



Managing European Shorelines and
Sharing Information on Nearshore Areas

messina

ENGINEERING THE SHORELINE

**Introducing environmentally friendly engineering
techniques throughout the World**

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**Component 4 *Engineering the shoreline*
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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 led coastal managers at the local level to pay 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 so far been 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) reducing the "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 outcomes expected from MESSINA are:

- (i) a "coastal manager toolkit" made of 4 practical guides ("Monitoring and modelling the shoreline", "Evaluating the shoreline", "Engineering the shoreline", and "Integrating the shoreline into spatial planning policies") and a demo CDROM featuring a GIS-based prototype of shoreline management planning;
- (ii) a series of 4 workshops in line with the topic of each practical guide; and
- (iii) a website giving 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 maximise the benefits of future investments in coastline management and to 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 Szczecin (Poland).

EXECUTIVE SUMMARY

Component 4's aims are to catalogue and analyse existing coastal defence techniques used inside and outside Europe, with particular attention to innovative techniques such as wetland creation, dune maintenance and beach drainage.

Through extensive bibliographic research, Component 4 found sites particularly affected by erosion and where coastal defence techniques are applied (present, under construction or projected).

Among these sites it selected those where the most innovative techniques are present or under construction.

Component 4's purpose is also to establish key factors of success related to each of the techniques inventoried and to share best practice with local authorities with responsibilities for coastal defence.

In order to create a "coastal management toolkit" as expected from MESSINA, Component 4 will draw up the book of guide-lines "**Engineering the Shoreline**".

The dissemination is *via web site* (www.messina-es4.org) where the guide is available: it is correlated to a database with all the defence techniques examined. The latter are reported in detail according to the geographical location of the site and its physical features, the type of the technique used, the date of its inception, etc. This database provides a guide to the success of each technique listed.

The study will then focus on selected sites in order to make a Cost Benefit Analysis.

In particular, the *University of Messina* partner aims to catalogue and analyse existing coastal defence along the coast of Sicily, where there are different types of coastal structures. It also aims to provide a case study of beach nourishment combined with groynes and submerged nearshore breakwaters.

The *Isle of Wight Council* is responsible for coastal defence on the island. The Isle of Wight has a varied and complex coastline and an innovative approach to coastal defence planning and implementation. The Isle of Wight Council belongs to a number of organisations at regional and national level concerned with coastal defence issues and also actively pursues exchanges of expertise within Europe and internationally.

Planned results are:

- a review of best practice and operational recommendations to implement sound coastal defence solutions;
- increased exchange of experience and knowledge among local authorities in the field of coastal defence, with a specific focus on innovative engineering techniques.

The best practice guide “***Engineering the shoreline***” will synthesise the results of Component 4’s activity. It should help coastal engineers and local stakeholders to choose the best solutions for shore protection interventions. It will be widely distributed through the MESSINA website.

The guide, as part of the *coastal management toolkit*, will contain the following main chapters:

- i. Introduction to shoreline management
- ii. State-of-the-art for shore protection interventions inside and outside Europe
- iii. Presentation of a comprehensive database of coastal defence techniques
- iv. Presentation of a world map illustrating the location of innovative techniques
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SECTION I

I. INTRODUCTION

1.1. An overview of innovative environmentally friendly engineering techniques throughout the World

World coast is under growing threat from erosion. Coastal erosion is the gradual destruction of land by the sea. A fifth of the enlarged European coastline is already severely affected, with coastlines retreating by between 0.5 and 2 metres per year, and in a few dramatic cases even by 15 metres. Coastal erosion has dramatic effects upon the environment and on human activity. It can make houses fall into the sea and destroy roads and other infrastructure. It threatens habitats of wildlife, the safety of people living at the coast, and economic activities such as tourism. It is largely caused by human activity in the form of intensive development and use of sand for construction and engineering purposes. Rising sea levels and increasingly frequent storms and floods have worsened the problem. To cope with it, new and sustainable forms of coastal management are needed.

Coastal areas perform several important functions. Coastal habitats such as mud flats, salt marshes, sandy beaches and sand dunes are valuable for wildlife. Dunes are an excellent natural flood barrier and natural filter for drinking water. And salt marshes absorb wave energy during storm surges, thereby counteracting erosion. It has been demonstrated from both field studies and theory that a wide beach provides significant benefits in the form of storm damage reduction. During storms with elevated water levels and high waves, a wide beach performs as an effective energy absorber with the wave energy dissipated across the surf zone and wide beach rather than impacting on the upland structures. Lastly, beaches and beautiful coastlines are an essential asset for the tourism industry.

Coastal erosion threatens all of this. It leads to loss of land of ecological value (out of 132,300 km² - within 500 metres inland from the coastline - that are under the direct influence of coastal erosion in the enlarged EU, 47,500 km² are natural sites of high ecological value: they are rich in biodiversity and represent important ecosystems); loss of land of economic value (within 500 metres of the coastline: beaches, agricultural land and industrial facilities); loss of property; risk to human lives (over the past 50 years, the population living in coastal municipalities has more than doubled. They are increasingly exposed to the risk of erosion and flooding); destruction of natural sea defences, as erosion makes natural sea defences, such as dune systems, vulnerable (in November 2001, part of the dunes on the Jurmala coast in the Gulf of Riga - Latvia collapsed during a storm: this led to flooding of the hinterland); undermining of artificial sea defences, potentially leading to flood risks as well (for instance in Essex, UK, where the erosion of protective salt marshes has resulted in frequent damage to traditional seawalls during storm events).

