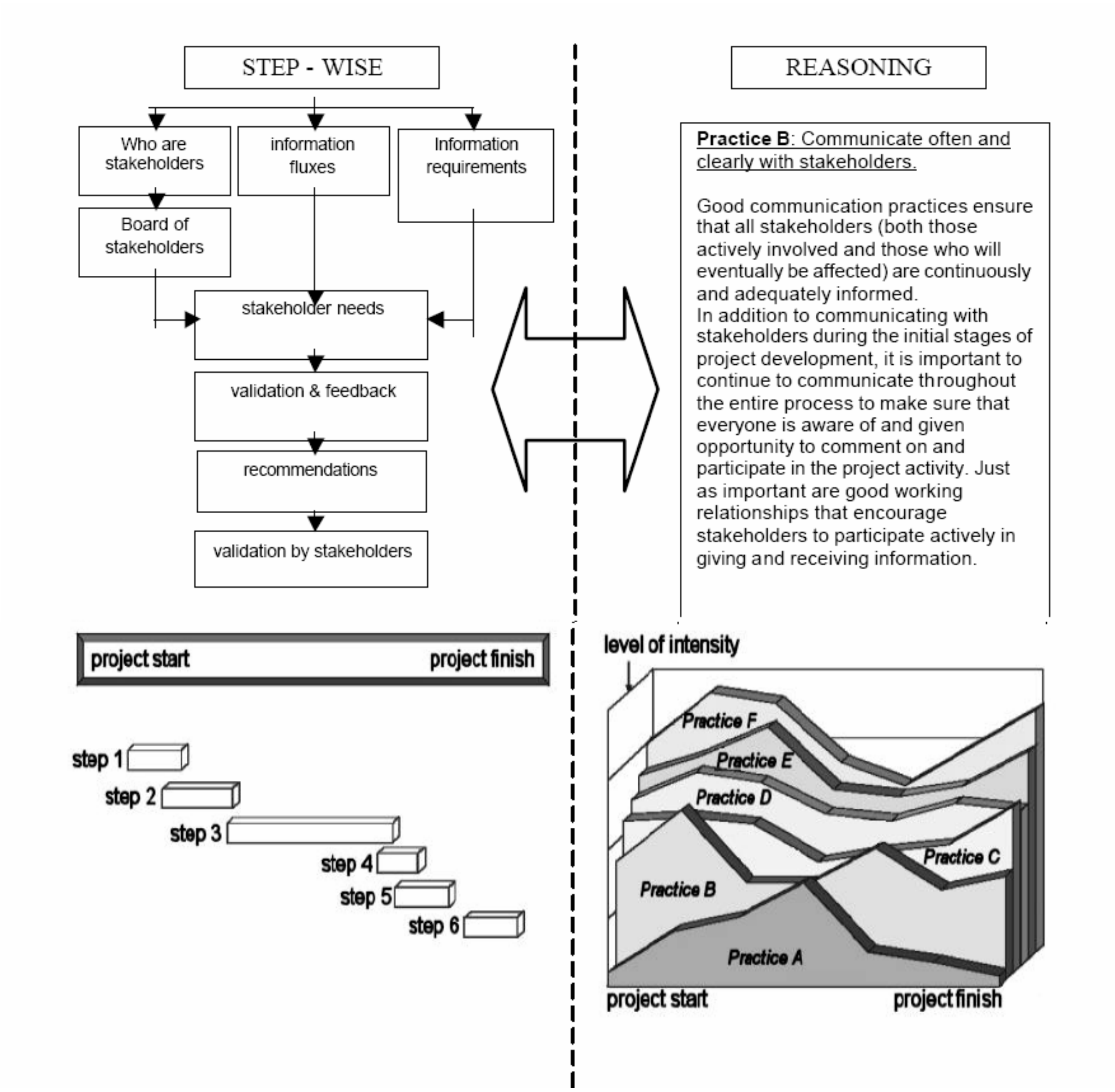


Fig. II-29. Stepwise approach considering ongoing best practices (from EUROSION)

II.4 Coastal risks assessment mapping

In order to come to a thorough coastal erosion risk assessment, it is necessary to combine different data. For instance, when planning a coastal construction such as a harbour extension jetty or coastal tourism developments in the form of a string of hotels at the shoreline, data is already needed in the planning phase.

Risk assessment is defined as the combined assessment of hazards and vulnerability.
Vulnerability assessment is driven by value shaping the coastal zone from an economical, ecological and socio-cultural point of view.
Combining this with the more physical oriented (storms, flooding, erosion) hazard assessment of the coastal zone will give a sound basis for coastal risk mapping.

The following excerpt from MESSINA Practical Guide *"Valuing the Shoreline"* (MESSINA PG3, 2006) shows that hazard and risk analysis is revealed as crucial for at different steps of the appraisal for coastal planning project.

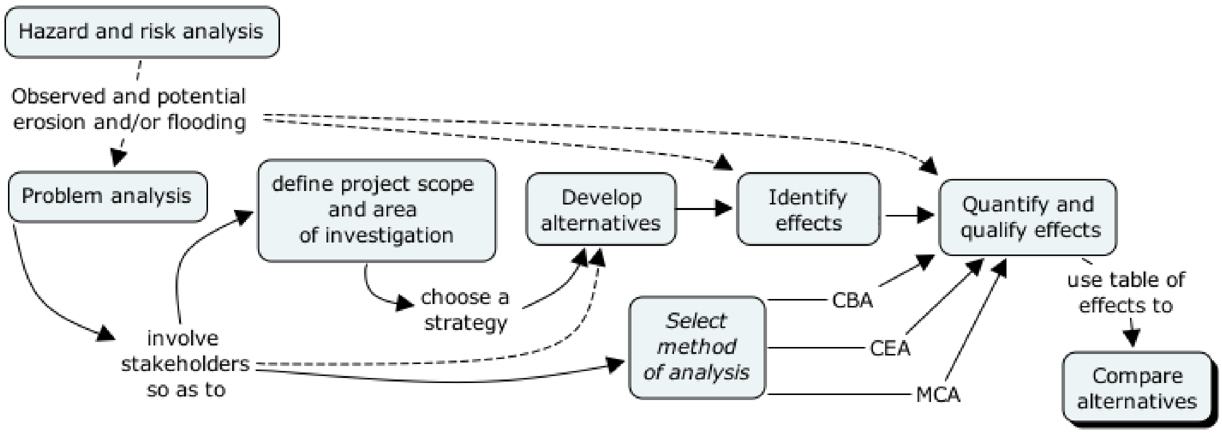


Fig. II-30. Major steps in appraisal of coastal planning projects

This baseline risk mapping of the coastal zone prior to any human construction will influence or even adjust the project option proposals that will undergo a (societal) cost benefit analysis (CBA). Here, guided by the results and maps of the coastal risk, again, economical, ecological and socio-cultural costs and benefits will be weighed to give advice in the options appraisal phase.

Moreover, coastal risk maps combined with the location of a construction work will give information on whether there is a chance on impacts of coastal erosion after the construction. The Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) procedures are essential in this. Input on hazard assessment, value shaping, EIA and CBA are interacting as described in the figure below.

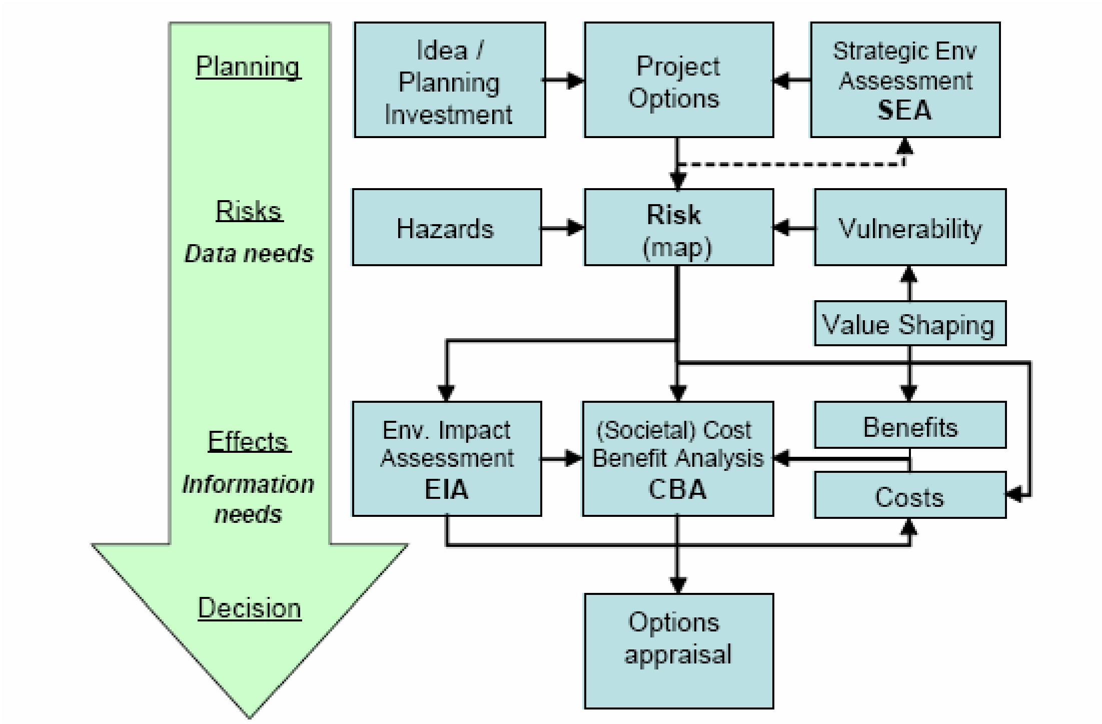
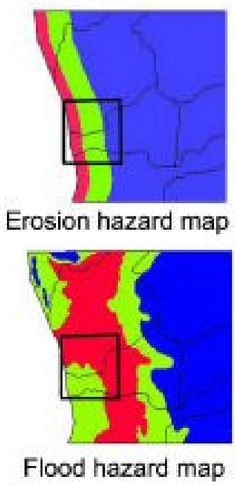


Fig. II-31. Spatial planning project process (from EUROSION)

Coastal risk mapping considers geography, geologic processes, storm characteristics… all of which control the property damage potential of coastal areas. Thus risk analysis involves two components: hazards and vulnerability assessments. Hazards are the physical processes of storms (wind, waves, surge…) whereas vulnerability is the built environment which is subject to the storm physical processes (houses, other buildings, infrastructure, utilities…).

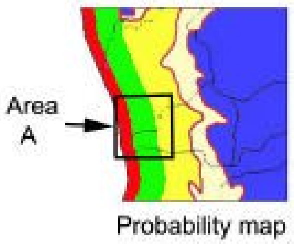
Hazard Assessment

Observations made indicate that elevation, exposure to wind, presence of dunes, absence of vegetation, high erosion rates, engineered structures, uncontrolled development and historic storm response are among others some factors inducing property damage.



Erosion hazards are related to long-term coastal dynamics and to flooding threats of areas lying close to or below sea level. Hazard analysis refers to the assessment of the (annual) erosion rate and flood incidence in a specific coastal area and to understand the scale and characteristics of the hazard. The probability can sometimes be assessed based on past records, like probabilities of high waves and floods or extrapolation of studies, like erosion contours.

Predicted rates of coastal erosion without further coast protection form the link between the physical process and the economic benefit of protection. Based on local historical and technical information and an understanding of the local processes a set of

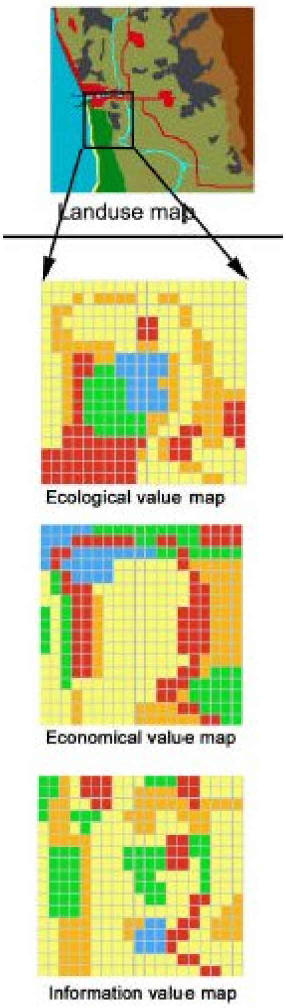


predicted erosions contours are generated over a time horizon of 50-100 years. Sensitivity analysis is undertaken to cover the issue of uncertainty. Similarly, maps of flood prone areas and flood probabilities can be used as a basis for flood alleviation projects. These predictions are sometimes erratic and difficult to make and may be subject to uncertainty (Hall, 2000); however, they are a necessary basis for analysis of the probability of loss of land, property, habitats etc.

Fig. II-32. Erosion and Flood maps, combined into Hazard probability maps.

This method for hazard mapping is fully described in Section III and applied for High-Normandy pilot site, and documented in Section IV.

Vulnerability estimation



Depicting contours of erosion and flood prone areas on a map, and combining these with land use and property data and population figures give insight in potential impact or damage of erosion and flooding. The Eurosion project called for risk mapping and recommended using such approach in spatial planning.

Hazard maps would indicate high-risk areas vulnerable for erosion and/or flooding and where protection measures are imminent. These maps could also be a lead for the selection of locations for commercial investments (hotel or industry). Vulnerable areas should be avoided for (commercial) development, as they require costly protection measures on a longer term.

Methods for estimating investments, properties and goods lying on coastal area are described within the MESSINA Practical Guide *Valuing the Shoreline* (MESSINA PG3, 2006). A comparison of each method but also recommendations regarding its context of application, and limitations is also proposed.

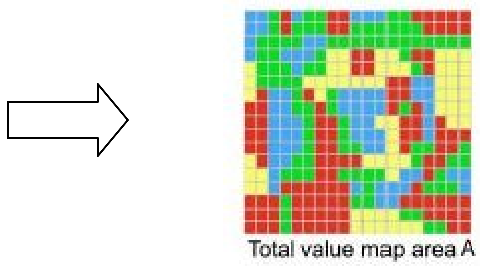


Fig. II-33. Based on Land Use map and valuing methods, thematic value maps (economical, ecological, social) are made and combined (weighted) in order to produce (Total value map) for the Area of interest

Risk mapping

Coastal Risk assessment estimates the risk that an event, for example erosion or flooding, causes damage to property, health, ecosystems etc. It involves identifying possible hazards and estimating their frequency or probability and analysing their likely impact. A risk value can be estimated as:

Risk = Hazard (Probability) * Impact Value (Potential damage)

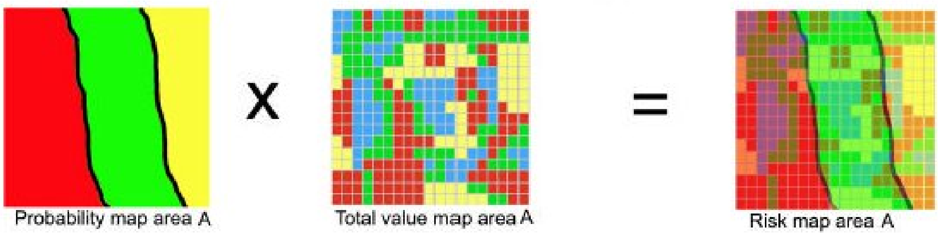


Fig. II-34. Risk map as a combination of Hazard probability map and Value map

The hazards identified are listed in a hazards/risks register. An evaluation is made on the probability of occurrence and consequence of each hazard. This can be done for different scenarios (worst, best, and normal). When the risks are delineated they can be ranked according to risk value and preventive measures can be planned and implemented. There are four ways of responding to identified hazards/risks: acceptance, avoidance, transfer or mitigation. The hazards/risks register shall continuously be updated and evaluated during the project assessment.

Risk and impact assessments provide essential information to take the right decision on the best use of investment capital against value at risk and the right approach to ensure shoreline stability.

This Practical Guide (esp. Sections III and IV) intends to demonstrate and promote the application of GIS technology to coastal risk mapping resulting in designating zones of relative risk for property damage. Coastal risk mapping is ideally suited to the application of GIS computer technology.

Applying Geographic Information System technology to hazard assessment benefits the communities by providing a basis for zoning, land use planning, and allocation of resources for post-storm property reconstruction and pre-storm damage mitigation plans. GIS may also be used to map and assess property damage or usefulness of attempts to protect and preserve coastal resources so that successful attempts may be continued and unsuccessful attempts abandoned. Such applications of GIS may ultimately lead to quantified assessments of ideal construction sites with areas of high risk left in a natural state - thus saving money and, possibly, lives.

The Section III of this Practical Guideline details for Coastal Managers the data sets to be collected and integrated to Coastal Geographical Information System to be able to perform risk assessment.

SECTION III – GUIDELINES FOR COASTAL GIS INTEGRATION

List of figures

In the 1960's and 1970's (geographic) information systems were used as tools for data processing, in the 1980's their role evolved to that of systems that supported stakeholders needs and take better decisions. Presently we see their role change to "strategic" that is systems that support a variety of players in different organisations, at different levels of government, in different locations, and sometimes in both the public and private or non-profit sectors.

This third part of the guidelines provides the bases of local geographic information systems dedicated to shoreline management (coastal erosion, flooding, spatial planning) and intends to support coastal managers within regional authorities willing to make a major contribution to coastal erosion management and coastal information sharing.

Although these guidelines are far from exhaustive they should help in providing basic cost-effective methods, primary ideas and references on how to establish a coastal GIS, which data integrating and for which purpose.

III.1. Definition of Coastal Geographical Information System

What is a local geographic information system?

A local Information System can be defined as “a set of technological, human, organisational, financial, and information resources organized in such a way as to produce, archive, retrieve, modify, process, combine, represent, exchange and/or disseminate information with a view to reach the objectives that the system is designed for”.

By local Geographic Information System (GIS) dedicated to shoreline management, and with reference to the above-mentioned definition, we mean that the objectives for which the system has been designed for, relate to a restricted geographical area, ranging from a municipality to a regional entity involved in shoreline management and of a specific area.

Although a number of other GIS definitions tend to put the technology upfront (computer-based), it is worth mentioning that institutional, organisational and political aspects account for the greater share in the success (or failure) of a GIS.

Consequently, developers of information systems are expected to cooperate with partners in economics, sociology, and engineering as well as with experts of natural, earth and life sciences, and computer sciences. These guidelines are to support these developers, and aims to be covering all aspects of the implementation of a local GIS. Although not all of these aspects are necessary because of the enormous variation in local conditions, the relevant parts may be selected during a step-wise implementation process, accompanied with clear technical specifications.

However, critical success factors for information systems are no secret: top management support, clear purpose, committed stakeholders, and realistic cost and benefit measures are just a few that contribute to a successful system. These factors are well known, but not easily achieved, even in systems that lie inside the boundaries of a single organisation.

The only justification for any GIS, or particular component, is that the benefits justify the costs. Those benefits must be identified, being justified not only in monetary terms but also considering e.g. improvement of access to information, awareness and a clearer sense of involvement amongst stakeholders, and finally, the support and efficiency it brings to the whole cycle of project planning, policy preparation, implementation, monitoring and evaluation.

Which aspects must be taken into consideration?

Designing, developing, installing and maintaining a local GIS dedicated to coastal erosion management requires taking a wide range of variants into consideration simultaneously. These variants may be grouped in six categories as shown in the figure below:

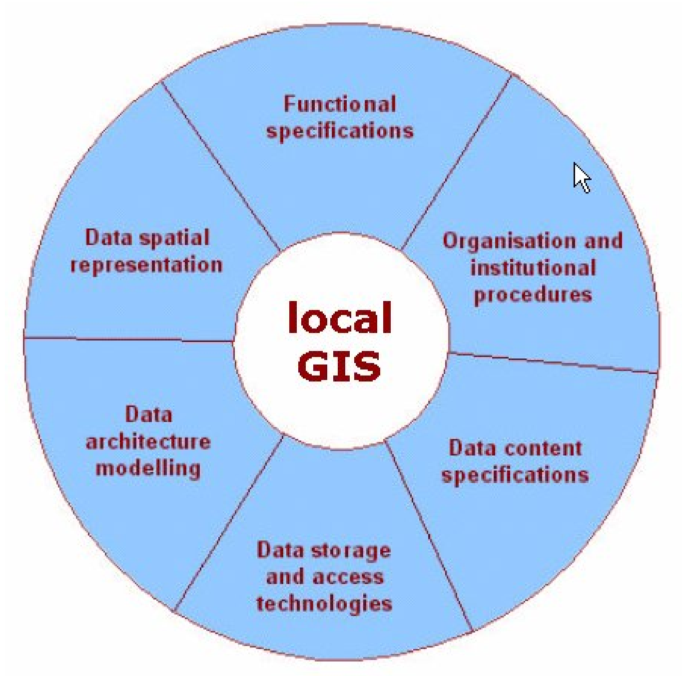


Fig. III-1. Functions of local GIS

More precisely:
Functional specifications aim at clarifying the objectives of the geographic information system. They describe which coastline management decisions are to be supported by the system, as well as their data requirements. To some extent, the functional specifications are the '*raison d'être'* of an information system.

Organisational and institutional procedures. The design, development, installation and maintenance of any geographic information system requires well-tried organisational procedures which aim at ensuring that the system will meet the expectations of the different stakeholders and is implemented within an agreed time schedule and budget constraints.

Data content specifications**.** Data constitutes the fuel of the geographic information system. This section thoroughly describes the typology and nature of data which have been identified by the technical specifications. Additionally, this section also provides information on the methods and costs associated to data production.

Data storage and access technologies**.** This part describes the mechanisms through which information is physically archived and made available to a wider public. It notably describes the standards to be used for exchanging data from one computer to another and for documenting the content, quality and access conditions of the data themselves.

Data modelling**.** Data modelling is about the architecture and the structure of the data, concentrating on the logical entities and the logical dependencies between these entities. Data modelling is a critical aspect of geographic information system development since the ability of the system to combine and cross analyse data will depend on it.

Data spatial representation. Data spatial representation deals with the location of physical objects or phenomena as described by the data collected and how this location will be characterized. A common way of describing location is to use geographic or cartographic coordinates which refer to a specific geographic reference system and a specific cartographic system. Failure to adopt a standard geographic reference system or a specific cartographic system may result in the impossibility to cross combine information and represent them consistently on one map.

Functional specifications.

The objectives assigned to local GIS may vary considerably from one site to another. In the fields of coastline management and associated spatial planning however, experience gained from pilot sites makes it possible to define these objectives as answers to frequently asked management questions. To a large extent, these management questions are linked to investment decisions, which can be summarized as follows:

- Will my investment be exposed to coastal erosion hazard during its lifetime?
- Will my investment impact coastal erosion processes?
- Do the benefits generated by my investment (including the environmental benefits) exceed its costs (including environmental costs)?

The answers to these questions are far from obvious and generally require a considerable amount of data from different nature and different sources. In line with these three questions, MESSINA builds upon EUROSION recommendations and proposes the development of local GIS comprising three main functionalities:

Function 1 - Hazard assessment
Function 2 - Impact assessment
Function 3 – Cost-benefit analysis

Function 1 - Hazard assessment

Depending on the type of coasts, erosion hazards may be related to the loss of lands, and together with them, the economical assets they support (e.g. cliff retreat or beach lowering), or it may be related to the flooding of coastal plains either as a direct result of acute dune erosion or as a result of sea defence undermining by chronic coastal erosion. In both cases however, the data requirements can be listed as follows:

- Aerial orthophotographs (alternatively satellite images)
- Current and historic coastline
- Terrestrial elevation
- Near-shore bathymetry (alternatively offshore bathymetry)
- Cross-shore profiles
- Coastline geomorphology and geology
- Seafloor sedimentology
- Sediment transport
- Near-shore wave regime and near-shore currents
- Offshore wave and wind regime
- Astronomic tide
- Still water level

- Coastal defence works

The local GIS should be able to generate maps of coastal erosion hazards.

Function 2 – Impact assessment

Human activities may impact coastal erosion processes in a variety of ways. In all cases, changes take place whenever one or more of the above mentioned natural causes of coastal erosion are modified. MESSINA proposes to consider the following typology of impacts on coastal erosion processes and impacting projects:

- Impact 1 modification of near-shore bathymetry and wave propagation patterns
- Impact 2 disruption of long-shore drift currents
- Impact 3 removal of sediment from the sediment system
- Impact 4 reduction of river debits
- Impact 5 reduction of volume of tidal basins
- Impact 6 modification of near-shore vegetation
- Impact 7 modification of soil weathering properties
- Impact 8 modification of Aeolian transport patterns
- Impact 9 land subsidence

A wide range of projects is concerned with such modifications. They can be grouped in 6 categories:

- Category 1: Land reclamation projects
- Category 2: River water regulation works
- Category 3: Sediment extraction projects
- Category 4: Construction of tourism and leisure facilities
- Category 5: Coastal defence works
- Category 6: Hydrocarbon and gas mining activities

In order to assess the impact of human activities on coastal erosion processes, the data requirements can be listed as follows:

- Aerial orthophotographs (alternatively satellite images)
- Current and historic coastline
- Infrastructure
- Hydrography
- Terrestrial elevation
- Near-shore bathymetry (alternatively offshore bathymetry)
- Cross-shore profiles
- Coastline geomorphology and geology
- Seafloor sedimentology
- Sediment transport
- Near-shore wave regime and near-shore currents
- Offshore wave and wind regime
- Astronomic tide
- Still water level
- Coastal defence works

Table below provides an overview of how above mentioned projects impact coastal erosion processes.

IMPACTS / PROJECTS	Modification of bathymetry and/or wave propagation patterns	Disruption of long-shore currents	Removal of sediment from the sediment system	Reduction of river debits	Reduction of volume of tidal basins	Modification of near-shore vegetation	Modification of soil weathering properties	Modification of Aeolian transport patterns	Land subsidence
Land reclamation									
• Harbour/airport extension	✓	✓			✓				
• Energy production plants (e.g. windfarms)	✓	✓			✓				
• Recreational parks	✓	✓			✓				
River regulation works									
• River damming			✓	✓					
• Irrigation systems				✓					
Sediment dredging									
• Channel dredging for navigation	✓		✓			✓			
• Aggregate extraction for construction	✓		✓			✓			
• Sand extraction for nourishment	✓		✓			✓			
Construction of tourism/leisure facilities									
• Marinas	✓	✓							
• Hotel resorts		✓							
• Recreational parks including golf amenities							✓	✓	
Coastal defence									
• Cross-shore hard defence including groins, breakwaters and jetties	✓	✓	✓						
• Alongshore hard defence including seawalls, bulkheads and revetments		✓	✓						
• Beach nourishment (see sediment extraction)	✓		✓			✓			
Hydrocarbon/gas mining									✓

Fig. III-2. Typology of projects having an impact on coastal erosion processes

Function 3 – Cost Benefit analysis

In a significant number of cases, investments related to shoreline management and/or coastal defence are decided though a poor attention has been paid to social, environmental and economical studies. This has lead to situations where the costs of shoreline management exceed its long-term benefits.

To avoid these situations, (MESSINA PG3, 2006) has reviewed a number of methods in connection with cost-benefit analysis of shoreline management investments and which can easily be applied to the development of local GIS.

These considerations put the emphasis on the role of the following data requirements:

- Infrastructure
- Land cover
- Land cover changes
- Demography
- Areas of high ecological value
- Cultural heritage
- Land market value
- Economic registered activities
- Fishery and aquaculture concession
- Mineral extraction concessions

Organisational and institutional procedures.

Political, institutional and organisational arrangements appear to be among the most critical factors when designing and implementing an information system. These arrangements express the willingness of a group of stakeholders to put their information resources on a common platform, and therefore guaranty its sustainability. In a sense, these arrangements define a “coastal information governance strategy” which will set the institutional basis for the design, implementation and operational functioning of local GIS. This governance strategy needs to be formally endorsed by all involved stakeholders in order to ensure commitment and responsibility division.

MESSINA proposes to build such coastal governance strategies upon 9 principles which are:

Principle 1: a lead authority working in partnership with a wide range of local to national stakeholders;

Principle 2: a commitment to share relevant information (or data);

Principle 3: use a well-documented web-based information system using internationally recognised standards;

Principle 4: institutions retain responsibility for their own data including quality, timeliness and for its dissemination;

Principle 5: the information system should be based on relevant and reliable data;

Principle 6: adequate training;

Principle 7: cost sharing by all partners;

Principle 8: the system is reviewed periodically;

Principle 9: regular review of the strategy realisation and performance.

Moreover, there is a need to adopt a project-wise approach to make sure that the GIS is implemented according to pre-established terms of reference and that its implementation receives appropriate guidance from the partner institutions.
This Guideline section builds upon and refers to EUROSION manual of procedures, to be formally amended and approved by all stakeholders, providing clear insight in the different phases of development, expected input and responsibility of each involved stakeholder, their interdependence and the obtained end result of the specific phase. The phases, responsibilities and results may vary along the process due to unforeseen changes, political choices or newly obtained knowledge, so flexibility is an essential element.

Data content specifications.

Which datasets will contribute to answer critical questions for coastline management and spatial planning? On the basis of the review of past and ongoing experiences in coastline management conducted in the framework of EUROSION (EUROSION PART5.6, 2004), 31 relevant datasets or “reference topics” that we have organised in nine topic groups have been identified. These reference topic groups and topics are presented further in chapter III.3 entitled *Data Collection and Integration*.
Obviously locally some adaptations shall be made according to data scaling, data availability and/or cost, specific needs or user specifications.

Data storage and access technologies.

These are described as the common requirements related to the technology used to make the data and information accessible. Besides requirements of the data and information (format, metadata, coordinates etc.) the technical specifications used allow broad access, requiring software and hardware standards. These requirements are intended for GIS architects, database designers, and software developers who will implement these requirements in different local GIS applications, and can be summarised as follows:

Storage. The data present needs to be stored into a physical place, supported by a hardware platform and into a professional (relational) database in order to provide a consistent structured methodology for standard compliance and embedding in long term knowledge. The storage of data is in principle is best guaranteed at the location where the main usage is for the data given, ensuring continuation and long-term homogenous information. Server capacity, backups and the stability need specific definition for both storage and access.

Access. Wide access to data (and information) for stakeholders (involved in risk mapping) can be facilitated through Internet technology; access requires limited effort, can be monitored and restricted if required. Distributed GIS software technologies allow access to local internet sites and ensures the provision of timely information; leaving storage at the place of origin. Options to define the exact information required by a user can be queried through the database. Existing technologies to facilitate the web-access are FTP-sites, websites which allow querying of the proper site, portals connecting multiple distributed databases and GIS and common used web navigators. The services to be provided need to encompass effective searching, viewing downloading, data transformation, and presence of metadata.

Security. Firewalls, specific user identification and passwords can improve the proper use of information

Maintenance. System maintenance at the information holder site includes regular hardware and software investments with licences for all kinds of applications.
Interface. Common interfaces used for data access, allowing Google™-like free text search or maps consultations as well as advanced access through GIS customized interface and remote database queries, glossaries and maps.

Data modelling.

Common requirements for modelling and documenting the architecture of data that is meant to be integrated into an “exemplary” local GIS is intended for system architects, database designers, and software developers who will implement these requirements in different spatial data applications. These requirements shall facilitate:

(i) interchange of data among data providers and users,
(ii) maintenance operations to the geographic information system, and
(iii) further improvements to the geographic information system.

To avoid confusion, these requirements do not impose or prescribe any particular architecture of the data themselves. Instead, they are meant to code and formalise the various elements and steps – including for example terminology, modelling language, and documentation - which are needed to develop and implement the architecture of data.
Finally, these requirements should be implemented for each Reference Topic meant to become part of the coastal GIS. Reference Topics are listed further in chapter III.3 entitled *Data Collection and Integration*.

Data modelling should build on standards where possible:
- ***Data modelling*** to be undertaken on the basis of ISO/TC211 standards, and are described in accordance to the reference model ISO 19101:2002. The terminology used during the data modelling process should comply with the requirements of ISO 19101:2002 and, in particular with the standard ISO 19104 - Terminology.

- ***The Unified Modelling Language (UML)*** to be used as the schema modelling language to define data interchange formats. Each of the Reference topic shall include an integrated application schema expressed in the UML according to ISO 19109 rules for application schema, and its normative references. The application schema will specify, as appropriate, the feature types, attribute types, attribute domain, feature relationships, spatial representation, data organization, and metadata that define the information content of a data set.

- Each of the Reference topic shall contain, as appropriate, documentation of all features, attributes, and relationships and their definitions. A data dictionary table shall be used to describe the characteristics of the UML model diagrams.

- ***The standard for metadata***, to be established in the framework of a coastal GIS should comply with ISO 19115, Geographic information - Metadata. ISO 19115 includes a minimal set of metadata that it is highly recommended to follow.

- Data modeller refers to national or regional Spatial Data Infrastructures which have defined permanent feature identifiers. A permanent ***feature identifier*** is an attribute attached to an object of the real world (e.g. roads, river, administrative units) which is common to several GIS applications. In that sense, using permanent identifiers makes it possible to combine data from different applications. It is of the utmost importance that during the design of the coastal GIS, the data modeller is knowledgeable of these features which have a permanent identifiers established by national authoritative standards. The management of a common or "permanent" feature identity needs to be undertaken within the community with permission granted to certain participant organisations to create or adjudicate these identities.

Data spatial representation.

The Earth's topography is a very complex. Its surface is divided by mountain ranges and deep oceans. In order to map its geography, a reference system or model is needed which will allow such topographic irregularities to be recorded and any single point on the Earth to be located unambiguously. The problem is that a variety of reference systems exist, particularly in Europe, consequently when combining or integrating data from different providers into a GIS, the various themes (inputs) are not in accurate alignment. To overcome these shortcomings, which may considerably undermine the overall quality of coastal applications, it is recommended that a number of standards are adopted by the various authorities willing to implement such coastal GIS, for instance from coastal sediment cell to an other.

- ***Geographical extent of the coastal GIS.*** It is strongly recommended to implement coastal geographic information systems at the level of coastal administrative regions extended to the boundaries of coastal sediment cells overlapping with the region's extent. A coastal sediment cell can be defined as a length of coastline and associated near-shore areas where movement of sediments is largely self contained. Sediment cells are separated from each other by rivers and sometimes by large promontories where the direction of longshore drift is changing; the length of sediment cells may be very small (less than a kilometre) or very large (100 km).

- ***Coordinate reference system.*** In line with the resolutions of European mapping agencies and the European Commission, EUROSION recommended the adoption of ETRS89 for producing and archiving spatial data on European coastal zones. In that respect, it is worth mentioning that some institutions, such as the International Association of Geodesy (IAG) which federates the national mapping agencies in the European Union, provide the methodology and the parameters needed (7 parameters) to convert coordinates from any coordinate systems into the system ETRS89.
Regional GIS initiatives could however use national coordinate reference systems with the condition that they are compliant with the European geodetic realisation, providing that GIS tools are now able to apply transfer functions on data to interoperate with other neighbouring systems…

- ***Vertical Reference System***. In line with the resolution of IAG and the European Commission, it is recommended to adopt the EVRF2000 as the vertical reference system for altitude related to spatial data in the European coastal zones. EVRF2000 is characterised by:
  - the datum of "Normaal Amsterdams Peil" (NAP),
  - gravity potential differences with respect to NAP or equivalent normal heights,

Vertical heights above see level can however be given with local height reference (e.g. Marseille tide gauge for France) providing that the difference with the European reference is known and height data can be adapted easily with GIS tool quick operation.

- ***Map projection***. It is quite common that coordinate reference systems include, beside the ellipsoid of reference and the datum, a map projection as well. A map projection is a mathematical model that transforms the locations of features on the Earth's surface to locations on a two-dimensional surface – a typical map - which is more convenient to visualize and handle than a three-dimensional surface. In that case, any single point of the earth's surface is located with two planimetric coordinates (x, z) instead of three as described above. Some projections preserve shape; others preserve accuracy of area, distance, or direction. None of existing projections can preserve all these features simultaneously.

When combining and integrating data coming from different providers, it is quite frequently realized that data providers have used different ellipsoids, datums and map projections, to locate their data. However contrary to 3-D coordinate reference system, the process of converting coordinated expressed in one map projection into another map projection is time consuming and subject to uncertainties, generating and cumulating localization mistakes.
It is therefore recommended to adopt a map projection for visualization purposes only (on computer screen or printed maps) and not for archiving purposes.

III.2. Risk assessment

With respect to decision making process, coastal managers have foreseen problematic issues affecting their area of interest. Once data is integrated into a coastal GIS, its main functions can be described, especially with coastal risk mapping.

Coastal risk assessment comprises of both the determination of the failure probability ***Pfailure*** of coastal defences and the estimation of losses (consequence) ***Cdamage*** in case of failure using the following concept to determine the risk:

Risk = *Pfailure* x *Cdamage*

= [probability of hazard] x [estimation of social/economical loss as a result of hazard]

Risk scoring approach

The ideal method for assigning priorities to the various hazard threats would be a scientific, quantifiable probability assessment. Unfortunately, probability data are not consistent among the different hazard types of coastal erosion and flooding, nor are they always available for useable at the local level.

As an alternative, communities can develop a relative priority matrix to use as a general guide for addressing the different hazards. Designing such a matrix requires you to determine which factors are most critical to your community and assign weights accordingly.

Factors can include hazard frequency, the amount of land typically impacted, or the magnitude of damages associated with the hazards, sometimes pragmatically based on a hazard assessment.

The purpose of this approach step is to foster internal discussions about the hazards and their potential impacts. It is a subjective exercise where the scores alone do not have absolute statistical significance. The comparison of hazard scores, however, will give relative rankings that can guide the vulnerability assessment process as well as the hazard mitigation priorities.

For example, one may use factors such as probability, magnitude or potential impact area to help establish relative priorities for dealing with different hazards. A scoring system could be (Source NOAA):

(Frequency + Area Impact) x Potential Damage Magnitude = Total Score

such as:

Hazard e.g.	(Frequency +	Area Impact) x	Magnitude =	Total
Flooding	4	4	4	32
Coastal erosion	5	1	2	10
Earthquake	1	4	3	12
Wind	3	5	2	20
(Etc.)	…	…	…	..

or other astute variation of this.

Within a risk consideration area there could be additional boundaries representing varying degrees of risk. These varying degrees of risk should be represented in the risk consideration areas both graphically (additional boundaries on the maps) and through some type of relative scoring system (higher scores for higher risk areas).
For instance, when developing a relative priority scoring system for storm surge inundation, Category 1 storm surge areas would therefore have the highest risk of being flooded since they are at risk of inundation in all storm events.

Using a GIS, the risk consideration areas are combined and the scores added together to create summary scores for every location in the area. These summary scores shall be used to develop a summary risk area map (see next figure or concrete realizations infra chapter IV)

For each valuation or impact map (e.g. ecological impact or economic impact) the degrees shall take normative values as of:

	Value
Very low	1
Low	2
Medium	3
High	4
Very high	5

Then the combination of impact maps with values between 1 and 5 gives a total value map of values.
If this total value map is multiplied with the risk score the risk map is born.

The Fig III-3 depicts a generic example of Risk mapping process: flood and erosion hazard map together gives the *Probability map* for a given area A (left part). Valuation of the land use map into ecological, economical and information (or socio-cultural) impact function of an area A gives the *Total value map* of area A.
The *Probability map* times the *Total value map* gives the *Risk Map of area A*.

Coastal erosion being a generic term which encompasses a variety of natural processes, a distinction is usually made between chronic, acute, and cliff erosion and the risk assessment can not be realized identically. The various methods for assessing those different kinds of risks are developed in Section III, chapter IV, after detailing which data are needed for.

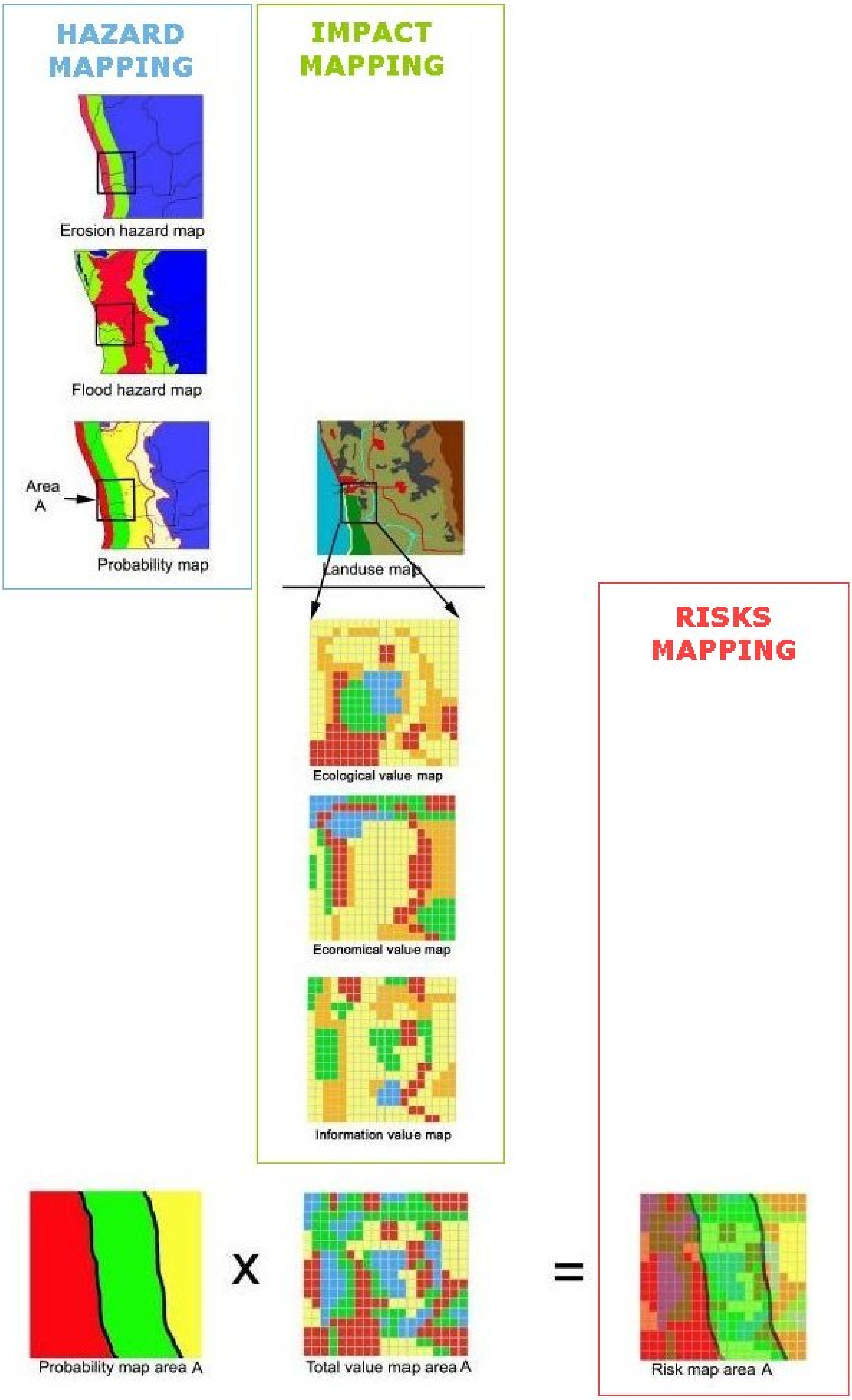


Fig. III-3. Risk mapping process on area A

III.3. Data collection and integration

Reference data

The most relevant data needed to assess both the probability of flooding and the extent to which land loss occurs has been categorized below.

Reference topic group 1 – Administrative boundaries
- Terrestrial boundaries
- Maritime boundaries

Reference topic group 2 - Topography
- Aerial photographs / orthophotographs / Satellite images
- Current and historic coastline
- Infrastructure
- Hydrography
- Terrestrial elevation
- Near-shore bathymetry / Offshore bathymetry
- Cross-shore profiles

Reference topic group 3 –Geomorphology, geology and sedimentology
- Coastline geomorphology and geology
- Seafloor sedimentology
- Sediment transport
- Sediment-dwelling (benthic) in fauna

Reference topic group 4 - Hydrodynamics
- Near-shore wave regime / Offshore wave and wind regime
- Near-shore currents
- Astronomic tide
- Still water level

Reference topic group 5 - Land cover
- Land cover / Land cover changes

Reference topic group 6 – Demography
- Demography

Reference topic group 7 - Heritage
- Areas of high ecological value
- Cultural heritage

Reference topic group 8 – Economic assets
- Land market value
- Economic registered activities
- Fishery and aquaculture concession
- Mineral extraction concessions

Reference topic group 9 – Coastal defence
- Coastal defence works

Key data sets collection

This chapter aims at reviewing which datasets are needed or encouraged to be gathered before undertaking hazard, impact value and vulnerability mapping. The Reference Topics data can be grouped by thematic, before being described.

Physical Environment

- Historical and current coastline positions
- Terrestrial elevation
- Nearshore bathymetry
- Cross-shore profiles
- Nearshore and foreshore sedimentology
- Nearshore wave regime
- Near-shore currents
- Astronomic tides
- Extreme water levels

Legal and policy framework

- Administrative boundaries
- Land Use
- Protected areas boundaries
- Remarkable boundaries
- Land and built-up ownership

Socio-economic profile

- Population
- Land Cover
- Infrastructure
- Economic activities
- Market value

Data sets for

HAZARD MAPPING

IMPACT VALUE MAPPING

Physical Environment

Historical and current coastline positions

Coastline can be defined as the interface between land, sea and air. However, due to the relentless fluctuations of the sea, its position cannot be precisely defined. To remove ambiguity, the coastline is therefore defined as the level reached by the highest high waters, i.e. the upper limit of the inter-tidal areas. This upper limit is generally easily identifiable on the ground (e.g. foot of the fore-dune) or can be derived from aerial photographs or very high resolution satellite images. The current and historical positions of the coastline are key information to understand coastal processes, anticipate future changes and prevent building in highly dynamic areas. In that respect, valuable information is provided by historical topographical maps from the early 1900s.