Sometimes natural features can affect the coastal equilibrium (the sand balance). Impediments along the way, such as an inlet, can push the sand balance in one direction, since sand cannot migrate across strong cross-shore currents easily. Sand accretes or gets trapped in shoals and on the beach "updrift" of the inlet, while the beach "downdrift" of the inlet erodes or is starved

of new sand. Erosion is a net effect over time when there is less new sand entering a coastal system than leaving it. Erosion by itself is not harmful, as long as the shape of the shoreline can change and allow for such losses.

A barrier island is a dynamic ecosystem that tends to migration towards land over geologic time. This is due to the effect of severe storms which break through or breach the dunes and deposit the sand they erode from the oceanside onto the bayside in overwash fans. This normally builds up the landward side of the island as the ocean side narrows. This erosion/accretion is a slow, natural movement of sand.

But what happens to coastlines when sea levels rise? Many coastal geologists believe that sea level is rising at a rate of one foot per century, depending on the coastline. This seemingly small amount of change in water elevation can cause extensive changes to the shoreline over time as a low sloping, flatter beach is inundated. The most dramatic effects are seen during extreme storms, when tidal range swings to even greater extremes. Increases in levels of bay waters as well as ocean waters will narrow barrier islands from both sides, causing flooding and erosion.

Another natural cause of localised erosion is hydrodynamic conditions. The bathymetry or sea bottom contours of a particular area may focus wave energy at one point along a coast. Material with little structure such as softer marsh sediments will often subside, lowering the shoreline. A shoreline which lacks a source of fresh sand, for example one which receives little direct flow of sediments from inland rivers, will experience erosion. Storms such as hurricanes and northeasters often are the most obvious precipitator of severe erosion, but much of the sand that does not travel too far off shore in the storm will return to the beach with favourable weather in the following weeks.

Some coastal experts argue that erosion is not a problem at all unless people build on or near the beach. However, it is impractical if not impossible in many developed areas to return the beach to a pristine condition. New development must be undertaken in a well planned, responsible manner in order not to make erosion a worse problem than it has to be. For example, if a beach builds outward during an atypical accretional phase, the newly created land should be considered temporary in its existence and not viewed as a new development opportunity.

Sometimes the very act of trying to prevent erosion will make the problem worse. Certain types of hard armouring that fight erosion, such as sea walls and bulkheads, may protect the land behind them at the eventual expense of the beach in front of them. This is because wave energy bouncing off these structures can scour or pull sand away at their base. Groyne fields, when constructed improperly or in the wrong order, may act as a block to littoral drift, in the same way as the inlet system described above. Hardened inlets where large jetties have been built and deep navigational channels are maintained may be especially troublesome. Flood control structures such as levees in river systems may block inland sand's usual migration to the sea. Removal or alteration of the natural beach system, such as bulldozing or building on dunes, will hamper the beach's ability to act as a buffer to erosion and flooding.

Coastal erosion is a quite natural phenomenon, but man-made works can aggravate the situation. The main causes of coastal erosion's worsening are dams, docks, building on sea (coast roads, edifices, etc). This can alter the local sediment transport by waves, but can also affect the regular supply of solid material by rivers. The decrease of river sediment and debris can be due also to excavations on the river-bed, upstream dams, or control interventions of inland erosion phenomena.

Coastal defence is the general term which covers all aspects of human initiated defence against coastal hazards such as flooding and erosion. Coastal defence efforts may be small scale, involving relatively small structures, or may involve extensive land claims, e.g. by establishing buffer zones.

Coastal defence structures are generally concentrated on coastal plains around cities and harbours, tourist areas, industrial complexes and infrastructure. In other words, coastal defence is concerned primarily with the protection of economic interests rather than natural habitats.

There are a wide range of engineering methods and techniques for coastal defence which operate in different parts of the shoreline. Offshore techniques operating away from the shoreline include offshore breakwaters, stable bays, and barrages and lately nourishment. Techniques operating on the lower shore between low and high tide include beach nourishment, groynes, revetments, and sedimentation polders. Sea walls, revetments and flood embankments are located at or just above high tide on the upper shore as is the landward extent of the managed retreat technique. Finally supra-shore techniques which operate at or above spring tides include dune building, cliff strengthening, and beach ridge restructuring.

There are two main types of approaches to coastal defence:

Hard engineering: establishment of structures which aim to resist the energy of the waves and tides. Such structures include: breakwaters and seawalls designed to oppose wave energy inputs; groynes designed to increase sediment storage on the shore; and flood embankments and barrages designed as water-tight barriers.

Soft engineering: establishment of elements which aim to work with nature by manipulating natural systems which can adjust to the energy of the waves, tides and wind. This approach has economic benefits while minimising the environmental impact of traditional engineering structures. The methods which can be used include artificial nourishment; the set back of structures; and plantations of osier hedges and marram grass. In practice most coastal defences incorporate aspects of both these approaches.

Current trends favour the concept of shoreline management, working with the dynamic nature of the coastal environment, rather than fighting against the forces of the sea. This is best exemplified by the widespread move away from hard engineering methods of coastal defence which act to restrain coastal processes, towards soft engineering approaches which recognise the dynamic nature of the coastal environment by utilising these processes to advantage. Soft engineering methods usually have a lesser impact on the environment and may require less maintenance.

Present and forecast sea level rise, and an increase in the frequency and force of coastal storms resulting from climate change, are likely to mean that coastal defence efforts will become increasingly necessary to protect against erosion and flooding.

The impacts of coastal defences vary widely according to the techniques used, their specific design and the characteristics of the local environment. Some generalised impacts of coastal defences include disturbances of natural ecosystem processes and biotope structures of beaches, dunes, cliffs and the nearshore zone by partial or complete modification of landforms and sedimentary processes both on a local and regional scale; continuous loss of characteristic marine influenced ecosystems, such as episodically flooded coastal and riverine wetlands, coastal wet-forests or active cliffs; an increasing threat to the biodiversity of coastal areas; and visual deterioration.

The impacts of hard engineering are usually more severe than soft engineering. Hard engineering generally results in long-term changes in coastal morphology, particularly erosion, alongside protected areas. It also often leads to a reduction in the width of the shoreline as low-lying backshore areas are reclaimed behind defences. This leads to a decrease in the size of shore habitats, a phenomenon termed *coastal squeeze*. Soft engineering is generally a more environmentally friendly approach which works towards providing a dynamic equilibrium at the coast whereby erosion and flooding are kept to a minimum. It also generally requires more space to be used, thereby reducing coastal squeeze. Defensive structures which are designed to reduce wave energy at the shore often result in the build-up of sediment in the wave shadow of the structure. In some situations this may lead to covering or other changes to existing shoreline ecosystems. Hard defence techniques which reduce upper shore and cliff erosion also disrupt longshore sediment transport which often leads to the accelerated erosion of adjacent shorelines.

Some structures can be visually intrusive or can limit access to the shore and sea. They often present serious navigational and/or safety hazards. Where low cost materials are used, such as motor cars, tyres or sunken ships, long-term breakdown presents pollution hazards.

Defence techniques located in estuaries to protect against flooding such as barrages, tidal surge barriers and flood embankments can seriously disrupt the natural processes of these ecologically rich environments.

Nourishment techniques, if not carefully designed and/or if improper fill material is used can result in increases in the turbidity of coastal waters, and the continued wash-out of fine material can have long term negative effects on adjacent benthic and inter-tidal ecosystems. Changes in beach grain distribution can lead to the incursion of coarse-grained material over supra-tidal ecosystems such as lower cliff or dune communities. Rapid sediment deposition can swamp inter-tidal invertebrate communities and have serious effects on feeding birds.

Sea walls and other upper shore structures, if placed too close to the waterline, reduce the active width of the beach and dune during storms. This significantly disrupts the sediment balance and causes erosion especially along downdrift stretches of coastline. They also result in wave reflection leading to a

lowering of the foreshore and sometimes to the undermining of the toe of the seawall, which may ultimately cause it to collapse. Sea walls prevent sediment transport between beach and dune resulting in the deterioration of these environments.

Finally, afforestation of coastal dunes with non-native species, primarily for the purposes of coastal defence, has disturbed the natural dynamics of coastal systems.

UNEP has estimated the potential impacts of climate change in the Mediterranean assuming a 1.5° C rise in temperature by 2025. It predicts less rain the South, more in the North, an increase in the number of hot, dry summers, and exceptional droughts, rainfall, floods, storms, tidal surges, water stagnation and eutrophication. As a result of these changes, degradation of land and water will increase, causing a decline in agricultural production and damage to ecosystems.

Sea level rise will also have an impact on low-lying areas, deltas and coastal cities, particularly in combination with land subsidence which is exacerbated by the depletion of groundwater. Solutions involving the construction of dykes, walls and so forth are not considered feasible in the longer term over so wide an area, and alternative solutions are being considered. For example, lagoons could be used for aquaculture and nature reserves while serving as a buffer zone between the sea and developed areas.



Tab. 1.1. Europe: map of the case studies

Preceding and following images highlight the localisation of European and worldwide case studies.



Tab. 1.2. World map of the case studies

1.2. Prior to shoreline engineering: understanding the coastal system

A *coast* is the boundary (interface) between the land and the sea. It can be thought of as a *system*: it has inputs and outputs of energy.

There are 3 processes which create and modify the nature of this boundary:

- marine erosion
- transportation (longshore or littoral drift)
- deposition.

Waves are undulations of the water surface caused by winds blowing across the sea. They consist of orbital movements of water molecules which diminish with depth.

- Waves are the main agents of change at the coastline.
- Wave energy brings coastal erosion and sediment transport.
- When the wind blows over the surface of the ocean, surface waves are generated by the transfer of energy in the form of momentum from the air to the water: a 'drag' effect.
- When the wind first begins to disturb the surface of the water, tiny capillary waves called 'cat's paws' are formed. These quickly dissipate but while they exist they roughen the surface and increase the transfer of energy from the wind to the sea surface.

If there is no pattern to the wind, the surface becomes a chaotic state, called 'sea' or 'chop'.

Over time, as the wind blows in the same direction, a swell will develop. Waves moving out away from a storm eventually organize themselves into a swell, and eventually, if they are not destroyed by interference, they will reach the shore. Waves are a form of energy. The energy of the wind is transferred to the water. The wind blows over the water and piles it up into waves. The stronger (faster) the wind, the bigger the waves.

The longer distance over which the wind can blow (called 'fetch'), the bigger the waves. The more days a given wind blows (time), the bigger the waves – this can be shown on a wind rose diagram.

Wave energy is equal to the square of its height. So a wave 2m high has 4 times the energy of a wave 1m high. Wave power takes account of velocity, so it is $H^2 \times V$.

Wave velocity (celerity) can be expressed in direct terms, as m/sec^{-1} or in terms of wave period (time interval in seconds between successive waves).

The movement of water particles in a wave is in an orbit in deep water. As the wave approaches the coast, and the water gets shallower, the wave path becomes an ellipse. It starts to touch bottom where water depth is around 1/2 the wavelength.

The seafloor shallows as the waves approach shore, and eventually the waves reach wave base.

Wave celerity decreases because of friction and wave celerity now depends on water depth. The wave height increases and the trough flattens out. The wave gets so tall it can't support itself, and the water crashes over the top. This is called a *breaker*, and breakers form in an area called the *surf zone*.