A number of techniques make it possible to delineate the shoreline position (either current or historical).
The coastline may be:

- Digitised directly from existing ortho-photographs **(see mapping of cliff erosion)** using computer-aided photo-identification functions offered by most GIS softwares, provided the coastline is easily identifiable as, for example, a characteristics feature of the cliff profile, the foot dune, or hard seafront structure.
- Interpolated from cross-shore profiles (see cross-shore profiles), i.e. the “probable” position of the shoreline is deduced from the position of the shoreline accurately known at certain locations along the shore. This method may be particularly efficient if cross-shore profiles are spaced 500 metres or less.
- Derived by intersecting the highest high water level (excluding storm level) known at a certain location with an accurate elevation model produced from remote sensing technologies (mainly LIDAR or aerial photogrammetry)

Aerial photographs and orthophotographs

The use of aerial photographs has been a popular method of measuring coastal change. Aerial photographs are taken from cameras embarked on aircrafts flying at variable altitudes. Typical photograph scales vary from 1:30,000 to 1:10,000 depending on the altitude. Aerial photographs provide a reliable picture of the ground at a specific time, including information on the type and position of buildings, infrastructure, vegetated and not vegetated areas. They also provide the position of “one” interface between land and sea (depending on the tide at the time of photo acquisition). In most cases however, aerial photographs are not usable as such as they have significant geometrical distortions - due to their conic perspective - especially at their edge. A mosaic of geometrically corrected aerial photographs is therefore preferred. These so-called “orthophotographs” are made super-imposable to a map and are more appropriate for further analysis.

To provide an accurate position of the coastline, the resolution of aerial photographs and ortho-photographs should be ideally sub-metric - between 0,2 to 0,5 meter – which require that the flight scale ranges from 1:10,000 to 1:25,000. In addition, aerial photographs should cover a minimal area which extends from 10 km inland to 2 km offshore. In the landward direction, aerial photographs are expected to provide information on urban, industrial, agricultural and natural assets located along the coast and potentially at risk of coastal erosion and flooding. In low-lying areas, it is however recommended to extend the spatial coverage of aerial photographs landwards up to the contour line corresponding to an elevation of 2 meters or more. Though aerial photographs provide few information on the wave regime near-shore, they can still provide indications on the topography of shallow waters including the locations of rip, flood and ebb currents, especially if aerial photographs are acquired at low tide. Metadata related to date and hour of flight acquisition are thus of the utmost importance.

1992 1999 2001

Fig. III-4. Example of aerial photographs - Happisburgh, North Norfolk, United Kingdom

In the case of historical coastline position, the coastline may be derived from ancient topographical maps (e.g. in France Carte d'Etat Major, 19th century) or old aerial photographs generally available in all Europe since the early 1950's.
The horizontal positioning accuracy of the coastline position should be better than 5 metres.

Terrestrial elevation

Terrestrial elevation is the altitude above sea level. In most of European countries, the altitude "zero" (referring the so-called vertical datum) corresponds to the mean sea level (MSL), i.e. the average level of the sea as recorded by tide gauges. This "zero" differs from the "zero" of the bathymetry (see near-shore bathymetry), which is defined as the mean lowest low water level (MLLW). The difference may reach a few meters; correspondences are measured within each European tide gauge. Terrestrial elevation is important to assess the exposure of human assets located along and behind the coastline to the sea processes (mainly storm surges and coastal erosion). This paragraph must be considered in complement to the section cross-shore profiles.

Terrestrial elevation should preferably be available for all terrestrial areas located within 10km from the coastline. In the case of low-lying areas, it is recommended to expand this spatial extent to areas located below the 2-metres contour line or more. Terrestrial elevation should be made available either as vector contour lines, or in a raster grid of elevation points. Key contour lines include the contour line "zero" corresponding to the mean sea level (MSL), the contour lines 1m, 2m, 3m, 4m and 5 m above MSL, and, above 5 metres, all contour lines with 5 metres equidistance (10m, 15m, 20m, 25m, etc.)

A wide range of techniques are available to determine the terrestrial elevation. Commonly used among these techniques are:

- Elevation contour lines in vector format are generally routinely distributed by national mapping agencies as part of digital topographic databases**.**
- Laser altimetry or LIDAR. LIDAR is an airborne device which sends laser pulses downwards and measure signal's echo. LIDAR is particularly efficient for near-shore areas as it can “sense” the elevation for both terrestrial and underwater areas (see near-shore bathymetry). The accuracy of LIDAR survey approximates 15 centimetres and its raster resolution can be one metre. Costs are decreasing reasonably while LIDAR use generalises but are still consequent and thus limits the possibility to use the technique for the complete coverage of the coastal areas.

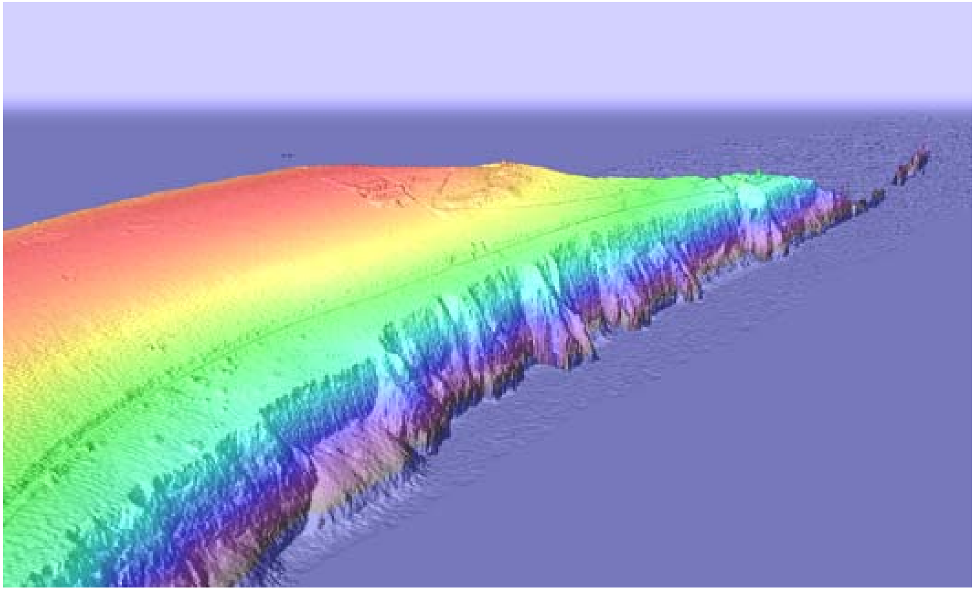


Fig. III-5. LIDAR view of “the Needles” – Isle of Wight (UK)

- Alternatively, terrestrial elevation can be extracted from “stereo-plotting”. Stereo-plotters are devices which can, from two aerial photographs of the same area but taken from 2 different perspectives, reconstruct a three-dimensional view of the area. This 3-D view makes it possible for an operator to “capture” from the aerial photographs the contour lines which are then digitised and structured in a database.

The accuracy of terrestrial elevation should be 5 metre for horizontal positioning, and better than 0.5 metre for vertical accuracy.

Nearshore bathymetry

Bathymetry is the depth below sea level. In most of European countries, the depth “zero” (referring the so-called vertical datum) corresponds to the mean lower low water level, i.e. the level reached by water at low tide during the period where the tidal range is the highest (spring tides). This “zero” differs from the “zero” defined for terrestrial elevation, which is defined by the mean sea level. The difference may reach a few meters.

Changes in nearshore bathymetry occur as a result of sediment processes or dredging activities. It is an important feature for understanding coastal erosion as erosion processes mainly occurs underwater and affect the sea bottom therefore coastline retreat is effectively observed. The bathymetry also plays an important role in nearshore wave propagation, as waves modify their courses as soon as they “feel” the sea bottom.
Bathymetry should preferably be available for a maritime area extending up to the 20 metres water depth. The 20-metres water depth approximately corresponds to the depth at which shoaling processes start. Near-shore bathymetry should be made available as vector contour lines (or “isobath”). The contour line “zero” corresponds to the lowest low water line (LLW).

A wide range of techniques are available to determine the bathymetry. Featuring largly among them are:

- Waterborne acoustic sensors. Acoustic sensors such as multibeam echosounders or sidescan-sonar which are emitters-sensors onboard ships. The sensor sends a signal in the direction of the sea bottom. After it has reached the seabed, the signal is back-scattered to the sensor, the delay is converted into a distance. Performance of echo-sounding for very shallow waters (0 to 3 metres) is limited since ships cannot get too close from the shore.
- CRAB echo-sounding. The technology of CRAB echo-sounding beamers is similar to the technology of waterborne echo-sounding. However, instead of being embarked on a ship, the beamer is mounted on a mobile crane able to move easily on the foreshore and in shallow waters.
- Laser altimetry or LIDAR. LIDAR is an airborne device which sends laser pulses downwards. Just like SONAR, the laser signal is reflected by the ground and a part is backscattered with a delay to the sensor. LIDAR is particularly efficient for water depths down to 5-10 metres (and with limited turbidity) and for terrestrial elevation (elevation of terrestrial and shallow waters are provided “seamless”). The performance of LIDAR however decreases for deeper waters. Since data recorded by echo-sounding or LIDAR sensors are not easily exploitable by a GIS, they need to be converted into either raster image or vector contour lines.
- Interpolation of cross-shore profiles (see section cross-shore profiles) that provide accurate information on the bathymetry of the foreshore at specific location. The bathymetry between these locations can be interpolated using standard GIS functions such as B-splines.

The accuracy of bathymetric contour lines should be compatible with scale 1:25,000, i.e. 5 metres for horizontal positioning. Contour lines should ideally have a 1-metre-equidistance, i.e. contour lines should be provided for the following water depths: 1m, 2m, 3m, until 20m.

Cross-shore profiles

Cross-shore profiling aims at providing highly accurate data on foreshore and backshore elevation and other relevant features. Contrary to remotely sensed elevation data which have a limited accuracy (typically 15 cm for LIDAR survey, one metre or more for aerial photogrammetry), coastline monitoring, especially along coast with low erosion rate requires a higher accuracy.

Since provision of extensive elevation data is extremely expensive and time-consuming, an alternative solution is to sample the coastline via profiles (or transects) set at right angles to the coastline and along accurate elevation data will be measured. It should be noted that some countries like the Netherlands and South England have been using systematic cross-shore profiling at the core of their coastline monitoring strategy (MESSINA CASE-STUDY STRATEGIC MONITORING PROGRAMME, 2006).

Cross-shore profile data should be made available for the entire coastline. The length of transects must cover both the backshore and the foreshore and should preferably extend to shallow waters (e.g. 2 metres water depth or deeper if surveying equipment makes it possible) and a few hundred meters inland, especially if dunes are present. Cross-shore profile data should be ideally provided as attributes of vector points. Each vector point correspond to one location along one transect. Profile data include the reference of the location, the elevation and the time of acquisition (or alternatively the reference of the survey campaign).

Cross-shore profiles result from ground surveying techniques. A profile (or transect) is a line of data collection points from a benchmark (or fixed point) located on the coastline, and set at right angle to the coastline (see picture). Profiles are spaced at regular intervals which may range from a few hundreds meters to a few kilometres. In turn the profile is divided into regular points for which the difference of elevation with respect to the benchmark is measured using surveying equipment which may range from traditional levelling equipment to sophisticated laser guided versions.

Profile elevation data collected at a specific time can be represented as a function of the cross-shore position. Comparison with former profile data for the same transect can be done.

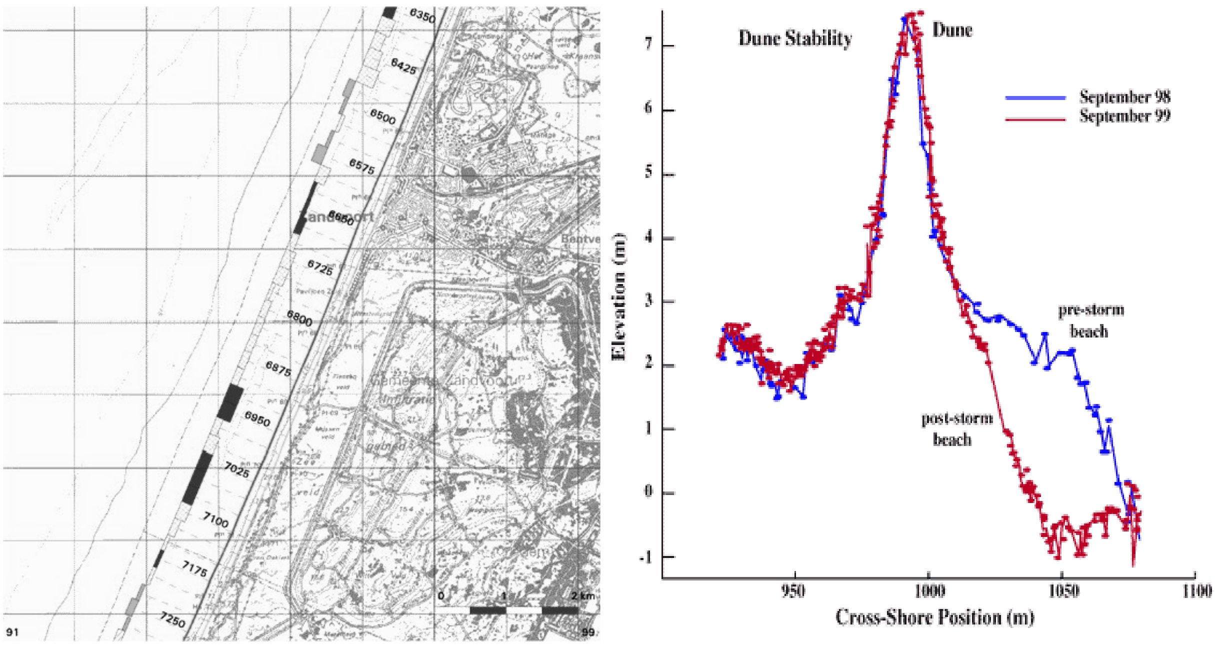


Fig. III-6. Example of cross-shore profiles: the JARKUS system in the Netherlands

To provide an accurate estimation of coastline retreat and sediment losses, the accuracy of cross-shore profile data must have a centimetric accuracy (0.01m) in elevation. Along a specific transect, elevation should be ideally measured every 5 to 50 meters depending on the width of the foreshore. The number of transects needed or the regular interval between consecutive transects may range from a few hundred metres to a few kilometres. Alternatively, the coastline may be divided into different sections with a different interval. Profile interval along sections known as highly dynamic should be smaller (e.g. 500 metres) than profile intervals along sections known as lowly dynamic areas (e.g. 2-3 kilometres).

Nearshore and foreshore sedimentology

Sediment is defined as fragmented material formed by physical and chemical weathering of rocks. As fragmented materials, sediments are more easily subject to transport by fluids (air and water) than their original rocks. This transport particularly affects the sediments deposited on the sea bottom and is the central element of morphological changes of the coastline. Nearshore and foreshore sedimentology aims at providing information on the properties and distribution of the sedimentary materials deposited on the sea bottom, and is therefore a key information layer to understand the interaction of seafloor sediments with water. Key properties include: (i) grain sorting (texture), (ii) grain size and grain size distribution, (iii) grain shapes (roughness), and (iv) grain density. Nearshore and foreshore sedimentology is complementary to the near-shore bathymetry.

In the framework of an operational coastal GIS, nearshore and foreshore sedimentology should ideally be made available for maritime areas extending up to the 20-meter-water depth, i.e. the approximate depth at which wave interactions with the bottom starts. Information mainly consists of sediment properties including size, size-distribution, density and roughness and should be made available as attribute of points scattered over the nearshore and foreshore area, representing a location where sediments have been sampled and their properties measured. Sediment properties are known through direct measurements, collected at a specific location via grab samplers or sediment cores.

The oldest, but still widely accepted, method for determining grain-and grain-size distribution uses a nested set of sieves in which the size of the mesh is progressively smaller down the stack. In the case of muddy sediments, pipette analysis is conducted. Sediment density and shape is determined via Rapid Sediment Analysers (RSA). It is recommended to use the following classification adapted from the Unified Soil Classification System (USCS)

Sediment type	**Sediment size**
cobble	greater than 75 mm
Gravel	4.75 to 75 mm
Sand coarse medium fine	 2.0 - 4.8 0.43 - 2.0 0.075 - 0.43
Silt	0.002 - 0.075
Clay	less than 0.002 mm

Nearshore wave regime

The wave regime defines the sea state in a specific area. It can be defined as the physical and statistical characteristics of wave propagation over this specific area. Wave regime is characterized by a number of parameters which include wave heights, periods and direction and their remarkable value, such as their mean or their extreme values. Waves are generated by the action of winds over the sea surface. Wave regime is closely related to coastal processes in so far as:

- Energy liberated by breaking waves is directly responsible for stirring up sediments deposited on the foreshore or undermining the cliff toe;
- Wave run-up and backwash on the foreshore transport sediments in the cross-shore direction and contribute to maintain the foreshore profile to an equilibrium profile.
- Waves breaking with an angle generate a current parallel to the shore and responsible for the long-shore transport of sediments

Accurate knowledge on the wave regime, and its changes overtime as a result of seasonal processes or human activities, therefore helps predict sediment movements.

Nearshore wave regime should preferably be known for a maritime area extending up to the 20 meter water depth. The 20-meter-water depth approximately corresponds to the depth at which shoaling processes start. Information on wave regime should be provided as attributes of vector point (GIS format) locations disseminated along the European coastline. For each location and for each directional sector (0, 45, 90, 135, 180, 225, 270, and 315 degrees), the following parameters should be provided as a statistical estimator of recorded values:

- Mean wave height
- Significant wave height (i.e. the average height of the highest third waves)
- Extreme wave height
- Mean wave period
- Peak period

Such parameters are determined through two alternative methods:

(i) direct measurement, and

(ii) wave modelling. In the case of direct measurements from wave gauges or buoys, these parameters are available as attributes of wave buoy locations. In the case of direct measurements fro high frequency (HF) Doppler radar (see figure) or in the case of wave modelling via wave transformation models, wave attributes are estimated over a regular grid of locations. Commonly used wave transformation models include SWAN (Delft Hydraulics), MIKE (DHI), and STWAVE (USACE).

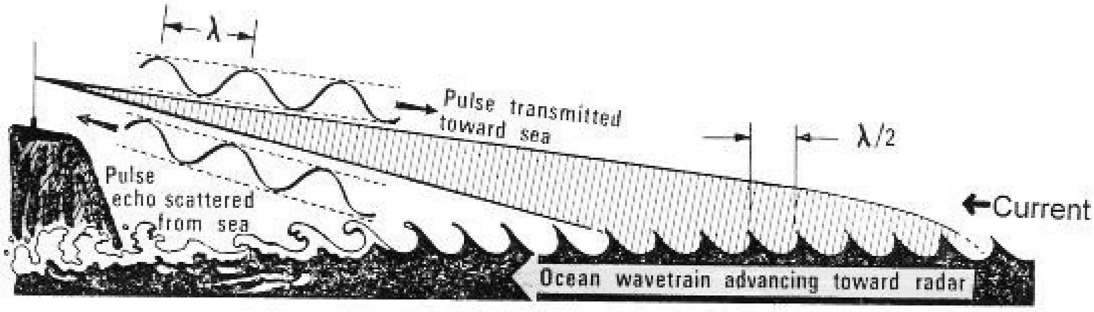


Fig. III-7. Production of near-shore wave regime via HF Doppler radar

Note that in the case of wave transformation models, information on offshore wave regime is needed. Major difference between offshore and nearshore wave regime is that offshore wave propagation patterns are not altered by changes in the bathymetry, but are mainly driven by winds.

Nearshore wave regime attributes should be ideally made available with a density higher than 1 point for every 1 km. These locations should be situated between 1 and 5 km away from the shoreline (or alternatively at locations where water depth is between 5 and 20 meters).

Near-shore currents

Currents can be defined as movements of fluid particles towards determined directions. In the near-shore, currents occur as the results of tides and waves. The impact of oceanic (or deepwater) currents can be considered as negligible in shallow water compared to tide and wave generated currents. More precisely:

- *Tidal currents*. Tidal currents are generated by the rising and falling tidal waters. During the rising tide, water flows onshore following specific paths ("flood" streams) along which water velocity is maximal. Current velocity is zero at high tide because the water has reached its highest stage and is about to begin its outward flow. As the water flows offshore, it follows other paths ("ebb" streams). Tidal currents are more pronounced in places where constrictions such as narrow entrances (inlet) to large bays cause strong flows. Such as the tidal range, tidal currents generated vary widely and consequently, have an effect that can range from strong in shaping the coast to almost no effect on beach processes.
- *Wave associated currents*. In shallow water, the movement of the water particles become very complex in terms of onshore and offshore motions resulting in an excess of water carried to the shoreline. This excess of water is translated to a long-shore movement (long-shore currents) and a cross-shore circulation movement (rip currents).

Current measurements through current meters, acoustic current profiler, GPS drifters or hydraulic tracers, should take place at different locations of the coastal sediment cell. Fixed measurement stations should be preferably located at key locations such as bay entrances or inlets (where tidal currents are expected to be the highest). Fixed or mobile measurement stations should be considered as well along the surf zone (where wave associated currents occur) and where ebb and flood currents are expected to occur. Near-shore current data should be made available as a time series for each measurement station, or as trajectories in the case of drifters. For each measurement station, both the current velocity and direction should be recorded. Velocity should be expressed in $m.s^{-1}$ (MESSINA PG2, 2006).

Astronomic tides

The tide is the periodic rise and fall of oceanic and coastal waters as a result of the relative positions of the earth, moon and sun. Tidal periodicities vary from semi-diurnal, through diurnal, fortnightly, monthly, seasonal, and annual to even longer. The tidal range (i.e. the difference in elevation between consecutive high and low waters) varies from a year centimetres (micro tidal) to up to 10 meters (macro tidal) according to the location on earth and the time during the year. Spring tides are associated with higher tidal range. In addition, the tide does not occur at the same tide everywhere: its propagation is governed by the geometry and the bathymetry of the sea basin. A distinction is made between the periodic and non-periodic components of the tides. The periodic component is referred as the astronomic tide and is governed by the relative positions of the earth, moon and sun as well as the geometry of the sea basin. The non-periodic component is referred as the meteorological tide or surge and is governed by weather conditions.

Astronomic tide data take two formats.

(i) the most commonly used format is the so-called “tide table” which give the daily prediction of the times and heights of high and low waters. They are generally computed at standard locations corresponding to major harbours. Other locations, corresponding to secondary harbours, are given in the form of time and height from standard locations;

(ii) alternatively to tide tables, mathematical models of tides can also be implemented directly in a GIS with a few developments: tide data can indeed be mathematically approximated as the sum of a series of sine waves of determined frequency "harmonic constituents". The parameters of each sine wave are called "harmonic constants", and are the amplitude (half the height) of the wave and phase, or time of occurrence, of the maximum.

A number of software packages and computer models specialised in the provision of tide data over a great number of locations (more than 7,000 locations worldwide) are available. Analysis of data observed by tide-gauges constitutes the basics for all of these models. Tide-gauges – generally at the locations of harbours – record the hourly fluctuations of sea level which includes both the astronomic tide, the meteorological tide and the wave height. If recordings are available for a sufficiently long period of time, the periodic elements of sea level corresponding to the astronomic tide can be calculated using such methods as least-squares tidal harmonic analysis amongst others. The primary role of tides in beach processes is exposure and submergence of the foreshore, and hence changes in how effective incoming waves may be in modifying the foreshore.

Extreme water levels

The fluctuations of the sea surface corrected from wave height, tidal range and relative sea level rise - known as the still water level or the surge - are driven by atmospheric pressure and wind stress which may have either a positive or negative influence on the sea level. The occurrence of a specific water level is difficult to predict long in advance. However, academic research has shown that a specific water level can be associated with an annual probability of exceedance. This probability defines the chances that a specific water level is reached or exceeded at a specific location and within a specific year. It is traditionally expressed in terms of return period (e.g. 100-year-return period = 1% annual probability of exceedance).

The probability of exceedance of extreme water levels can be derived from tide gauge observations, by deducing wave height (known from nearshore wave regime), the tide level (known from astronomic tide predictions) and long term sea level rise (known by averaging mean sea levels recorded by tide gauges per year over a long time series and analysis their trends). An exponential mathematical function known as the Generalised Extreme Value (GEV) function is then assumed to link the corrected resulting water levels with their probabilities of exceedance.

Extreme water levels should be made available as a mathematical formula and its calibration parameters. Since this function is not unique for the entire coastline (the probability of exceedance may vary significantly if the coastline length is long or the coastline shape is complex), several sets of calibration parameters should be provided. Ideally a different set of calibration parameters shall be estimated for each tide gauge location (based on the observation of this specific tide-gauge). Should no tide gauge with exploitable data be available in the area covered by the coastal GIS, a set of approximated calibration parameters shall be estimated for a number of locations within the area to be mapped, by interpolating observations recorded by the nearest exploitable tide gauges (outside the area).

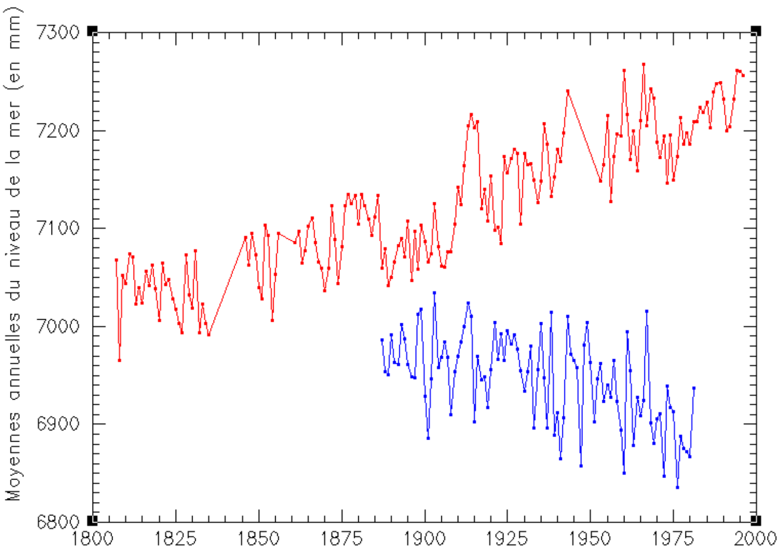


Fig. III-8. This example shows the annual mean sea level as measured by the tide-gauge of Brest in France (in red) and Varberg in the Baltic (in blue).

Legal and policy framework

Administrative boundaries

Terrestrial administrative boundaries provide a geographical delineation of administrative units – ranging from national borders to the infra-municipal district. Though the spatial extent of coastal erosion processes has little to do with administration, administrative boundaries are important in the sense that they help identify which local authorities are potentially exposed by coastal erosion and therefore arrange appropriate platforms of dialog and participation. Moreover a number of analyses require data of administrative boundaries - involving for example demographic data.

In the framework of a coastal GIS, terrestrial administrative boundaries should be made available for all municipalities located within 10 km for the coastline. In low-lying areas, it is however recommended to extend the spatial coverage of administrative boundaries landwards up to the contour line corresponding to an elevation of 2 metres.

Information on administrative boundaries should be provided as vector polygons. Each polygon represents an administrative unit ranging from national borders to infra-municipal districts.

Boundaries of administrative units can be found at the level of national mapping agencies and are generally part of digital topographical databases. For the infra-municipal level, it is recommended to adopt the units used for census purposes (e.g. "*enumeration districts*" in the UK). The boundaries of these units may be accessible through national statistics office (see also *demography*) but their availability in GIS format varies from one country to another. In case this information on infra-municipal districts is not available in GIS format, the method recommended is to digitize this information from existing plans or textual descriptions obtained from the statistics office. This process is not expected to be time consuming since not all the municipalities are divided into census units (a typical census unit regroups approximately 2000 people, but this varies from one country to another).

The planimetric accuracy of terrestrial administrative boundaries should ideally be better than 5 meters, which is consistent with the existing sources of administrative boundaries in digital format (in general 1:10,000 or better).

Nevertheless if administrative boundaries represent the baseline to which responsibilities may be reach, in order to delineate potential obstacles between natural processes as a continuous system (e.g. coastal sediment cells) and administrative ' irregularities' it is essential to provide *with* other data contents.

Protected areas boundaries

Europe and national regulations host an outstanding amount of natural areas with high ecological values, and which are regularly challenged by human activities. Yet, these areas fulfil a wide range of regulation functions from which human beings - and nature in general – benefit. These regulation functions include for example natural protection against storm surges, preservation of inland freshwater, provision of breeding and nesting facilities for animal species, etc. A number of these areas benefit from a protection status but not all of them. These areas include NATURA 2000 sites, RAMSAR sites, National Parks, Regional Parks, Biosphere reserves, etc. In that sense, potential effects of development projects on coastal erosion processes susceptible to impact such protected areas must be investigated or even identified.

In the framework of the coastal GIS, information on natural habitats should be ideally gathered for areas lying from 2 kilometres offshore to 10km inland.

Information on areas of high ecological value should include at least:
- the geographical boundary of the area of high ecological value
- the name of the area as an attribute of the area object.
- its designation status as an attribute of the area
- the natural habitats it hosts as relation tables between the area object and the table of natural habitats (see data acquisition and production method for the natural habitat classification table).

Usually information on those areas can be found at the level of public authorities in charge of nature conservation. There are a number of designation levels which refer to international conventions, European directives or agreements, or specific national regulations. The table below lists the different types of designations encountered in Europe.

Level of designation	Type of designation
Areas of international importance	UNESCO Biosphere Reserves (UNESCO) Wetlands of international importance (Ramsar convention) World Heritage Sites (UNESCO) Specially protected areas of Meditteranean importance (Barcelona Convention)
Areas of European importance	*proposed* Special areas of conservation (under the Habitat Directive) Special areas of conservation (under the Habitat Directive) Special protection areas for birds (under the Bird directive) Biogenetic reserve conservation (Council of Europe)
Areas of national and regional importance	*Commonly found designation statutes, only:* Natural heritage sites National and regional parks Nature reserves Wildfowl reserves Sites of special scientific interest Areas of Outstanding Natural Beauty (AONB) National scenic areas Environmentally sensitive areas

Fig. III-9. Examples of designation types in Europe.

Ecological heritage is a sometimes forgotten aspect in the whole management of the coast, especially for spatial planning concerns. This must be embedded in the societal cost benefit analysis of the coastal zone and forms a basis to deal with legislation on environmental protected areas.

Remarkable boundaries

Remarkable boundaries other than protected areas – for example setback lines, limits of public domain, cultural heritage sites – are important features to take into account as well. Europe's historic structures, archaeological fields and natural sites are major contributors to the quality of life enjoyed by the citizens and visitors of the state. These places are of substantial economic value, contribute to urban revitalization, serve as sources of recreation, and provide important tangible links to Europe's heritage. In Europe, there is about 1.5 million registered sites which benefit from a specific protection and conservation statutes, a significant part of which is located in coastal areas.

In the framework of the coastal GIS, information should be gathered for registered cultural heritage sites located within 10km from the coastline. Information on cultural heritage sites should be made available as attributes of vector objects. Each object – point or polygon – depicts the location or the boundaries of cultural heritage sites (e.g. a point for a church, a polygon for a historic park). There is no standard classification of cultural heritage sites in Europe. In practice however, the following types of sites are commonly encountered in Europe:

- Designated buildings
- Ancient monuments
- Archaeological sites
- Historic gardens of parks
- Historic battlefields
- Remarkable sites

Beside boundaries and locations, information on cultural heritage sites shall include the area, the type of site (ancient monument, archaeological site, etc.), the registration year, an abstract, the state of designation progress, and possibly a picture of the site.

Availability of data in cultural heritage varies from one country to another. A great deal of information on existing inventories and databases on cultural heritage has been established by the European Heritage Network (http://www.european-heritage.net) under the lead of the Council of Europe.

Coastal ecosystems contribute to the maintenance of human knowledge by providing scientific and educational information. They are also a part of the cultural heritage and provide information about the cultural history of a landscape and a country or can even give spiritual enrichment towards people.

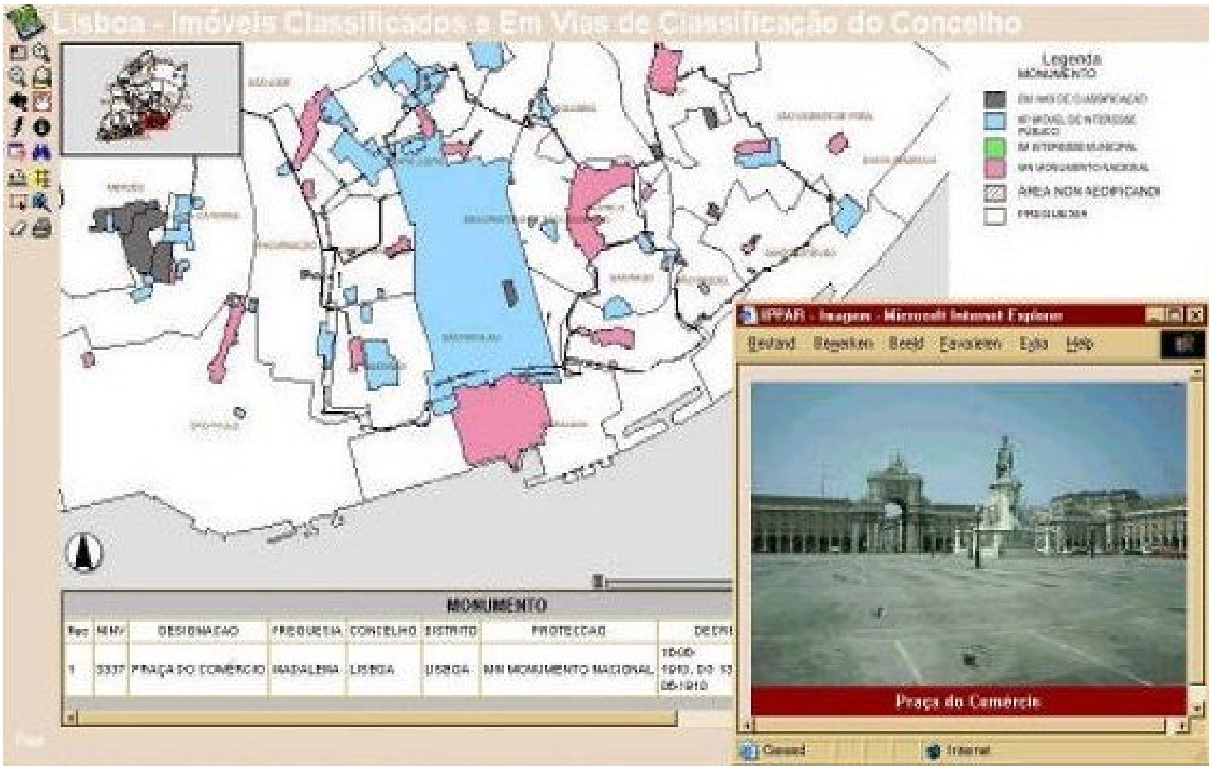


Fig. III-10. Example of cultural heritage database in local GIS for the city of Lisbon (source IPPAR – Portugal).

Land Use

Land use plans specify what the various land parcels should be dedicated to. They specify as well what kinds of operations are authorized and what kind of operations are not authorized (e.g. building). They also help quantify land-based pressure on the coast such as hotel resort construction or industrial development, and provide a good proxy of economic assets at risk.
As for land use, it can be defined as the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Land cover and land use can be used alternatively since it is possible to infer land use from land cover and conversely. But situations are often complicated and the link is not so evident.
The production of land use is quite similar to Land Cover (see Land Cover) except that land use production builds on ancillary data such as urbanisation, cadastre, planning orientation, existing at national, regional or local level.

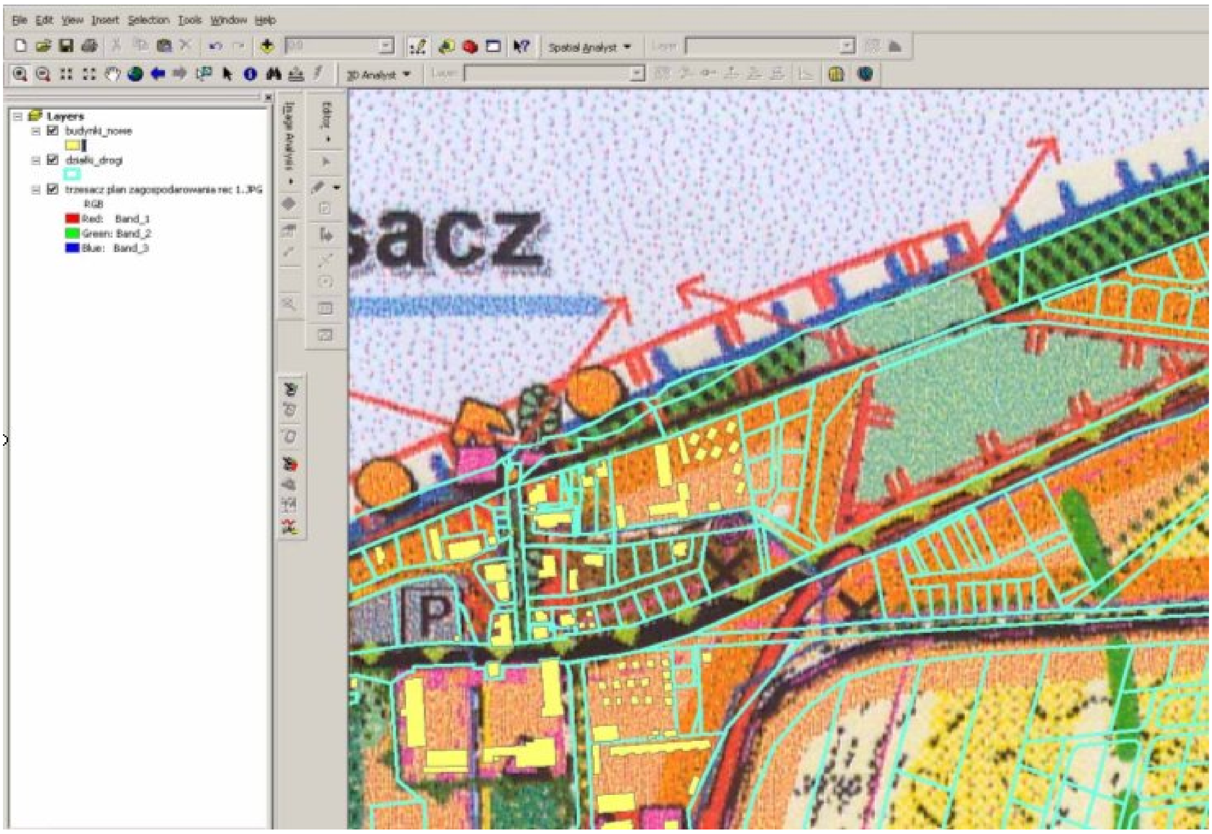


Fig. III-11. Example of land use in local GIS of Rewal, Poland (MESSINA - 2006)

Land and built-up ownership

Land ownership zoning comprises the private domain (extended to the State private domain and the municipality private domain) and the public domain.
Through an adequate land tenure policy, data sets showing built-up areas, parcels delineations linked to property database allow decision-makers to minimize uncontrolled coastal development which would impact coastal erosion processes,

shoreline management or even impeach coastal planning project realisation. Knowledge of the land ownership patterns is therefore important.
To create or integrate those databases, data can be derived from cadastral plans or topographic databases, but also as a visual checking on aerial photograph or orthophotographs.

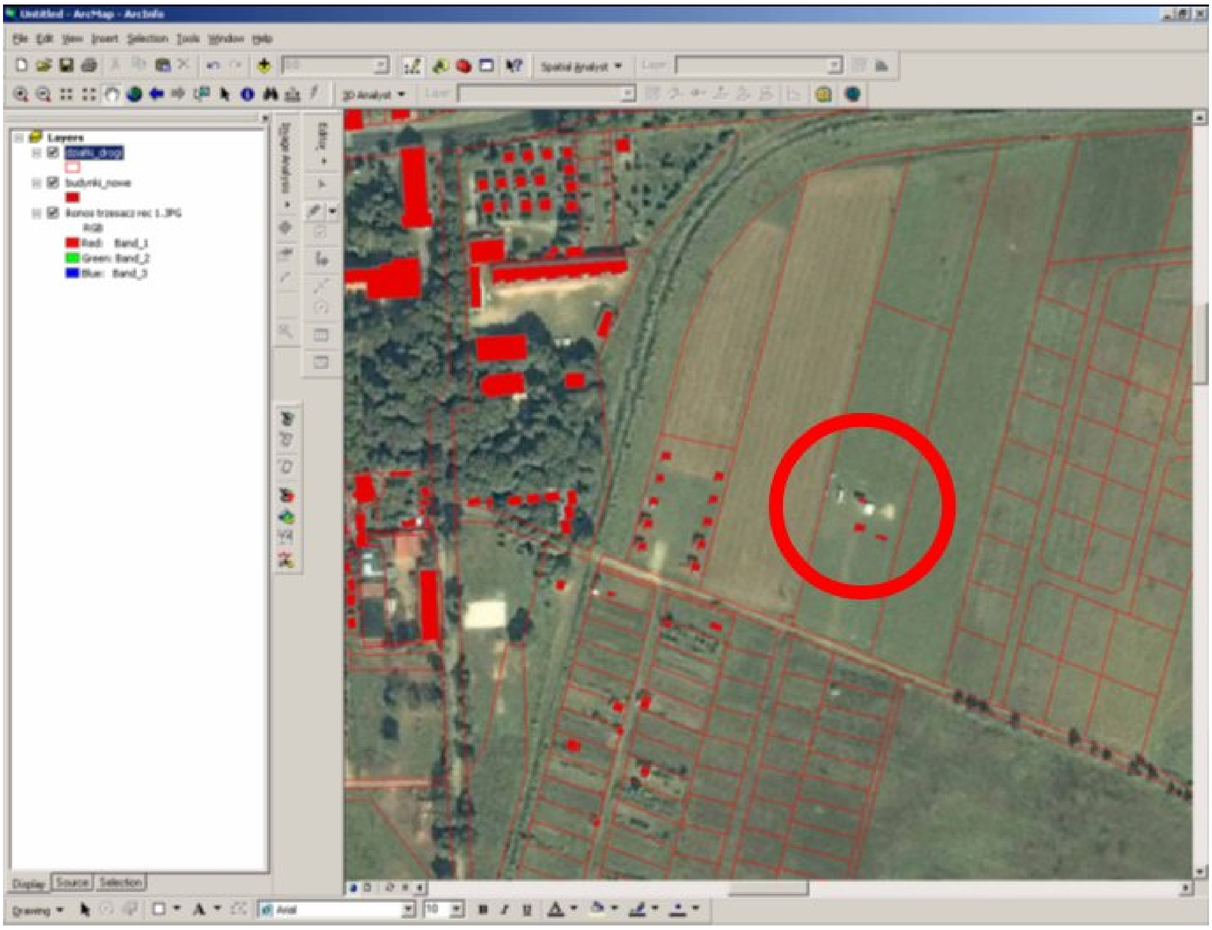


Fig. III-12. Illegal built-up development localized thanks to GIS tool, Rewal, Poland.

Socio-economic profile

Population

Demographic data and their trend analysis provide valuable information to assess the attractive power of coastal areas on citizens and define potential pressure on the coast regarding pollution, the need for tourism and seasonal fluctuations pose an indicator for the economical value. They also provide key information for assessing population at risk of coastal erosion and coastal flooding and therefore identifying areas where coastal investments become a priority.

In the framework of coastal GIS, demographic data should be made available for municipalities located at less than 10 km from the coastline.
Demographic data should be made accessible as attribute of census units which represent areas at the submunicipal level typically regrouping 2000 inhabitants (the size may vary from one country to another).

Key demographic data include:
- The total population,
- The population by age,
- The population by professional categories

Best sources for demographic data are national census. In general, censuses are conducted every 10 years and provide statistics at the level of municipality or ínfra-municipal. Note that most of European countries have demographic data at an infra-municipal level (in general, parcels of approximately 2000 inhabitants or less).

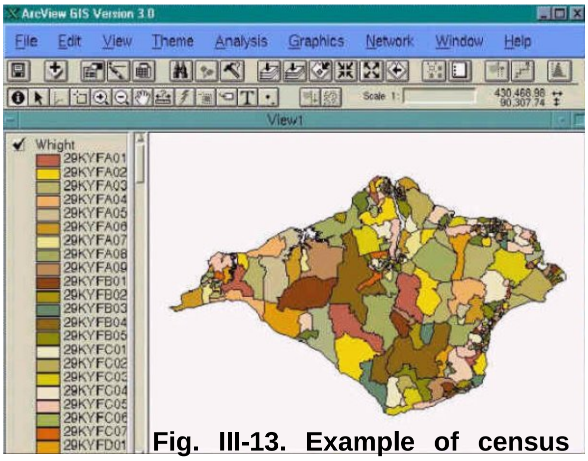


Fig. III-13. Example of census unites (Enumeration districts) within coastal GIS, Isle of Wight.

Demographic data and their trend analysis provide valuable information to assess the attractive power of coastal areas on citizens, and define potential pressure on the coast regarding pollution, the need for tourism and seasonal fluctuations pose an indicator for the economical value.
This is also essential for the use of cost-benefit analysis for multi-purpose constructions or planning in the coastal zone.

Country	*Statistics office*	*Website*
Belgium	National Institute of Statistics Belgium	http://statbel.fgov.be/home_fr.htm
Denmark	Statistics Denmark	http://www.dst.dk/HomeUK.aspx
Estonia	Statistics Office of Estonia	http://www.stat.ee/
Finland	Statistics Finland	http://www.stat.fi/
France	National Institute for Statistics and Economic Studies (INSEE)	http://www.insee.fr/
Germany	Statistisches Bundesamt Deutschland	http://www.statistik-bund.de/
Greece	National Statistical Service of Greece	http://www.statistics.gr/
Ireland	Central Statistics Office in Ireland	http://www.cso.ie/
Italy	National Institut of Statistics of Italy	http://www.istat.it/
Latvia	Central Statistical Bureau of Latvia	http://www.ksh.hu/
Lithuania	Lithuanian Department of Statistics	http://www.std.lt/
Netherlands	Statistics Netherlands	http://www.cbs.nl/
Poland	Central Statistical Office of Poland	http://www.stat.gov.pl/english/index.htm
Portugal	Instituto Nacional de Estatistica	http://www.ine.pt/
Scotland	General Register Office for Scotland	http://www.open.gov.uk/gros/groshome.htm
Slovenia	Statistical Office of the Republic of Slovenia	http://www.sigov.si/zrs/
Spain	Instituto Nacional de Estadistica	http://www.ine.es/
Sweden	Statistics Sweden	http://www.scb.se/
United Kingdom	National Statistics	http://www.statistics.gov.uk/

Fig. III-14. List of national statistics offices in Europe

Land Cover

Land cover corresponds to a (bio) physical description of the earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished - basically, areas of vegetation (trees, bushes, fields, and lawns), bare soil, hard surfaces (rocks, buildings) and wet areas and bodies of water (watercourses, wetlands). Contrary to land use which defines land parcels according to their usage or anticipated usage, land cover provides information on the nature of the land surface regardless of its usage. However in practice, land cover can be considered as a proxy of land use, if land use is not available. Land cover can enter the assessment of assets at risk.