The wave losses most of its energy by breaking, and the remaining energy causes the water to rush up the shore. It loses the rest of its energy to friction in this manner, then gravity pulls the water back out to sea. The surge onshore is called *swash*; the slump back to sea is called *backwash*. Swash and backwash occur in the *swash zone*.

There are 2 types of waves: surfing breakers and surging breakers. The first ones are high energy, steep and with short wavelengths waves; the second ones are low energy, shallow and with long wavelengths waves.

Waves interfere with each other and when two wave trains meet, crests and troughs can add together to make a bigger wave, or crests meeting troughs will cancel each other out.

These phenomena together are called respectively *constructive* and *destructive interference*. As waves approach the coast they are also refracted. They start to take on the shape of the coastline, which means that wave energy is concentrated at the headlands and dispersed in the bays.

Beaches, therefore, cannot be considered as a stable environment to be overworked without any consequences.

Coastal landscape modelling is an interactive complex phenomenon, because it is ruled by several dynamic processes, all linked in a non-linear way. Therefore, according to modern geo-physical assumptions, it is incorrect to simplify the study of the coastal environment by applying the classic theories of equilibrium.

These transitional systems are overlooked by *not-equilibrium* physical principles and each physical, biotic and anthropic element interacts with its contiguous elements accelerating the dynamic of the geomorphic processes.

Sandy coasts are made of loose mobile materials and so are subject to continuous evolution by the dynamic sea action. It is evident that to carry out effective management and safeguard of the coastal environment it is necessary to consider all the processes, factors and phenomena of the examined system, and how they are distributed in space and time.

Particularly, to verify the processes acting along a littoral, it is necessary to analyse the morphology and lithology of the emerged beach and of the forthcoming sea floor.

An understanding of the physical and biological processes associated with beach and littoral systems is needed to minimise the effects of uncertainties and to accommodate regional differences in physical and biological processes. A more complete understanding is also needed of the following factors: the natural variability of beach profiles and their response to natural processes; physical processes with respect to closure depths; sand characteristics (i.e., grain size, shape, density) and their effects on project performance; process-based cross-shore sediment transport models related to profile changes; and the causes of erosional hot spots.

1.3. The coastal sediment cell

Erosion of the cliffs can provide direct sediment input- However, there are lots of other sources of sediment such as currents bring in material from the sea bed. In all areas the sediment is either stored as a depositional landform or as a nearshore feature such a bank or offshore bar. Alternatively it is transported as a throughput and become outputs from the system being deposited either in deeper water or away from the coastal area in question.

Sediment can be divided into 2 types

- a) Clastic Sediment
- b) Biogenic sediment

Clastic sediments are from rock weathering and erosion- these can vary in size from really small clay and mud particles to sand, pebbles and boulder size Biogenic sediments are the shells and skeletons of marine organisms.

Waves, currents, tides and wind provide the energy inputs for the erosion and transport of sediment from the source areas to create coastal landforms which exist in a state of dynamic equilibrium with the local conditions.

These depositional landforms such as beaches, sand dunes, salt marshes and mudflats, act as a dynamic sediment store and sediments are transported onshore, offshore, and alongshore to create them. These stores in turn provide sediment for stores further down the coast.

The sand and larger particles are transported grain by grain as non-cohesive sediments. The energy of the waves and currents needed to erode and transport such sediments varies with the size of the particles (you might expect smaller clays and muds to require very little energy but they are sticky or cohesive. Their particles tend to cling together by electromagnetic bonding. These sediments require a much larger velocity to become entrained (get moving) than their individual grain size would suggest. Once they have been dislodged and set in motion they are moved very easily with little velocity needed.)

As particles are transported they become rounded by attrition.

Large sediments are deposited in high-energy environments to form beaches. Smaller particles such as silt and clays are carried in suspension and settle in areas of reduced wave energy but high tidal energy to form salt-marshes, mudflats etc.

The landforms which reflect these local conditions are in a state of dynamic equilibrium. In areas of mobile clastic sediment these adjustments take place continuously in response to short term wave and tidal conditions, as well as eventually reaching a long term equilibrium. The erosion, transport and deposition processes sustain the equilibrium both offshore and onshore. At low tide and on sandy beaches, the wind can act as a transport agent by entraining and transporting small sand and silt particles. These particles are quickly deposited again and may form sand dunes.

The movement of sand and shingle in the nearshore zone by longshore drift (littoral drift) occurs in discrete, functionally separate sediment cells. Sub-cell boundaries identify smaller cells associated within the major cells. There is some movement of sediment between cells. These cells are called open systems.

There are 2 sorts of sediment cell boundaries: *littoral drift divides* and *sediment sinks*.

Littoral drift divides (longshore drift divides) form where the coastline abruptly changes direction such as at major headlands. They also occur where wave conditions cause a change in longshore drift direction. Since material is moved outwards from a drift divide there is a net output of sediment from the area. This results in a dominance of erosional processes and landforms e.g. eroding beaches and cliffs.

Sediment sinks form where sediment transport paths meet so that sediment builds up in depositional environments. Sediment sinks occur in deeply indented bays and estuaries, although spits and cusped forelands may form sub-cell sinks.

1.4. The physical system

The shoreline is a very dynamic environment. The exposed strip of sand that we think of as the beach is actually only a small part of the entire coastal system. A natural coastline includes primary and secondary dunes, the emergent beach, the intertidal zone, the surf zone, near shore bars and the submerged beach out to a point of closure. Beaches can be connected to the mainland. This is called a headland beach. Beaches can also be long strips separated from the mainland by a bay or pond. This is called a barrier island. When one end is connected to the mainland only, this is called a peninsula. The mouths of rivers or bays that empty into the ocean are known as deltas, inlets or beachways.