In the framework of a coastal GIS, land cover (or land use) data should be available for inter-tidal and terrestrial areas up to 10 km inland. In low-lying areas, it is recommended to extend the spatial coverage of land cover/land use up to the contour line corresponding to an elevation of 2 metres.

Land cover data should be ideally provided as vector polygons. Depending on the scale of consideration and use, the recommended specifications are that:

(i) polygons should be delineated with a geometrical accuracy of 5 metres (resp 1 metre), or an equivalent scale of 1:25,000 (resp 1:10,000)
(ii) Polygons should cover a minimum area of 5 hectares (resp 1 ha).
(iii) Each polygon should be assigned a land cover code compliant with CORINE Land Cover classification[1] (CLC TECHGUIDE, 2000) which is now a key to enable comparison between different areas throughout Europe.

The experience of CORINE Land Cover in Europe has demonstrated that most reliable land cover data are obtained from computer-aided photo-identification of satellite images or aerial photographs. Photo identification consists of a visual recognition and delineation of land cover patterns on-screen (using GIS tools) and is facilitated by ancillary data (such as existing maps), discussions with experts and through ground truth surveys.

“Supervised classification” is an alternative methodology for obtaining land cover data. Contrary to computer-aided photo-identification, supervised classification does not require the assistance of an experienced photo-identification specialist. A number of predefined land cover classes are defined as ranges of values that a pixel may take: each pixel of the satellite image or the aerial photograph is given the land cover code corresponding to the range of values it belongs to. But contrary to computer aided photo-identification, the final product of supervised classification is a raster image.

To enable efficient analysis, land cover/land use data should be at least compatible with scale 1:25,000.

Depending on the economic or ecological value of a certain area, Land cover needs to be updated every 3-5 yrs.

Such existing programmes as CORINE Land Cover provide land cover data at scale 1:100,000 which might not be sufficient for local applications. However the methodology implemented by CORINE Land Cover can be adapted at a higher scale (e.g. 1:25,000 or 1:10,000) upon better resolution for the satellite (even aerial) source of imagery, convenient for high scale projects.

Infrastructure

Spatial data on infrastructure (and hydrography) constitute the backbone of most land GIS. Infrastructure data include a graphical representation of roads, railways, high voltage lines, large jetties, large human constructions (harbours, airport, energy plants), and remarkable objects (e.g. lighthouse, geodetic benchmarks). In most of countries, such data exist in digital format at a typical scale of 1:10,000 (in some

[1] CORINE Land Cover classification features 44 land cover classes grouped in 5 major land cover types: (i) urbanized areas, (ii) agricultural areas, (iii) natural and semi-natural areas, (iv) wetlands, and (v) water bodies.

countries, the scale may reach 1:5,000). They are distributed by the National Mapping Agencies.

In the framework of a coastal GIS, the spatial extent of infrastructure data should encompass all terrestrial areas located within a 10 km land strip from the coastline. In the case of low-lying areas, it is recommended however to extend it to areas located below the 2 metre contour line.

The position of infrastructure features shall be made available as vector polylines or polygons. The nature of the infrastructure (road, railway, high voltage lines, jetties, harbour, airport, benchmark, lighthouse, etc.) is represented as attributes of the vector objects. In case spatial information does not exist or is not easily accessible, the data production process shall consist in extracting infrastructure features from ortho-photographs using computer aided photo identification functions offered by GIS tools. In practice however, a combination of both method (acquisition of existing datasets and photo identification) is preferable. Indeed, due to their high production and maintenance cost, digital databases distributed by national mapping agencies are updated with a frequency ranging from 10 to 20 years depending on the country. Recent changes in the infrastructure may therefore not be reflected.
The planimetric accuracy of infrastructure objects should be better than 5 metres while vertical accuracy should be less than 1 metre. Infrastructure objects should be updated with a frequency of 5 to 10 years or as it evolves.

When performing a risk assessment (probability of hazard x potential damages), geo-referenced data on infrastructure works are essential for the assessment of capital at risk but also for the assessment of pressure on coastal sediment transport processes

Economic activities

Such as demography, economic activities provide valuable information to assess the attractive power of coastal areas on citizens and provide as well key input for capital at risk assessment in terms of jobs, turnover, value, production. If the information on economical activities exist in digital format in almost all European countries with a rather good level of details (for tax and statistical purposes), the greatest challenge is to access the data which are stamped "confidential", and when eventually they are made accessible, another challenge is to link these activities with their geographical locations.

In the framework of a coastal GIS, information on economic activities should be made available for areas located within 10km from the coastline. In case of low lying areas, it is however recommended to broaden the spatial extent up to the 2-metres contour line.

Those Informations should be ideally made available as attributes of vector points. Each point representing the location of a company duly registered at the level of public authorities (in general chambers of commerce, ministries of finances, or bureau of statistics), and should include at least

- the name of the company, its address
- the economic activity code (according to the NACE code)
- the initial capital

- the number of jobs
- the turnover
- the value of assets

Integration of information of economic activities into a coastal GIS requires two steps:

(i) *collection of data on economic activities*
Information of economic activities is available at the level of chambers of commerce, ministries of finances, or bureau of statistics.

(i) *geo-coding of economic activities*
In general, information obtained from national registration companies are not geo-coded which means they cannot be automatically displayed on a map, since they contained no geographical coordinate. Instead, each company has an address (street name, number, postal code) duly registered which may be linked to geographical coordinates. This operation is theoretically simple but time-consuming since specialised GIS companies report more than 50 millions of street address in Europe. A cost-effective solution therefore consists of acquiring GIS database of street locations for Europe. The world leading products in the provision of GIS based street locations.

Information on economic activities and companies is found at the level of chambers of commerce, trade registries or statistics offices, depending on the countries. A number of national registration authorities have formed a network called the European Business Register (www.erb.org) to make it possible for everybody to obtain comparable, official company information from the countries connected to the network, at a reasonable price.

Economic activities enter both the assessment of economic assets at risk but also the assessment of pressure on coastal sediment transport processes
Some examples of economic informations that can be mapped:

- Dredging license boundaries and volume dredged;
- Fishery license boundaries, annual fish captures, and employment;
- Aquaculture and agriculture farm boundaries, annual production, and employment;
- Seasonal population (tourists);
- Hotel nights within 1 km of the coastline.

Market value

Land market value is defined as the most probable price in cash, or terms equivalent to cash, which lands or interest in lands should bring in a competitive and open market under all conditions requisite to a fair sale, where the buyer and seller each acts prudently and knowledgeably, and the price is not affected by undue influence. Such a value can be said to comprise two main components: land (or location) and improvement (buildings, etc.).

In the framework of a coastal GIS, land value data should be available for inter-tidal and terrestrial areas up to 10 km inland. In low-lying areas, it is recommended to extend the spatial coverage of land value up to the contour line corresponding to an elevation of 2 metres.

Land value scale is best represented by so-called “isovals”. Just like contour lines (“landscape”), isovals are vector polylines which join points expected to have the same value per unit area. Land value data may vary from one country to another and usually consists in three elements:

- the location of the land parcel (more precisely the coordinates of one point of the land parcel)
- the size
- The real estate value as recorded by the cadastre land registration system.

Once collected, land value data are converted into a scattered set of points characterised by their location and value per unit (parcel value divided by the parcel size). Once in this format, the data can be converted into data surface using one of a number of interpolation techniques including splines, inverse distance weighting and/or kriging. These functions are not standards but they may be found in a number of commercial GIS tools.
Land value may vary quite considerably over time, as a result for example of new investments in the neighbourhood. It is therefore recommended to update this layer every 5 years or before. Not all national land registration systems in Europe enable a quick and easy access to land value data. When it is not possible, a survey can be conducted among local real estate agencies or association of clerks to retrieve samples of land value data.

Market values are highly sensitive to changes in the local environment (e.g. reduced beach width resulting in reduced tourist frequentation). In addition, they are relevant to assess “capital” at risk, and make simulation before implementing managed realignment.
Some examples of economic informations that can be mapped

- Market value of built residential sq-metres within 1 km from the coastline;
- Market value of built commercial/industrial sq-metres within 1 km from the coastline;
- Market value of undeveloped sq-metres within 1 km from the coastline.

As an illustration an application has been developed in Section IV within High-Normandy coastal GIS for land market housing value.

Data integration

The extensive development of geographic information systems (GIS) for terrestrial information greatly exceeds the attention given to marine systems. However, recent developments demonstrate that GIS has become a powerful tool for all types of operations in the coastal and near-shore zones of the marine environment, from fisheries and recreation to hazard mitigation and search and rescue, to name a few. Continuing advances in GIS now permit the integration of previously distinct types of data, including digital aerial photographs, vector data, and field-collected data via GPS and sonar.
The exponential growth in marine and coastal data volume accompanied by the rapid rise of spatial information technologies can be overwhelming to practitioners, and GIS tools can seem to be of limited value without a practical framework to apply them. It should also noted that although the benefits of integrating GIS with the

modeling of coastal processes is seen as important for the future, it is a far from trivial task. In achieving that goal, the concept of data interoperability is a critical requirement. Data interoperability consists in formatting data coming from various sources in such a way that cross-combination (e.g. wave data with near-shore bathymetry) will be made possible. Data interoperability requires two important steps:

- the development an integrated data model
- the adoption of a unique spatial reference system

A data model is formally defined as a set of fundamental conceptual objects and mathematical and logical rules that govern their behaviour. The rules are usually expressed in terms of how and why objects may exist, and what interactions are permitted (CODD, 1980). The formal objects and operators of a data model are generally abstract in nature and form a language in which real world situations may be expressed. Generally such languages are intended to be mapped into computing constructs, easing the transition from the real world, to the abstract and finally to the computer. This process requires the identification of key concepts within a specific real-world domain and an expression of their interactions using the data model conceptual objects and operators. In this sense, a data model may be seen as a tool kit composed of concepts, operators, and their rules of behaviour, all used to describe some real world phenomenon for computing purposes. In its most abstract sense a data model provides the logical framework in which the real world may be described for computing.

The process of defining a data model dedicated to coastal erosion hazard mapping shall be governed by the type of processing which is required to perform hazard mapping analysis. By way of illustration, the possibility to automatically or semi-automatically convert a net loss of sediment budget quantified for a specific cross-shore profile into a shoreline retreat requires that appropriate links are established between the objects “coastline”, “cross-shore profiles”, and “sediment budget“. Defining a data model that fulfills the requirements of coastal hazard mapping was one of the objectives of each GIS pilot sites developed in the framework of MESSINA initiative and are explained in Section IV.

III.4. Methodologies for mapping erosion

Background information

The goal of these specifications is to propose a review of the most cost-effective methods which can provide a first low-cost estimate of erosion extent in those areas where precisely no such assessment has been conducted so far. The methods suggested are all derived from well-tried techniques and are applicable to a wide range of coastal types in Europe. Moreover some have been experimented and results are shown within Section IV of this Practical Guide.

Coastal erosion is a generic term which encompasses a variety of natural processes. A distinction is usually made between chronic, acute, and cliff erosion:

- Chronic erosion is mainly driven by the actions of waves breaking along the shore at an oblique angle. When breaking, waves release their energy which is transformed into turbulences causing sediment deposited in the sea floor to be stirred up and be transported away from their original location and parallel to the shoreline. This sediment transport is referred to as the "long-shore drift". At any given place along the shoreline, the balance between "incoming" sediments (i.e. sediments brought by the long-shore drift from beaches located up-drift) and "outgoing" sediments (i.e. sediments stirred up and transported away) determines whether the coastline suffers from a sediment deficit or a sediment excess. A sediment deficit result into a medium-to-long term coastline retreat, though a sediment excess results into a coastline accretion (or sedimentation). Another form of chronic erosion is driven by sea level rise and causes the near-shore profile to adjust to higher water level by filling in the sea bottom with sediments taken from the shore (thus causing shoreline retreat). In that case, sediment is cross-shore and not long-shore.

- Acute erosion refers to coastline retreat induced by extreme water levels and wave energy which occur during storms. Acute erosion affects sedimentary coasts – mainly beaches and coastal dunes – and may result into several tens of meters of coastline retreat during stormy seasons (winter). In the case of acute erosion, sediments removed from the coast are not transported parallel to the shore (like in the case of chronic erosion) but are "simply" redistributed along the beach profile. This causes the beach and the dunes to progressively recover their initial profile - and therefore the coastline its initial position - during calm seasons (i.e. when water levels are significantly lower)

- Cliff erosion should be considered as variant of chronic erosion but its driving processes are more complex. Along soft-rock cliffs, erosion occurs as a combination of marine and terrestrial processes. Wave attacks undercut the toe of the cliff, thus undermining its stability. Meanwhile, soil weathering processes – mainly rain water seeping into the cliff geological structure and alternating freeze and thaw periods – reduce the cohesion of the cliff rocks which collapse under the action of gravity. Rocky debris deposited in front the cliff toe is progressively transported along shore by longshore drift and cross-shore by the combined actions of waves and tides. Cliff erosion occurs as landslide events which are hardly predictable, however the average erosion speed is found to be quite constant over long period (e.g. over 100 year period or more).

Methodologies for mapping chronic erosion

This part outlines the basic concepts and key processing underlying the mapping of chronic erosion which is the most commonly found form of coastal erosion along European coasts. It occurs to coasts made of sedimentary deposits fringed by sandy beaches.

The basic idea behind the mapping of chronic erosion is that erosion results from a gradient in the sediment transport alongshore, or said differently, that the volume of sediments transported per unit of time (the *sediment flux*) in the long-shore direction is not constant along the coastline.

The Figure below depicts a typical coastal sediment cell delimited by headlands. In this example, waves approach at an oblique angle with the coastline. The division of the coastline in equidistant cross-shore profiles (or cross-section) is quite common and constitute the basis for estimation of sediment transport patterns.

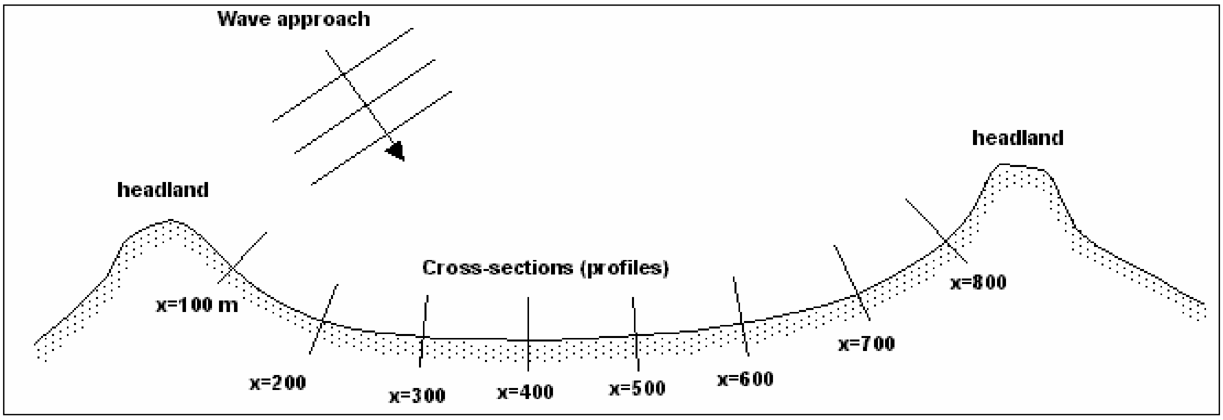


Fig. III-15. Schema of a coastal sediment cell

Estimation of sediment transport

Since the 1950's, a particular attention has been paid by coastal engineers to the development of appropriate models for estimating long-shore sediment fluxes. A wide range of formulas have been developed and adopted worldwide to quantify such fluxes. All of them have pros and cons as they were developed to reflect specific situations and not all situations simultaneously. Only three of the most used formula is reviewed hereafter.

<u>*CERC Equation (1950)*</u>

The CERC Equation is among the first formula developed to estimate longshore sediment transport. Though simple, it provides rather good result along wave-dominated straight coasts. However, it may not be adapted for coastal zones with complex bathymetry or in nearshore areas where currents are not negligible (e.g. tidal inlet).

The CERC equation is given as follows:

$$S_X = A.H_b^2 c_b \cos(\varphi_b)\sin(\varphi_b)$$

where S_x : longshore sand flux through the profile X (in m^3/s)
A : dimensionless coefficient generally taken as 0,040 or to be calibrated with field measurements
H_b : significant wave height (i.e. the average height of the one-third highest waves) at breaking depth
c_b : wave celerity at breaking depth
φ_b : angle between the wave crest and the coast at the breaking line

Improved version of the CERC equation considers the coefficient of A as a function of the sand grain size.

Bijker transport formula (1971)

The CERC Equation only considers longshore transport induced by waves. The approach developed by Bijker (1971) considers the combined actions of waves and currents which can give a significant rate of sediment transport. The Bijker formula estimates sediment transport by modeling a bed load transport and a suspended load transport. Those are a function of the deep water wave height, period and approach angle, current velocity, grain size and density, particle fall velocity, and bottom roughness.
Bijker formula is given as follows:

$$S_x(y) = \frac{5D_{50}V\sqrt{g}}{C}\exp\left(-0.27\frac{(\rho_s-\rho)\rho g D_{50}}{\mu\tau_{cw}}\right)\left(1+1.83\left[I_1\ln\left(\frac{33h}{r}\right)+I_2\right]\right)$$

With:

$\mu = \left(\frac{C}{C_{90}}\right)^{1.5}$ (Ripple factor)

$C = 18\log(\frac{12h}{r})$ (Chezy coefficient)

$C_{90} = 18\log(\frac{12h}{D_{90}})$ (Chezy coefficient based on D_{90})

$\tau_{cw} = \frac{\rho g V^2}{C^2}\left[1+0.5\left(\xi\frac{2\pi a_0}{TV}\right)^2\right]$ (Bed shear stress due to waves and current)

$\xi = C\sqrt{\frac{f_w}{2g}}$ (Bijker's parameter)

$a_0 = \frac{H}{2}\frac{1}{\sinh(\frac{2\pi h}{\lambda})}$ (Maximum horizontal velocity "at the bottom")

$f_w = \exp\left[-5.977+5.213\left(\frac{a_0}{r}\right)^{-0.194}\right]$ If $\frac{a_0}{r} > 1.59$ (friction factor)

$f_w = 0{,}30$ If $\frac{a_0}{r} < 1.59$ (friction factor)

$I_1 = R\int_A^1 \left(\frac{1-\zeta}{\zeta}\right)^{z_*} d\zeta$ (first Einstein integral)

$I_2 = R\int_A^1 \left(\frac{1-\zeta}{\zeta}\right)^{z_*} \ln(\zeta) d\zeta$ (second Einstein integral 2)

$\zeta = \frac{z}{h}$ (dimensionless height)

$A = \frac{r}{h}$ (dimensionless roughness)

$$R = \frac{0.216 A^{(z_*-1)}}{(1-A)^{z_*}}$$

$$z_* = \frac{w}{0.4\sqrt{\tau_{cw}/\rho}}$$

$V = 1.388 \frac{\sin(\varphi_0)}{c_0} \frac{C}{\sqrt{f_w}} \gamma \sqrt{g} hm$ (Longshore water velocity in m/s)

(Note that current velocity may also be derived from direct measurements)

$\gamma = \frac{H_b}{h_b}$ (Breaker index)

$c_0 = \frac{gT_o}{2\pi}$ (Deep water wave velocity)

$$r = 3D_{90}$$

$$r = 1.1\mathrm{K}(1 - \exp(-25\frac{\mathrm{K}}{\Lambda})$$

Where S_x(h, t): distribution of sediment transport rate at depth h along the cross-section x (in m3/m/s)

φ_0	:	angle of deep water wave approach
T_0	:	period of deep water waves
H_b	:	wave height at breaking depth
h	:	water depth
h_b	:	water depth at breaking
m	:	beach slope
ρ_s, ρ	:	sand and water density
D_{50}	:	median sand grain diameter
D_{90}	:	grain diameter which exceeds the diameter of 90% of the sand grains in weight
w	:	water fall velocity
r	:	bottom roughness
K	:	ripple height (bed form geometry)
Λ	:	ripple length (bed form geometry)

It is obvious that the Bijker formula is much more complex and time-consuming to implement than the CERC formula. Plus, it requires computation for different water depths (or y positions) between the coastline and the outer edge of the breaking zone, then integration over the entire cross-shore profile. Nonetheless, the applicability of the Bijker formula is wider than the CERC formula (e.g. within estuaries where currents become dominant, nearby harbors, semi enclosed basin). It is also adapted to river sediment transport since the formula derives from river transport theories. Since its first formulations in 1971, the Bijker formula has undergone many modifications and sophistications which are judged irrelevant to report in this document.

The figure below illustrates how longshore sediment transport occurs in the breaking zone. Waves approaching and breaking at an angle φ_b liberate their energy which cause sediments deposited in the breaking zone to be stirred up and transport along shore. Sediment transport S_x is not constant cross-shore but depends on the water depth h and varies overtime. As the shoreline evolves, it tends to become parallel to the wave crests and therefore S_x tends towards 0.

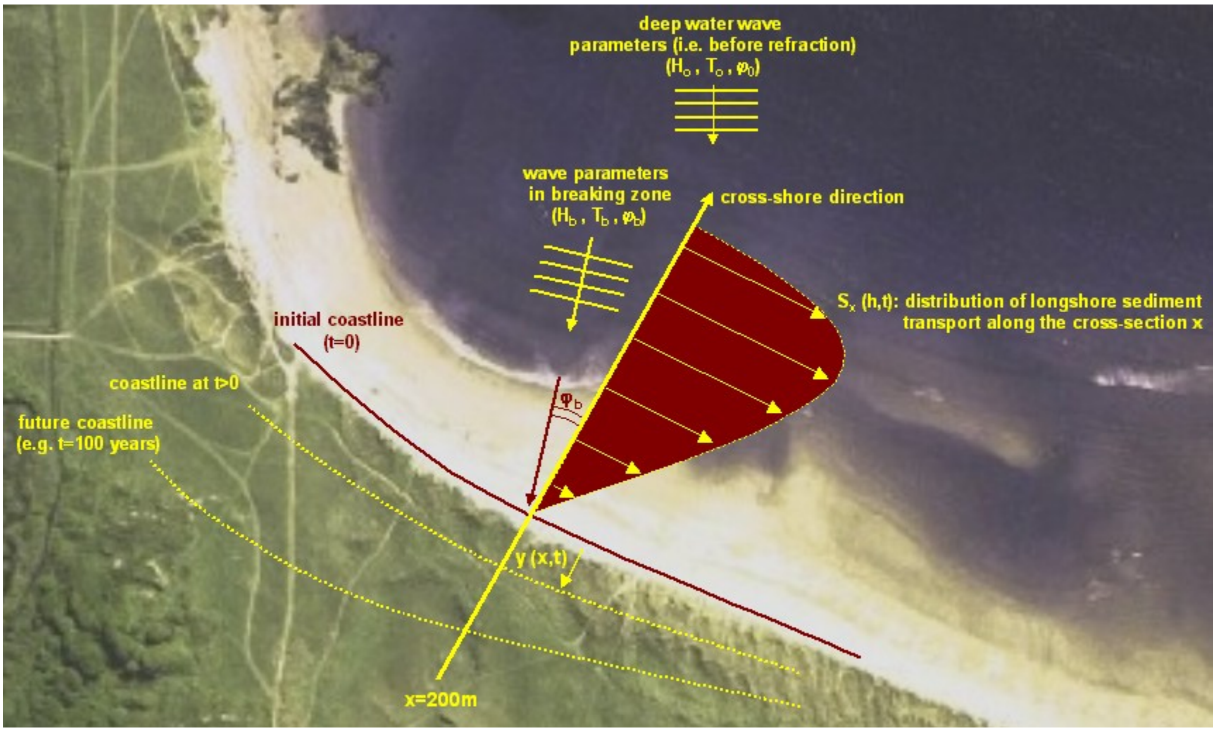


Fig. III-16. Illustration of Bijker formula calculation

<u>*Sediment transport software packages*</u>

Beside the CERC and Bijker formulas, a wide range of software packages have been developed as an attempt to assist sediment transport calculations. Among the most popular packages are UNIBEST (developed by Delft Hydraulics), MIKE (developed by the Danish Hydraulics Institute), and SBEACH (developed by US Army Corps of Engineers). These models integrate near-shore wave regime, coastline geometry, and sediment properties as input data and deliver estimates of net sediment transport based on different formula (including but not restricted to CERC and Bijker).

Coastline response to longshore sediment transport

In the case of a longshore sediment flux S_X which is constant all along the coastline, sediment inflow and outflow through any given cross-section along shore is equal and the coastline remain stable. However, in case there is a gradient in the longshore sediment flux - in other words, S_X is not constant but a function of x – the difference between the sediment inflow and the outflow equals the volume of materials eroded (if negative) or accumulated (if positive). The resulting advance or retreat of shoreline is governed by the following differential equation, which reflects the conservation of matters (continuity):

$$\frac{\partial S_X}{\partial x} + d\,\frac{\partial y}{\partial t} = 0$$

Or alternatively:

$$\frac{\partial S_X}{\partial \varphi}\,\frac{\partial^2 y}{\partial x^2} - d\,\frac{\partial y}{\partial t} = 0$$

Where y(x,t) : cross-shore change of the coastline compared to the initial coastline at the position x and at time t

S_x : sediment flux at cross-section x (m3/s)

$\varphi(x)$: angle between the wave crest and the shoreline at the position x

d : closure depth, i.e. water depth above which the new profile and the initial profile converge

Numerical resolution of this equation requires defining "boundary conditions", which are specific to the sediment cell considered. They include for example:

at t = 0, y(x) = 0 for all x (i.e. no erosion nor accretion compared to the initial coastline), if the sediment transport is disrupted at $x = x_0$ (because of a groin or a rocky headland), then $S_x = 0$ at $x = x_0$

at $t = +\infty$, $\varphi(x) = 0$ and $S_x = 0$ for all x (erosion or accretion stop as soon as the coastline becomes parallel to the wave crest)

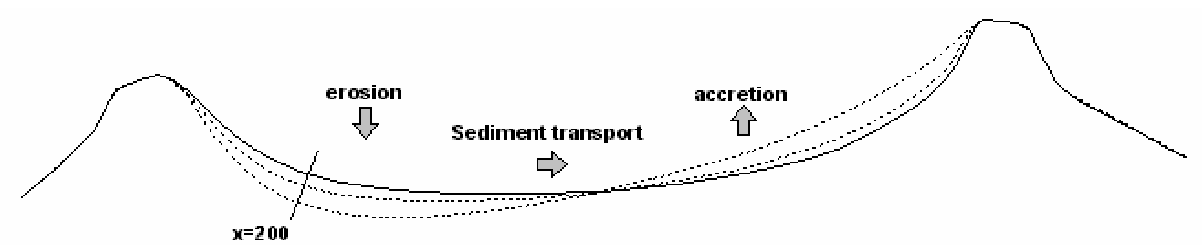


Figure at the top show shoreline evolution in a coastal sediment cell. In this example, long-shore sediment transport moves eastwards causing erosion on the western side and accretion of the eastern side. Below, a cross-section profile is depicted (here x=200 m) and shows how the beach profile is translated landwards and threatened assets located on the coast.

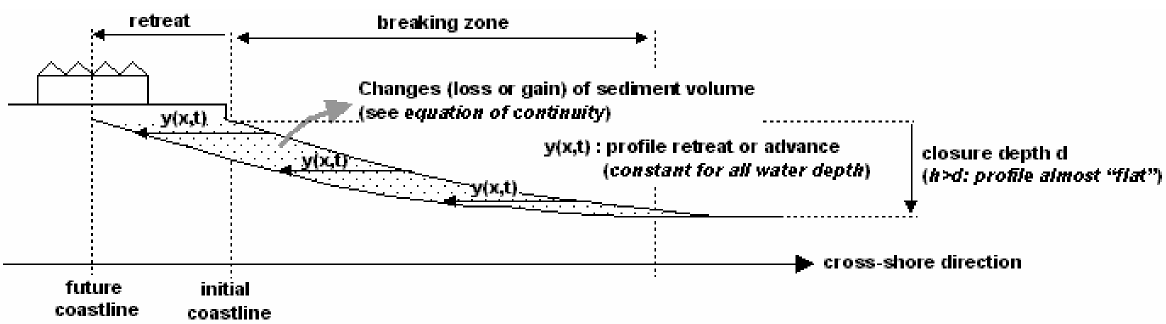


Fig. III-17. Shoreline evolution in coastal sediment cell

Methodology for mapping acute erosion

This part outlines the basic concepts and key processing underlying the mapping of acute erosion which mainly affects dunes and may result in flooding of the hinterland.

Selecting extreme water levels

In theory, the most extreme water levels may occur, though with a very low probability. We recommend to conduct the assessment on the basis of water levels corresponding to an annual probability of exceeding fixed at 1% (return periods of 100 years). It is assumed that a 100 year-return period water levels can be reliably derived from analysis of existing tide-gauge observations.

Determination of response to storms

In this paragraph “storms” is understood as water levels identified in the previous step and with a typical duration of 6 hours.

It is assumed that during a severe storm surge, the arbitrary initial profile is reshaped under a “storm profile”. This profile is known as the Vellinga’s model and is described by:

$$\left[\frac{7.6}{H_{0sig}}\right] y = 0.47\left[\left[\frac{7.6}{H_{0sig}}\right]^{1.28}\left[\frac{w}{0.0268}\right]^{0.56} x + 18\right]^{0.56} - 2.00 \qquad (\textit{Equation 1})$$

$$w = \sqrt{\frac{4(\rho_s - \rho)Dg}{3\rho c_D}}$$

Where H_{0sig} : significant “deep” water wave height
- w : fall velocity of bottom particle (depends on the particle size)
- ρ_s : mass density of the particle
- ρ : mass density of the fluid
- D : diameter of the particle
- C_D : drag coefficient (function of particle shape or “roughness”)
- x : distance from the new dune foot
- y: : depth below maximum storm profile

The erosion profile stretched from the new dune foot to a distance of

$$x = 250\left[\frac{H_{0sig}}{7.6}\right]^{1.28}\left[\frac{0.0268}{w}\right]^{0.56}$$

in the seaward direction. A slope of 1:1 is assumed above the dune foot; the seaward limit of the erosion profile meets the initial profile at a slope of 1:12.5. The amount of erosion follows from a mass balance of eroded and accreted volumes of sand.

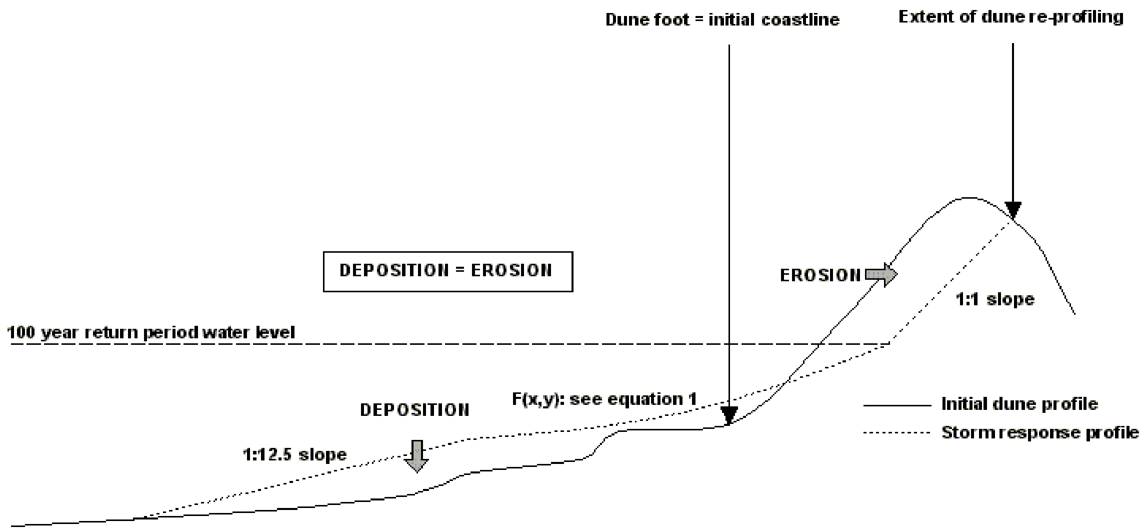


Fig. III-18. Dune response profile to a storm surge (dune retreat)

Coastline response to storms

The previous paragraph provides guidance on how to estimate a particular profile response to storms. The response of the entire coastline to the same storm conditions is derived by interpolating the profile responses obtained for a sufficient number of profiles.

Methodology for mapping cliff erosion

Contrary to evolution of sandy coastline, cliff retreat is a unidirectional and irreversible process, which involves coastal landslides, as well as cross-shore and long-shore transport. The long-term cliff retreat rate can be defined as the average value of cliff retreat as measured over a sufficient time interval that increasing the time interval has negligible effect on the average value. This definition implies that the long-term cliff retreat rate is linear, an assumption that certainly is not valid over time scales of more than a few centuries, or in periods of rapid sea-level change.

In this part, two approaches for mapping cliff erosion are proposed:

- The first one considers the historical trends deduced by comparing old and recent aerial photographs. This approach provides a first assessment but neglects the effects of sea level rise.
- The second approach is based on an empirical formula developed by Kampuis (1981) which models the erosion rate as a function of wave energy. In that respect, the effect of sea level rise may be modelled. This second approach has been specifically developed for the erosion of soft cohesive shores (including sedimentary rocky cliffs, but also flats or marshes

Approach 1: Extrapolation of historical data

The traditional approach to map cliff erosion is to estimate historic rates and make the assumption that these rates will remain unchanged in the future. This technique is quick and simple, but is only appropriate under certain conditions. When recession rates from a historic period are extrapolated forward an assumption is made that the conditions that existed during that period will continue into the future. This assumption is never, strictly speaking, true but in many cases in the past it has been the only available prediction method and considered as a proxy.

The best historical data for mapping cliff erosion are provided by aerial photographs which have been photogrammetrically rectified. Photogrammetry aims at correcting the distortions inherent to aerial photography (due, for example, to tilting of the camera, variations in the distance from the camera to various parts of the photograph, and differences in elevation across the photograph). Sometimes such data have been gathered as parts of specific studies of coastal cliff retreat, but more commonly they are collected as part of other works, and must be sought out for coastal erosion studies.

Step 1: Production of orthophotographs

The first step in mapping cliff erosion consists in producing orthophotographs from aerial photographs available. Ideally, two sets of aerial photographs taken with a time interval longer than 50 years shall be used. The longer the time interval between the two sets of aerial photographs, the better the estimate of long-term cliff erosion is. Ortho-photographs consist of a mosaic of aerial photographs which aims at correcting the aerial photographs from important internal distortions induced by the camera, and therefore making the information contained on aerial photographs super-imposable to a map.

Beyond aerial photographs, production of ortho-photographs requires the accurate coordinates of a number of ground control points (GCP) as well a fair overlap rate between consecutive aerial photographs (i.e. the same ground control points should appear on at least two consecutive aerial photographs). GCP are details easily identifiable on both the photographs and the ground (e.g. cross-roads, angle of significant buildings, etc.), and their coordinates are measured via GPS techniques. It is of the utmost importance the different sets of aerial photographs are orthorectified into the same coordinate systems (including map projection).

Step 2: Extraction of the coastline

The coastline is extracted from orthophotographs by visual photo-identification. Coastline extraction is performed with a standard GIS package. In the case of cliff, the coastline is normally taken as the upper edge of the cliff top. Accordingly, a great deal of effort often is focused on defining that “cliff edge”. The cliff edge is simply the line of intersection between the steeply sloping cliff face and the flat or more gently sloping cliff top. Defining this line can be complicated, however, by the presence of irregularities in the cliff edge, a rounded or stepped bluff edge, a sloping cliff top, or previous grading or development near the cliff edge. Whatever the definition for the cliff edge, it should remain consistent when extracting the coastline from different orthophotographs.

Step 3: Estimate of historical erosion rates

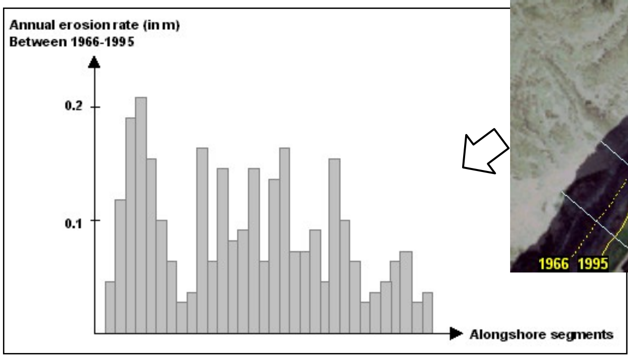
Once extracted, the various coastline positions are superimposed in a same coordinate system. The methodology prescribed to estimate the erosion rate consists in dividing the coastlines into regular segments (e.g. 50 or 100 metres wide segments) and determining for each segment the area of land comprised between the two coastline positions (i.e. the land lost). The erosion rate per unit of length is derived by dividing the area of land lost within each segment by the segment length (50 or 100 metres)

Step 4: coastline projection in the future

Once an historic long-term cliff retreat rate has been estimated, mapping the future coastline is a simple matter of multiplying that rate, B, by a time horizon usually taken as 25, 50 or 100 years for risk assessment mapping.

1. This photograph depicts a segment of the coast of Haute-Normandy which is characterized by highly erosive chalk cliffs. Two coastline positions, respectively from 1966 and 1999, were extracted from orthophotographs.

The coastline was then divided into equidistant segments for which the loss of land between 1966 and 1995 was estimated. Here, an equidistance of 100 metres was selected.



2. The loss of lands between 1966 and 1995 is converted into an annual erosion rate for each 100 metres long segment. Annual erosion rates for the entire coastline are reflected into a histogram as depicted above.

3. In turn, the erosion rate is used to estimate the future shoreline position by simply multiplying the erosion rate by the number of years considered (e.g. 50 or 100 years in the future)

Fig. III-19. Approach for estimating cliff erosion rates and future coastline positions

Approach 2: Cliff erosion modelling

In case the cliff is made of soft cohesive materials, the equation governing cliff erosion rate (E) can be given as:

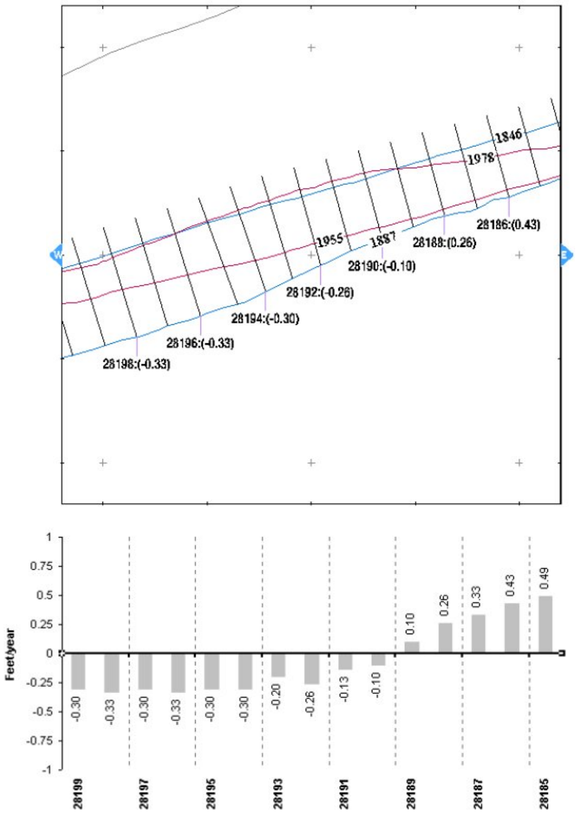
$$E = \frac{H_b^{13/4} T^{3/2} \cos(\beta) Tan(\alpha)}{R}$$ (Kampuis, 1987)

where
- Hb : breaker height
- T : wave period
- β : angle of wave approach
- α : platform slope
- R : material strength and some hydrodynamics constants to be found by calibration

Coastline recession displaying

for shoreline retreat

Digitally rectified aerial photographs have become an important tool in historical shoreline mapping. They are replacing the need for traditional methods such as using a zoom transfer scope to project shorelines onto a base map. Digitally rectified aerial photographs have all the elements of a photograph, but the image distortion caused by tilt of aircraft, camera lens, and relief displacement has been corrected. Also, the image is geo-referenced and therefore may be combined with other forms of geographic data in a geographic information system (GIS). See Figure III-21.



Vector based shoreline change analysis also provides a model of temporal erosion and accretion for any set of linear historic shoreline data. The vector approach to analyzing historic shoreline change data contrasts with a raster approach in its sampling flexibility and temporal scale-ability. The vector approach as illustrated in the figure beside can accept any number of temporal linear representations of the shoreline and can flexibly sample those shorelines to calculate past variability and project future changes. A limited section of the shoreline change data and analysis approach are presented below.

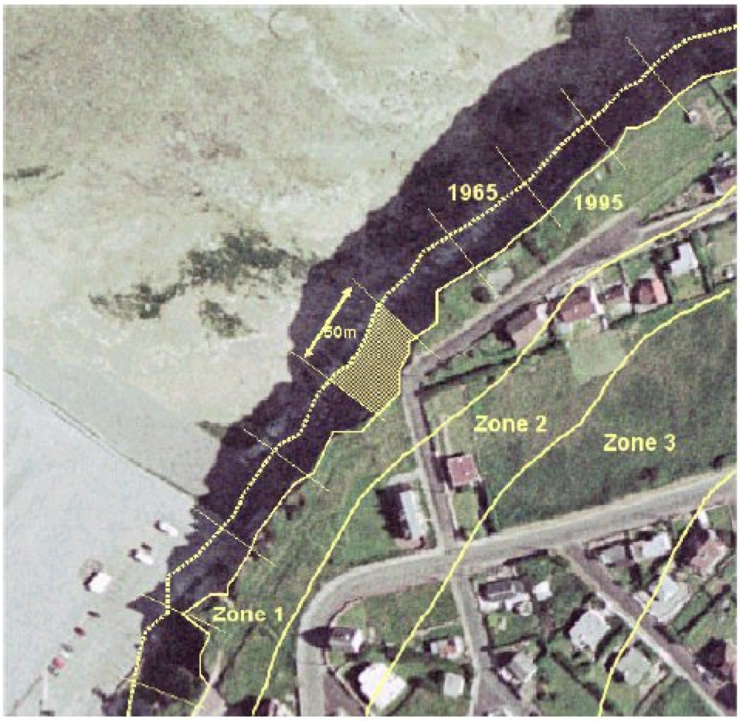
Note the shift from net overall loss (erosion) to net overall gain (accretion) as the analysis moves from left to right. Uplands are at the top of the image, offshore areas at the bottom of the image. Transects are spaced at 50 meter intervals. Scale is 1:4500.

Fig. III-20. Vector diagram display

for cliff retreat

Short-term predictions of cliff top recession can be misleading when the cliff evolves through episodic events occurring, on average 100 years or so. Cliff recession data and predictions can be presented in a variety of ways, including:

1. Tabular form;
2. Graphical form, including:
   - Annual and cumulative measured recession;
   - Cliff profile measurements;
   - Plots of cliff recession simulations and predictions;
   - Probability density functions of the cliff position at a given time;
   - Probability density functions for the time required for cliff recession to reach a given point.
3. Map form showing at an appropriate scale:
   - The best estimate of cliff position after a given time including confidence limits and prediction limits;
   - A zoning based on the cumulative probability distribution of cliff recession over a given time (Figure 10 and 11).



Zone 1;
It is certain that land within this zone will be affected by recession within a given time period.
Zone 2;
There is a 50% chance that land within this zone will be affected by recession within a given time period.
Zone 3;
There is a 10% chance that land within this zone will be affected by recession within a given time period.
Zone 4;
There is a 1% chance that land within this zone will be affected by recession within a given time period.

Fig. III-21. Cliff recession display

SECTION IV – EXPERIENCES ON IMPLEMENTING COASTAL GIS

List of figures

European coastal areas offer a variety of recreational and economic opportunities to the continent's citizens and these depend largely on maintaining the environmental quality and character of beaches and coastal systems. With the continuing migration of citizens towards coastal areas however, the character and quality of the shoreline is changing. High population density is affecting the natural processes that govern both environmental and geological processes. This, in turn, has increased public exposure to the risks associated with coastal storms and erosion, such as property damage.

Despite efforts by many European public authorities to compile information on the hazards facing coastal systems, there is still much to discover and suggests the need for increased partnership amongst European coastal authorities. The MESSINA - for Monitoring European Shorelines and Sharing Information on Near shore Areas - initiative intends to partly bridge these gaps by breaking "knowledge isolation" of some local authorities and institutions in Europe, by raising their managerial and technical capabilities through a mutualisation of the experience accumulated by each of them, and by upgrading existing shoreline management guidelines through an integration of the latest innovative techniques and methods available in Europe. The objectives of this 3 years project are:

- to provide a state of the art of shoreline monitoring and modelling techniques supporting coastline management policies, with a particular attention paid to innovative techniques;
- to review concrete examples of economic analysis methodologies applied to shoreline management policy inside and outside Europe;
- to embed lessons learnt from existing coastal defence engineering practices - including hard and soft engineering - into coastal planning processes at the local level;
- to assess information requirements to better integrate coastal erosion processes into spatial planning policies and to design and implement pilot GIS-based information systems dedicated to shoreline management planning at the local level.

This last described activity actually consists in developing information tools meant to support spatial planning and local investment decisions in the fields of shoreline management. Among these tools, those derived from Geographical Information Systems (GIS), which enable a visual representation of key indicators such as coastline projections in the coming years, assets at risk of coastal erosion and flooding, land value indicators along the coast, and potential impact of investments on coastal processes, built upon the following recommendations of the EUROSION project:

- Investment decisions relating to shoreline management should be based on information which is not restricted to the investment area only, but on information which is made available for the entire coastal sediment cell. Experience gained from EUROSION study has indeed demonstrated that activities occurring along the same coastal sediment cell are likely to impact other parts of the cell, while activities which take place in different coastal sediment cells are not likely to interfere from a sediment budget point of view. The accurate delineation of coastal sediment cell boundaries is therefore a pre-requisite to any GIS-based decision-support information tools;

- GIS-based decision-support information tools in the fields of shoreline management should fulfil three main functions: the mapping of coastal erosion and associated flood risk areas, the balance of cost and benefits of future investment decisions, and the assessment of potential environmental impact of investment decisions on adjacent areas. These core functions should in turn orient data collection and integration efforts;

- GIS-based information tools should be developed in partnership with the various local data providers. This is meant to avoid duplication of efforts, facilitate access to existing up-to-date data, and improve updating processes. The willingness to design, develop and implement such tools should be manifested at the highest hierarchical level by all the participating institutions. Political leadership - possibly from the regional authority - is a key prerequisite.