Sand migrates in wind-driven currents, similar to a river, along the shore, as well as inshore and offshore with each wave. This effect is called longshore current. These currents can switch back and forth with wind but usually have predominant direction. This migration of sand keeps each beach along the way nourished with new sand as it sweeps the beaches' sand along to another, maintaining a sand balance.

1.6. The social and economical system

Internal costs are the investment and recurrent expenses relating to the implementation of the shoreline management scenarios.

They include:

- ✓ the preliminary costs, which is to say the costs of preliminary studies including technical feasibility, environmental impact assessment, cost-benefit analysis, and social perception studies.
- ✓ the investment or capital costs necessary to implement the Shoreline management scenario. These costs include the collection and production of baseline data and indicators, consulting fees for shoreline modelling and technical design, expenditure related to input materials and field operations, and the costs of project management and administration.
- ✓ the operating and maintenance costs, which are the costs to be spent annually to maintain the effectiveness of the Shoreline management solution over its life expectancy. These costs should be calculated at present bank interest rate.
- ✓ the operating cost of environmental monitoring procedures, which is to say the costs of measures and procedures to monitor and mitigate the adverse effects of the Shoreline management scenario, as defined by the

environmental impact assessment study. These costs should be calculated at present bank interest rates.

External costs and benefits respectively reflect a decrease or increase of values induced by the different scenarios. These values include:

- ✓ the human value (marketed benefits and costs), which is to say the value derived from goods (including lands) which can be extracted from, or built on near-shore areas, as a direct result of mitigated coastal erosion, such as new infrastructure built in areas less prone to coastal flooding, new hotel resorts built along waterfronts and to a lesser extent small scale mining activities of sea products. Once estimated, annual direct use benefits should be calculated at present bank interest rate.
- ✓ the economic value (marketed benefits and costs), which is to say the value – mainly in monetary terms – that humans can extract from the sale of products, services and/or rights derived from a land parcel or from assets built on this parcel (such as infrastructure). The economic value may be expressed in a variety of ways including in terms of capital invested, land market value, replacement costs, turnover, or jobs. It may concern a wide range of economic sectors: tourism, mining, agriculture, aquaculture, fisheries, services, etc. Once estimated, annual economical benefits should be calculated at present bank interest rate.
- ✓ the ecological (or regulation) value (non-marketed direct benefits and costs), which is to say the value derived from functions fulfilled “naturally” (i.e. without human intervention) by a coastal land parcel. This includes, for example, dunes protecting freshwater lagoons and filtering waters; wetlands and local marine habitats providing suitable conditions for fisheries and aquaculture, marshes and flats absorbing nutrients and contaminants drained by rivers. Ecological value may be expressed in terms of replacement costs or willingness of the public to pay for protection. Once estimated, annual ecological benefits should be calculated at present bank interest rate.
- ✓ the heritage (or existence or information) value (non-marketed indirect benefits and costs), which is to say the value derived from the benefits which do not involve using the site in any way, the value that people derive from the knowledge that the site exists, even if they may never actually visit it. Heritage value may be estimated for designated buildings and monuments (e.g. churches), designated natural parks (national, regional parks, site of scientific interest), archaeological sites, historic gardens, parks, or battlefields, and sites of special interest. The annual budget spent on the conservation of heritage sites, or willingness to pay for their conservation, can be taken as indicative of heritage value. Once estimated, this value should be calculated at present bank interest rates.

1.8. The technical and financial environment

Although proven engineered shore protection measures exist, there are no quick, simple, or inexpensive ways to protect the shore from natural forces, to mitigate the effects of beach erosion, or to restore beaches, regardless of the technology or approach selected. Available shore protection measures do not treat some of the underlying causes of erosion, such as relative rise in sea-level and interruption of sand transport in the littoral systems, because they necessarily address locale-specific erosion problems rather than their

underlying systemic causes. Furthermore, all shore protection and beach restoration alternatives are controversial with respect to their effects on coastal processes, effectiveness of performance, and socio-economic value.

For these reasons, the MESSINA project pays strong attention to the balance of costs - including environmental costs - and benefits - including environmental benefits - related to the various technical solutions for the shoreline protection.

Such solutions, in fact, must always be “sustainable” by local communities either in financial or in socio-economic terms. In order to examine the relevance or irrelevance of certain solutions, it is recommended that a cost-benefit analysis is carried out, the result of which can help to identify the optimal solution, including the “do nothing” option.

Carrying out a cost-benefit analysis is a technical exercise involving numerous choices and calculations. The more complicated the decision being addressed, the more care should be taken to identify and measure key variables and to analyse them appropriately. However, the technical nature of the analysis should not obscure the fact that the exercise is being carried out to inform the decision process. Each decision under analysis must be documented and described in a manner which will reassure those who are party to the decision process that the choices are sound.

Once a decision to carry out a cost-benefit analysis is made, the conceptual concerns raised above are set aside and the pragmatic business of specifying the overall framework to be used, the input variables to be included, how to measure them, and many other decisions must be made. These decisions are not inconsequential, because seemingly innocuous choices, if arbitrarily made, can cause large swings in the outputs of the analysis.

The cost-benefit analysis must generally measure the net benefits of projects that generate costs and benefits over a period of time, with costs and benefits often occurring in different time periods. This increases the complexity of the analysis, because a euro of costs or benefits ten years from today is not directly comparable to a euro of costs or benefits today. Because comparisons require a common metric, cost-benefit analysis uses a process called discounting to express all future costs and benefits in their present value equivalent. This takes place by discounting costs and benefits in each future time period and adding them to arrive at a present value.

This gives rise to one of cost-benefit analysis weaknesses. Because the discounting process calculates its results from the present generation's perspective, one needs to be concerned about intertemporal equity issues, that is, to the fairness of the decision to future generations. In fact, costs that occur far into the future may be given little weight in traditional cost-benefit analysis.