Three different sites with various thematic were proposed for implementing MESSINA GIS prototypes with the aim of supporting decision-making:

(i) the lido of Sète-Marseillan (France), managed by the Community of agglomeration of Thau Basin, which is in charge of the rehabilitation of semi-natural processes materialized by the realignment of traffic infrastructures landwards and the restoration of dunes system at the seafront, combined with strong coast engineering protection for critical erosion places.

(ii) the chalk cliffs of Haute-Normandie (France), for which both the Regional Council of Haute-Normandie and the Departmental Council of Seine-Maritime shall implement a coastal observatory, aiming at monitoring the coastline evolution, assessing the areas at risk of coastal landslides and ensuring the French Coastal law correct observation.

(iii) the waterfront of Rewal (Poland), subject to high season massive tourist accommodation demand and facing growing but not yet controlled built-up areas. As a first functionality the coastal GIS should be able to provide vulnerability maps projection of the coast.

IV.1. Rehabilitation of the natural environment

The Case of Sète-Marseillan' lido in Languedoc-Roussillon region (France).

1.1. Starting the GIS project

Geographic situation of the Lido

The coastline of the Languedoc-Roussillon region is characterised by large sand dunes that are of great ecological importance, whilst also providing a natural barrier to the threat of coastal erosion. However, with the potentially increasing erosion rates as a result of sea level rise and the intensification of land-use along the coastal strip, the coastal features are becoming threatened and destroyed.

The Lido of Sète can be described as a narrow strip of land that separates the lagoon of Thau and the Mediterranean Sea. This 12 kilometres band of dunes and sand is located between Marseillan and Sète, in Southern France. Among about thirty costal lagoons in the Languedoc-Roussillon region, the lagoon of Thau is the largest (75 km2) and the deepest.

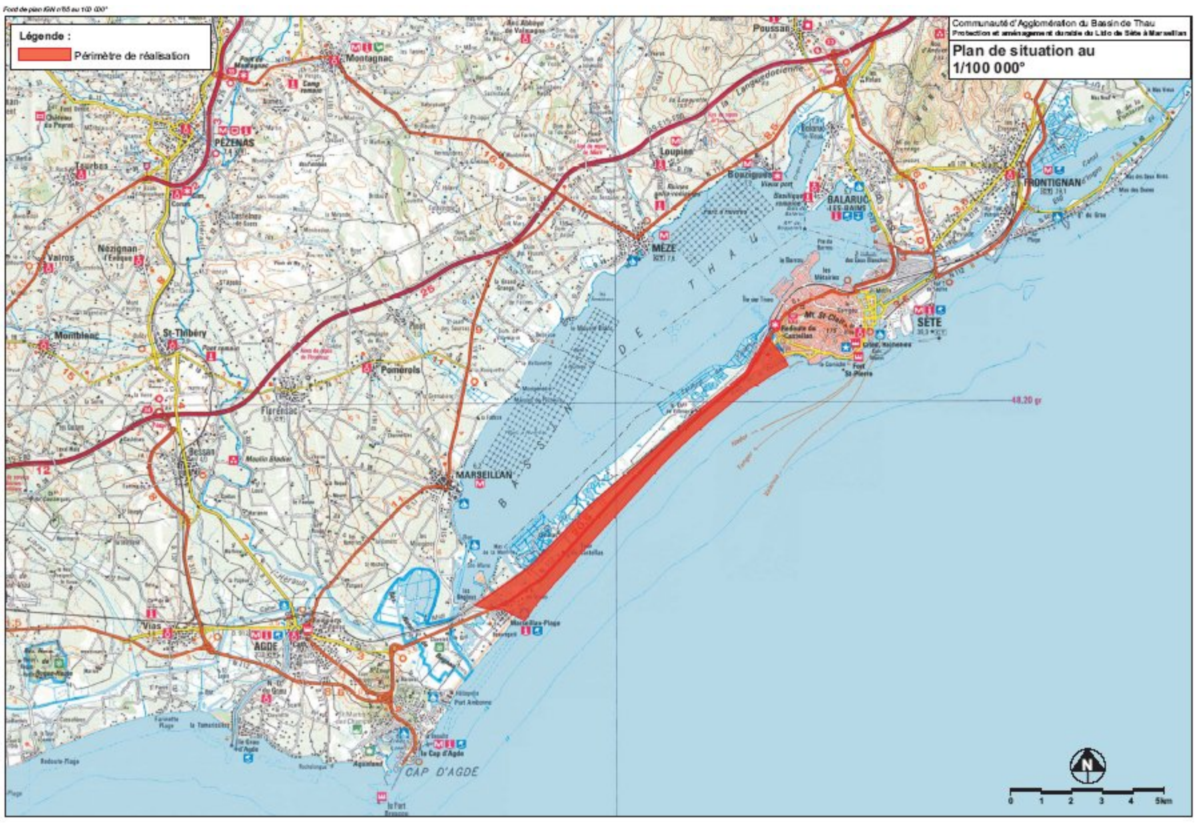


Fig. IV-1. Lido of Sète Marseillan – Situation map (IGN)

The coastline from Sète to Marseillan suffers particularly from the effects of erosion with almost 45 hectares having disappeared between 1954 and 2000. The storm of 1982 caused significant damage to the coastline with a huge reduction in beach material and the destruction of coastal businesses and infrastructure, including the main coastal road.

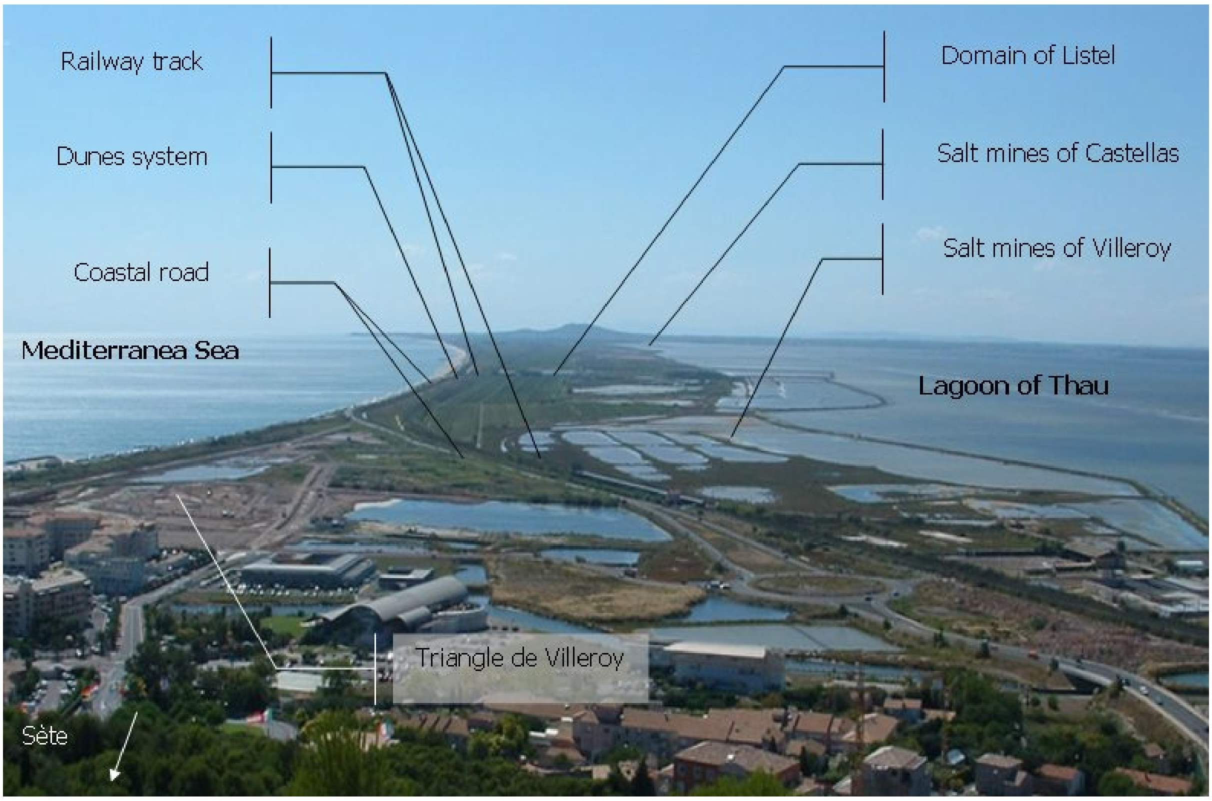


Fig. IV-2. View of the Lido of Sète Marseillan – with comments

In 1953, three groynes were constructed along the southern end of the lido in order to protect a 400m stretch of the coastal road and the adjoining campsite. An additional groyne was constructed in 1954 to aid beach nourishment of the Lazaret beach on the south side of the strip.

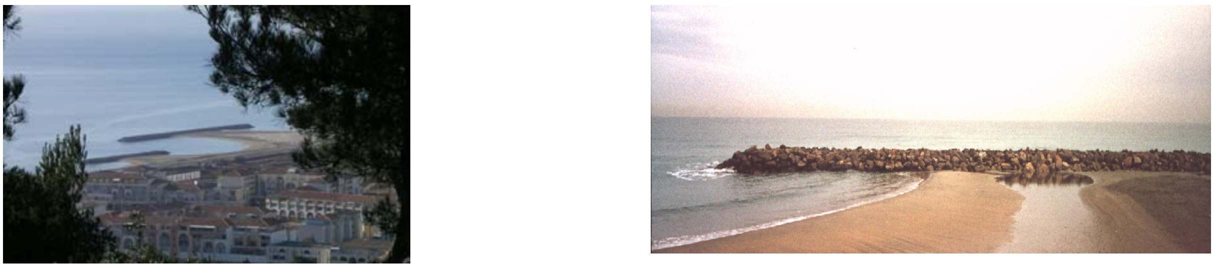


Fig. IV-3. Breakwater and induced tombolo

Technical studies undertaken following the storm of 1982 suggested a need for the installation of hard engineering protection works along the whole coastline.
The construction of a number of offshore breakwaters between 1987 and 1993 allowed for the creation of tombolos behind the structures and increased the beach size by 150m. However, the effectiveness of these coastal protection measures has

been questioned because of their negative impacts downdrift of the last breakwater, showing a high erosive trend, especially intensive in the section where the coastal road is close to the beach (MESSINA PG3, 2006).

At the end of the nineties, local authorities started to search for a long-term solution to the management of the Sète coastline. Currently, this solution implies moving backward hard infrastructures (e.g. coastal road) and restoring the dunes to increase the system's resilience against erosion. People are aware that the ideal solution is to remove all the hard infrastructures from the lido (road, railway track, etc.), but this alternative is not accepted socially because of the high use of the road. Therefore, a long-term solution is required in order to avoid any further significant impacts on the environment.

A number of studies have been carried out, looking into potential solutions for managing the lido:

- A first "*General study for the protection and the long-term installation of the Lido Sète Marseillan*" was outsourced in 2001. This consisted in identifying the general problems of degradation of the site of the Lido and proposing effective strategy on the long term preferring the techniques known as "soft". This study make the discussions of experts arise on the natural sediment lost, the impact of the presence of ripraps on the berm; the arguments and/or enthusiasm for the evoked strategy of coastal realignment on the whole site.

- A finer second investigation called "*Thorough inquiry of site frequentation* " was launched in summer 2002, with the intention of determining how infrastructures shall be moved; identifying necessary connections to the existing networks; defining the principles of new car parks; identifying the needs regarding transports; enquiring the local users on services they would like to find on the site; specifying the choice to be operated with respect to the "view-points" and the "sanctuarisation"; evaluating a possible calendar for the operation and finally analyzing the further management of the site. The study stresses the importance of the littoral road, quoting usage figures of almost 12,000 vehicles per day with figures reaching 18,000 in high season. Between 1991 and 2003, the usage of the road increased by 30% with figures rising from 9 000 to 12 000 vehicles per day.

- In 2003 a further "*Study for the definition of the general program of the operation"* was carried out based on the findings from the previous two studies. The aim of this was to establish a detailed programme, following full consultation, illustrating the procedures and costs involved in such a scheme. The project was estimated to cost €48 million and involved eight local authorities. The programme design was based on the use of soft engineering techniques in order to protect the dunes and the relocation of sections of the main road.

The operational and pre-technical studies have been carried out between 2004 and 2006 and have involved the compilation of data from topographical surveys, geotechnical investigations, and hydro-geological and geological surveys. The geological, hydro-geological and geotechnical investigations intended to determine the feasibility of the investments and to identify the constraints likely to affect construction, maintenance, and the conditions for implementation of the projected works. The topographical surveys include measurements taken from photogrammetric surveys as well as measurements taken on foot. In addition, bathymetric surveys were also carried out where necessary.

Role of the CABT

As the importance of the project largely exceed competences of the communes of Sète and/or Marseillan, the great scale project was transferred to the Community of Agglomeration for the Thau Basin (CABT), circle of eight local authorities. The Community voted on December 2004 the adhesion to the Coastal Sustainable Development.

The Community of Agglomeration of the Thau Basin (CABT) is an operational organism in charge of managing projects devoted to the whole Agglomeration of The Thau Basin. The decision are taken by a Committee representing elected people towns and villages of the Agglomeration and currently presided by the major of Sète - the main city: they are seconded by technical services and maritimes services as well as engineers and territorial agents of the CABT.

For the current rehabilitation project of the Lido of Sète-Marseillan, the CABT is managing the project as a whole: administrative management, search for financing, information to the public, follow-up of technical studies and further realisations, considered as Client ("*maître d'ouvrage*") controlling and validating the outsourced works with external Project Managers ("*maître d'oeuvre*").

Project Steering Committee

All the local actors involved in the preservation of the sites and spatial planning decisions have joined a Steering Committee. This committee consequently gathers the local authorities like Marseillan, Sète and the Agglomeration elected people, the Maritime Services of Languedoc-Roussillon, the General Council, the Regional Council of Languedoc-Roussillon and the Littoral Mission of Languedoc-Roussillon (entity created by the National government)

Fig. IV-4. View of the Lido of Sète Marseillan

Aims of the rehabilitation project:

The main objectives of the study are as follows:

- *To restore a normal functionality of the beach and to ensure a long-lasting protection against erosion*

  In last 50 years, the Lido has lost 45 hectares. If no measurement is quickly committed, this strong erosion will continue, and even worsen in the sectors where the littoral road is protected by ripraps. The strategic retreat seems to be the best adapted solution for a sustainable protection against erosion: it indeed makes it possible to restore the sedimentary balance that the construction of the road broke.

- *To ensure an effective and long-lasting protection of ecologically rich wetlands and salt marshes.*

  The project should contribute to ensure safeguarding and restoration of wetlands and salt marshes due to their significant ecological importance. Public access to such areas will be restricted to less fragile areas with areas of high ecological importance being strictly protected.

- *To maintain the local function of the littoral road*

  About half of the traffic using the littoral road uses the route between Sète-Balaruc-Frontignan and Agde-Marseillan: this local road of the southern part of the basin of Thau is therefore to be preserved.

- *To preserve viable conditions for the wine activity*

  The vineyards are one of the major characteristics of the landscape of the Lido de Sète, with more than 270 hectares being used for such purposes. It is therefore essential that a favourable environment be maintained for such activity.

- *To ensure the maintenance of the existing economic activities*

  The two major economic activities located on the Lido must be preserved. The unit of Listel produces 42 million bottles of wine per year with 120 employees and over 7000 visitors per annum.
  In addition to this, the campsite of Castellas offers nearly 1000 pitches and creates almost one-sixth of all Sète's tourist trade.

- *To support the maintenance of the traditional activities such as fishing and hunting.*

- To allow the visitors to discover the richness and diversity of the lido environment and to gain a better understanding of the delicate balance between human intervention and the natural environment.

- *To ensure the protection of the most diverse and ecologically rich areas, visitors will be restricted to certain areas of the reserve. Information and interpretation exhibits will be on display to visitors interested in the site.*

July 2004 December 2004

Fig. IV-5. Views of the Lido of Sète Marseillan at different periods of time

Overview of the principles of the current rehabilitation project

Before starting further investments, the "operational pre technical studies" were committed from 2004 to 2006.
It consists in a study of the impacts to establish the Public Declaration of Utility (DUP) and collect necessary documents to obtain the authorization compliant to the Water Act; as well as for geological, hydro geological and geotechnical acknowledgements, topographical surveys and identification of dwells possibly impacted by the project.

The geological, hydro geological and geotechnical investigations intended to determine the feasibility of the investments and to identify the constraints likely to affect construction, the maintenance and the conditions for implementation of the projected works.

The topographical surveys include photogrammetric surveys overall with 1/1000 and if necessary bathymetric surveys over the working area in the sea; numerical surveys by terrestrial method to scale 1/500 or 1/200 complementary to the photogrammetric surveys; development of the land ownerships file (research and identification of occupants impacted and getting rights and authorizations from them) and finally elaboration of the documents of land surveys necessary to land acquisitions.

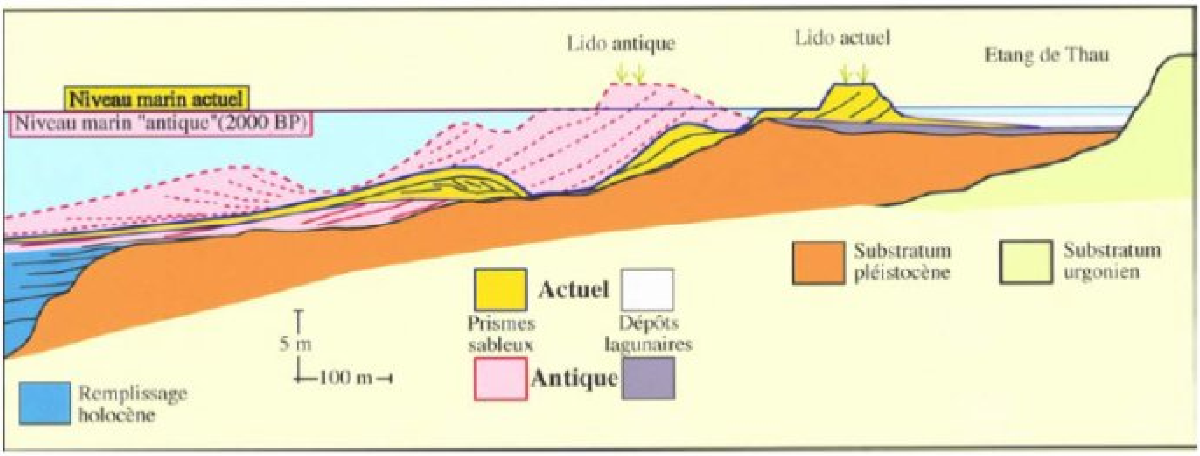


Fig. IV-6. Historical study on the Lido of Sète Marseillan (thanks to J. Serra - UAB)

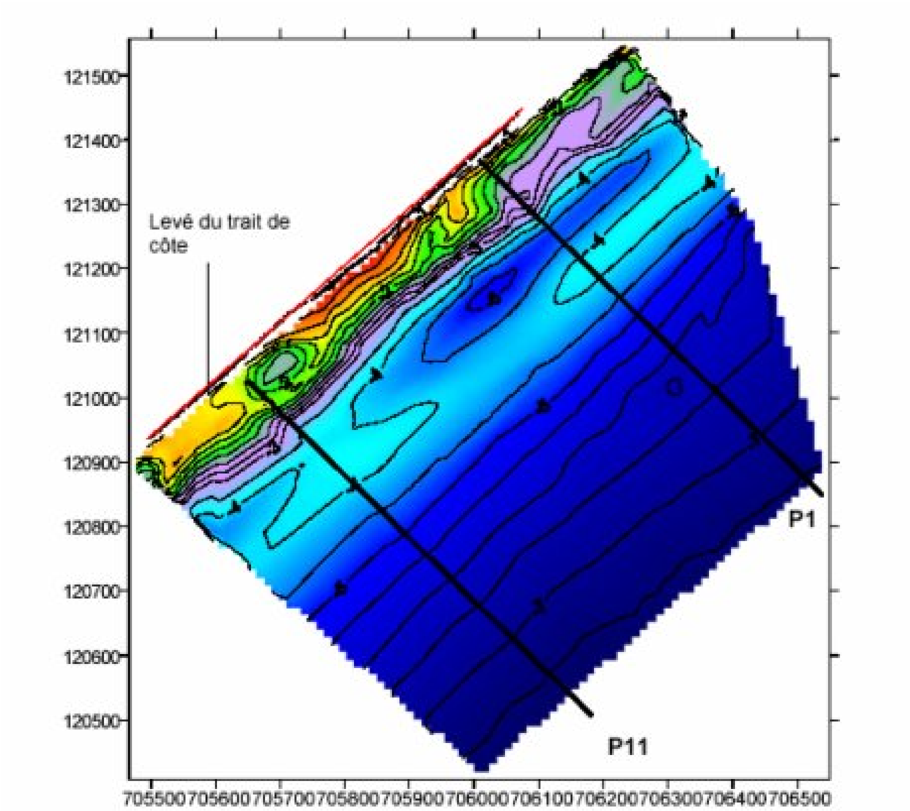


Fig. IV-7. Bathymetry survey on the Lido's near shore

1.2. Engineering and Prototyping the GIS

Relevant Data

Mosaic of rectified aerial photographs BDOrtho® (Data provider IGN)

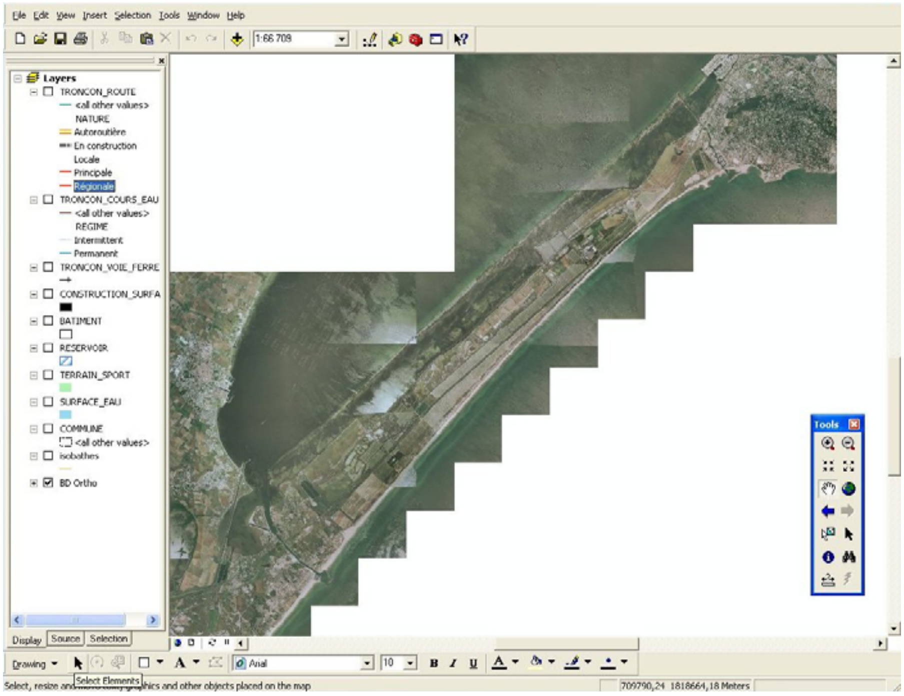


Fig. IV-8. BDOrtho® on the Lido of Sète-Marseillan

Topographic database BDTopo® (Data provider IGN)

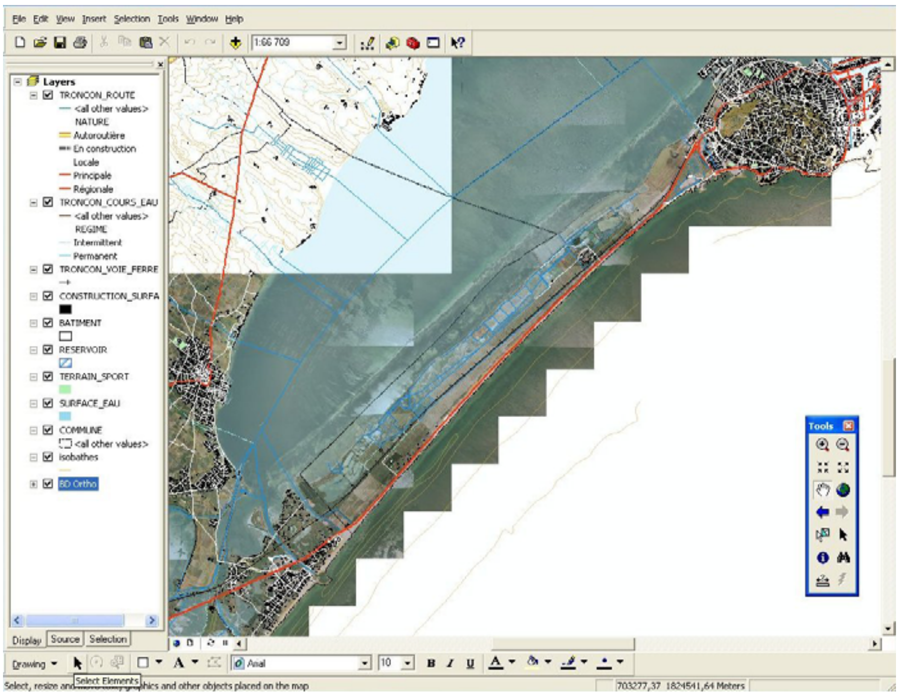


Fig. IV-9. BDTopo® and BDOrtho® on the Lido of Sète-Marseillan

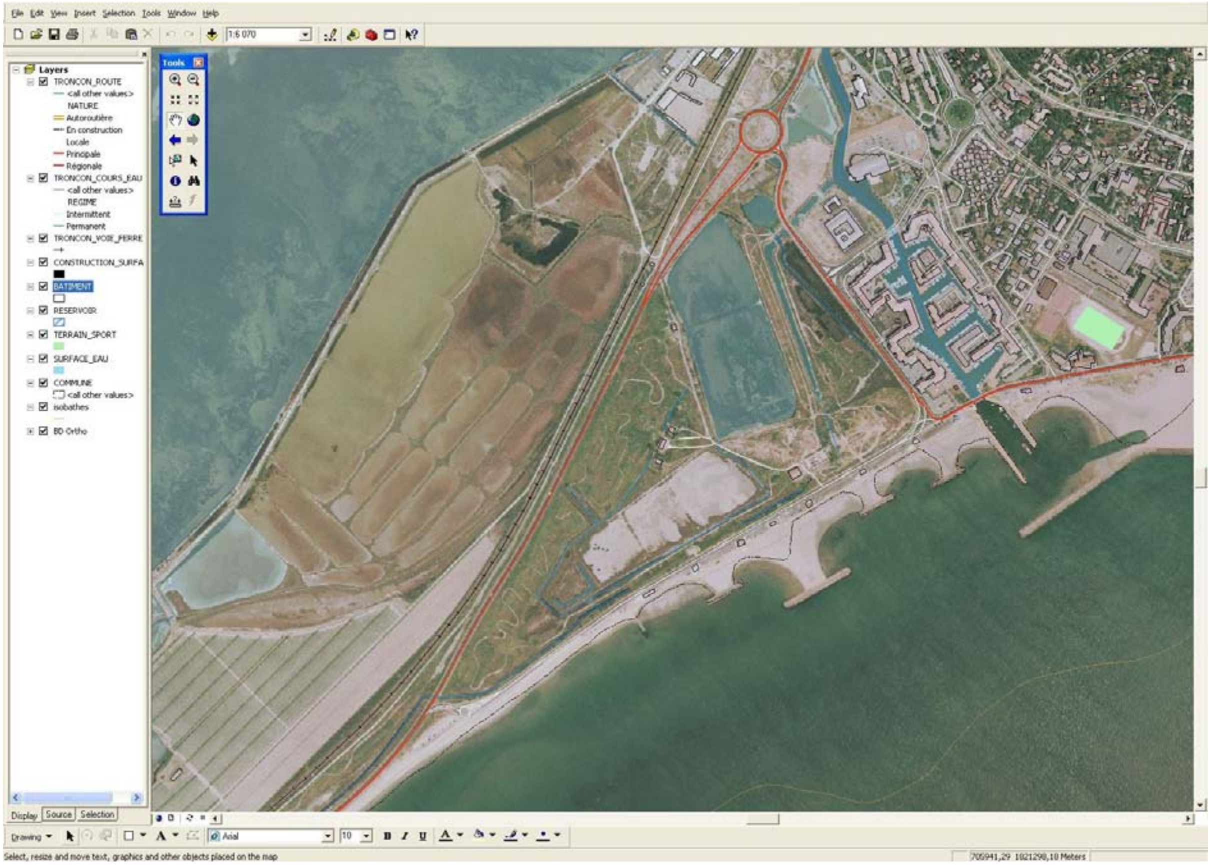


Fig. IV-10. BDTopo® and BDOrtho® on the Triangle de Villeroy (Sète)

Geology and geomorphology data

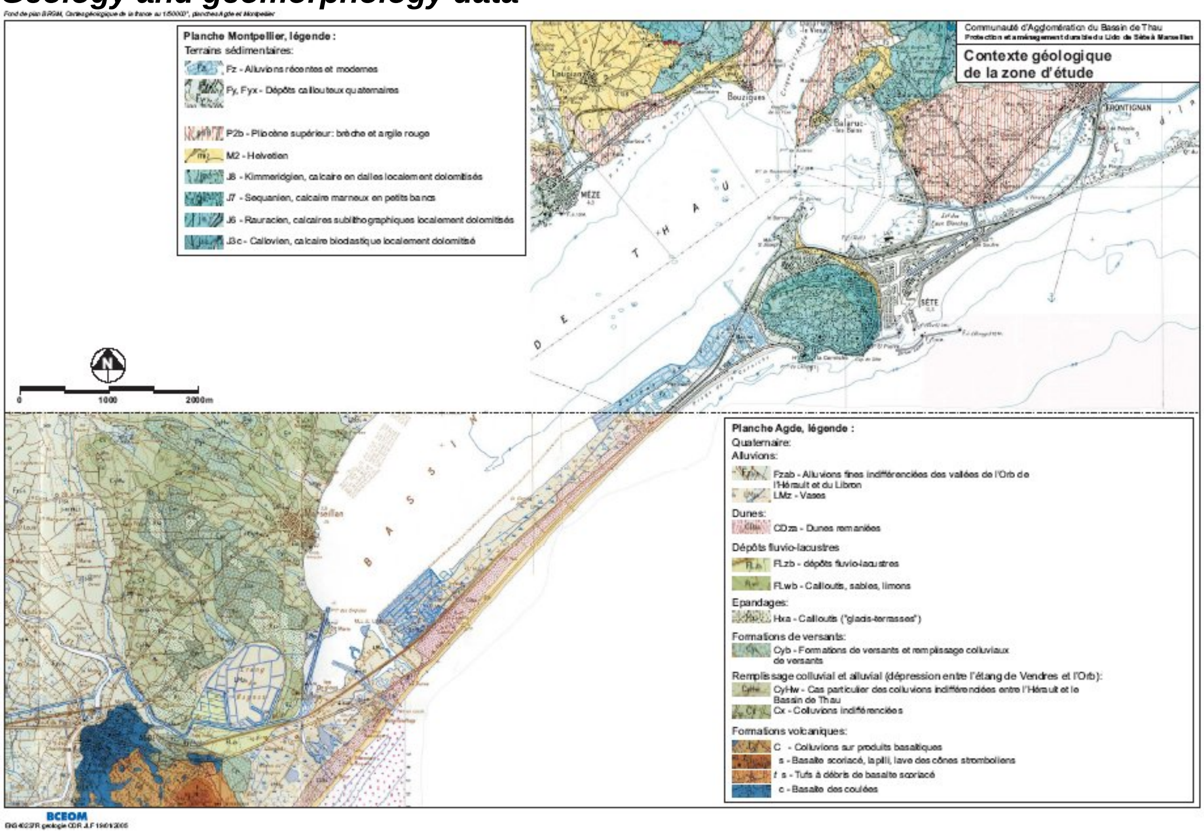


Fig. IV-11. Geology map of the Lido of Sète Marseillan

Coastal CORINE Land Cover changes, 1975 - 1990 (source: EUROSION)

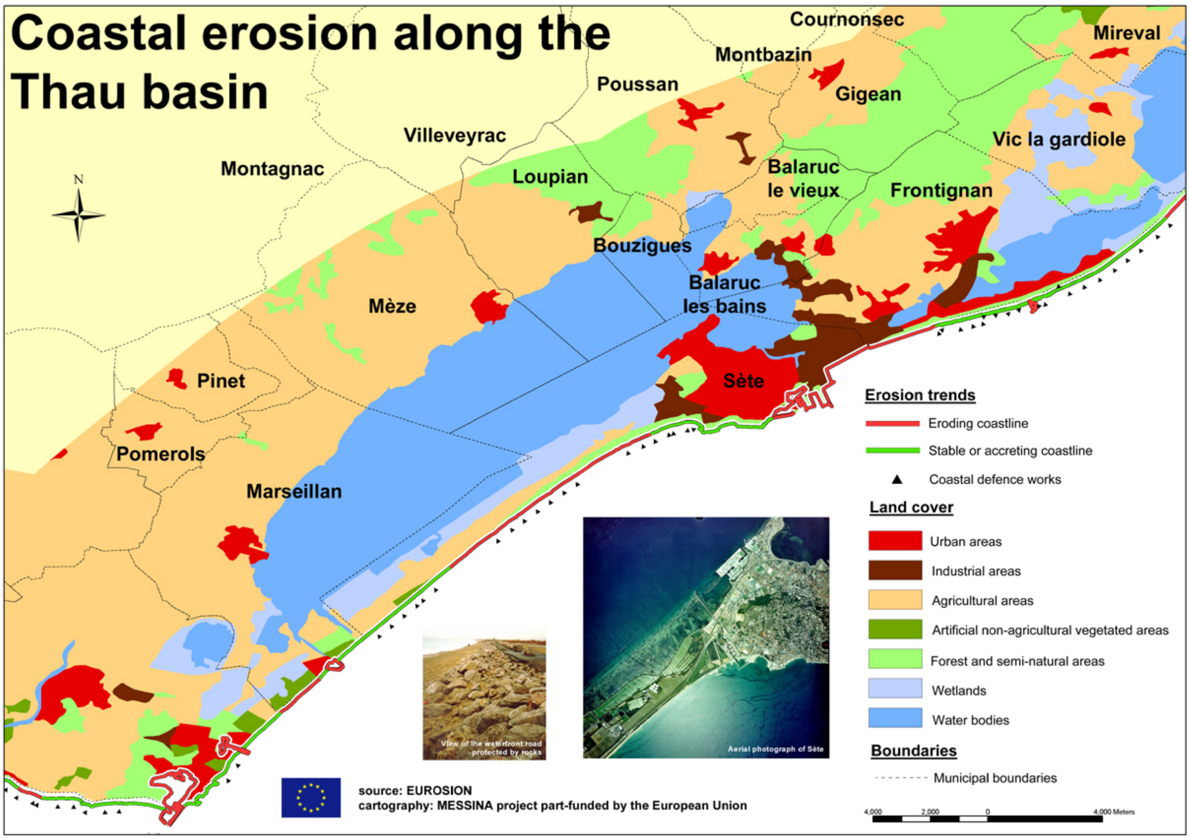


Fig. IV-12. Coastal Land Cover for the Thau Basin

Integration of Data

Due to the outsourcing to research consultancy companies the implementation of data layers, the integration to data models has not been made by the local community partners. As the project progressed the CABT team acquired both tools and capabilities in handling data integration and are now able to manipulate the relevant data mentioned.

During last quarter of 2006, the most relevant data layers should be delivered to the CABT who will be able to implement new applications (e.g. coastline monitoring)

1.3. MESSINA recommendations for the project of rehabilitation

Recommendations for the feasibility study and solutions proposition

During a workshop organized in Sète (January 2005) the coastal experts who drafted the Practical Guide *Engineering the Shoreline* (MESSINA PG4, 2006) have insisted on the importance of simulations prior to choosing one defence work or another. This was not the case for the current project and the solutions proposed was comprising new breakwaters for fighting erosion at the most critical place (Triangle de Villeroy – Western part of the Lido) and eastwards. MESSINA experts were drafting the guideline describing the advantages, drawbacks, context of application, limitation and costs of innovative solutions. They visit the outsourced company in charge of proposing defence solutions in spring 2005 and made the proposition changed in favour of submerged geo textiles filled with sand (and/or artificial reefs) and limited beach nourishment. This has retained the attention of the Steering Committee which clearly remained against new hard protection along the coast, with possible domino effects later. MESSINA experts also militated for preliminary laboratory simulations and cooperation with universities has been initiated accordingly.

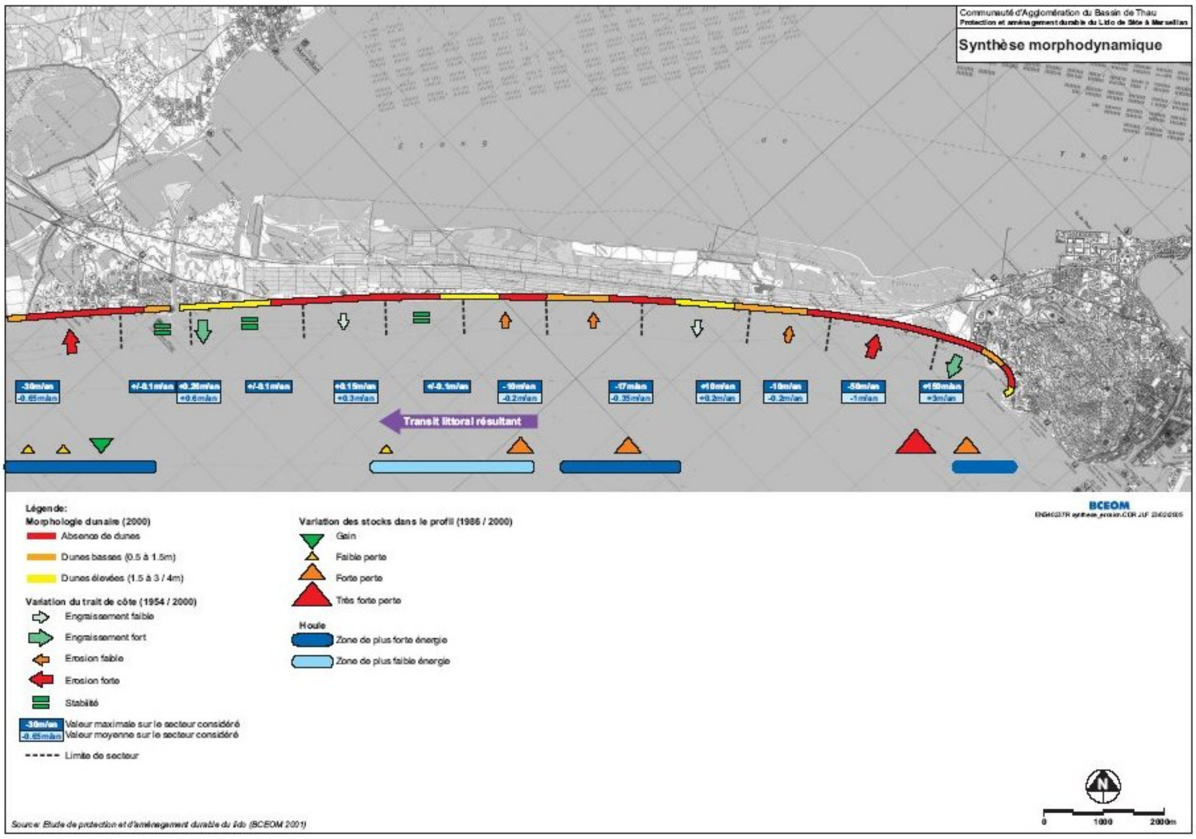


Fig. IV-13. Morphodynamic Synthesis along the coast

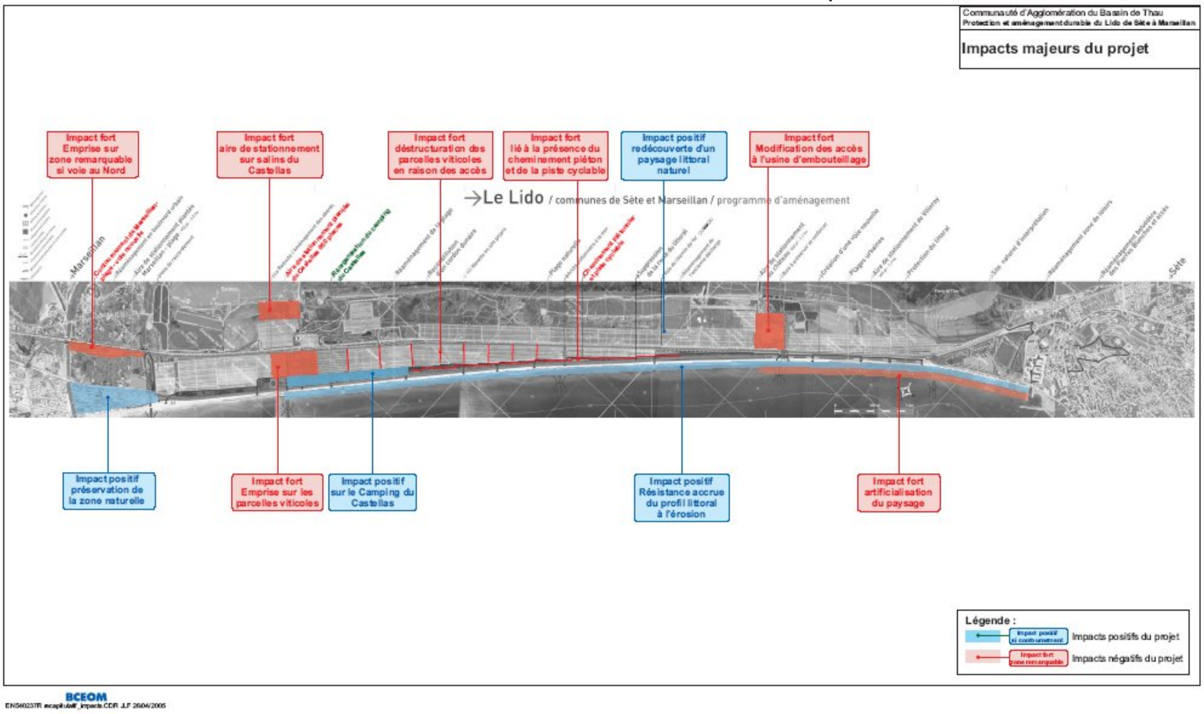


Fig. IV-14. Synthesis impact study map for the Rehabilitation project

Recommendations for the socio-economic assessment

Based on the methods of socio-economic evaluation described, discussed, and recommended within the Practical Guide *Valuing the Shoreline*, the CABT benefited of a Social Multi Criteria Evaluation for the project of rehabilitation. The experience was very instructive and the analysis of scenarios comforted most of the projects orientations (MESSINA PG3, 2006)

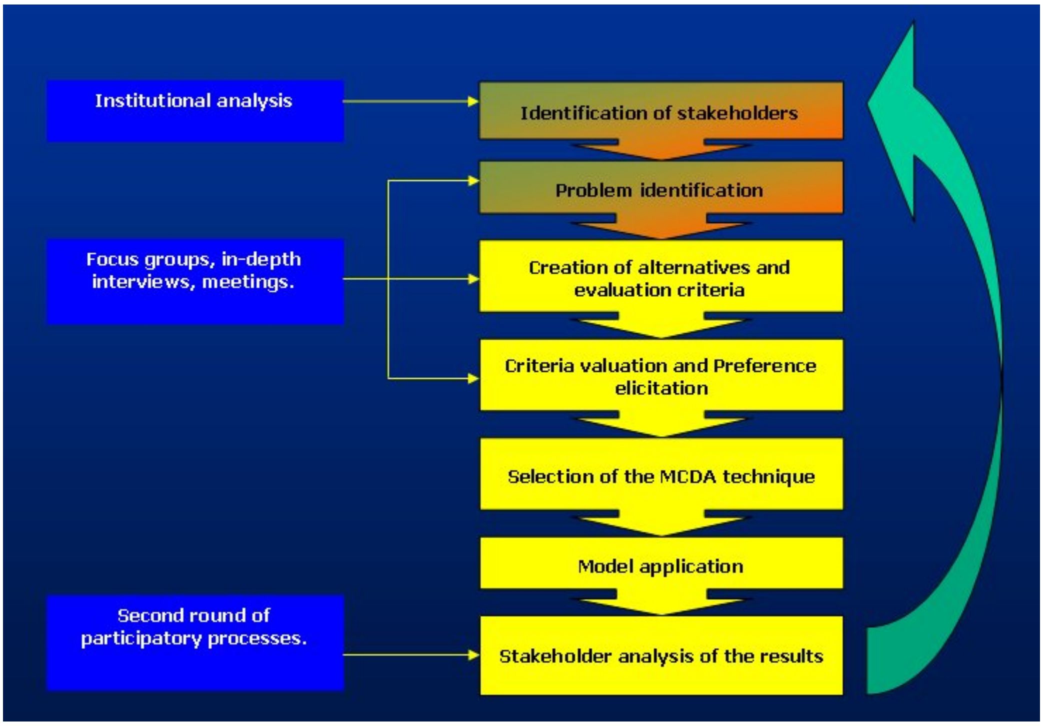


Fig. IV-15. Socio-economic analysis diagram

Recommendations for the use a coastal GIS

Prior to MESSINA project, all spatial planning studies were outsourced externally to the CABT to private research consultancies. Project propositions were then exposed and submitted for approval to the Steering Committee.
Like people of Rewal Community met during the workshop in Sète, the CABT has seen the interest of getting and using Geographic Information System for managing coastal concerns, even continuing the outsourcing for specialized or practical studies. Obviously all applications could not be made internally, but the management within preliminary phase, for the validation or the acceptance of implemented solution, for the monitoring phase should be eased providing internal well trained resources.

The CABT has purchased GIS software; recruited trained staff; started the integration of data with one first concrete environmental and spatial planning related topic to address before end of 2006.

The approach of the CABT in the framework of MESSINA is considered as precursor for the Languedoc-Roussillon region. A second GIS application is now envisaged related to the monitoring of the coastline of the Lido between Sète and Marseillan.