SECTION II

II. ENGINEERING TECHNIQUES

1. *Beach nourishment*

1.1. Purpose of beach nourishment and expected results (protection vs. nourishment)

Beaches – transition zones between land and sea – provide a measure of protection to the shore from damage by sea but are above all valued as recreational resources. Visiting beaches has become synonymous with coastal recreation. Beach amenities are an important factor in the commercial and residential development of most upland areas behind beaches.

In the past, development of coastal areas often began behind dunes or in back bay areas, which provided substantial buffers between buildings and the sea. However, modern development of beach areas has predominantly occurred in close proximity to the beachfront and has often resulted in the replacement of dune system with buildings. A number of engineering approaches have been used to counteract the effects of erosion by stabilising or restoring beaches.

Traditional protective measures have included *hard* structures such as seawalls, revetments, groins and detached breakwaters. These structures can reduce flooding hazards, armour the coastline, reduce wave attack and stabilise the beach. None of these shore protection structures, however, adds sand to the beach system to compensate for natural erosion. Beach nourishment is the shore protection alternative that directly addresses the problem of a sand budget deficit, because it is a process of adding sand from sources outside the eroding system. The result is a wider beach that improves natural protection while also providing additional recreational area. Such a measure does not treat the coastal landscape as such, causing rise in sea level or interrupting sand transport in the littoral system, because it necessarily addresses locality-specific erosion problem.

Most coastal engineering practitioners consider beach nourishment a technically sound engineering alternative when properly designed and placed in an appropriate location. Beach nourishment projects in some locales have performed better than predicted, whereas others have performed more poorly than predicted. In some cases, often as a result of inappropriate or uninformed perceptions about project performance, public expectations have not been met even when design performance criteria were achieved. Opponents often view the sacrificial aspect of beach nourishment as little more than building sand castle to protect against an advancing sea. The controversy over the technical merits of beach nourishment has been exacerbated by national concerns over the economic effects of beach restorations.

Advancing the state of practice of beach nourishment requires an improved understanding of project location, complex shoreline processes, prediction, design, cost-benefit analysis, sand placement and distribution, cost-sharing allocations and monitoring.

Beach nourishment is a viable engineering alternative for shore protection and is one of the principal techniques for beach restoration; its application is suitable for some, but not all, locations where erosion is occurring. Beach nourishment can provide protection from storm and flooding damage when

viewed within human time scales (decades not centuries) in those situations where its use is technically feasible, provide that erosion rate is reduced. Beach nourishment may not be technically or economically feasible or justified for some sites, particularly those with high rates of erosion.

1.2. Basic principles

Beach nourishment, a technique used to restore an eroding or lost beach or to create a new sandy shoreline, involves the placement of sand fill with or without supporting structures along the shoreline to widen the beach. It is the only management tool which serves the dual purpose of protecting coastal lands and preserving beach resources.

It consists basically of a contribution of sand to a coastal zone that has a negative sedimentary budget or in which the beach section presents slighter dimensions than those desired.

It uses artificial methods, such as offshore dredging and pumping. The primary objective is the creation of a sedimentary beach with the minimum conditions of stability and duration.

Regarding the stability of the coastal front, artificial regeneration causes a positive effect by the immediate contribution of sediment to the environment, modifying the sedimentary balance in favour of accretion. One of the aspects to consider is the quality of the contributed sand which will need to possess very similar characteristics to the original. Taking sandy materials from coastal zones has a significant environmental impact, and can lead to materials pollution, the destruction of fish spawning habitats and coastal weakness. Consequently, taking sand from places where the water path is dredged is recommended.

This is a very soft method which adapts easily to natural coastal processes and does not mar the landscape of the beach. But beach nourishment does not affect the causes of erosion. *Artificial* beach is put under the same rate of erosion as the original beach, and in time will disappear in the same manner. Artificial nourishment therefore needs to be replenished periodically.

Sometimes the best design includes the use of structures such as groynes or breakwaters along with the placement of sand. The use of structures in combination with renourishment may better hold the new beach sand and slow the rate of erosion. While rock groynes sit perpendicular to the shore and inhibit the littoral drift of sand, breakwaters are positioned near the shore and parallel to the beach.

Soft nourishment is nourishment by sands picked up from submerged caves or inland areas and distributed over the eroded beach. Many academics believe it is the better solution for coastal defence from the efficacy point of view (wave energy is dissipated), and from the functional point of view (the under-wave littorals are less compromised), and from the environmental point of view (the previous habitat is re-created).

Protected nourishment provides coastal structures able to dissipate part of the wave energy and reduce the littoral transport, and to retain the new fill material. The most effective solutions include an offshore underwater rock barrier fixing the natural dynamic sandy bar, as a “perched beach” scheme. The submerged bar should hold the artificial beach at a shallower slope, reducing both offshore sand losses and longshore transport, enhancing the development of marine fauna, without endangering bathing and leisure navigation.

1.3a FIRST Application : *Ostia Lido case study*

1.3.1. *Description of the site*

The coast of Ostia in Italy an example of the application of this technique.

Lido di Ostia is located near Rome (Lazio). The Lazio territory is situated in the middle of the Italy with a coast of about 350 Km on the Tyrrhenian Sea. About 230 Km of the Lazio coast are characterised by sandy beaches, crowded with tourists during the summer months.

Along the Lazio coasts there are many shore protection works, some of which are very old (1910-1920), but the problem of shore protection began to be pressing from the early sixties when several direct and indirect factors contributed to a serious situation:

- increase of tourism with new beach areas in demand;
- increase of urbanisation on the coast with destruction of dunes and many infrastructures built close to the seaboard;
- decrease of solid transport by rivers (dams, sand borrows, soil protection, etc.) with regression of shoreline.