Recommendations for the project implementation phase and further monitoring of the coast

Considering the Practical Guide *Monitoring and Modelling the Shoreline* (MESSINA PG2, 2006), and the conference during the workshop on the Isle of Wight (July 2005) related to the "South East regional strategic coastal monitoring programme", a number of recommendations have been put forward with regards to the monitoring of the Sète coastline.
Recommendations which could be made are:

- The development of a comprehensive monitoring programme requires procedures that are standard and repeatable. It is essential that there is a fixed structure both in terms of timing and procedure, by which all monitoring should adhere to. Monitoring should not be allowed to occur on an ad-hoc basis.

- It is crucial to ensure a correct training to all staff. Choices have to be made by policy makers with the best of technological and scientific input and that these decisions are fed down to those carrying out the practical work. The data collected by staff can only be as good and as accurate as the training that they have been given.

- Finally, where possible, securing funding for a long-term programme is best. There is little value in data collected over short time periods. Long-term data sets are essential to build up a picture of trends in data and allow for accurate predictions to be made. Benefits of coastal monitoring programmes are often developed over long periods of time, typically more than ten years. A clear vision is needed to plan for the development of strategic programmes over a period of 25 years or more; this can be achieved only when high quality data is available for decision-making. In order to secure funding, a good rapport between the local and national politicians and technicians is important.

- The survey programme should be designed on a risk basis, developed from a conceptual model of data requirements. More data is generally required at those sites that are most vulnerable or heavily managed.

- A robust position-control network within which the surveys can be conducted needs to be established using GPS. A single control network should be developed that will provide a framework for land surveys, aerial surveys, and hydrographic surveys.

- The provision of post storm profile surveys should be incorporated into the programme. These will typically be required once or twice per year, depending on exposure and the degree of storm action. Surveys should be conducted within 24 hours of the storm, ideally on the low tide following the storm.

- Data collection and analysis should be managed within a central database. A meta-data record should be recorded for each survey and each data set.

Recommendations for collaborations and partnerships

- Where possible collaboration with other thematic partners within the same area of interest should allow mutualisation of data, trained/specialized resources or methods. In Sète further cooperative projects are foreseen with the BRGM (French GeoSurvey), the Regional Maritime Navigation Services, the General Council (Department), the Water Agency Rhone-Mediterranean-Corsica to set the specifications of the video monitoring of the coastline of the Sète-Marseillan's Lido.

- Contacts have been set between partners of the INTEREG Project BEACHMED-e which let appear sound results on the research of useful sand potentials in deep Mediterranean. This is linked to the solution proposed for the lido (geo textiles) and beach nourishment.

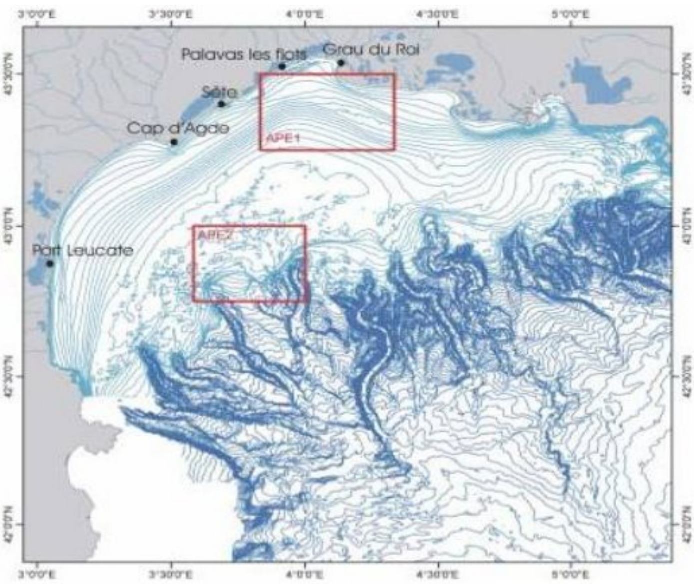


Fig. IV-16. BEACHMED output map in Lyon Gulf

Rehabilitation of the Lido: Road realignment: planned realisations

Fig. IV-17. Road realignment along the railways (site of *Mas de Castellas*)

Fig. IV-18. Spatial planning project (site from *Triangle de Villeroy* to *Listel*)

IV-2. Monitoring the cliff retreat of High-Normandy

The case of the Alabaster Coast (France)

The objectives of this study proposed by MESSINA partners were to provide the coastal authorities of High-Normandy (France) with applied reproducible methodologies, data layers and GIS tools to be used for spatial planning observing the regulatory obligations issued from the French Coastal Act (*Loi Littoral*[1]), the Environment Act (*Loi Barnier*[1]) and the Building Act (*Loi SRU*[1]).
The specifics of the Alabaster Coast are its retreat due to the erosion of chalky cliffs which revealed as a site of interest for MESSINA initiative.

The study of this High-Normandy comprises:

- a description of the geographic context
- the coastal authority requirements
- the wished GIS functionalities
- the data and methodologies
- the realisation of the functionalities
- the validation of the results by the coastal authorities
- the recommendations for coastal GIS sustainability

Fig. IV-19. Varengeville sur Mer – Alabaster Coast

[1] In French in the text

2.1. Starting the GIS project

With a never ending French process of decentralization together with the existence but fuzzy application of the Coastal Act, the Building Act (Loi SRU) is now encouraging the French coastal authorities, with support of Ministries and relays at departmental, regional level and European level, to concert all relevant body and local stakeholders within participatory processes, to propose pragmatic and concrete ideas for inter-related problems, to find consensus of local opinions, to act for long-term sustainability, to make a broad use of financing instruments; in short to realise the integration of the coastal zones management.

2.1.1. User needs and requirements

In that context, the High-Normandy coastal authorities organized a preliminary meeting with stakeholders, associations, scientists, deputies from General (Departmental) Council and Regional Council, responsible for Urbanism, for Spatial Planning, agents from Ministry of Ecology and Sustainable Development (MEDD) from Ministry of Equipment, Transport, Territory Planning, Tourism and Sea (METATM). The main objective was to identify the functional specifications, based on the user needs and requirements:

- To develop and experiment methodologies of assessment and follow-up of main existing coastal natural risks, based on the establishment vulnerability indicators, quantified using methods of economic, ecologic and heritage valuation.
- To contribute to a better anticipation and planning of coastal natural risks, to a better consideration of the Coastal Act principles, strengths and weaknesses, by assessing the technical feasibility of local GIS and appropriation by coastal authorities for regular monitoring of the coast retreat.

Beyond those functional specifics for the implementation of a coastal GIS, concrete tools and functionalities are wished:

(i) The determination of hazard areas,

(ii) The experimentation of valuation methods,
  a. the experimentation of vulnerability indicators
  b. the method of economic quantification
  c. a goods and real estate assessment

(iii) The mapping of risks,
  a. typology of risks
  b. risk impact on tourist activity

(iv) Follow-up indicators for the application of the French Coastal Act
  a. the delimitation of the theoretical 100 m setback line from the shoreline where new settlements are severely controlled even sometimes prohibited
  b. the creation of fit-to-purpose coastal indicators,

(v) A study for the capability of integration of results to urbanism documents or the establishment of prevention risks plans

(vi) The recommendations for local coastal observatory.

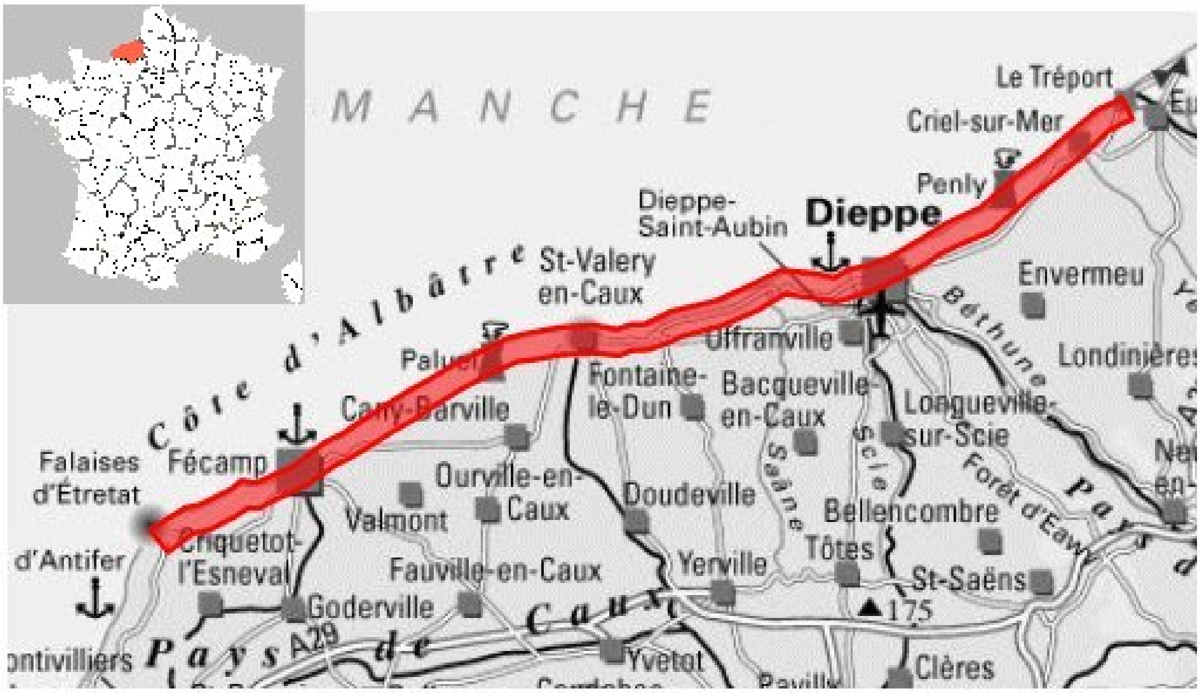


Fig. IV-20. Map of the Alabaster Coast, from Antifer to Le Tréport

2.1.2. The geomorphologic context: High-Normandy emblematic coast

This part of French coast did not escape the twentieth century's characteristic urban sprawl devoted to seaside tourism or harbour and industrial facilities. Thus from punctual activity, the waterfront sustained such a linear urbanization increasing the damages value in case of erosion and maritime flooding. This progressive appropriation led the policy makers to refuse considering the natural implacable retreat of the shoreline.

The intense regressive dynamic of the coastline seems logical for chalk cliffs, but somehow surprising if we consider pebble beaches born from sediments accumulation indeed. This part of the coast lies on 130 km from the bay of Seine to the bay of Somme, and, geologically speaking, the north-west end of the Paris river basin. This plateau is deeply notched with hydrographical network, especially drained or dry valleys mostly perpendicular to the coastline, where human settlements constitute the main links from the sea to the inlands.

The sector of study is characterized by cliffs of 70 meters mean height, made essentially in chalk from Upper Cretaceous, more or less rich in flint clay. Due to this not resistant structure subject to atmospheric alteration the cliff retreat observed is particularly important. This erosion, combination of maritime and aerial factors free large volumes of flint which constitute the only current source of pebble bars, located right at the bottom of the steep slope or at the seafront of urbanized valleys. This mass of sediments reveals particular interest, depending of their volume fluctuations, by conditioning the intensity of the hydrodynamic factors at the cliff bottoms on one hand, and at the outlet of urbanized valleys on the other hand, whose altitude generally are lower than high spring tides. The multiplicity of storm submersion within the three last decades, notably this of 1990, is increasingly worrying the threatened population and involved decision makers (COSTA, 1997)

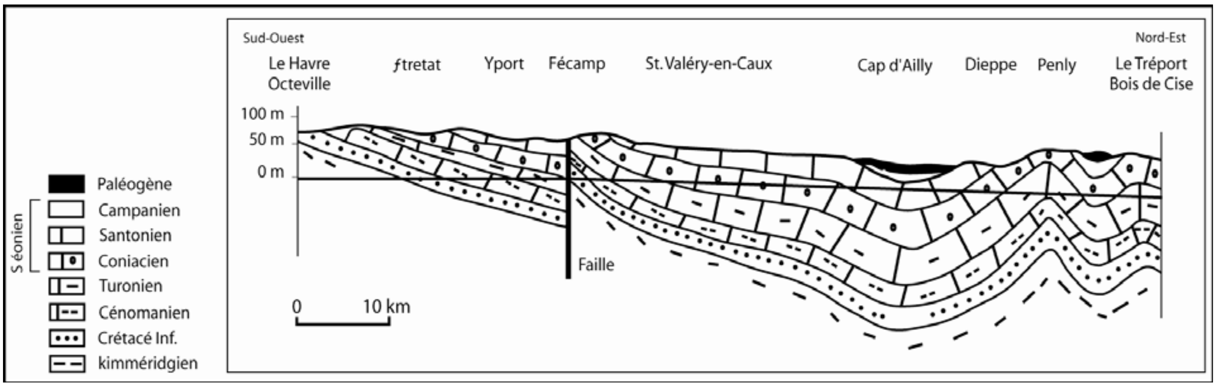


Fig. IV-21. Geological simplified transect of chalky cliffs of the Alabaster Coast

Among rocky coasts, the chalky cliffs of High Normandy coast constitute specific cliffs with rapid retreat and an erosion abrasive platform.

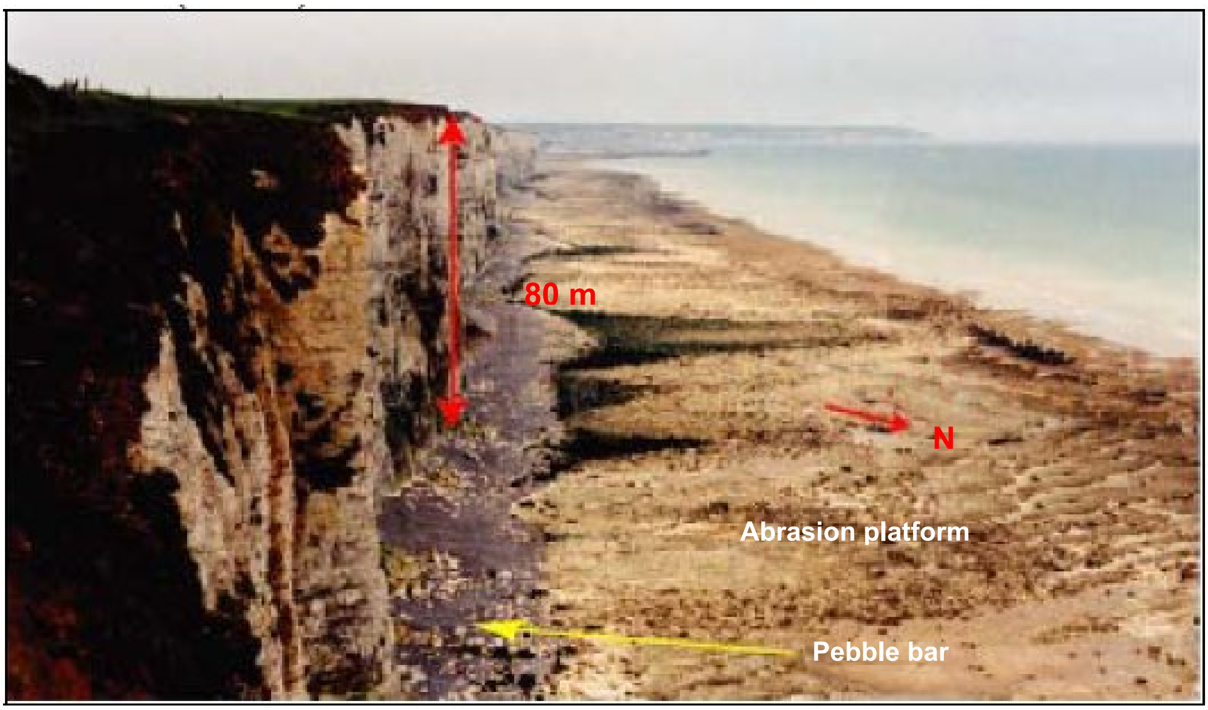


Fig. IV-22. Simplified geological cut of the chalky cliffs of the Alabaster Coast

Eastern Channel seabeds are mainly relief poor and depths not exceeding 50 meters. From its SW-NE orientation, the coast is extremely exposed to west-coming flows, and consequently the strongest and most frequent swells. The strongest swells measured near the centre of the study area, have significant wave height respectively of 3,8 m yearly and 4,7 m decennial. Their mean period is from 7 to 9 s, and major upcoming direction is from west sector. Nevertheless the swell significant wave height is 90% of time less than 1,5 m and exceeds 3m no longer than 25 hours.yr^{-1}.

Eastern Channel tide range is in order of 8,5 meters for mean spring tide (SHOM). Wave directions are approximately parallel to the shore (except in the Bays of Seine and Somme), but the shape of the coast and also meteorological conditions may induce local variations.

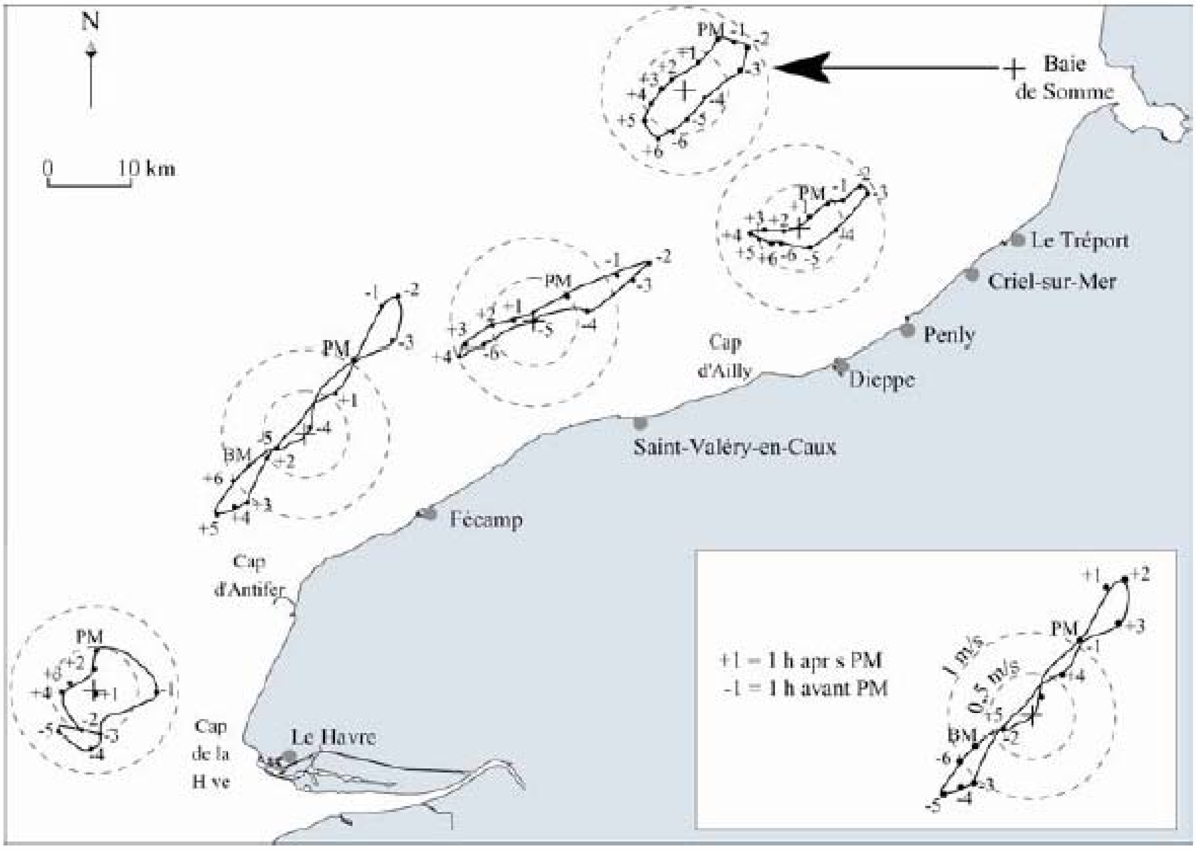


Fig. IV-23. Wave speed and directions (spring tide) for the High-Normandy Coast

2.1.3. Political context and shoreline management

The High Normandy coast disposes of rich cultural and landscape heritage, as well as natural habitats to be protected… Therefore tourist attraction plays a determinant role along the coast, and remains crucial for communes like Etretat, Veules-les-roses or Fécamp.
Coastal existing structures do not only serve local functions (fishing harbours, cross channel ferry lines) but also national sites with nuclear plants right on the sea (Penly and Paluel), artificial deep water harbour of Antifer. All those realisations have perturbed the dynamic of the currents, generating erosion problems which remain hardly measurable and for which the management can even not be assumed at local level.

The coastal front line was not affected so much by the urbanization growth of the 60's with the same extent than Languedoc, Vendean or Mediterranean coasts. For that matter agricultural activity is predominant on cliff's edge. Most of coastal communes have however been rebuilt following the World War II bombings and scattered blockhouses remain good indicators of the cliff/coast retreating.

The French Coastal Act, adopted in 1986, is the juridical framework for the follow-up and monitoring of developments in coastal areas. Its vocation is to weight the interests of parties and to ensure the balance with coastal spatial planning. It builds upon lot of administrative and regulatory instruments (Prevention Risks Plan, Local Urbanization Plan, Schema of Territorial Consistency, Urban Development Plan for Spatial Planning and Water Management …) coexisting at different levels. The applicability has become complex, involving urbanism, environment considerations and administrative difficulties. Moreover the choices are influenced by political stakes and conflicts linked to decentralized finances.

The local coastal authorities involved in the application of regulatory instruments are:

- Regional Direction for Environment (DIREN): in charge of the application of the Coastal Act (for protected and remarkable areas) with a mission of coastal observation and reporting towards national level (Ministry of Ecology and Sustainable Development)
- Regional Direction of the Equipment (DRE): in charge of the coordination, reflection, observation (coastal areas, urbanism, spatial planning, transport), management and finances affectation for coastal zones protection.
- Departmental Direction of the Equipment (DDE): in charge of the follow-up of the Coastal Act with respect to urbanism (building permits, urbanism documents modification at communal level)
- Maritime Services: in charge of the planning and management of harbour public domain, regulations in the Maritime Public Domain, the infrastructures linked to navigation and boating, Schema for the good Exploitation of the Sea, coastal paths.

Should be added the Department called General Council, the Regional Council, all the coastal communes, and agglomerations of communes.
With all those actors willing to manage the shoreline, with environmental, socio-economical component in a sustainable way, the principles of ICZM are really welcome.

Effectively since the adoption of Integrated Coastal Zone Management by the European Council, the following recommendations are being adopted locally:

- consideration of all economic sectors involved in
- decision taken in consultation of all actors
- permanent structure for the management and follow-up
- better consideration of the diversity and different types of coastal zones
- avoid the local level being blocked by too many objectives and constraints that should be set a different levels.
- setting a consistent decision scheme based on several spatial criteria (cultural unit, ecosystems, economic basin, life basin)
- in depth knowledge of natural processes and uses, allowing sustainable management, using monitoring tools like GIS
- endeavouring the coastal management beyond administrative units, considering not only the shoreline but the whole coastal area, encompassing the hinterland as well as the maritime near shore.

2.1.4. What is at stake for the follow-up of the cliff edge evolution?

The major economical impacts are the loss of terrains and goods: camping places, walking paths, coastal roads, buildings of different nature: residences, religious edifices, elements of historic and cultural heritage.

The engineers of the 50s built hard protection works to defend the urbanize valleys against storms and reduce the shoreline retreat at the level of beaches mainly. But this systematic response with hard structures implied large side-effects.

These artificial works on coastline indeed perturbs the balance between level of erosion and volumes of materials delivered by the cliff retreating. The beach system is effectively provided with pebbles which take a significant part in the wave energy dispersal inducing natural protection to the coast. The joint hydro sedimentary system cliff/pebble bar is highly affected along this coast by human interventions, increasing cliff retreat and impeaching the pebble bars to play their role of natural protection of the low and urbanized valleys: coastal areas defended by groins and/or dykes often trap the pebbles, preventing the cliff toe of their natural protection and increasing locally the cliff erosion (e.g. Criel sur Mer). The impact analysis of perpendicular works on coastal retreat showed that ablation rates in immediate down drift has doubled.

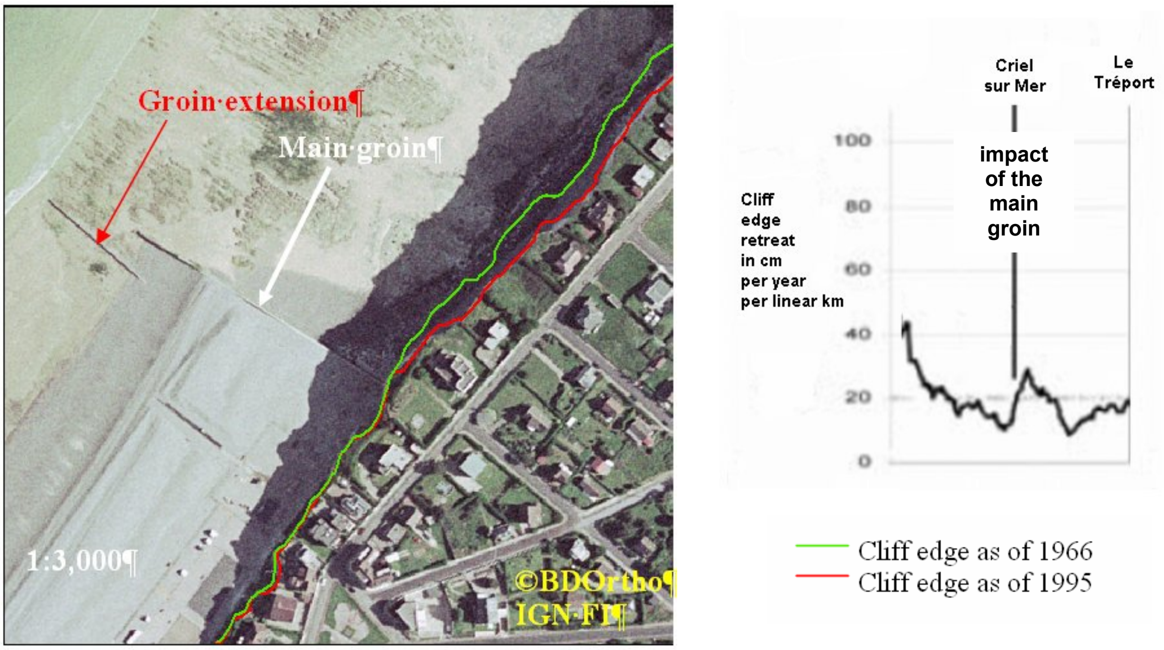


Fig. IV-24. Artificial coastline and cliff protection - Criel sur Mer.

On the other side, those artificial works are of economic interest for tourist visits because of the accretion zones provoked by groins and dykes. Also ports and industrial sites right on the sea require protection against storms (dyke, jetty).

2.1.5. Coastal categories of risk

The actual generalisation and intensity of coastline retreat which will not be attenuated by climate change either, lead to a risk management more and more disputed. The fight against coastal erosion, for a long time admitted as imperious necessity, comes down to fixing the coastline by rigid works perturbing the dynamic balance, even increasing erosion locally. In front of those induced effects, not satisfactory if we consider economical, technical and environmental aspects, we now may consider the relevance of the actions to be made in terms of coastal protection and the way we should intervene anew.

The coast is naturally exposed to erosion and most of urbanized valleys are threatened by sea flooding in case of extreme storm. If each situation might be different, the schematic figure below summarizes the main potential risks generated by erosion for the study area. Depending of the cliff type, the width of hazards can be less or more large and threaten goods and people even far from the cliff edge.

The Alabaster Coast presents different types of coastal natural risks: the loss of terrains and constructions, the sap, breach or overtopping of defence works implying flooding and/or people damaging. Those risks result from climatic hazards (storms, extreme tidal conditions) or geomorphological hazards (landslide, collapse).
If nearly 25% of French coastline is currently affected by erosion phenomenon[2], almost the whole Alabaster Coast is concerned.
Houses already collapsed in Saint-Pierre-en-Port and Criel-sur-Mer. Some house owners were thus expropriated. The Environmental Act (known as Loi Barnier) of 1995 indeed authorises the expropriation for houses located in highly hazardous areas and the indemnity shall be based on the market value in absence of any hazard, preserving the interests of expropriated people.

Other infrastructures are currently threatened such as churchyard of Varengeville-sur-Mer and part of the church, blockhouses and other buildings, some roads and coastal walking paths; as well as people living on top of the cliffs in the city of Quiberville.

Landslides are also important at the cliff bottom with respect to tourist activities (walkers circulating or staying there), or leisure activities (fishing on foot).

[2] IFEN – Observatoire du littoral

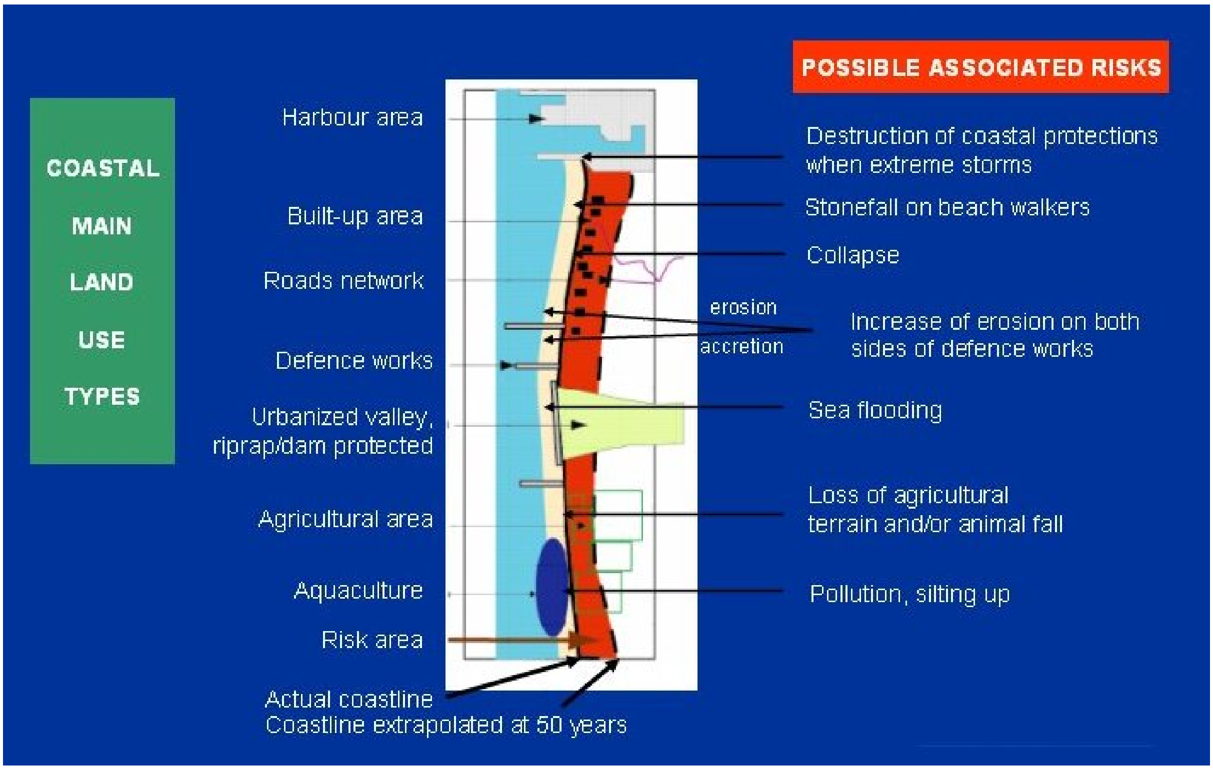


Fig. IV-25. Possible coastal associated risks

The risk finally regards three main categories of places:

- agricultural terrains
- tourist areas
- urbanized areas on top of bottom of cliffs.

2.2. Engineering the GIS

After describing the context of study, the second step is to better define and commit with the beneficiaries which tools/functionalities have to be developed based on available relevant data.

2.2.1. Relevant available data on Alabaster Coast

Most of the studies on rocky cliffs are considering the top of the cliff as the coastline. The reasons are that the cliff edge is really more remarkable on documents than the bottom, often shadowed but mainly because it determines the upper limit for the start of cliff landslides inducing the risks.
Evaluating the retreat of cliffs require to gather and analyse old data and study the reported position of the coastline within

Cadastral sheets

France can be proud of the existence of cadastral unique document called Napoleonic cadastre, started on XIXth century, and ordered by the Corsican Emperor. Within its large scale (1:1,000 to 1:2,500) this document is updated permanently. To measure coastline position mobility, one shall overlay the digitized cadastral sheets after having adjusted its scale, should this happen.

However we should bear in mind that cadastral parcels were delineated exclusively for imposition purposes, meaning that surfaces should be correct but the accuracy of the parcel boundaries on instable abrupt of 80 m or more might be subject to discussions.

Limitations of the exercise were demonstrated locally by the overlay of Napoleonic cadastre sheet (even with higher scale) and current orthophotograph showing that the coastline progressed where experts know there is a significant retreat there! To remain prudent, it should be clear that old cadastre sheets are convenient near urbanized areas. Moreover some factors such as the enlargement of roads altering the landscapes of 1824, the progress of topographic levelling and cartography, make the comparison more difficult. The estimation of the planimetric error for the position of cliff edge is of ± 2,39 m, inducing coastal retreat error of ±1,48 cm yearly.

The results of this study on a long time basis (1824-2006) have led to determine a maximum retreat of 51 cm.yr^{-1} on one specific site, while min value is 0,06 cm.yr^{-1}.

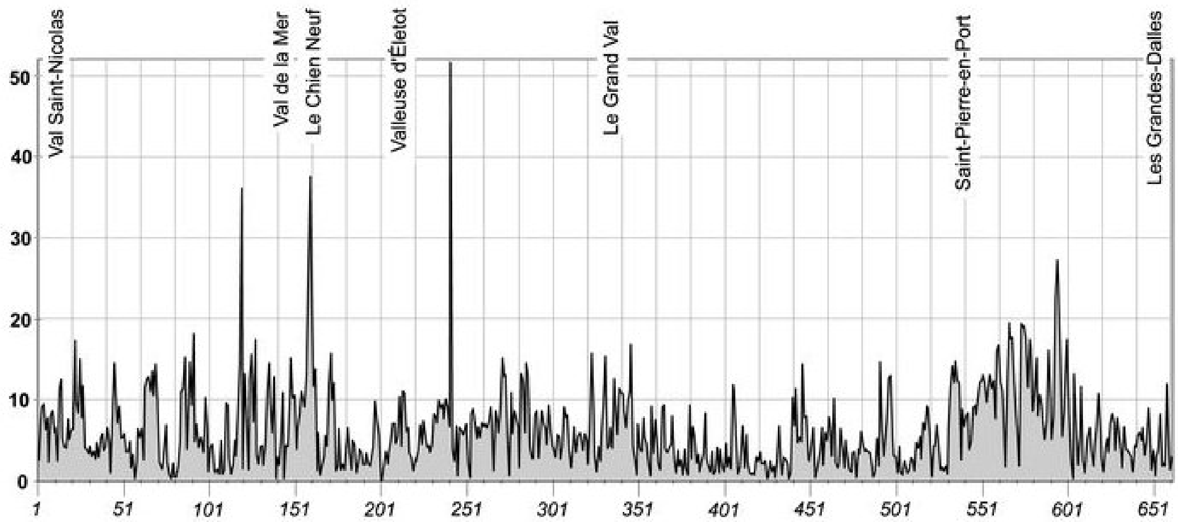


Fig. IV-26. Cliff retreat estimated by comparing cadastral plans dated 1824 to 1986 between between Fagnet Cape (Fécamp) and Les Grandes Dalles (HENAFF, 2002).

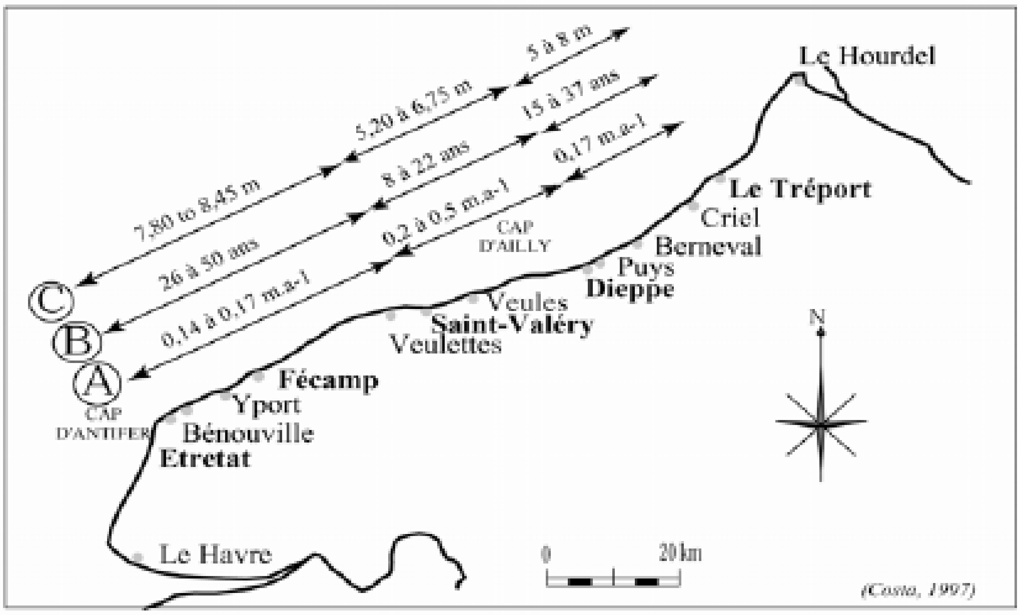
Aerial photographs

Without any orthorectification the vertical orthophotographs are not relevant for the study of the coastline (COSTA, 2000) because of unsolved problems of parallax between the vector of acquisition (the plane) and the geographic elements on the ground, of distortion of scale of the image from its centre to its periphery, and this, without mentioning the relative quality of different data acquisitions.
However the interest of simple aerial photographs lies in repairing the marks of landslides starts on cliff edge, and estimating a proxy of the volume lost with the extent of the rocks collapsed on the bottom (when not shadowed!).

Keeping in mind the limitations mentioned the analysis of vertical aerial photographs from 1947 till 1995, available at the French National Geographic Institute (IGN) has been use to document, for each part of the High-Normandy coast, the localisations of collapses as well as a proxy of the volume of collapsed rocks, the mean retreat values.

This study (COSTA, 1997) has revealed various sector-based regressive dynamics:

- between Etretat and St-Valéry-en-Caux and Eastern between Berneval and Le Tréport, the coast is affected with limited retreat (0,14 to 0,17 m. yr^{-1}) and rare but massive collapses (return period of 20 to 45 years, 8 metres mean retreat by event).
- between St-Valéry-en-Caux and Berneval, the coast is characterised by a more important retreat (0,20 to 0,51 m. yr^{-1}), frequent not voluminous collapses (return period of 15 years maximum, 6 metres mean retreat by event).



(A) Spatial distribution of cliff mean annual retreat
(B) Mean return period of landslide / collapses
(C) Mean retreat by event between 1947 and 1995

Fig. IV-27. Mean cliff retreat estimation along coastal High-Normandy (Costa, 1997).

Photogrammetry analysis: high accuracy geolocated data

Facing important errors with imprecise measurements and/or weaknesses in spatial and temporal representativeness of studies, the coastal authorities have endeavoured the setting of group of reflection and concerted actions for inter regional environment (Contrat de Plan Interrégional du Bassin Parisien – CPIBP). The first step of this plan was the cooperation between authorities and scientists for establishing a reliable and homogeneous methodology for the follow-up and monitoring of the coastal dynamics. A photogrammetric survey was realized, in partnership with the IGN, based on two aerial vertical acquisition campaigns dated 1966 and 1995. Stéréopréparation and aerotriangulation on the stereo couples were performed and a manual digitization of the coastline at 1:2,000 scale followed. All geographic objects (cliff edge, pebble bars, abrasion platform, sand facing are well delineated and within appropriate Coordinate Reference System and suitable projection.

This technique using photogrammetry provides relatively high accuracy measurements for coastline cartography, with respect to the retreat value observed, offering a real reference database to the community of users and scientists. Effectively its precision remains decimetric (± 0,40 m) while estimated errors generated by not rectified aerial photographs (± 5 m).

However the cost of photogrammetry acquisition prohibits the coastal authorities to financing by themselves. If one study can be considered as a reference, other monitoring tools should be derived then.

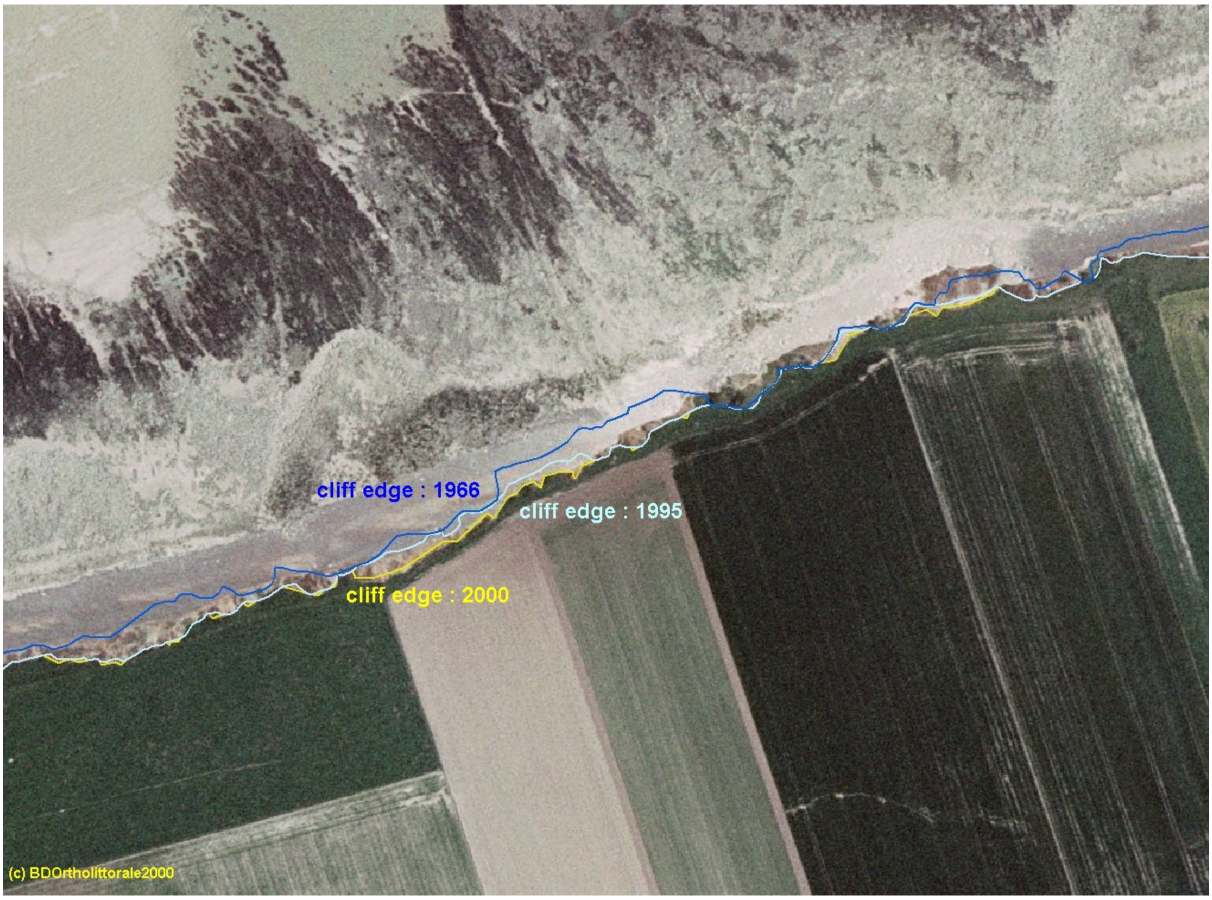


Fig. IV-28. Photogrammetric data for cliff edge dated 1966, 1995 and 2000 (Data Provider IGN)

Those coastlines of 1966 and 1995 resulting from photogrammetry digitization are of a real interest as a basis of the study for estimating the coastal retreat and especially the erosion rates.

Orthorectified aerial photograph mosaic.

If aerial photographs provide a reliable picture of the ground at a specific time, including information on the type of buildings, infrastructure, vegetated and not vegetated areas, in most cases however, they are not usable as such as they have significant geometrical distortions - due to their conic perspective - especially at their edge. A mosaic of geometrically corrected aerial photographs is therefore preferred. These so-called orthorectified aerial photographs or "orthophotographs" are made super-imposable to a map and are more appropriate for further analysis.

To provide an accurate position of the coastline, the resolution of orthophotographs should be ideally sub-metric - between 0,2 to 0,5 meter – which require that the flight scale ranges from 1:10,000 to 1:25,000. In addition, aerial photographs should cover a minimal area which extends from 10 km inland to 2 km offshore. In the landward direction, aerial photographs are expected to provide information on urban, industrial, agricultural and natural assets located along the coast and potentially at risk of coastal erosion and flooding. In low-lying areas, it is however recommended to extend the spatial coverage of aerial photographs landwards up to the contour line corresponding to an elevation of 2 meters or more.

For the study area the project disposes of mosaics of orthophotographs called BDOrtho® littorale 2000 - acquisition date - available at the following URL http://siglittoral.test.application.equipement.gouv.fr/. An excerpt on Dieppe city is shown below.

Fig. IV-29. Orthophotograph over the city of Dieppe ©*BDOrtho littorale 2000*

This database freely available was proposed by the French government. However the acquisition and orthorectification was realized by the French National Mapping Agency (IGN). The national product promoted by the IGN on the whole territory - the BDOrtho® - is a mosaic of orthorectified aerial photographs available in digital format and with a ground pixel of 50 cm. The mean update frequency for one department is about 3 to 5 years. Most of the General Councils or Regional Councils have established data providing conventions to use such digital databases, easing the local authorities to run their tools and use their GIS with recent data.

Data collection & Integration

As a first attempt to search for relevant data, we considered the sediment cell between Seine and Somme rivers as boundaries of the area of investigations, as recommended in Section II. We also limited the data collection where possible to 10km inland. Gathered data characteristics and the GIS layers and product created from, are summarized below.

Raw data	*Product created*
SPOT 5 satellite image, dated 2003	Refined Land Cover, 1:10,000 scale
Existing data	
Coastal CORINE Land Cover changes, 1975 - 1990 (source: EUROSION)	Analysis of land cover changes between 1975 and 1990, between 1990 and 2003
Ecological value data - natural ecologic and heritage areas (data provider: DIREN)	integrated
Administrative boundaries for communes	integrated
©BDOrtholittorale 2000 (data provider: IGN)	- Cliff edge coastline extraction - Erosion rate calculation - Setback line of 100m (buffered)
BDTopo® (data provider: IGN)	Evaluation of assets at risk of coastal erosion and flooding

2.2.2. Refined functionalities required

After describing the context of study, the second step is to better define and commit with the beneficiaries which tools/functionalities have to be developed based on available relevant data.

The commitments on the GIS tools and functions to be implemented are:

- the determination of hazard areas based on the mosaic of orthorectified images ©BDOrtholittorale 2000
- the experimentation of valuation methods:
  - to determine a typology for vulnerability indicators,
  - to quantify economic assets at risk,
  - to experiment a method for the assessment of goods and real estate;
- the risk mapping:
  - erosion risk assessment,
  - coastal frequentation risk assessment;
- the indicators for the follow-up of the French Coastal Act application:
  - with the delimitation of the theoretical 100 m setback line from the shoreline,
  - with the creation of fit-to-purpose coastal indicators.

2.3. Prototyping the GIS

2.3.1. Setting tools for hazard mapping

Method for the estimation of mean annual erosion rates

Step 1: we dispose of coastline positions dated 1966 and 1995. The current position of the coastline is to be digitized from the mosaic of orthorectified images ©BDOrtholittorale 2000. This 'cliff edge coastline' constitutes a new GIS layer.
Step 2 is the determination of mean annual erosion rates based on the exploitation of the historical and current positions of the 'cliff edge coastlines'. The methodology is fully illustrated in the following figure.

1. Display of reference 'cliff edge coastline' dated 1966 or 1995

2. Digitization of 'cliff edge coastline' on recent ©BDOrtho littorale dated 2000

3. Integration of polylines into single GIS layer and generation of polygons from those polylines => Reference polygons

4. Thanks to a grid perpendicularly oriented to the coastlines: creation of rectangle polygons with width of 50 m

5. Intersection between the 'reference polygons' with the '50m width rectangle' layers.

6. The intersected polygon area called *A* is calculated with GIS default functionalities. Cliff retreat is estimated to the length of the segment as a proxy: A/50

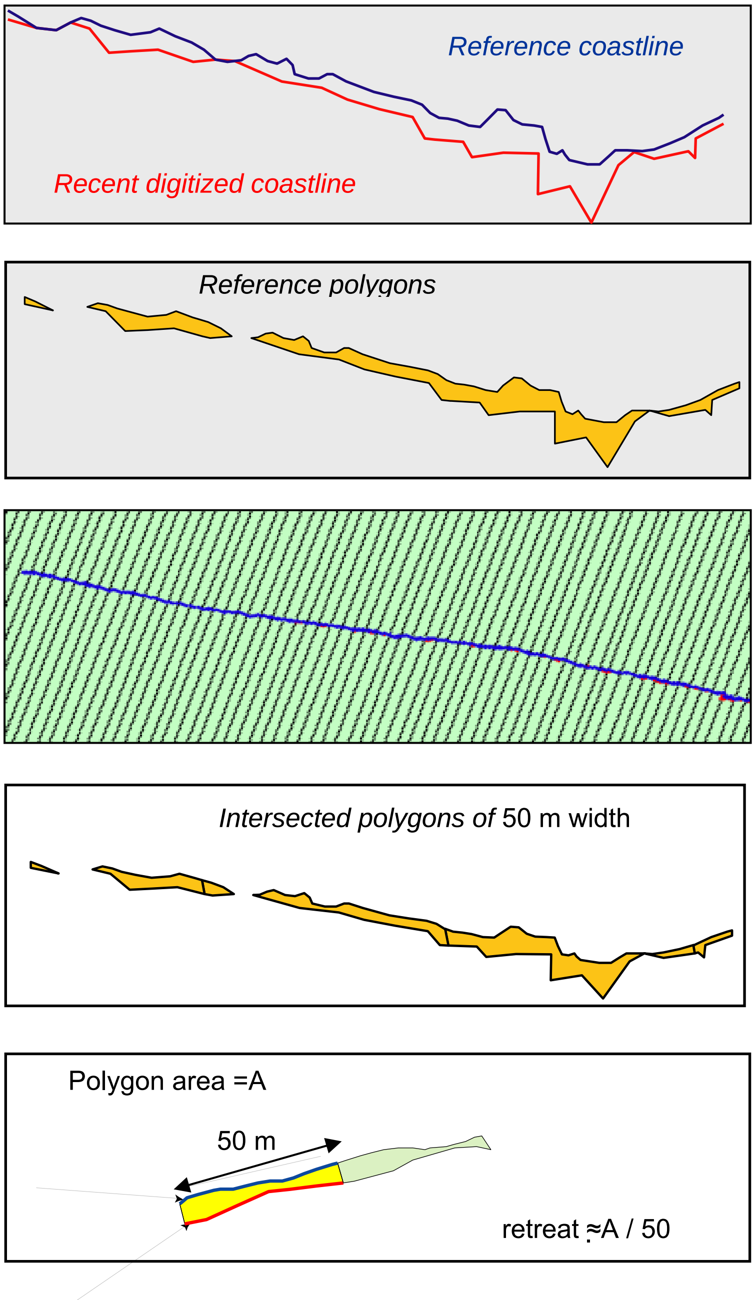


Fig. IV-30. Method for the estimation of mean annual erosion rates.

Step 3: deduction of annual erosion rates.
Once the cliff retreat between the two dates estimated, the annual erosion rate can be easily deduced by dividing the cliff retreat (in metres) and the difference of years.

Step 4: comparison with historical estimated rates
We dispose of studies (COSTA, 1997) and expertise allowing us the comparison of the annual erosion rates estimated and the statistical series of data, from 150 years. This comparison is of the utmost importance since it validates the method or not. Our study proposed.

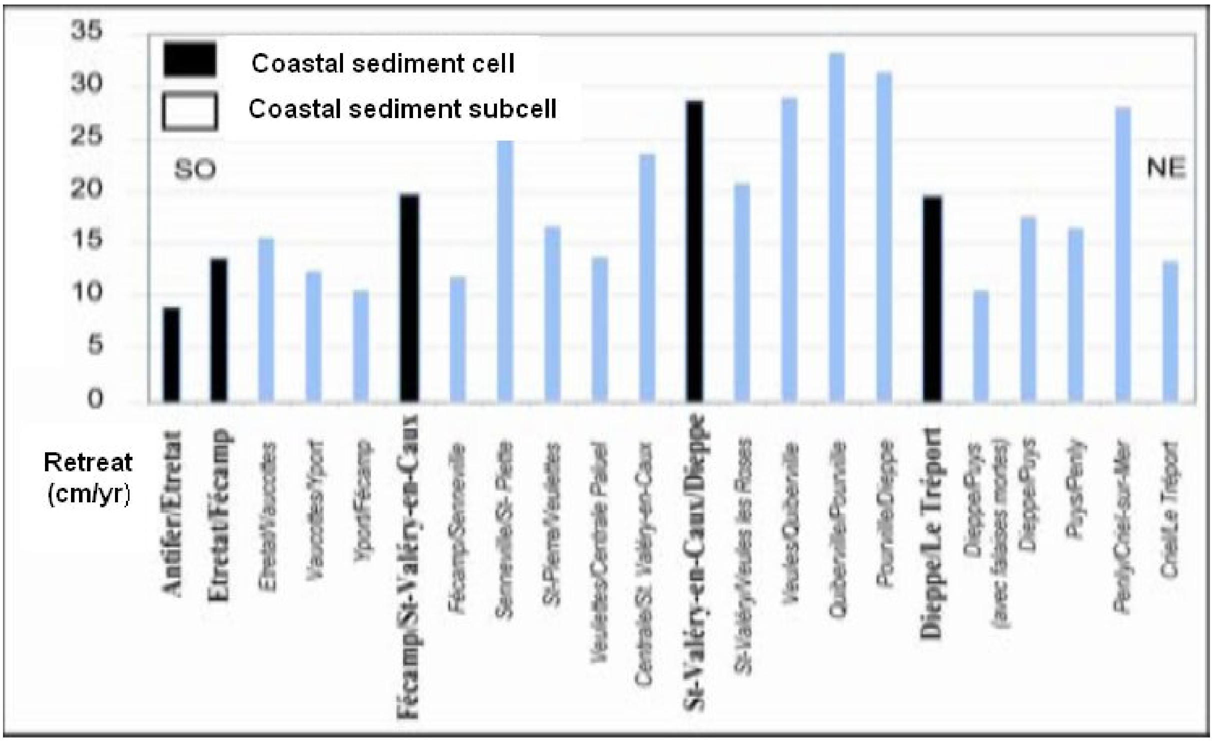


Fig. IV-31. Spatialisation by coastal sediment cell of retreat speeds along the chalk cliffs coast, between 1966 ad 1995 (COSTA, 2000)

Step 5: extrapolation to 25, 50, 100 years.
This extrapolation is the multiplication of the annual erosion rate determined in Step 3 by the number of years wished. The result is a position of each 50m segment relatively to its position on the recent date image.

Results and discussions

The study was based, as a reference, from the cliff edge coastline of 1966 and 1995, and with a digitized coastline dated 2000. As well as the reliability of results the GIS basic functions have eased data treatments such as the estimation of coastal retreat by sub sediment cell of 50m width.

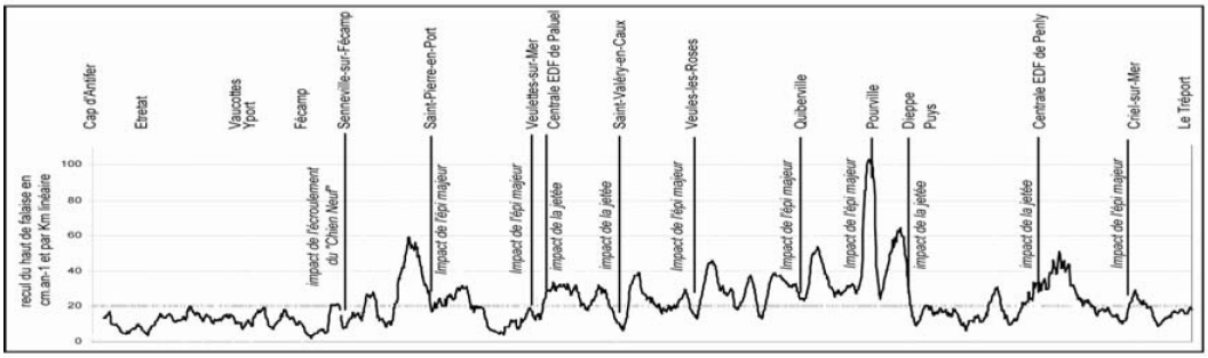


Fig. IV-32. Spatial variations of the retreat of High-Normandy chalk cliffs, between 1966 and 1995 from Etretat to Le Trépord

The spatial assessment of the retreat of the chalky cliff edge every 50 m reveals the spatial variability of the retreat, and especially the retreat induced by the presence of natural obstacles (landslides) or anthropogenic obstacles (jetties, major groin) perturbing the transit of the pebbles along the coast, sometimes implying immediately, down drift, an increasing cliff retreat locally.

The spatial display of the cliff sped retreat revealed three distinct retreat sectors.

- a first sector of light retreat (0,8 to 0,13 $m.yr^{-1}$) from Antifer to Etretat and then from Etretat to Fécamp,
- a second sector with moderate retreat (order of 0,19 $m.yr^{-1}$) from Fécamp to Saint-Valéry-en-Caux, and then from Dieppe to Le Tréport,
- a third sector with strong retreat (0,21 to 0,28 $m.yr^{-1}$) from Saint-Valéry-en-Caux to Dieppe.

For the realization of decision making tools, the high scale is demonstrated as very relevant for the knowledge of cliffs retreat, proposing the spatial zoning of the hazards and risks, which would be less pertinent with mean rates determined on wider areas and at lower scale.

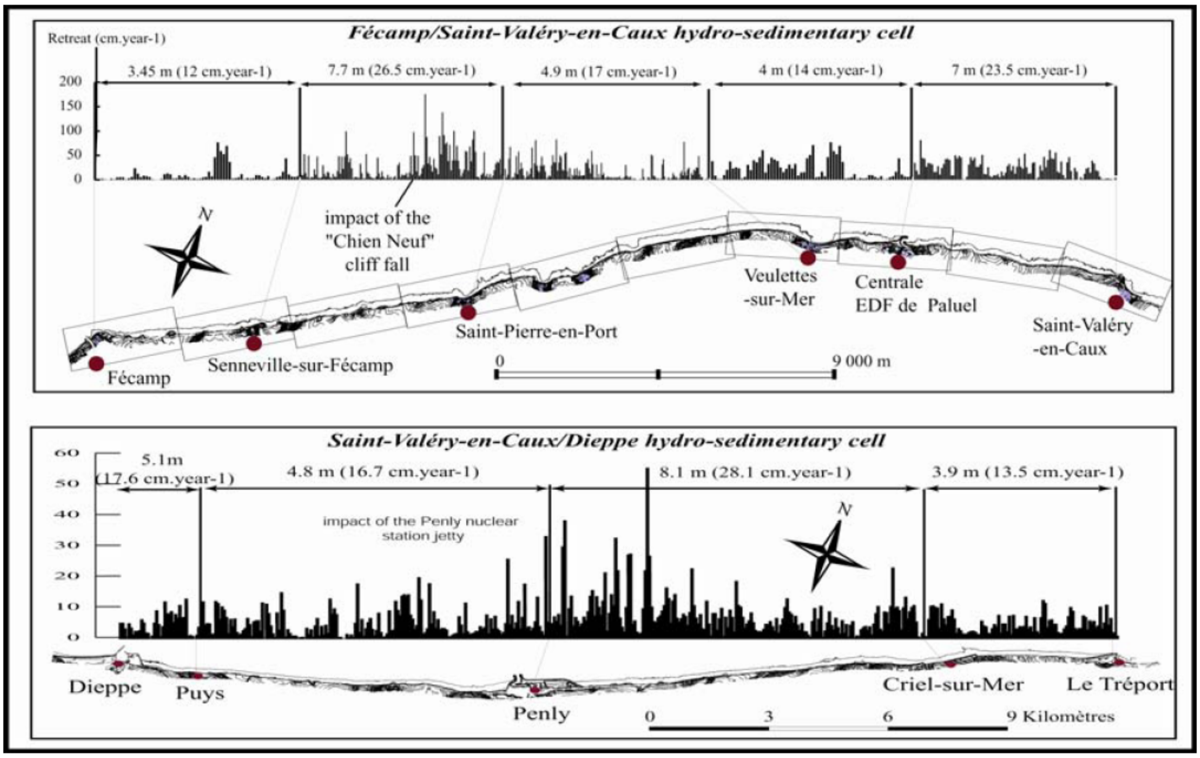


Fig. IV-33. Cliffs retreat estimated every 50 m between 1966 and 1995

However we questioned ourselves on the relevance of the results with a timeframe equal or lower than the observed phenomena.

We also wondered, even if the photogrammetric analysis is of high accuracy (made at high scale), that the temporal timeframe between two dates (about 35 years) remains very relative in terms of calculating erosion rates from.
The results are matching quite well for the area of study but assumptions made should vary on other areas; for instance the initial simplifying assumption regarding climate change impact that is neglected here.

As a perspective of this study the known scenarios of climate change and accelerated sea level rise could be applied and the results of the study should vary accordingly. For instance when recession rates from a historic period are extrapolated forward an assumption is made that the conditions that existed during that period will continue into the future. This assumption is never, strictly speaking, true but in many cases in the past it has been the only available prediction method thus used (PASKOFF, 2001). With a foreseen accelerated sea level rise of 44 cm near 2100, the top edge of those cliffs could be around 20 m landwards, that is to say an erosion rate 2,5 times greater than the one currently measured. However cliff erosion causes are not limited to wave attacks at the toe of the cliff, even if the action of waves is to be reinforced by water level increasing, it also results in rain water percolation into rocks fissures subject successively to freeze and thaw weakening those chalky rocks…those phenomena unless awaited could be modified by the global warming in a unpredictable way that we are today not able to model at regional level (PASKOFF, 2005) (CLUS-AUBY, 2005).

2.3.2. Setting tools for vulnerability mapping

Refined Land cover

Get a very high resolution land cover changes database (as mentioned in Section II) allows the better calculation of local statistics as well as the locations where the changes occurred between two dates. For instance urban growth along the coast may be observed in straight continuity of urbanized centers? along structuring communication axes? near the cliff edge? instead of pastures or other natural places? Such questions found answers with land cover changes analysis.

Built upon IGN France International involvement in CORINE Land Cover production and qualification activities (CLC TECHGUIDE, 2000), and specifically linked to coastal locations (LACOAST, 2000), a refined land cover database has been produced on the Alabaster Coast strip band of 10 km inland and 1 km seaward. A full SPOT5 scene was used and the resulting scale is 1:10,000.

The image interpretation methodology used is highly reproducible allowing a hopefully years to come database on land cover changes as made during EUROSION (LC CHANGES, 2002), easing the discussion for the integration of those land cover/use changes into urbanism documents.

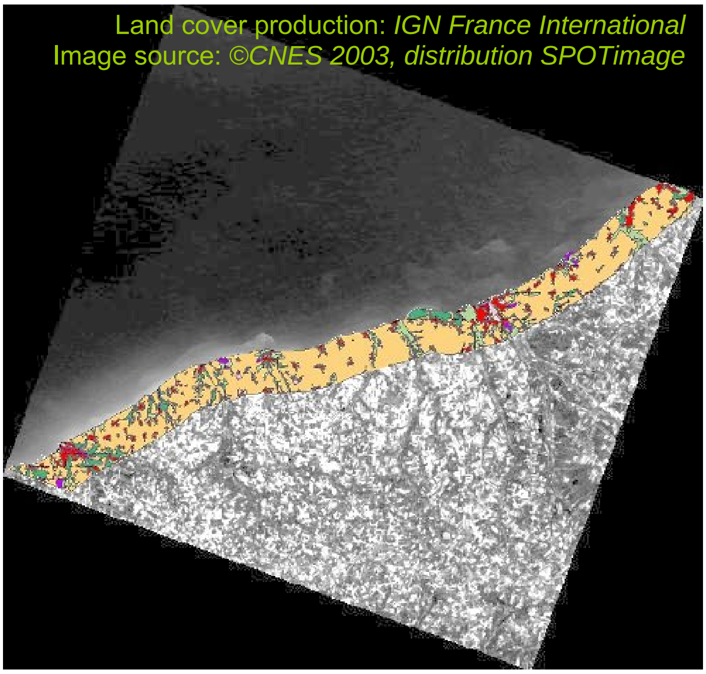


Fig. IV-34. Land Cover changes database between 1975 and 2003, displaid over the SPOT5 image.

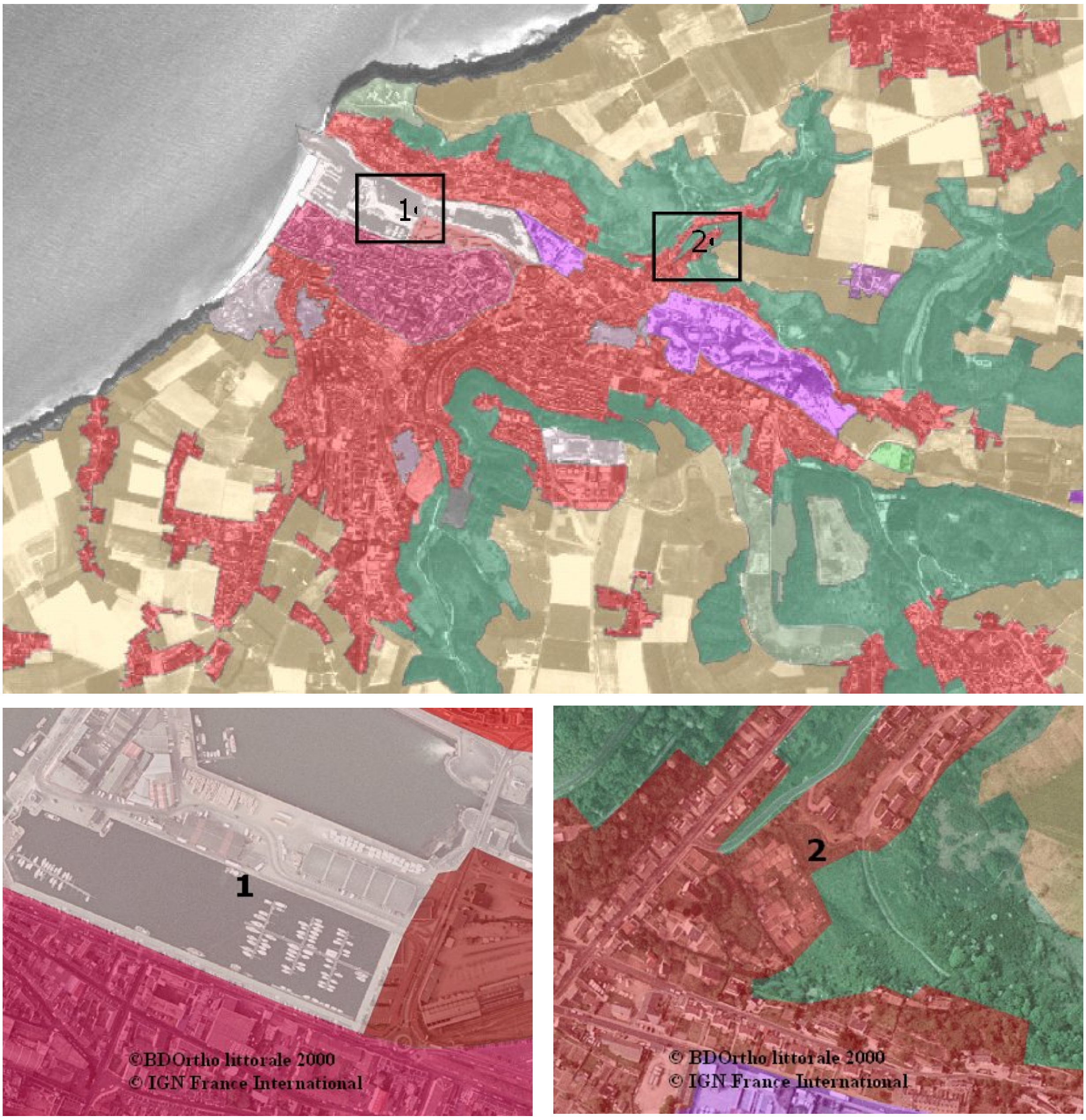


Fig. IV-35. Land Cover changes database between 1975 and 2003, details over Fécamp.

Analysis and Discussion

As a first statistical evaluation between the two dates, the agricultural ground occupancy is still predominant (over than 80%). The diffuse urban class is slightly progressing whist other classes remain steady. The valleys kept their attractiveness and urban sprawl is noted along roads and in continuity of villages. However the higher accuracy of the SPOT5 imagery allows a better discrimination than LandSat imagery used for the CORINE Land cover changes databases. This implies that urban sprawl appears clearly with the refined land cover created at 1:10,000 scale with SPOT5 imagery.

We used this database for determining vulnerability indicators and quantifying economic assets in the city of Quiberville, but also for assessing goods and real estate over Fécamp area.

2.3.3. Typology setting for vulnerability mapping

The exercise consists in creating a typology of vulnerability to the risk of erosion and localizing hazard areas homogeneously and the most automatically as possible. This methodology could be very useful for local authorities for the Risk Prevention Plan and spatial planning projects.
The typology is the combination of hazard – cliff collapsing areas – with stakes – presence of goods within each coastal part. For that weights are proposed function of the degree of exposure for defined themes. Finally the sum of weights determines the level of risk associate to each portion of coast (VIMONT, 2005)

Methodology and application.

First of all, from the cliff edge coastline create segments of width 100m or 200m. The nature of the cliff should ease consistent segments partition of the coast locally. To determine homogeneous risk areas, we must consider the groups of buildings, harbour constructions, main dykes and location of valleys.
We dispose of the topographic database from the IGN (called BDTopo®) containing defence works, roads, buildings, hydrology and all other infrastructure elements.

The themes are shored up over the city of Dieppe, where co-exist protected cliffs or not, and with variable retreat rates on both sides of the city.
Proposed weights for themes:

1. Type of cliff
   - dead cliff (known stable or basal protection) code 1 2 points
   - simple cliffs (or straight cliffs), code 2 4 points
   - complex cliffs, code 3 4 points
   - urbanized valleys, code 4, with only extrem event submersion risk, lowest level of risk by default 0 point.

2. Presence of building at cliff bottom

The area at risk could be located either on the top or on the bottom of the cliff. The experience has shown effectively that constructions (e.g. small fishing shelters) are exposed to landslide risk even with cliffs specialists considered as stable (see illustration below).
Bottom of cliffs near beaches are often favoured by walkers, fishers or beach attendants. That is the reason why it has been chosen to add this weighting, which could be improved by seasonal (summer) frequentation indices for instance.

Fig. IV-36. Dieppe urban risky area.

Presence of infrastructure at cliff bottom
If yes 10 points
Otherwise 0 point

3. Erosion rate remains crucial for detemining the coastal part the most sensible towards this phenomenon. Based on the average calculated between 1966 and 1995, we can define 10 levl of retreat thus 10 weights:

betw.	1 and 10 cm a year		1 point
"	11 and 20	"	2 points
"	21 and 30	"	3 points
"	31 and 40	"	4 points
"	41 and 50	"	5 points
"	51 and 60	"	6 points
"	61 and 70	"	7 points
"	71 and 80	"	8 points
"	81 and 90	"	9 points
beyond 90 cm a year			10 points

4. The distance between the collapsing zone and the closest construction (including roads, excluding blockhouses). 7 classes can be weighted:

- 30 points for a construction less than 10 metres
- 25 points " more than 10 metres
- 20 points " more than 20 metres
- 15 points " more than 30 metres
- 10 points " more than 40 metres
- 5 points " more than 50 metres
- 0 point if no construction

Typology results and display

This typology allows the distinction between:

- *very high risk* (red): presence of constructions under influence of risk of heritage loss and/or inhabitants at risk between total of 41 and 54 points
- *high risk* (orange): presence of constructions within reasonable distance for short-term between total of 27 and 40 points
- *prudence* (yellow): presence of people, buildings near protected or *a priori* stable cliff, between a total of 13 and 26 points
- *low risk* (light yellow): no construction nor frequentation, non protected area, often agriculture when total is between 0 and 12 points
- no data (light grey)

This experimentation should be the basis of methodologies being used for the determination of risky areas within the documents to be addressed by Local Urbanism Plan (PLU), Risk Prevention Plans (PPR) and associated Territory Consistency Schema (SCOT).

Fig. IV-37. Exposure to risk in Dieppe.

2.3.4. Impact mapping

Quantify building assets at risk

The application of the above described methodology to the city of Quiberville revealed a very high rated segment of coast. Effectively, if Quiberville down town is located in the valley, a very important residential part of the city was settled on the top of the Western Cliff: our study showed that around 20 parcels are threatened by possible collapse in the next 20 years. The residences there are still occupied and owners made investments for comfort or isolation in. Two houses are noticed as dangerous structure (*arrêté de péril*), owners have been expropriated and indemnified by their private insurance accordingly. The major, as for him, published a municipal decree to prohibit the circulation on top and bottom of the cliff in order to prevent the municipality legally of any accident. The inhabitants are aware of the danger and the probability of risk, but seem to resign to fate. The town council has not undertaken any local policy yet. Last residential purchasing dated 1999 regarded the biggest house for the amount of 90 k€. In this part of Quiberville our investigations showed that the second home rate is around 70% meaning that owners are living there during (summer) holidays.

The typology defined here above combined with the extrapolated 'cliff edge coastlines' as of next 25, 50 and 100 years revealed, given the fact that the annual retreat is locally 30 cm, that the distance from the cliff edge to the closest building is reducing severely, increasing the probability of risk and induced damaging costs.
Buildings are displayed using BDTopo® IGN database.

Policies to be driven to answer this problem might be maintaining the top of the cliff with a coastline protection coast, or programming a gradual realignment or leave as it.
The delineation of those areas at risk will provide data, values and indices to realize at more or less long term scenarios of mitigation more powerful and more realistic from socio-economic point of view: leaving risky areas and realign goods and people

in the hinterland (like in Criel s/Mer) proved that the cost for classical protection would have largely exceeded the value of goods to protect on a long-term basis, meaning that the strategic realignment was somehow a more reasonable solution.

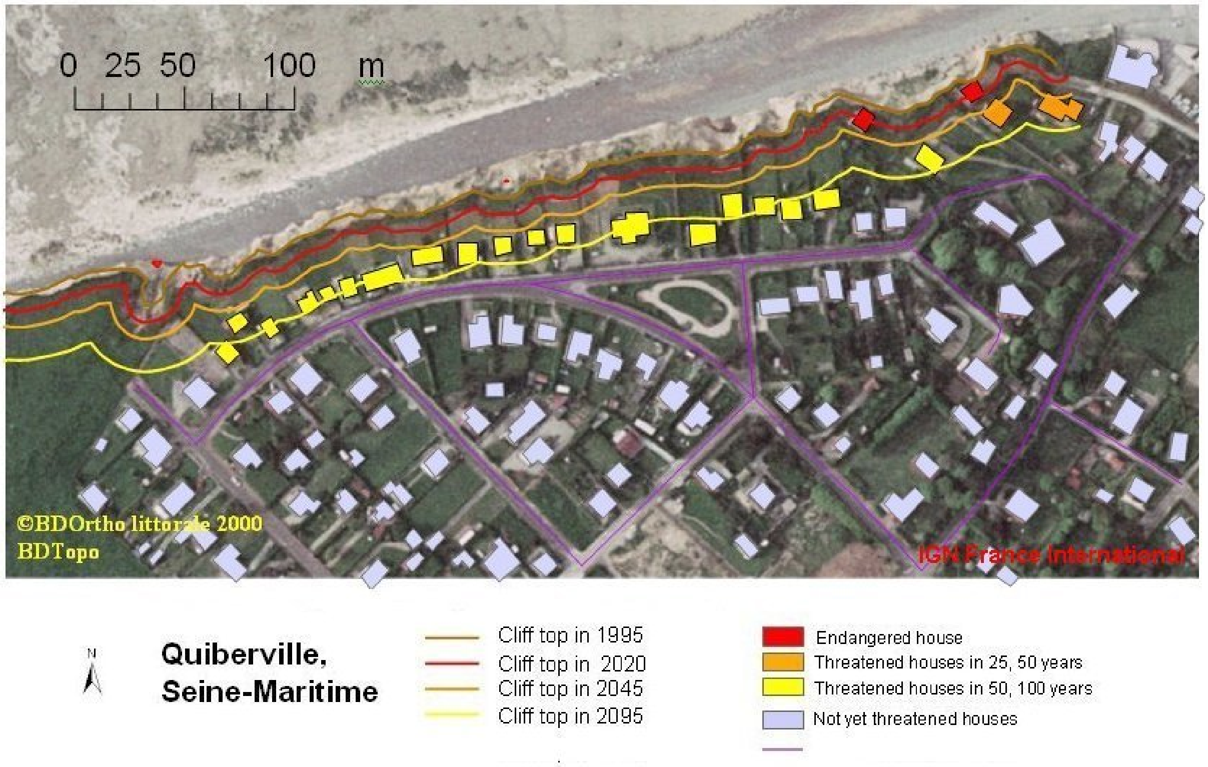


Fig. IV-38. Vulnerability of built-up and infrastructure areas in Quiberville.

Method for the assessment of real estate property at risk

The Land cover refined layer provides only informations on the nature of the ground, not its occupation nor its value. If we know the real estate values for private - vs. state – constructions and ownerships, the possible economic losses within areas at risk can be estimated. The method proposed allowing a rapid determination of the average value of the terrains, is based on field investigations.

First of all and to prepare field inquiries, a (ir-) regular grid of 20 to 100m sided is prepared on the orthorectified mosaic (©BDOrtho littorale 2000) using common GIS functions.

Then through interview with rural owners, consultations with local councillors, real estate agencies, notaries, cadastral or fiscal agents a field investigation is carried out using a questionnaire, the orthorectified map printed under the arm and a pocket calculator to get the values of the ownerships, parcels or buildings.
Sometimes the value is not easy to be determined and methods such as *Hedonic Pricing Method*, *Contingent Valuation Method, Production Factor Method* could be applied (MESSINA PG3, 2006) accordingly.

Back to the coastal GIS, the collected data shall be reported on the grid. This statistical series is interpolated to generate such a "Digital Value Model" following the example of Digital Terrain Model but with price per square meter value.
It is then possible to display with a specific range and establish automatic or customized thresholds for a classification. A market indicator is born.

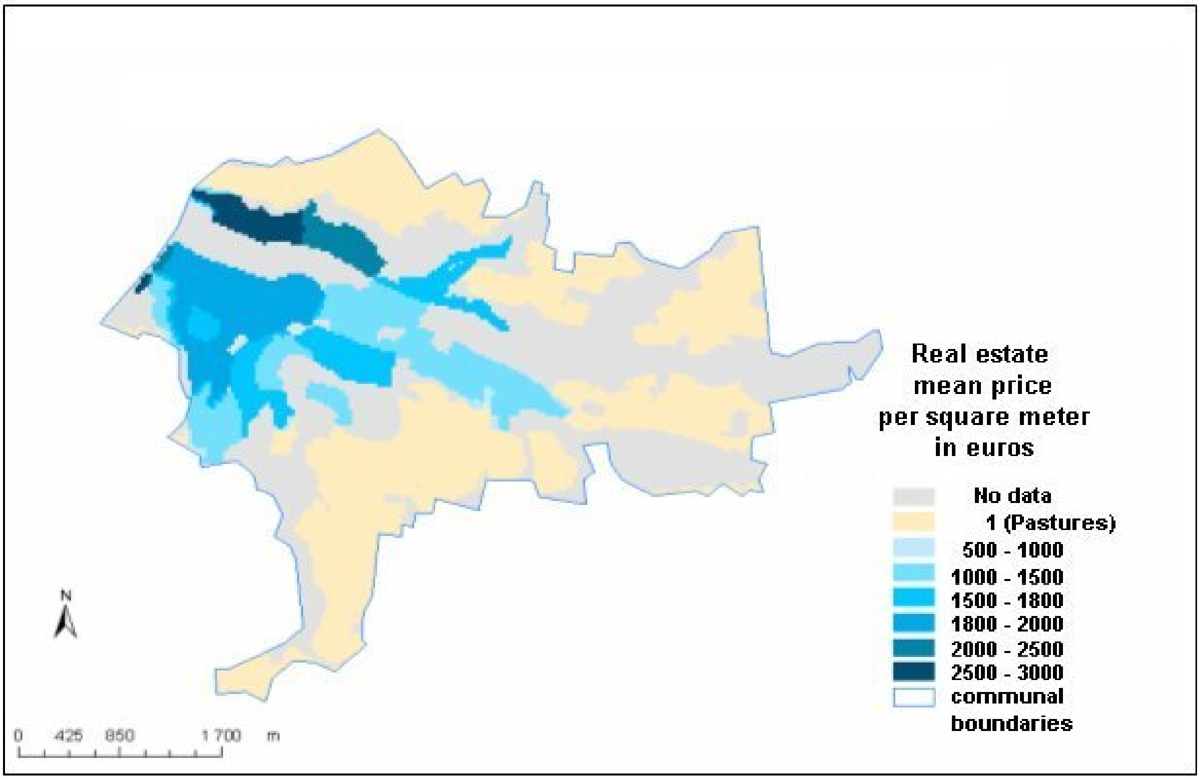


Fig. IV-39. Real estate assessment application over Fécamp.

More than this, the combination of this indicator with hazard map on the same area makes it possible to assess the values at risk and thus the economical impact of the associated hazard (e.g. flooding).

2.3.5. Setting tools for risk mapping

Erosion risk assessment in Le Tréport

If the measure of the erosion on beaches between two dates is there more difficult than locations with sandy beaches affected by remarkable retreat, it is however possible to evaluate the volume of pebble locally (COSTA, 2000). In Le Tréport the littoral drift, materialized by a transfer of pebbles from West to East (as for the whole Alabaster Coast), is stopped by the main jetty, which protects the harbour entrance channel source of an important accretion of pebbles on its western side. As a dynamic effect, the coast immediately at the Eastern side of the jetty is impoverished of pebbles and therefore highly eroded.

The following figure is a synthesis of the situation. The values used to determine the erosion trends (represented with arrows) on the cliffs are provided by the annual erosion rates calculated while the erosion or accretion values on the beaches are coming out from university studies (COSTA, 2000).

The cliff part protected by a dyke on the foreshore is quite steady (mean retreat of less than 5 cm/year) essentially due to subaerial factors (rain, wind, freeze and thaw alternation). The western part of the cliff more exposed to maritime erosion is evolving much more (more than 10 cm/year mean retreat)

The local policy consists in organising a by-pass of pebbles from West side of the jetty to provide the Eastern part with pebbles missing this part and thus mitigate the negative effect of the jetties.

Integrating in this database other informations like collapse location when occurred, with attributes date, extent on the beach, estimated volume of sediments, … would complete this preliminary qualitative study and demonstrating, where needed the use of coastal GIS to evaluate the impacts of the defence works on the erosion and vice-versa, and thus contribute to refinement of local risk prevention plans.

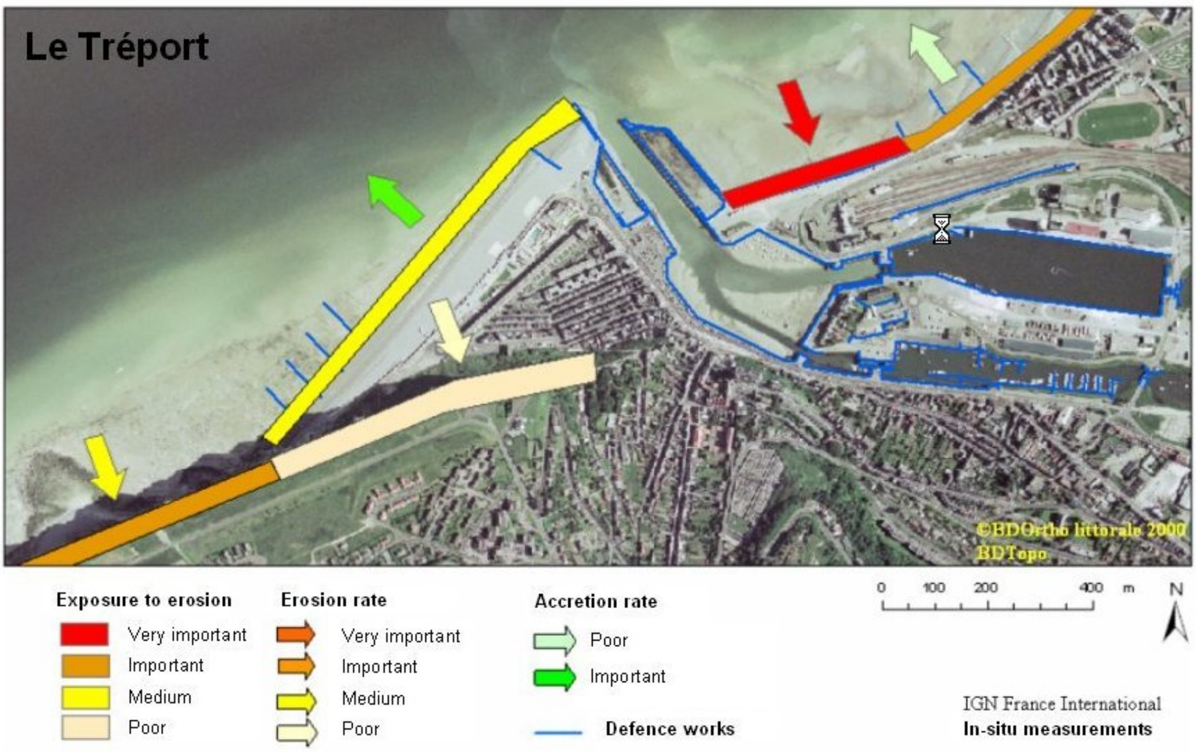


Fig. IV-40. Exposure to erosion in Le Tréport.

Coastal frequentation risk assessment in Criel sur mer

The occurrences of collapse are somehow occasional. The probability of presence of people at the same time than landslide is however increasing with the cliff area frequentation, on the top and the bottom seasonally. To prevent accidents but also limit their own responsibility, majors settled interdiction notice boards. This does not mean any frequentation of the site at all! In Criel s/Mer the risks are twofold: houses threatened by collapse but also people walking or staying on top or at the bottom of cliffs.

Providing that investigations are led to get seasonal frequentation indices (e.g. monthly numbering of people, or derived from person-nights declared…), the model proposed could be cleverly completed by local authorities.

The figure below shows levels of risks function of the frequentation at the top and bottom of the cliffs, both sides of Criel s/Mer, using an adaptation of the topology explained in chapter 2.3.3. Weights proposed are:

1. **Distance to the central beach** of Criel s/Mer. Effectively the nature of the beach of pebble and the lack of beach access are limiting in some extent the frequentation of the cliff bottom platform. The evaluation of the distance is made when the cliff is visible on the data support.
   - from 0 to 500 metres : 20 points
   - from 500 to 1000 metres : 15 points
   - from 1000 to 1500 metres : 10 points
   - from 1500 to 2000 metres : 5 points
   - more than 2000 metres : 0 point

2. **The width of the pebble bar at high tide** (mean coefficient) at the bottom of the cliff or the width of the coastal path on top is essential factor too:
   - no pebble bar : 0 point
   - from 0 to 10 metres : 5 points
   - from 10 to 20 metres : 10 points
   - from 20 to 30 metres : 15 points
   - more than 30 metres : 20 points

3. **The width of abrasive platform** where fishers can fish shells **at low tide**:
   - no abrasive platform : 0 point
   - from 0 to 50 metres : 5 points
   - from 50 to 100 metres : 10 points
   - from 100 to 200 metres : 15 points
   - more than 200 metres : 20 points

3. **The importance of local seaside resort** in terms of nights or simply visitors (the thresholds could be adjusted with more accurate seasonal data):
   less than 20 000 visitors per period : 5 points
   betw. 20 000 and 40 000 visitors per period : 10 points
   betw. 40 000 and 80 000 visitors per period : 15 points
   more than 80 000 visitors per period : 20 points

Typology results and display

Combining the obtained indices for each segment of the coast, the scale of risks is as following:

- from 0 to 20 points: low risk
- from 20 to 40 points: moderate risk
- from 40 to 60 points: high risk
- from 60 to 80 points: very high risk

the following figures proves - if needed - that coastal GIS could be used for prevention but also for the information to the public, with notice board near promenades, coastal paths, within tourist offices or in the City Hall, or where danger exists.

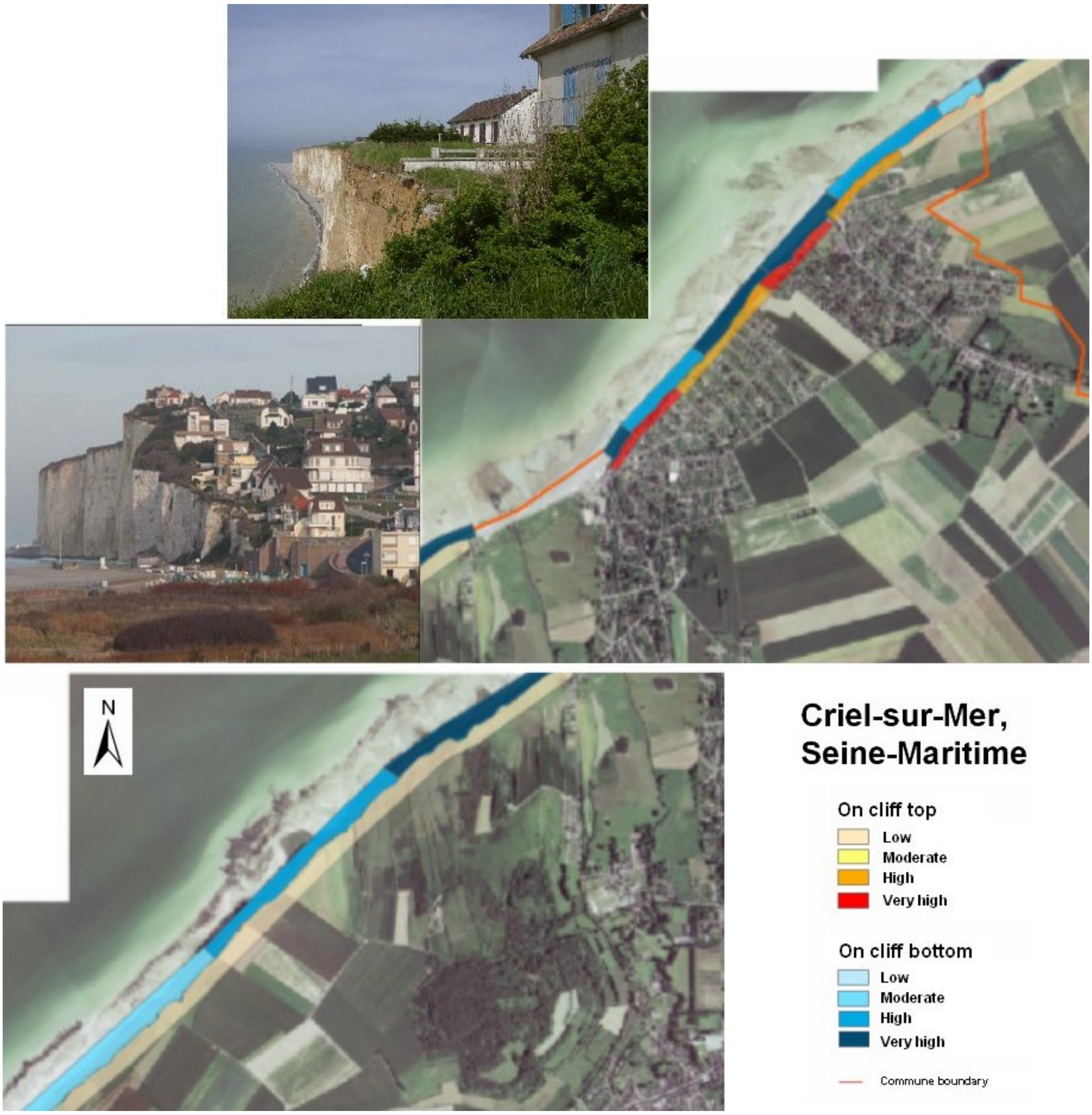
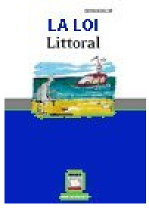


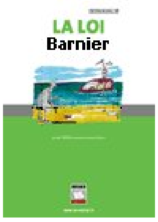
Fig. IV-41. Coastal frequentation risk at cliff bottom and cliff top in Criel s/Mer.