Since 1907, with the first Italian Law on beach defence declaring a *beach defence work* is “every work having the aim of stopping the corrosive process” (Law no. 542/1907), the Superior Council of Public Works defines the *beach* as a *coastal defence structure* (“beaches can efficiently dissipate the wave energy and so they are classified among the defence structures of the coast”; Delib. no. 151/1991). Under the laws of the Region of Lazio, coastal defence works have as their main aims the protection of the inhabitants and important coastal infrastructures, containing erosive processes and re-shaping of beaches (if necessary through artificial nourishment), the re-naturalization of the coastal stretch, and the protection and rehabilitation of littoral dunes. Every intervention has to consider the local geo-morphological setting and minimise the environmental impact.

The sandy beaches of Lido di Ostia stretch along the southern delta cusp of the river Tiber, some 25 km from Rome, on the Tyrrhenian Sea, and have provided for many years a very popular holiday resort for the Roman community. The cusped delta was formed by alluvial sediments carried by the river, producing a progressive coastline advance of more than 4 km from the Roman age until this century. Particularly in the last 25 years, a severe erosion process has been taking place reversing the evolutionary trend to a recession rate of 1.7 m/year. The main cause has been the severe reduction of river sediment supply (due to upstream dams and extraction of building materials from the river bed) with a consequent deficit in the coastal budget and a trend towards the cusp straightening and smoothing out.

The local tidal range is very small (below 0.5 m), but deepwater waves may exceed a significant height of 5 m and a period of 10 s. The local climate shows a typical bimodal distribution and the resultant of the wave energy vector is directed from 225 N, angled to the coastline normally oriented at 210 N, so with a southbound littoral drift.

Past coastal protection works have been partially successful, such as the system of detached breakwaters constructed near the river mouth: erosion was

shifted downdrift, causing damage to the beaches and the littoral road southward.

1.3.2. *Previous interventions*

A beach nourishment project was designed in 1988 (Toti et al., 1990).

The artificial nourishment was protected by a submerged sill carried out at Lido di Ostia in 1989-1991.

The aim of the project was to recreate a wide protective beach but, successively, financial constraints restricted the project area to the most vulnerable 3 km stretch of coast.

The proposed beach nourishment needed to be protected by an underwater rock barrier.

Because of the very fine grain size of the native beach sediments, fill material was quarried inland on the alluvial Tiber delta. It was a graded mix of well rounded sands and gravels.

The protection scheme is shown in Figs. 3-4 and basically consisted of a sill made with a submerged rubble mound parallel to the shoreline at a distance of some 150 m, -4/-5 m b.s.l.; a multilayer rock mound placed above a geotextile; a fill with a double layer of quarry material; a lower layer of mixed sandy gravel; and a thick upper layer of sand.

The average planned shoreline advance was about 60 m. Mathematical model studies carried out by Drecht Hydraulics (1989) found a dynamic equilibrium position 5 years after construction.

From May 1989 and for the following 14 months the works progressed from the south part of the Lido (Pescatri Canal) to the north against the littoral drift direction.

Monitoring plans followed and no adverse effects were *initially* observed on the adjacent beaches. The elevation of the emerged beach was increased up to MSL +1.5/+2.0 m, while the submerged beach profile generally deepened as shown in Fig. 5. The sediment transport rate varied between 5,000 and 15,000 m³/year.

After some years of monitoring and the occurrence of many severe storms, the behaviour of the new perched beach at Lido di Ostia seemed to be satisfactory. The observed longshore and cross-shore redistribution of sediments were in accordance with the design predictions. Ecological and aesthetic impacts were also acceptable: the quality of beach and of seawater was satisfactory, as confirmed by the large tourist crowds in summer. The submerged rubble sill was stable and did not affect the beach recreational activities (apart from surfing). This structure is nowadays seen as a dark blue strip in the sea, and it has favoured the development of marine fauna, being now fully covered with mussels and stimulating leisure fishing.

1.3.4 *Actual applied methodology*

The works of Ostia beach, performed in 1999, covered a littoral of about 3.500 m and involved about 1 million cubic meters of sand. The increased beach area was about 155.300 m², with 44 m as the average beach

progression, considering a ratio of sand need / beach progression (SB) of about $6,2 \text{ m}^3/\text{ml}$.

The source of sand for the nourishment project was the offshore area at Anzio (8 km from the coast, 45 km from Ostia) which had a capacity of more than 10 million cubic meters. A series of deep logs were done to select the proper area of sampling. This *soft* beach nourishment has taken 600.000 m^3 of sand from the selected marine caves at 50 m depth, piled up through dredging.

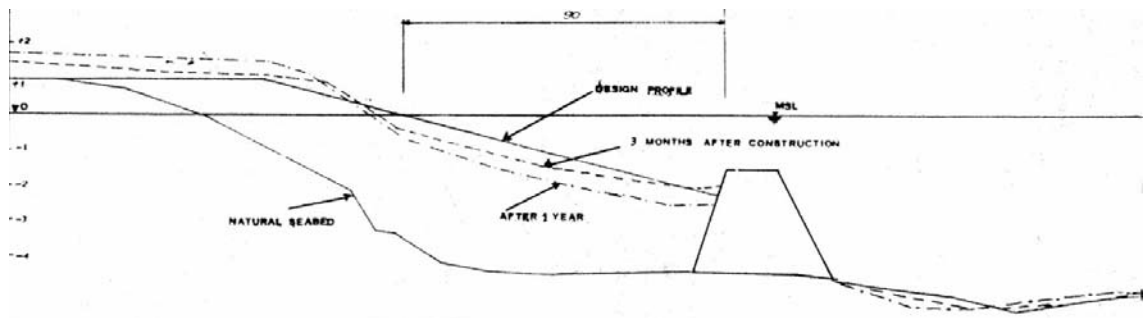


Fig. 1.1. Protected beach nourishment scheme.