2.3.6. towards Coastal Act indicators



In France the Coastal Act was adopted on 3rd January 1986, and regards the spatial planning, the protection and development of coastal zones.

The Environment Act (Loi Barnier) of 2nd February 1995. reinforcing the protection of the environment and natural spaces as mentioned but not defined in the Coastal Act.



The Building Act (Loi SRU) of 13 December 2000, concerning the solidarity and urban renewal, amended on 16 July 2006, intends to reinforce the consistency of urban and territorial policies by udapting the existing instruments for urbanism and spatial planning.

The French Coastal Act is the main juridical framework devoted to the management and follow-up of the coastal zones in France. It aims at preserving all the local interests as well as the sustainable balance of coastal spatial planning. The Act itself is linked with administrative and regulatory existing instruments (PPR, PLU, SCOT, SDAGE). The law application is particularly difficult since many specifics are involved: urbanism, environment and administrative bodies, without mentioning the influence of political stakes regarding the spatial planning decisions.

Within the Coastal Act is recommended a strip of 100 metres minimum from the coastline where new constructions are severely controlled (in continuity of urbanized centres) and even prohibited. The determination of this 100 m setback line is eased by coastal GIS providing that the data figuring the official (cliff edge) coastline exists, even if the cliff retreat induces progressive erosion. The French National Land Parcel Information System (BD Parcellaire©) will be an efficient tool to visualize parcels to be integrated into this 100m area even if the delimitation is not applied *stricto sensu*. The commune of Saint-Valéry-en-Caux has for instance annexed to Local Plan of Urbanism an adapted strip of 100m minimum in which the new constructions are forbidden, with the variants shown below:

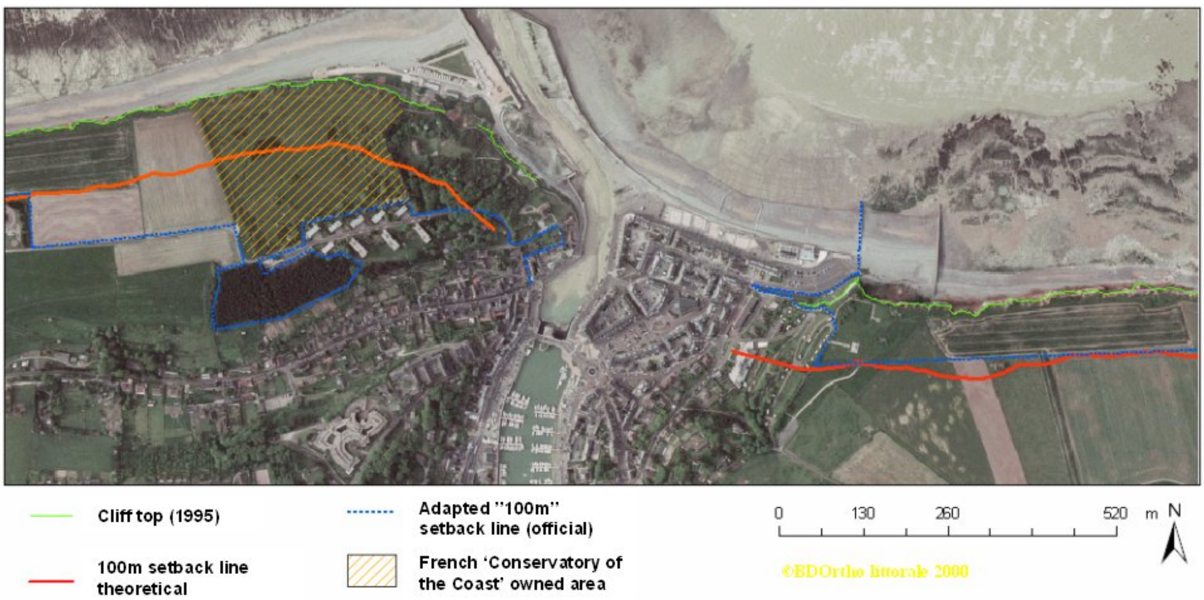


Fig. IV-42. Adaptation of the 100m setback line to local specifics in St-Valéry-en-Caux.

The French Coastal Act texts imply regular evaluation of procedures set for its application. The frequency is not fixed by law itself nor by the government either.
The application of this law is given to local authorities at communal level, even grouping of communes, unless prefectoral decree prevails. Following a report presented in front of the French Senate assembly (GELARD, 2004) and the Inter ministerial Committee dedicated to Spatial Planning (CIADT, 2004), the local authorities or councils try to get finances allowing them to handle coastal management responsibilities. They currently are trying to assume these responsibilities.

During a seminar organized by the French national Coastal Zones Observatory (OBSLITT, 2003), several indicators were promoted which, in turn, can be defined at local level, using the methodologies described in the current Section:

- Ind 1. Value and nature of goods and ownerships in hazardous areas,
- Ind 2. Assessment of the cliff retreat and 'cliff edge coastline' position in time,
- Ind 3. Indicators for the assessment of the Coastal Law on spatial planning applications and impact on coastal zones,
- Ind 4. Determine the coastal locations which should not be affected by urbanisation or limited and integrate them into coastal GIS,
- Ind 5. Frequence and intensity of storms, based on meteorological, maritime, statistic series compilations,
- Ind 6. Measures and forecast of sea level rise locally,
- Ind 7. Length of protected coasts (cf. EUROSION study),
- Ind 8. Area and volumes of sediments/pebbles take,
- Ind 9. Presence of people in areas at risk.

As a general statement from 1986 the Coastal Act has not equally been applied on the Alabaster Coast. The attractiveness of the coastal areas makes it difficult to manage and elected representatives of small communes do not dispose of financial or operational capabilities to apply the Law or make use of regulatory defined instruments. Such management tools and functions as coastal GIS - if not fully satisfactory – can bring them a real technical support, collect and stock data, basis of the analysis to understand and decide, prevent and inform the public.

2.4. Demonstrating the GIS *- validation workshop*

A Validation workshop was held with the main beneficiaries for the coastal GIS on Alabaster Coast in September 2005.

The coastal authorities were provided with coastal GIS and analysis comprising:

- (i) The determination of hazard areas based on the mosaic of orthorectified images ©BDOrtholittorale 2000; the refined land cover as a tool to spatially quantify the assets
- (ii) The vulnerability maps based on a typology to quantify economic assets at risk, and to assess goods and real estate;
- (iii) The risk maps: erosion risk assessment, coastal frequentation risk assessment;

(iv) The tentative for deriving indicators helping the French Coastal Act application with the delimitation of the theoretical 100 m setback line from the shoreline, with the proposition of fit-to-purpose coastal indicators.

Demonstration was made that a coastal GIS brings the main technical tools enabling them:

- To localize hazardous events and derive vulnerability, impact or risk maps for action, prevention or information,
- To anticipate coastal erosion by planning solutions against,
- To consolidate the knowledge base in terms of management and planification,
- To assess impacts and compare costs of classical and alternative solutions with simulations,
- To manage the Maritime Public Domain with property databases linked to the coastal GIS (e.g. linking juridical texts),
- Accompany urbanism projects often outsourced by local authorities to private (specialized) companies.

The coastal GIS allows the improvement of:

- The description of processes by the collection of available informations with their relevance, their limitations and their potential,
- The quality of indicators for validate or invalidate a decision,
- The design of conceptual data model adapted to coastal management,
- The mutualisation of informations and data exchanges thanks to standard model at local level as well as inter regional level, facilitating the updates,
- The production of normalized information, with common and measured quality,
- The necessary pre-treatments and analysis.

2.5. Sustainability of the GIS

Recommendations for coastal GIS sustainability

The selection and collection of data are crucial and costly for the integration of a GIS. Needs and user requirements must be correctly defined. We recommend to find out and inventory the tremendous amount of informations local authorities may already have (even in hard copies) or purchase sparingly relevant existing data needed, even bargaining or establishing data ownerships conventions or agreement. The Intellectual Property Rights (IPR) should be carefully observed. For instance while publishing computed resulting maps, a mention of the data provider or owner must be clearly stated on.

Recommendations for the methodology applications

The safer manner to sustain GIS as well as the associated methodologies developed in the present Guide are to keep updated, maintained the functions of the Coastal GIS delivered with ad hoc documentation, the possible integration of new functions, the data updates, with their metdata and new maps production.

Few months after the delivery of the coastal GIS layers, the associated documentation and metadata, the coastal authorities have published their own customized erosion prone frequentation map during the *Journées d'Etudes de l'ANEL* (National days of the National Association of Coastal Elected representatives) end of April 2006.

Recommendations for local Coastal Observatory

An interregional committee of reflection was set between High-Normandy and Picardie regions (both sharing the Alabaster high cliffs coast) to foster the creation of a local Coastal Observatory. Its aims would be to sustain the coast adopting ICZM principles. This consulting group would be made of scientist, politics representatives, local associations, coastal authorities and urbanism representatives, involved in coordinating important meeting, diffuse information to the public (for instance the assessment of global warming at local level and its derived environmental policies).

Fig. IV-43. High-Normandy Cliffs – Artist view

IV-3. Coastal erosion vs urban sprawl along Polish coast

The Case of Rewal (Poland)

For a few years the polish city of Dziwnow has been hosting a GIS developed by the University of Szczecin. This GIS features a number of layers mainly focused on topography and socio-economical aspects of the city. Sharing this previous experience the University of Szczecin has proposed to the neighboured **Community of communes of Rewal** to provide tools and GIS integrated layers fitting the needs of Rewal regarding spatial planning consecutive to seasonal accommodation and urban sprawl and the possible impacts of the eroding coast.

Local stakeholders' needs and expectations have been expressed and considered of interest. A presentation was made to present and review the possibilities of GIS applications for management and monitoring issues: daily decision support for local community management, monitoring of changes according to the Community of Rewal Strategic Development Plan, prediction of natural hazards damages and their socio-economical consequences, support for tourist infrastructure management, provision of public access to information with help of web-GIS functions.
The objective is also to improve the local authority knowledge (employers training and involvement, participation to data analysis model) and the awareness level of local decision makers.

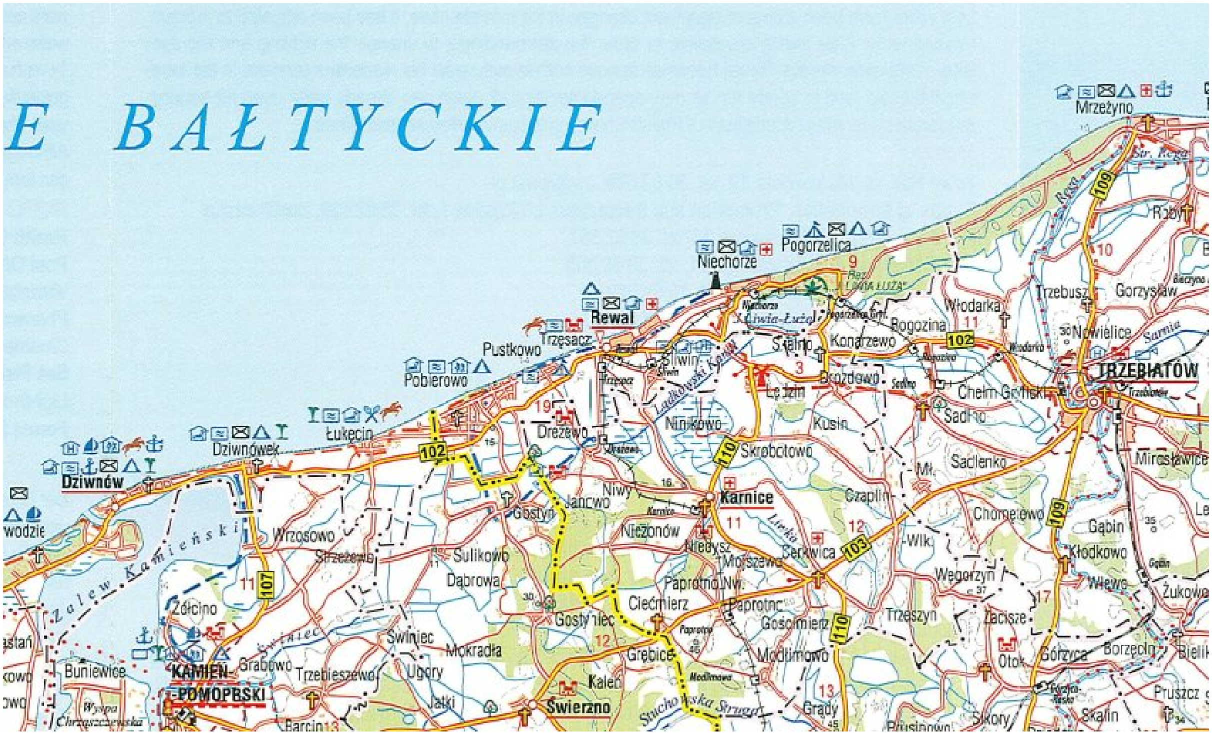


Fig. IV-44. Rewal Community map

The Rewal Community comprises seven villages: Pobierowo, Pustkowo, Trzęsacz, Rewal, Śliwin, Niechorze, Pogorzelica. Pobierowo and Niechorze being the most populated. All of them are coastal villages which became holiday resorts in the twenties of the 19th century.

With the Rewal Community, the small village of Trzęsacz with its 1 km long coast reveals a particular interest. If developed area at present time is about 400 m long, located at the top of 14 m high cliff, the ruins of a XIII century Gothic church are located right at the cliff edge. This church suffered from erosion effects piecemeal. It is locally said that it has been settled at approximately 2 km of the seaside! Nowadays only on plain of the initial walls remains. This area has become a real attraction and the local government never resigned to leave the last parts of the church to the sea.
The aims of the study are clearly to build a coastal GIS to monitor past and future cliff erosion so as to provide the coastal authorities and the local government with well elaborated scenarios and maps, helping them to better conduct spatial planning locally.

Fig. IV-45. Trzęsacz church attraction

3.1. Starting the GIS project

Overview of Coastal Processes along Pomeranian Bay

The Polish coast basically comprises soft rocks including Pleistocene glacial deposits and recent alluvial and littoral zone Holocene sediments.
This part of the coastal area present two types:

- a cliff coast of Pleistocene deposits, in places where morainic plateaux come directly to the shoreline.
- a barrier-dune coast of Holocene deposits has developed where lowland meet the sea.

On the study area both types coexists. Their distribution is presented in next figure.

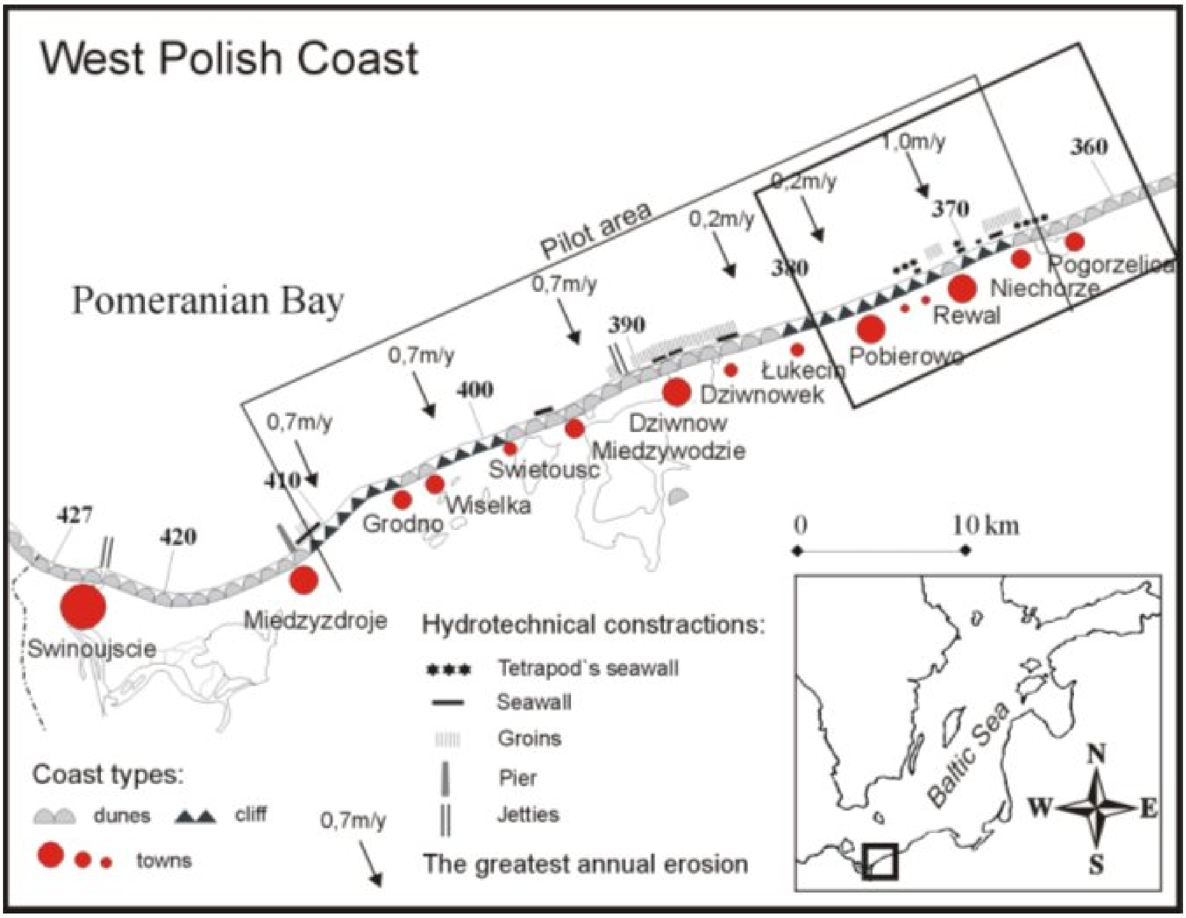
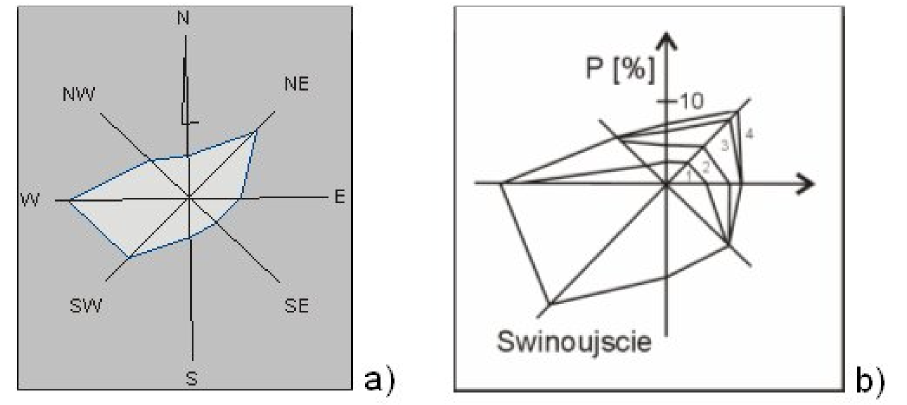


Fig. IV-46. West Polish coast

Atmospheric circulation create winds regime of the Southern Baltic area. The superposition shows the predominance of SW and W directions (Fig. IV-47.a), throughout the year with the exception of spring months. The percentage of situation with wind above 6 degrees Beaufort is highest in the period from October to March, and exceeds 15-20% in particular months. In the coastal zone, the highest mean monthly wind speeds (5 – 7 ms^{-1}) from NW, W and SW directions are characteristic for the autumn-winter months, whereas the lowest are recorded from May to August (2,5 - 3,5 ms^{-1}) from NW, W and SW directions, when the Baltic Sea basin is characterised by weak pressure gradients (ZEIDLER, 1992). The autumn-winter seasons contains the greatest number of days with strong wind (more intensive cyclonic circulation, westerly on the Polish coast). In the coastal waters, the cases of stronger wind are more frequent than in the hinterland reaching 20-25%. On a base of wind rose for the Pomeranian Bay the wave climate rose was calculated (Fig. IV-47.b) (ZEIDLER, 1992).



(1) 0<H<25 cm;
(2) 26<H<50 cm;
(3) 51<H<100 cm;
(4) H>101 cm.

Fig. IV-47. a) Wind rose for the Pomeranian Bay coast. b) Wave rose for the Pomeranian Bay coast:

Longshore currents depend of wind direction and wave climate. They are observed in both east and west directions, but most of them have west direction. It means that longshore transport predominates towards west direction (MUSIELAK, 1999).

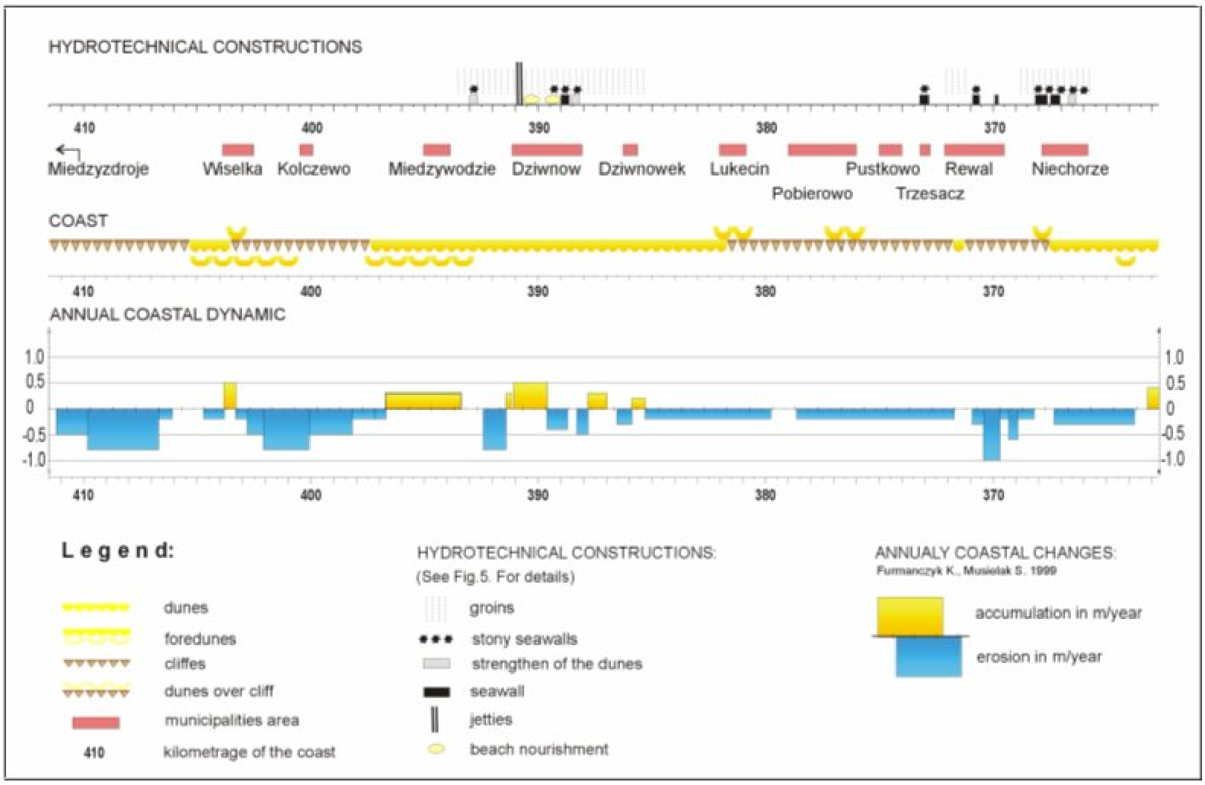


Fig. IV-48. Spatial structure of the erosion and Defence works

Annual rate of coastline changes were calculated on a base of the comparison of aerial photographs with 40 years interval and the last field of observation from 1996 to 1999. The spatial structure of the erosion is presented on the next figure (MUSIELAK, 1999).

Area of Study: Trzęsacz

Main considerations for this study will regard the coastal sector and both sides of Trzęsacz for the preservation of the church ruins.

These ruins are threatened by cliff collapse as a result of progressing coastal erosion. It is assumed, although there is no direct proof, that this 13th century Gothic church was built about 2 km away from the shoreline. With that assumption, the erosion pace between 1280 and 1880 is measured 5 m per year retreat, while the erosion rate corresponding to 1880-2005 interval is only 0.5 m/yr.

According to historical data intense erosion of the cliff caused gradual collapsing of the church. A little fragment of the south wall still exists on the edge of the cliff scarcely.

On the specific site of Trzesacz, the erosion speed is relatively slow (order of 0,2 m/yr. Between 1984 and 1989 the ruins were protected by seawall made by tetrapods and stones. They today benefit of a combined protection system: the ruins were connected with the cliff and the foot of the cliff was protected by 90 m long seawall made by gabions.

Value of these ruins is resulting rather from their symbolic meaning, than from aesthetic, historical or religious reasons. The Church in Trzęsacz is a very famous example of progressing erosion processes from the last half century in Poland and is often presented in school textbooks. From all these this reason the ruins are being visited by school trips as well as other people resting up in a very attractive Rewal community and surroundings.

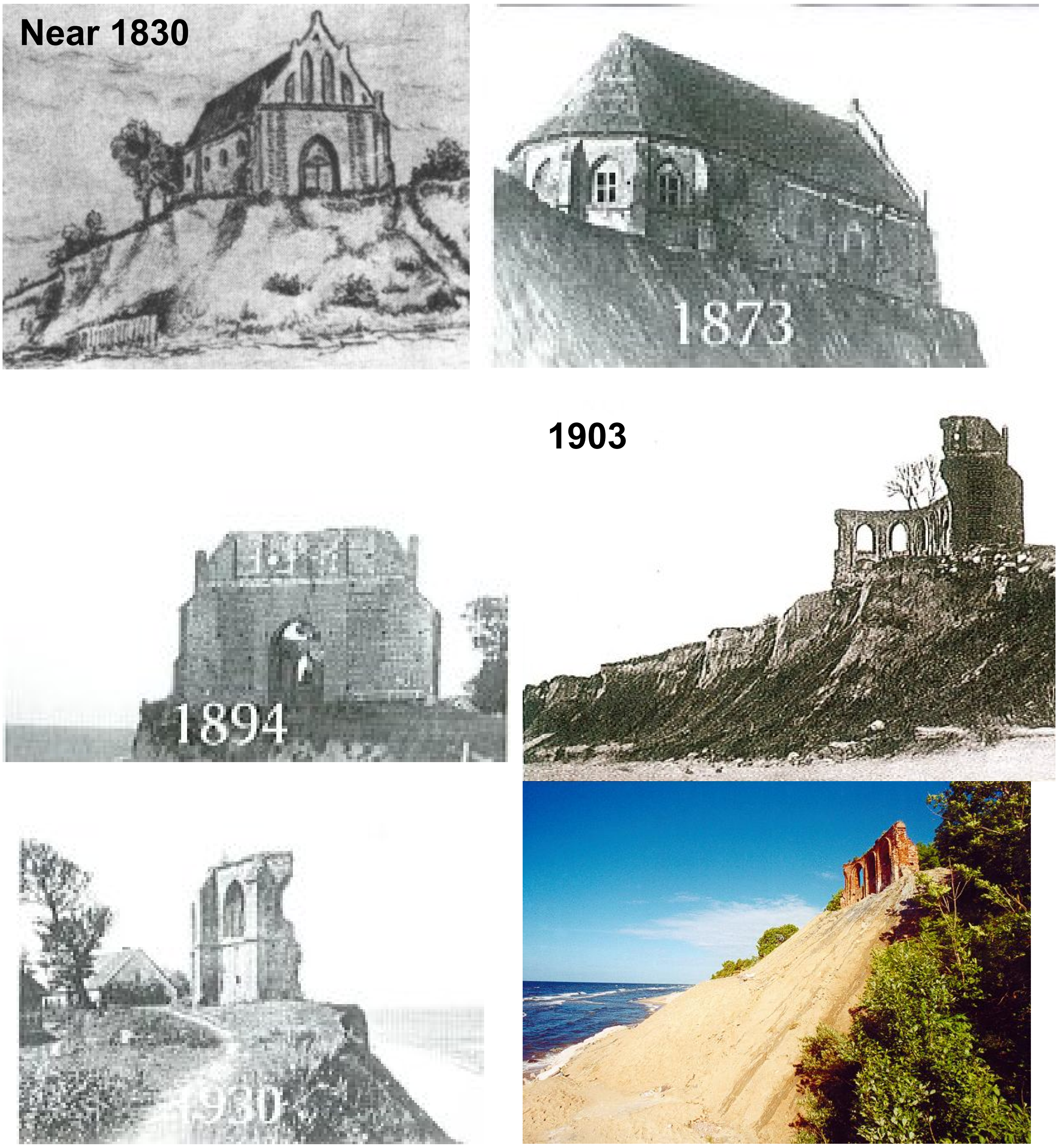


Fig. IV-49. Ruins of XIII century church in Trzesacz.

Analysis of the situation and current shoreline management policy

The efficiency of coastal defence protections vary from one place to another, and the local successive government have faced the problem very frequently. The most effective methods are very expensive like heavy seawall used as coast protection in front of the lighthouse in Niechorze. These infrastructures stopped erosion, but made the sandy beach disappeared and generated strong side effect. In front of combined seawall in Rewal-Sliwin the beach remains very narrow.

Within MESSINA timeframe a historical study on coastal protection over the time for this part of the Polish Pomeranian Bay has been realized. An excerpt on rewal-Trzesacz is provided below.

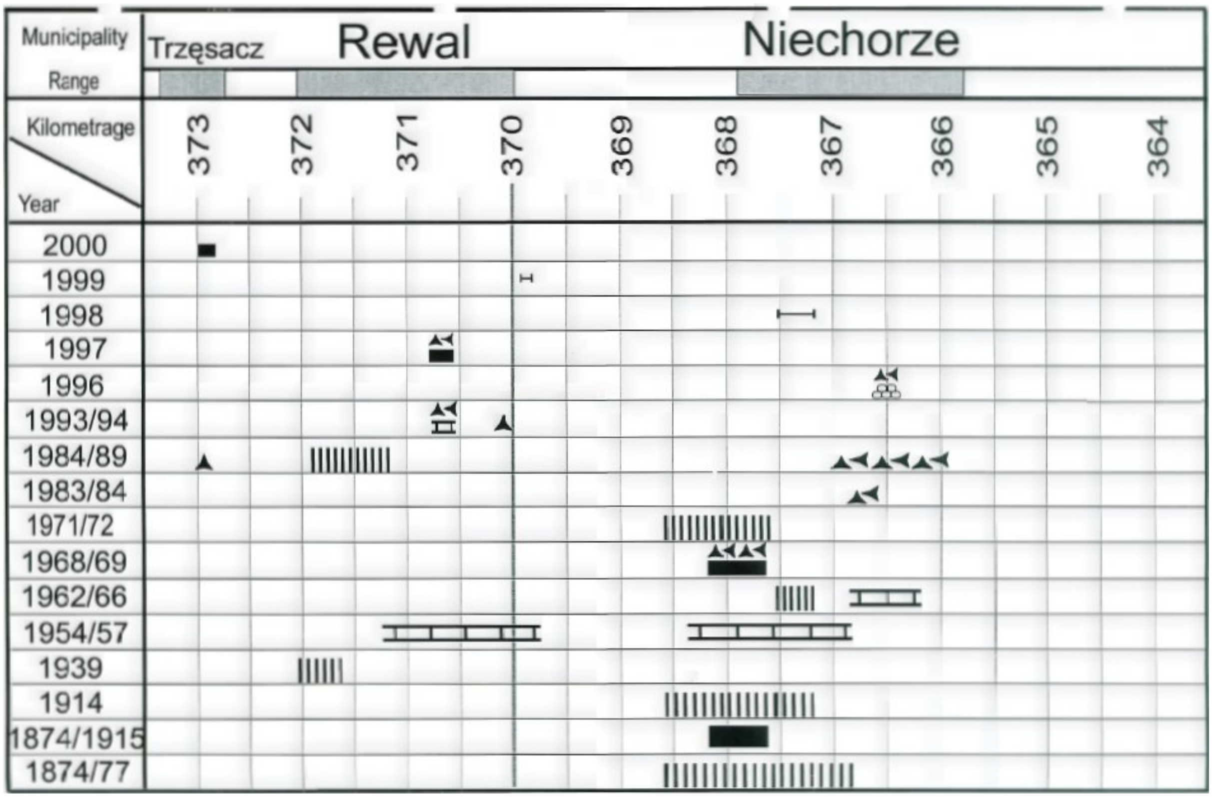


Fig. IV-50. Historical study of coastal protections at the study area.

User needs and requirements for Trzesacz

Through multiple interviews and field visits, the team of the University of Szczecin collected requirements for their study from the coastal authorities and local government in order to get prioritised the tools to realise within a local Coastal Geographical Information System.

Amongst other the first priority to be developed over Trzesacz remain the integration of past erosion data (coastline position, topographic database, erosion rates measurements) in order to predict future erosion of the coast and assess the economic impacts.

This study will be made by:

(i) Integrating the relevant existing data, even producing or purchase others.
(ii) Elaborating scenarios to simulate coastal erosion and analyse them.
(iii) Discussing the resulting maps with the authorities and government.

Two variants for the ruins protection were being considered according the opinion of the Maritime Office too (which is the responsible for planning in the Public Maritime Domain called *Technical Belt* in Poland):
- The first suggests to carry on protecting the cliff using new or combined systems.
- The second variant is to propose moving the ruins towards a new safety location.

Both variants were revised before MESSINA project starting. And due to lower assessed costs the first option was approved. Direct costs for the preservation of the bank were estimated to 2,5 million PLN (about 600.000 EUR) while the costs for moving ruins (estimated by specialist company) reached the range of 12,5 to 25 million PLN.
However no supplementary expenditures or possible benefits from both variants were integrated to the model. During MESSINA an Cost Benefit Analysis has been performed to integrate most of the parameters and presented within the Practical Guide Valuing the Shoreline (MESSINA PG3, 2006).

3.2. Engineering the GIS

The existing relevant data for the creation of the coastal GIS for Rewal coast are:

Satellite data and Aerial photographs

- o Ikonos (2002)
- o Old aerial photographs (1938, 1951, 1973, 1996) and recent

Fig. IV-51. IKONOS image of Trzesacz (2002)

Fig. IV-52. Old aerial photograph example (1938)

Cadastral/ land parcelling data

Fig. IV-53. Mosaic of cadastral sheet for Trzesacz

Fig. IV-54. Excerpt of topographic vector parcels and infrastructures database for Trzesacz

Topographical database

- Dune base line position changes (coastal changes)
- Historical Development of the coastal protection
- Raster maps 1:500, 1:2000 (2005) and Historical (1930)
- Vector maps 1:500 (2005)

Fig. IV-55. Excerpt of topographic map for Trzesacz

3D Models (Digital Terrain Model) 1:10,000 and 1:500

Local Development plan and strategy

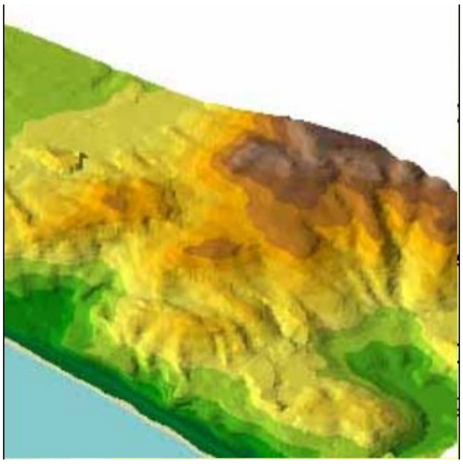


Fig. IV-56. Excerpt of 3D model for Trzesacz

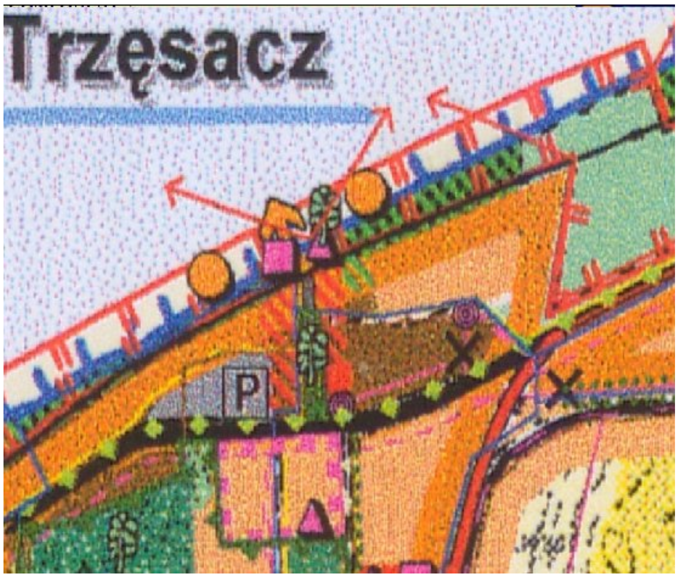


Fig. IV-57. Excerpt of Development Plan for Trzesacz

Socio-economical data

Those data are used to assess the values of properties and ownerships, as well as infrastructures and coastal works costs. They are derived from:

- Regional Data Bank
- Documentation from the Maritime Office
- Municipalities, Statistical Offices.

Most of ancillary data are also provided by "research" data from the Institute of Maritime Sciences of the University of Szczecin, in charge of implementing the coastal GIS.

3.3. Prototyping the GIS

Data collection and integration

An outstanding amount of efforts has been produced to geo-locate the numerous hard copies found (cadastral, paper maps); as well as the orthorectification of aerial data (old and current) to be able to realize the comparison over periods; The digitization of topographic elements to get digital topographic databases; the harmonisation of the documents found at various scales (from accurate 1:500 to large 1:250,000)

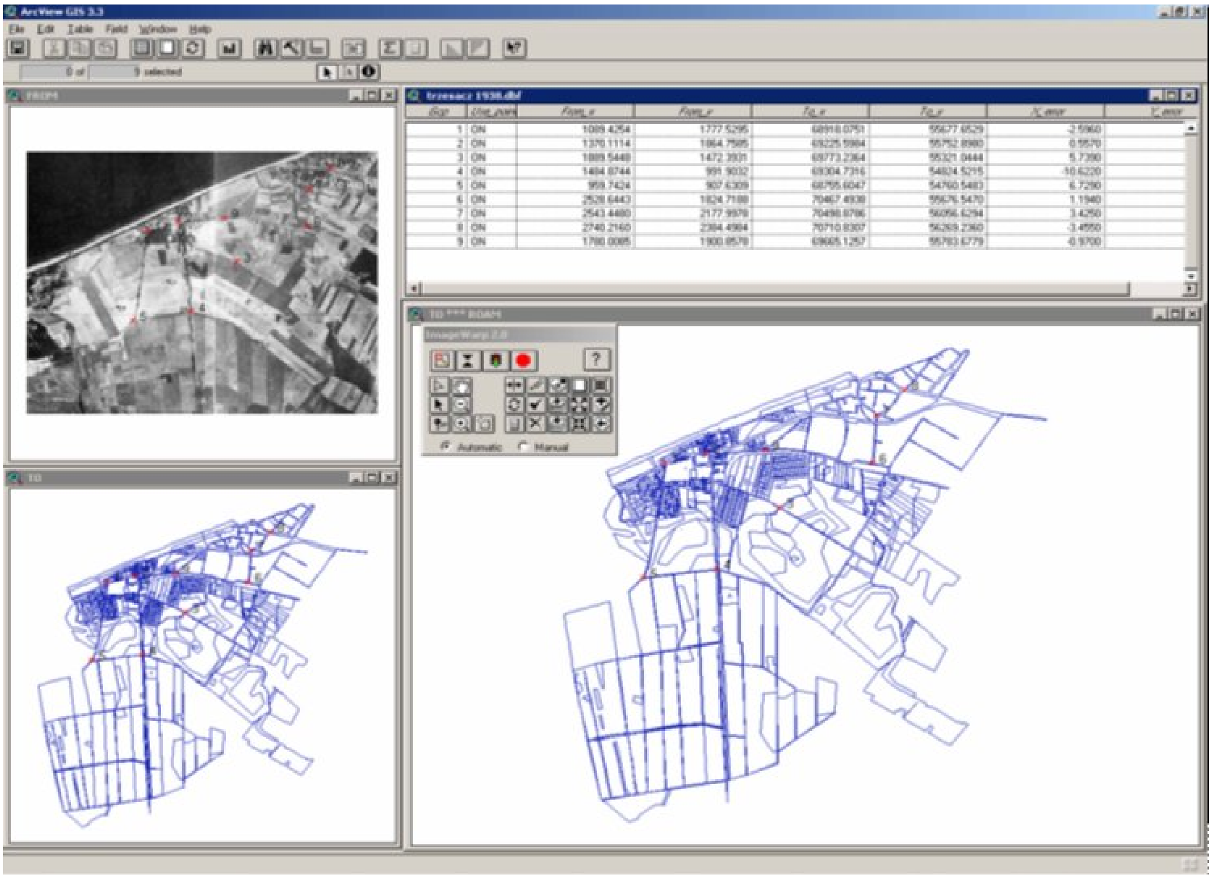


Fig. IV-58. Geo-rectification works

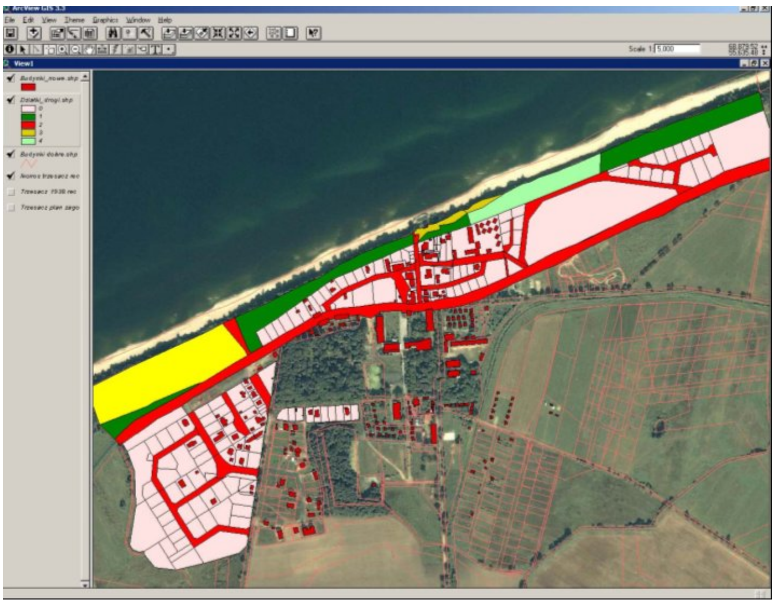


Fig. IV-59. Overlay of topographic, parcel database and satellite map

Analysis of past erosion

Erosion rates are measured comparing rectified air photographs dated 1951, 1973 and 1996. Results are presented at Fig. 6 (Dudzinska, 2006):
Period 1951-1973: the erosion rate was not exceeding 0,10 m/year,
Period 1973-1996: was greater than 0,2 m/year. Both sides of the church are affected by erosion with an asymmetry, the western side keep more stable.

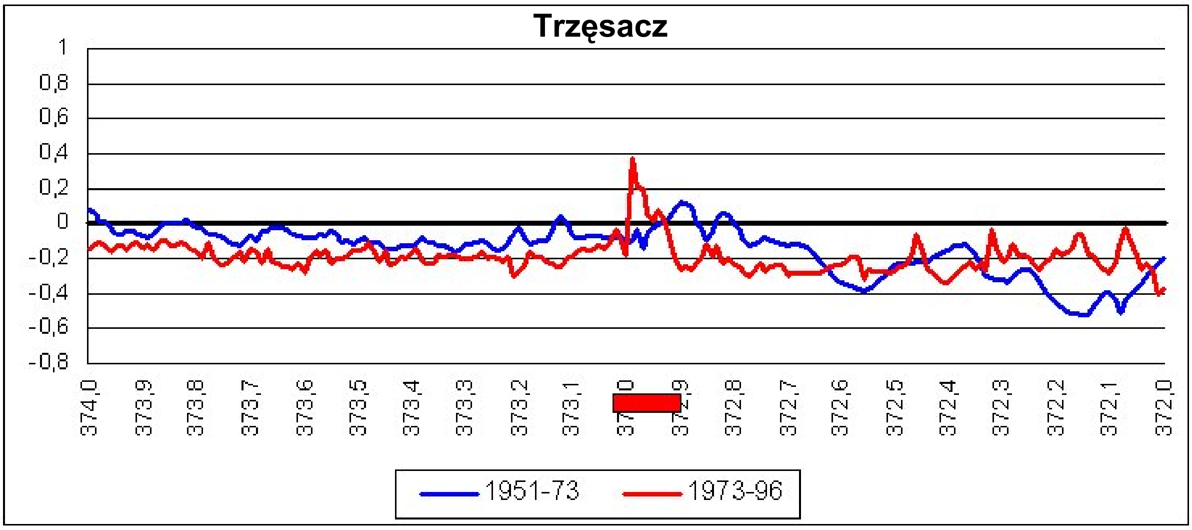


Fig. IV-60. Diagram of the erosion rate in m/y (cliff foot line changes) at two periods of time

Solution set up by local authorities

Fig. IV-61. Last combined protection system, achieved in summer 2005.

The last combined protections set seawards consist of connecting the ruins with the cliff edge and build a seawall of about 90 m made by gabions at the foot of the cliff. The protected scarp of the cliff was covered by vegetation.
This kind of protection will undeniably generate a “link side effect” in both sides of the seawall which shall be monitored stringently.

There were taken two options of activity:

- to continue the process of protection
- not to protect the coast and move ruins to safety place

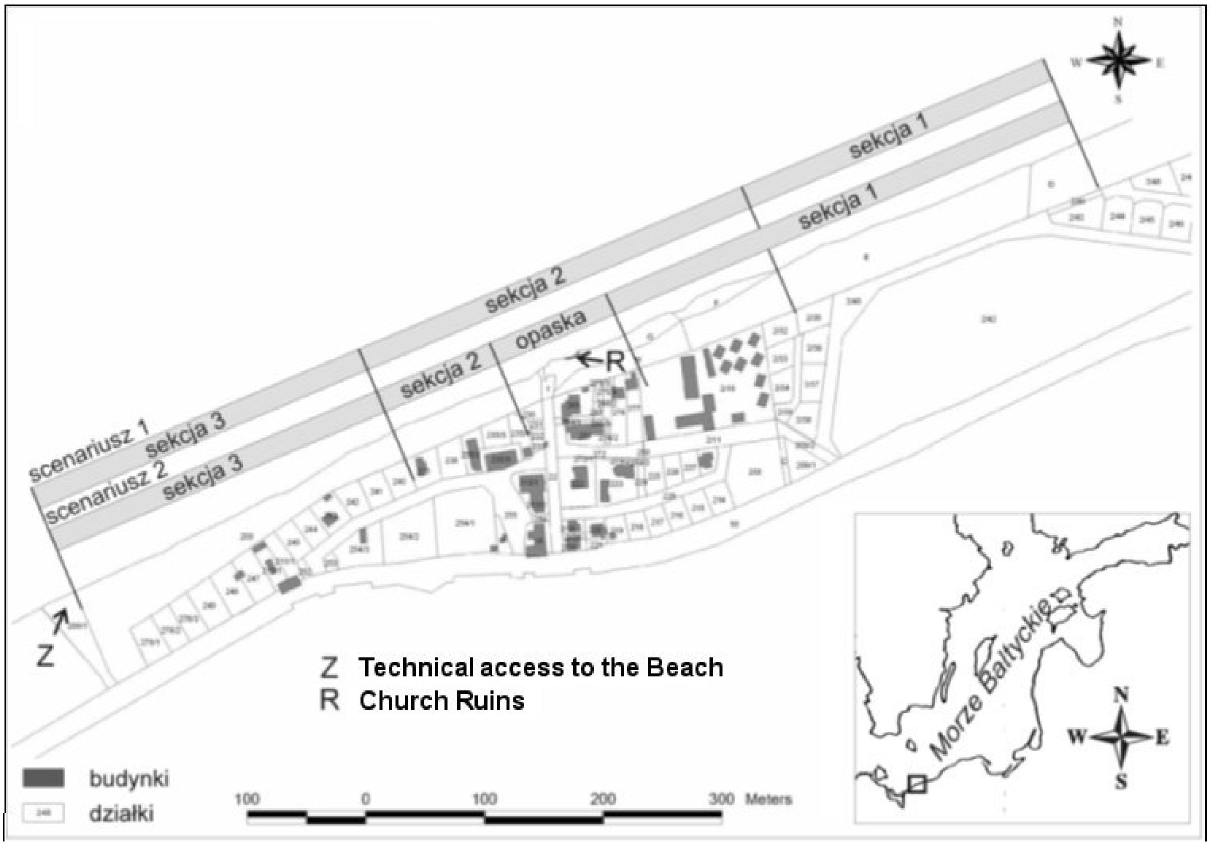


Fig. IV-62. Area of investigation divided for sections In options: 1 and 2.

Elaboration of erosion scenarios

For the elaboration of the erosion scenarios in the future, given the past erosion rates knowledge, the two variants exposed are considered:
Scenario/Option 1: to carry on protecting the cliff using new or combined systems.
Scenario/Option 2: to propose moving the ruins towards a new safety location.

1. To continue the process of protection (Scenario/Option 1).

The erosion on both sides of the gabion and tetrapods seawall – which protects the Trzesacz Church’s ruins – will increase, especially from the east side.
It is assumed that:

- Section of the coast that is protected by 115 m long seawall will not be affected by erosion;
- Coastal erosion rate will be similar than the rate observed in period 1973-96, because tetrapod's seawall already protected cliff with the ruins since 1986 and it significantly affected size of erosion in the neighbourhood of this construction.

To assign particular section of the coast and calculate tempo of changes the diagram of cliff foot line position changes in period of time 1973-96 was analyzed. There were eliminated 4 sections of the coast with different rates of erosion. The length of these sections was: 405m, 115m [section protected by seawall], 100m and 300m.

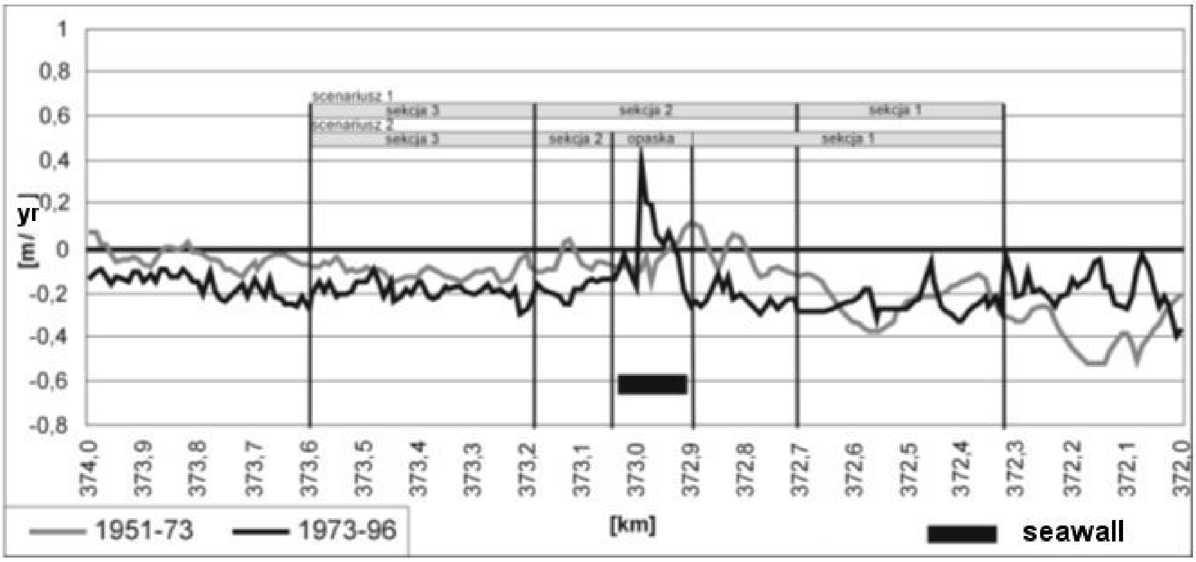


Fig. IV-63. Changes of cliff foot line in Trzęsacz in time periods 1951-73 and 1973-96

During the study of Scenario 1, two visions were discussed:

- The **optimistic** one:
  - o The erosion rate in the section 1 was assumed for its highest level and for years 1973-96 rated as a value of 0,3 m/yr.
  - o For section 2 at the western side the construction showed an average pace in time period 1973-93 of 0,2 m/y only.
  - o In the Section 3 it is not possible to consider the defence system constructed in 2003 to protect the technical and emergency exit. In that situation an erosion rate is assumed with the value of 0,25m/y for a optimistic variant (an average pace for period 1973-96)

- The **pessimistic** one: Values of erosion used for calculation were taken in another area of similar geology and geomorphology, in closer Rewal, where a 300 m long defence system took since 1993:
  - o Based on a analysis of graph presenting changes of cliff foot line in Rewal in a period 1973-96 it is deduced that effect of a seawall in Trzęsacz will correspond to the lowest erosion rate of the defence system in Rewal and will have a value of 0,6 m/y.

- o For the Section 2, the maximum value, 0,3 m/y, observed during the same period is proposed.
- o For the Section 3 the same assumption than for the optimistic variant increased by 30% reaching 0,4 m/y.

Tab.1. Coastal erosion rates [m/y] for Scenario 1.

	section 1 405m	seawall 120m	section 2 100m	section 3 300mm
Optimistic variant	0,3 m/y	0	0,2 m/y	0,25 m/y
Pessimistic variant	0,6 m/y	0	0,3 m/y	0,4 m/y

Following assumptions were adopted for these options:

- erosion pace in the next years should be the same as in the time period 1973-96 and no information about see level rise and higher storm activity will be included,
- erosion rate of areas that are impacted by seawall will be an indirect value observed between seawall and defence system in cliff area in Rewal,
- erosion rate observed after an impact of a defence system constructed to protect the technical and emergency exit.

2. No further protection of the coast and move ruins to safety place (Scenario/Option 2).

If there is no more defence and the ruins are moved to a safe location we may suppose that the natural erosion, not disturbed by any defence work will occur just like it happened in a period 1951-1973. The graph below present the changes of cliff foot line changes for this period.

The results are presented on three different parcels which vary from each other with the rate of erosion. They are described as sections of respective lengths of 280m, 340m and 300m.

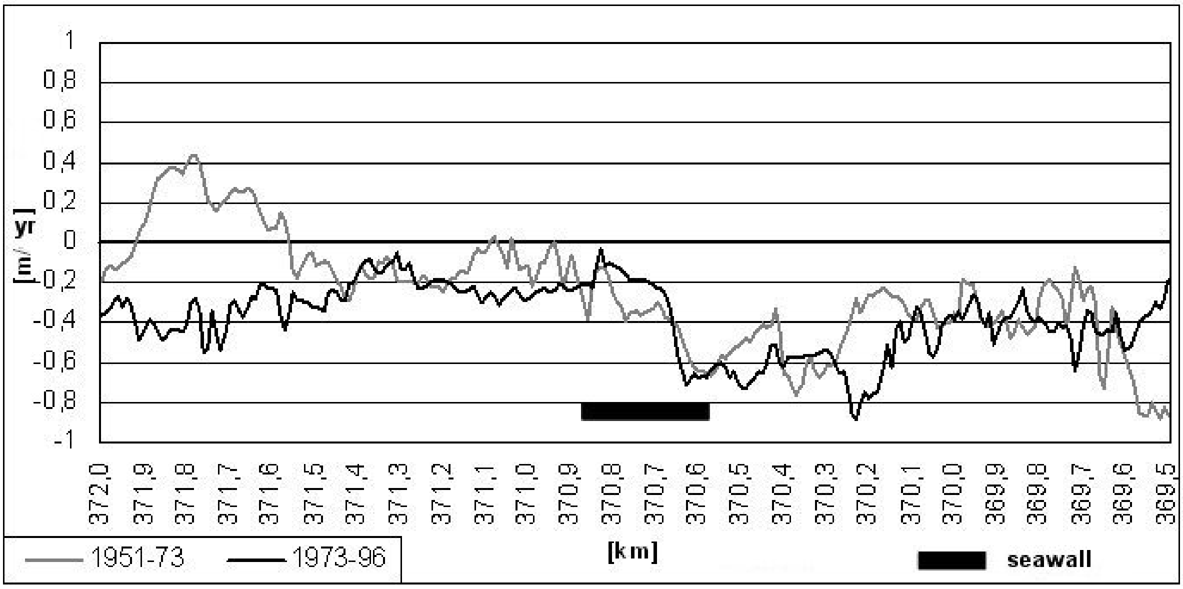


Fig. IV-64. Changes of cliff foot line in Rewal in time periods 1951-73 and 1973-96

For the Scenario/Option 2, optimistic and pessimistic variants are considered too:

- Within optimistic variant the annual erosion rate is equal to average value of each section of the coast in the period of time 1951-73 (shown in the above figure).
- Within pessimistic variant the annual erosion rate is equal to the maximum value in each section of the coast in the period of time 1951-73 (shown in the above figure).

The values of the predicted annual erosion rates for each section and both variants are summarized in the following table.

Tab. 2. Coastal erosion rate[m/y] in scenario “to move the ruins”

	section 1 280m	section 2 340m	section 3 300m
Optimistic variant	0,2 m/y	0,1 m/y	0,15 m/y
Pessimistic variant	0,35 m/y	0,2 m/y	0,2 m/y

Following assumptions were adopted for these options:

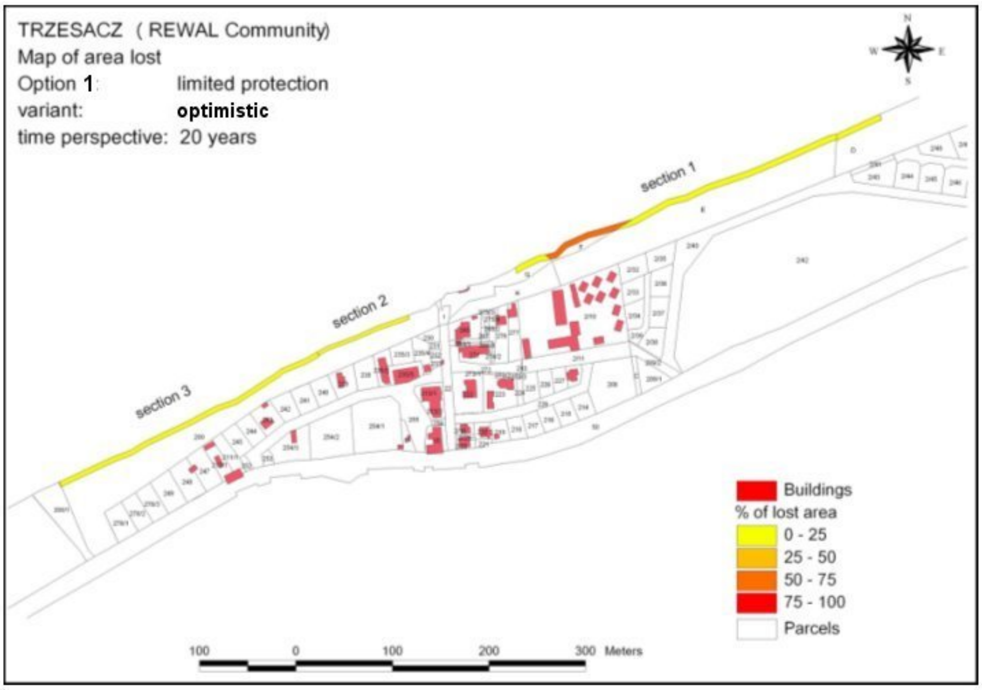
- erosion pace in the next years should be the same as in time period 1951-73 and no information about see level rise and higher storm activity will be included,
- the impact of the defence system constructed to protect the technical and emergency exit will have no additional impact to erosion.

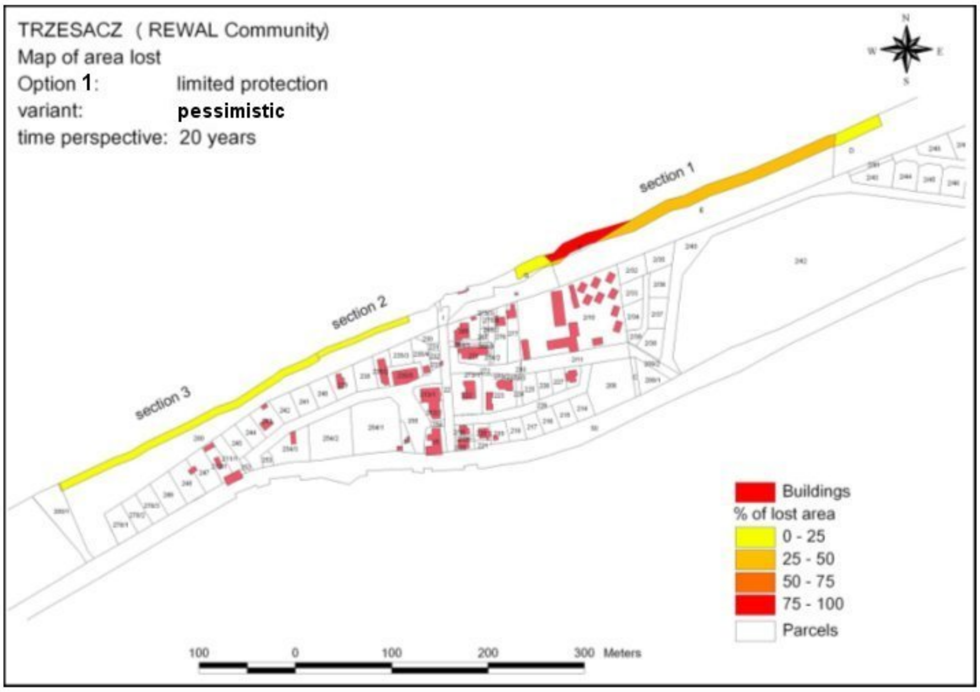
Results and Discussions

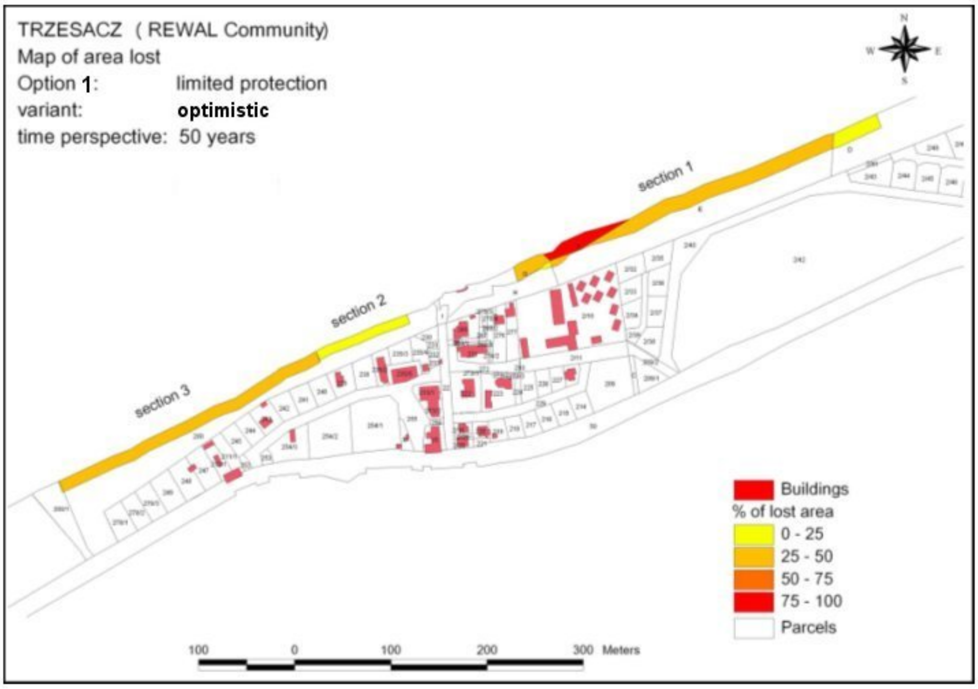
The resulting risk maps from this application is generated for next 20, 50, 100 years, as recommended in Section II.

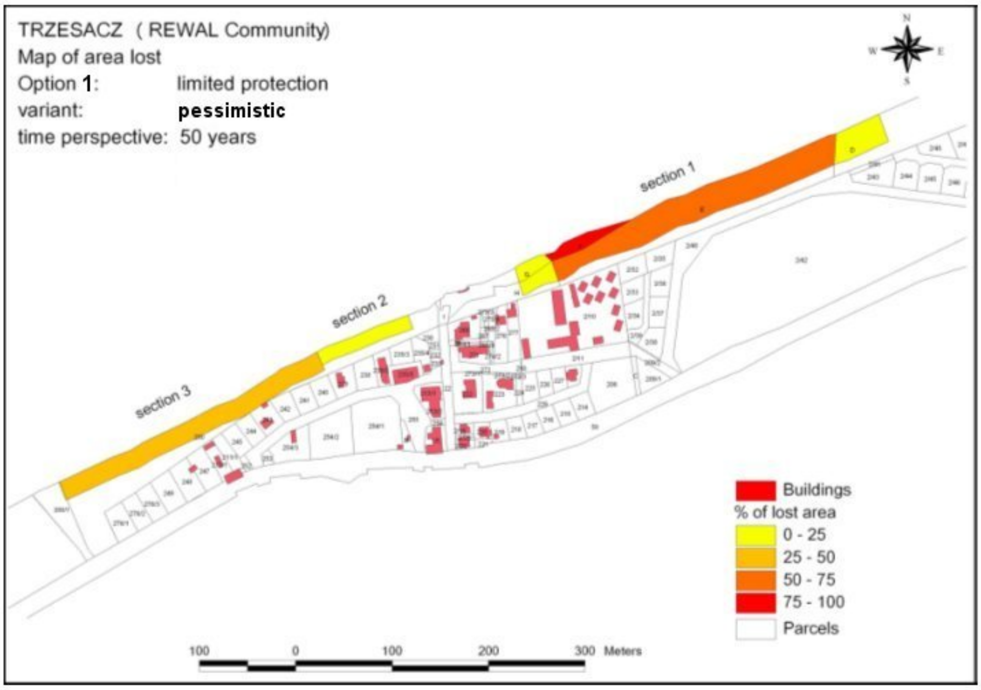
Scenario Option 1 – Limited Protection

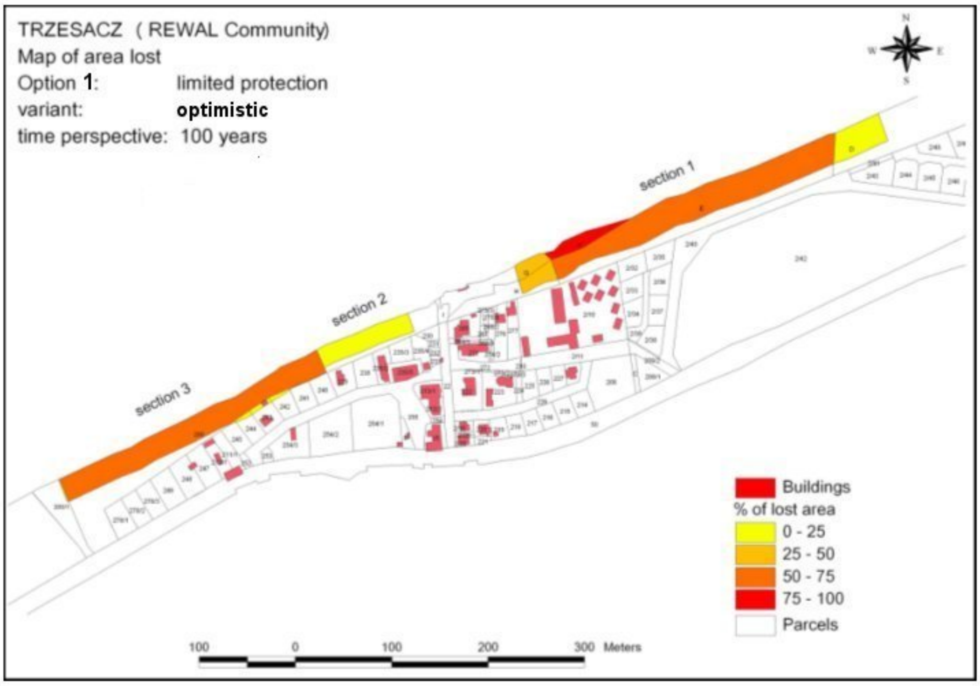
Left side Optimistic variant ***Right side : Pessimistic variant***

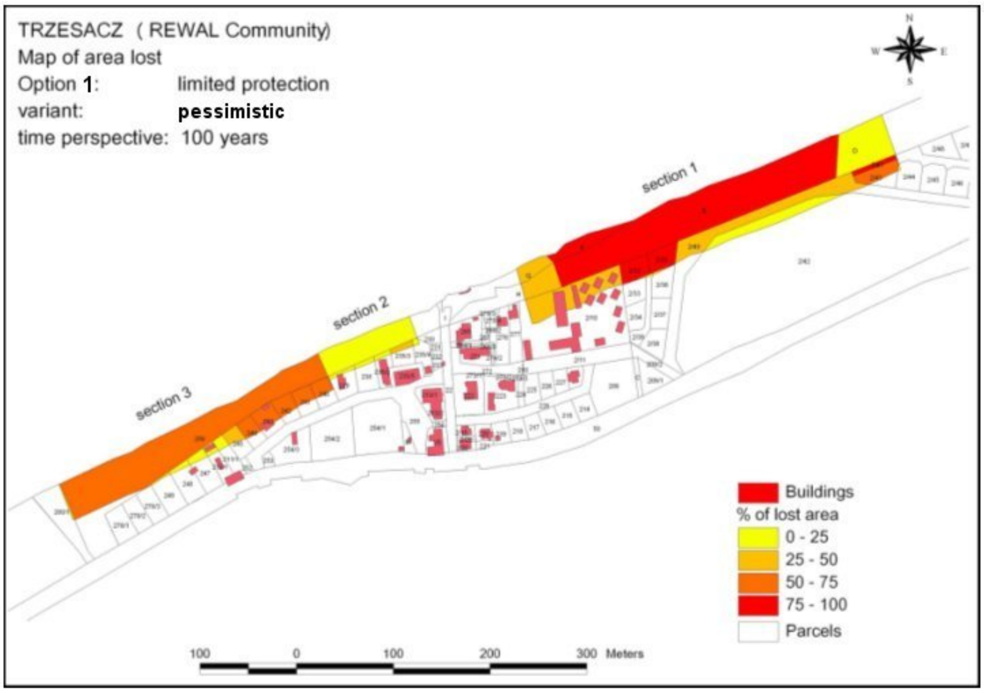





TRZESACZ (REWAL Community)
Map of area lost
Option 1: limited protection
variant: optimistic
time perspective: 50 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters

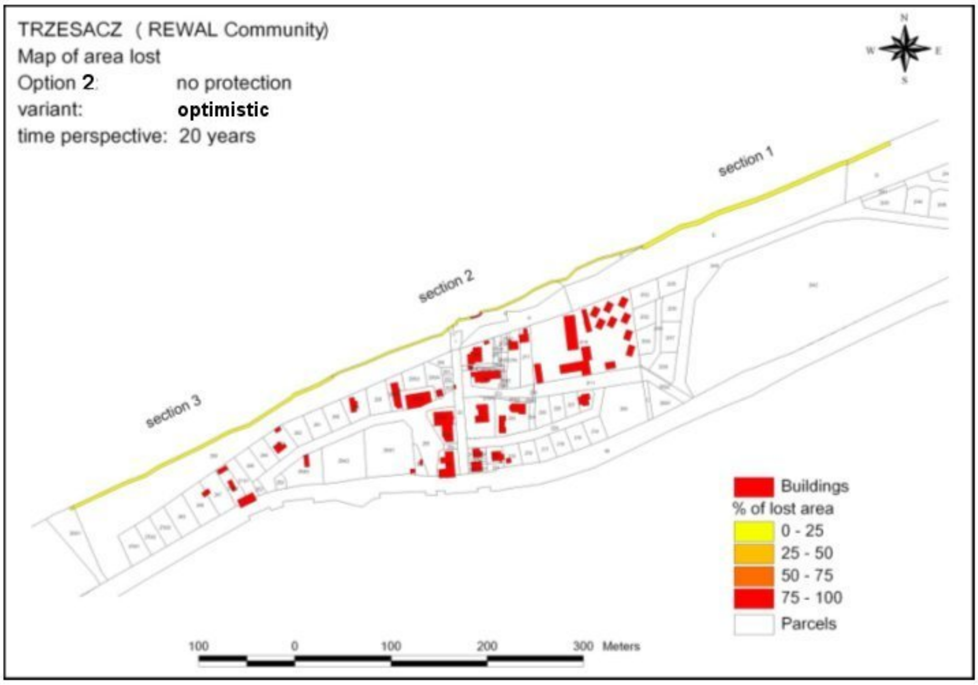

TRZESACZ (REWAL Community)
Map of area lost
Option 1: limited protection
variant: pessimistic
time perspective: 50 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters

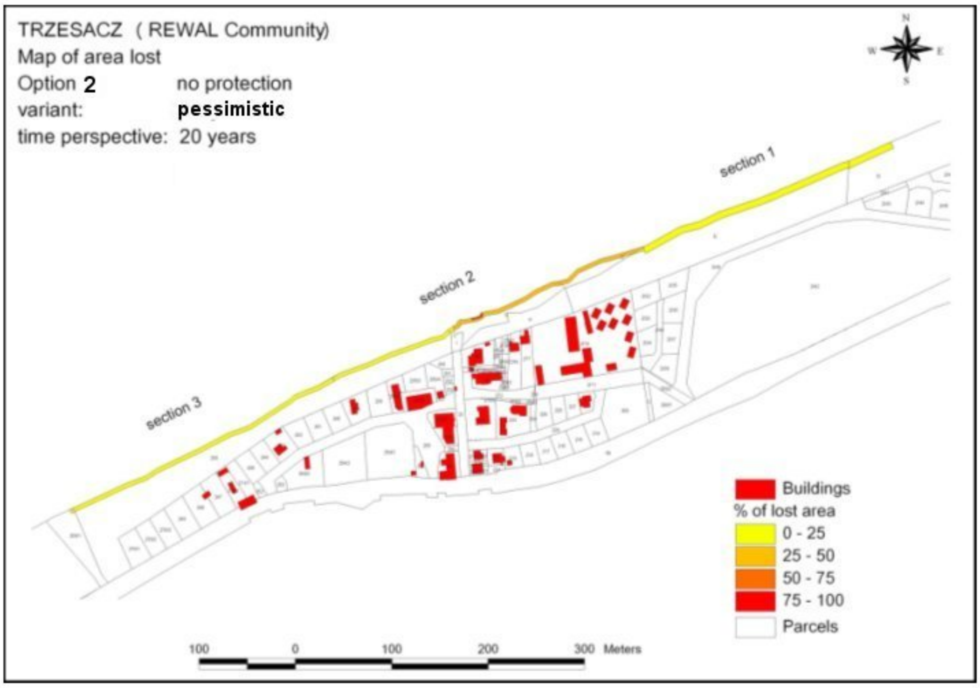

TRZESACZ (REWAL Community)
Map of area lost
Option 1: limited protection
variant: optimistic
time perspective: 100 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters

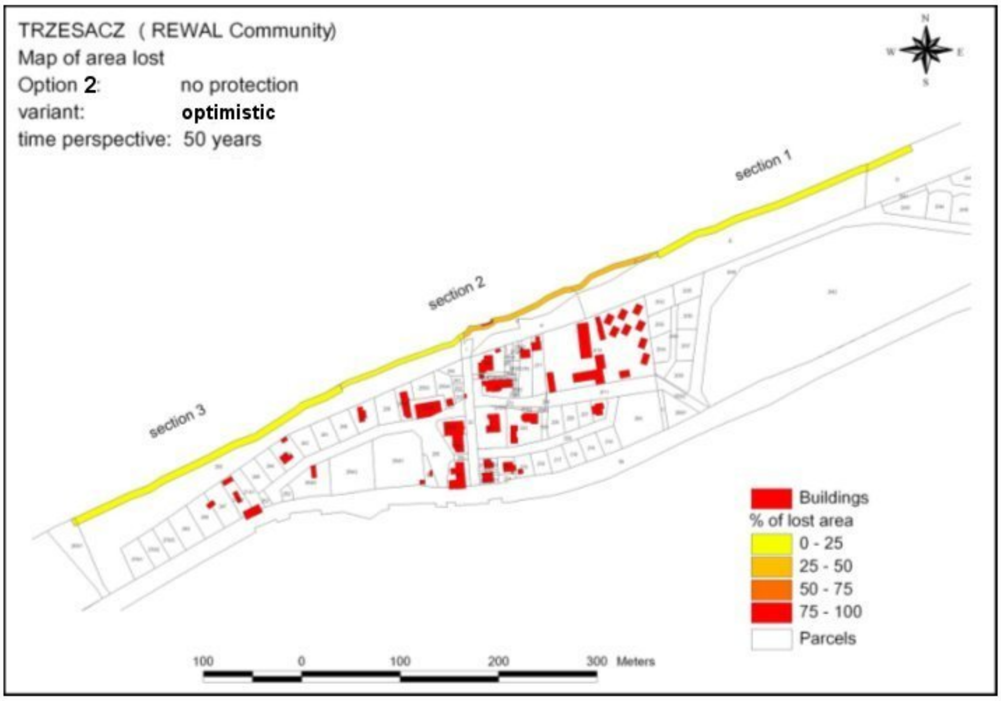

TRZESACZ (REWAL Community)
Map of area lost
Option 1: limited protection
variant: pessimistic
time perspective: 100 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters

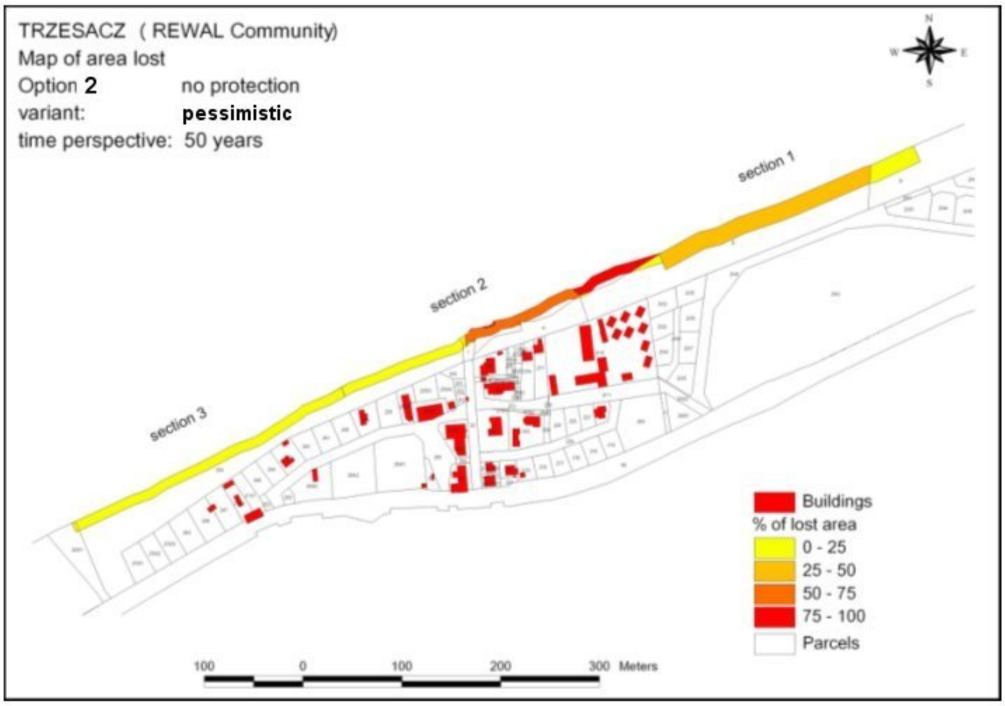
Scenario Option 2 – Move of the ruins and NO further protection

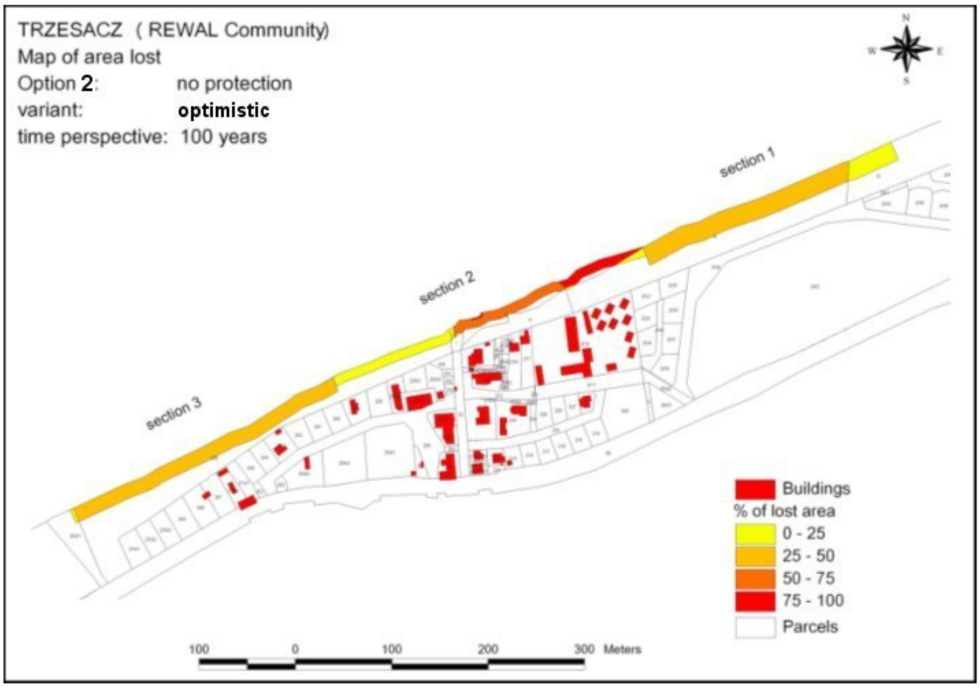
Left side Optimistic variant ***Right side : Pessimistic variant***

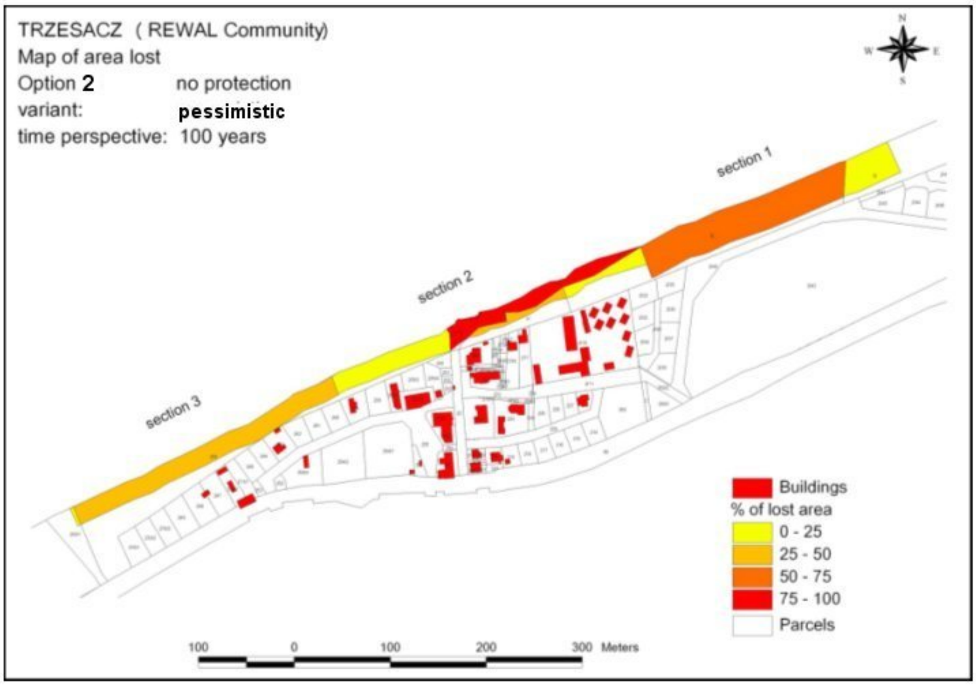





TRZESACZ (REWAL Community)
Map of area lost
Option 2: no protection
variant: optimistic
time perspective: 50 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters


TRZESACZ (REWAL Community)
Map of area lost
Option 2 no protection
variant: pessimistic
time perspective: 50 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters


TRZESACZ (REWAL Community)
Map of area lost
Option 2: no protection
variant: optimistic
time perspective: 100 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters


TRZESACZ (REWAL Community)
Map of area lost
Option 2 no protection
variant: pessimistic
time perspective: 100 years
section 1
section 2
section 3
Buildings
% of lost area
0 - 25
25 - 50
50 - 75
75 - 100
Parcels
100 0 100 200 300 Meters

3.4. Demonstrating the GIS - validation workshop

Constructive field visits and preliminary presentations have been made during the timeframe of the MESSINA initiative. Besides PhD thesis of students from the University of Szczeczin are currently going to be completed on that topic. This led to frequent exchanges with local government and coastal authorities.

Other GIS functions have been developed which do not lead to analysis but might reveal useful to manage urban sprawl, based on the existing parcels and buildings integrated database, it remains possible:

- To detect new settlements (providing new data are integrated), possibly illegal or not yet registered,
- To insert new parcels (record new development) or anticipate update of parcels regarding erosion,
- To set the debate for further spatial planning updates,
- To compute statistics from Land Use database,
- To insert multimedia data such as professional addresses (guest houses), for instance for tourist information,

For timely reasons the presentation of the final results (within MESSINA context) – but a real starting cooperation with Rewal Community - is planned for the 23 September 2006 in Rewal, under the auspices of the Major of Rewal. The coastal GIS is being installed there beforehand and GIS demonstration conducted, denoting the efficiency of the system, and presenting the results of the study. A round table is planned to discuss and validate the results.

3.5. Sustainability of the GIS

The brand new GIS proposed to the Municipality of Rewal is being presented in September 2006, during a meeting where MESSINA activities will be exposed. This early GIS pilot should allow the municipality to handle, integrate and manipulate more and more local data, providing a decision-easing tool for observing the Strategy Development Plan, especially to better manage current urban sprawl.
Even if staff from the Municipality is trained to use the early coastal GIS, the University of Szczecin – Institute of Marine Sciences, which developed the coastal GIS will propose adaptations, and new functionalities, linked to its research and integration programs.

SECTION V –CONCLUSIONS.

This Practical Guide *Integrating the Shoreline into Spatial Policies* summarizes the process followed by three coastal authorities willing to (make) create their Coastal Geographic Information System (GIS).

These Guidelines are perfectly illustrating how coastal GIS dedicated to shoreline themes, problematic and management should be created. Guidelines built upon the main recommendations from the EUROSION project (2002-2004) as a first global view. The same principles are adapted to local level. The role of GIS and associated procedures is demonstrated pedagogically and progressively towards risk assessment functionalities and mapping.

Three different coastal GIS were finally implemented for and with coastal authorities, MESSINA partners or beneficiaries, mainly to support decision-making process and shoreline management, around three different coastal themes.

For the lido of Sète-Marseillan (France), a very long process is currently managed by the Community of Agglomeration for the Thau Basin (CABT): the rehabilitation of semi-natural processes by realignment of infrastructures landwards and the restoration of dunes system at the seafront, combined with strong coast engineering protection for critical erosion places.

Through MESSINA workshops and partners involvement, the CABT has immediately seen the interest of a coastal GIS and required cartographic support from geographic information specialized partners. Effectively a coastal GIS allows a real time management of current realizations outsourced, the future elaborations or modifications of local spatial planning, for instance.

They also discover how coastal monitoring are set through very detailed and fruitful case-studies of Monitoring and Modelling the Shoreline partners, and thus intend to take part to Coastal Sustainable Plan of their region.

The application of valuation techniques on the Lido has not only benefited the CABT comforting the choices made before the evaluation but also provided a Best Practice that validated the use of the valuation method in a given and described context.

Another crucial contribution was the intervention of the MESSINA experts who recommended simulating and, upon results, using innovative engineering structure - submerged geo textiles combined with light beach nourishment - as part of a solution to fight erosion problem on the eastern part the Lido.

For the High-Normandy coastal authorities a coastal GIS has been realized for assessing the possible damages and risks associated to the cliffs retreat.

This implied a thorough assessment of the methodologies commonly used to determine the erosion rates for cliff coast – a link with the monitoring techniques collected by other partners has been established at this occasion.

In order to assess the possible values at risk (goods, ownerships…), the valuation method that better suited to the context was selected in the corresponding Practical

Guide Valuing the Shoreline and applied, validating its applicability on this concrete case of the Alabaster Coast.

Generic functions for coastal GIS were implemented and the methodological transfer granted for success, if we go by the publication of new risk maps by the local coastal authorities themselves few months after the completion of the study.

The perspective of a local coastal Observatory, if not too marred by politics, would be a real godsend for the follow-up of the application and monitor of French Coastal Act locally with local stakeholders, elected people, scientists, associations and citizens.

For the Polish waterfront of Rewal, subject on one hand to high season massive tourist accommodation demand and facing growing but not yet controlled built-up areas; and on the other hand affected by severe erosion of most of the Community of Rewal cliffs.

As a start for a coastal GIS setting the emblematic site of the church ruins of Trzesacz retained the attention of MESSINA partners. If the coast protection locally is a duty to maintain the attractiveness of the site, the need for simulations of the defence works made has been analysed by MESSINA partners who integrated data and elaborated scenarios of coastal vulnerability projections in next 20, 50 and 100 years.

Even if the Polish university partners who realized the coastal GIS benefited the *Monitoring and Modelling the shoreline* Practical Guide, they produced the needed data by their own.

They also disposed of a very huge information base (in hard copy) of historical coast protection settled over the whole Pomeranian Bay (T-shape wooden groynes, seawall with gabions, jetty refection date…). This contributed to a clear case-study description for the Practical Guide *Engineering the Shoreline*.

Urban sprawl and future assets at risk have not been forgotten while completing a socio-economic evaluation for the village of Trzesacz.

After three years of project the MESSINA - Monitoring European Shorelines and Sharing Information on Near shore Areas - initiative has met its initial objectives and requirements by breaking the "knowledge isolation".

Local authorities and institutions in Europe, through a mutualisation of the experience and coastal management knowledge, have raised their managerial and technical capabilities. They are now the starting nodes for new comers willing to learn and share the knowledge gathered. They obviously won't stop their efforts now but benefit of the outstanding amount of informations collected in the four written Practical Guides.

As a conclusion the current Practical Guide represents a real *Integration* of the notions, methods, principles and recommendations of the other Practical Guides constituting the MESSINA Coastal Toolkit, drafted, assimilated by all the partners of MESSINA initiative for the elaboration of three Coastal GIS (and possibly others later), proving the usefulness and the efficiency of the MESSINA Coastal Toolkit.

Glossary

Common acronyms

ANEL	Association Nationale des Elus du Littoral
CBA	Cost-Benefit Analysis
CEA	Cost-Efficiency Analysis
CORINE	COoRdinated INformation on the European Environment
CPIBP	Contrat de Plan Interrégional du Bassin Parisien
CSMP	Coastal Sediment Management Plan
DDE	Direction Départementale de l'Equipement (Departmental Direction of the Equipment)
DIREN	Direction Régionale de l'Environement (Regional Direction for Environment)
DRE	Direction Régionale de l'Equipement (Regional Direction for Equipment)
EIA	Environmental Impact Assessment
GCP	Ground Control Point
GIS	Geographical Information System
GPS	Global Positioning System
ICZM	Integrated Coastal Zone Management
IFEN	Institut Français de l'Environnement (French Environment Institute)
IGN	Institut Géographique National (French National Mapping Agency/Institute)
LIDAR	LIght Detection And Ranging
MCA	Multi Criteria Analysis
MEDD	Ministère de l'Ecologie et du Développement Durable (Ministry of Ecology and Sustainable Development)
MESSINA	Monitoring European Shoreline and Sharing Information on Near-shore Areas
METATM	Ministère de l'Equipement, des Transports, de l'Aménagement du Territoire, du Tourisme et de la Mer (Ministry of Equipment, Transport, Territory Planning, Tourism and Sea)
MSL	Mean Sea Level
MLLW	Mean Lowest Low Water level
PLU	Plan Local d'Urbanisme (Local Urbanism Plan)
PPR	Plan de Prévention des Risques (Risks Prevention Plan)
SDAGE	Schéma Directeur d'Aménagement et de Gestion des Eaux (
SEA	Strategic Environmental Assessment
SHOM	Service Hydrographique et Océanographique de la Marine (French Hydro and Oceanographic Maritime Service)
SCOT	Schéma de Cohérence Territorial (Territory Consistency Schema)
SPOT	Satellite Probatoire d'Observation de la Terre
SRU	Solidarité Renouvellement Urbain
UCBN	Université of Caen – Basse Normandie
URL	Uniform Resource Locator

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