Fig. 1.2. Protected beach nourishment in Lido di Ostia.

1.3b SECOND Application: *Gulf of Riga case study*

1.3.1 Description of the site

To look at beach nourishment, the Gulf of Riga (Latvia)'s beaches have been examined. The length of the Latvian coastline along the Baltic proper and the Gulf of Riga is 496 km. Circa 123 km of the coastline is affected by erosion. The case area '*Gulf of Riga*' focuses on coastal development within the Riga metropolitan area, which includes the coastal zone of two urban municipalities (*pilsetas*) – Riga and Jurmala (Fig. 1.3). Riga is the capital city of Latvia. It is located along the lower stream and the mouth of the Daugava river. Its several districts (Bulli, Daugavgriva, Bolderaja, Vecdaugava, Mangali and Vecaki) lie in the deltas of Daugava and Lielupe rivers and on the Gulf of Riga coast. Jurmala municipality is adjacent to Riga from the west. It stretches ca. 30 km along the Gulf of Riga. It is the largest Latvian and Eastern Baltic seaside resort.



Fig. 1..3. Location of the coastline of Latvia and the case study area, including harbours, main rivers, and direction of integral load transport.

Coastal morphology and dynamics. The morphological features of the study area show that the Jurmala – Riga region represents a graded and flat coastal area. It has a shape of two concave arcs, which are intersected by the mouth of the Daugava River (Fig. 1.4). The Jurmala – Riga coast is characterised by 40– 60 m wide sandy accretion beaches, which gradually descend into morphologically similar sandy foreshore ($i = 0.003$). Up to 3 shore-parallel underwater sand ramparts feature the flat foreshore of this area. The onshore part of the sedimentary coast is framed by the artificially created 3 – 6

m high foredune behind the beach. Behind the modern foredune there is an ancient 8 -15 m high dune ridge left after the Littorina sea transgression. The landscape of the Lielupe and Daugava deltas is typical of the deltaic lowland where coastal marshes and meadows are interspersed with deltaic branches, oxbow lakes and dunes.

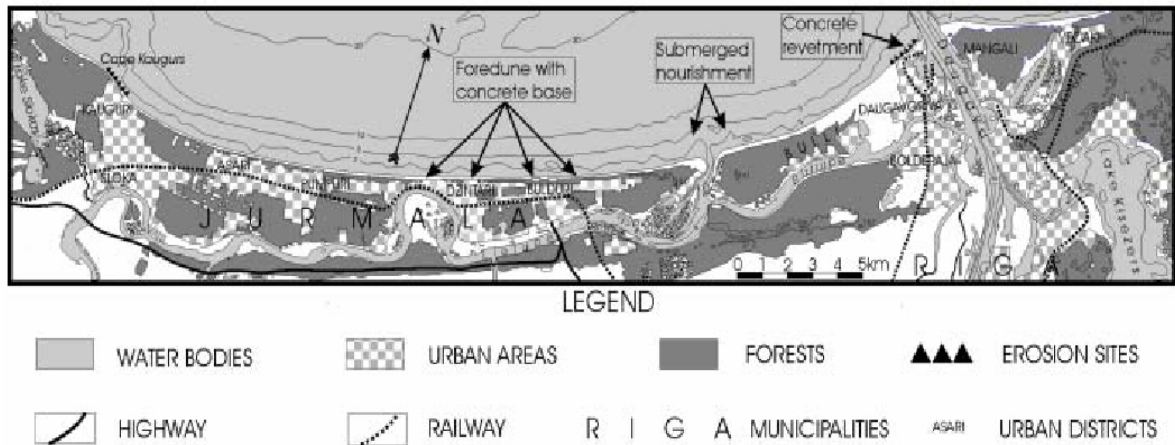


Fig. 1..4. Study area. Source: Shoreline Management Guide EuroSION case study Gulf of Riga

The principal dynamics processes involved in the case study area are:

- *Waves and storm surge:*
 - Wave activity and the wind-induced surge during storm events are the principal physical erosion agents in the study area. The concave and flat coast of Jurmala and Riga is exposed and extremely susceptible to the storm.
- *Ice:*
 - Sometimes, in winter, an ice cover develops in the Gulf of Riga, which ends wave action for the winter period, but in spring when the increasing water level raises the ice, the ice-sheet breaks up and is pushed on to the coast by strong winds, where it piles up in 5 – 10 m high hummocks. Ice, which is pushed onto the shore, damages the coast (beach and dunes). However strong ice pile-up might have been so far it has only had a very limited long-term impact on coastal development within the study area, as the spatial distribution of ice-scours randomly varied with every event. However, the combination of ever more frequent disastrous wind-induced water level rises in the foreshore with ever-higher winter- and/or spring-flood events at the river mouths does increase the threat from ice pile-ups upon the coast.
- *Eustasy vs. Isostasy:*
 - The south coast of the Gulf of Riga is in tectonic equilibrium with resulting insignificant movements of the Earth's crust, which have negligible impact on secular coastal development in the study area.
- *Tide:*
 - Regular tide ranges in the adjacent Baltic Sea foreshore are less than 0.25 m; therefore tidal action plays virtually no role in coastal development.

- *Weathering and underwashing:*
- Impact is possible at cape Kaugurs, which is an eroded residue of a coastal dune formation overtopping the Palaeozoian sandstone bedrock.

- *Decline of sediments:*

Since the 1930's the construction of the cascade of dams on the Daugava river and the dredging of sand for construction purposes from the Lielupe lower stream has essentially reduced the amount of river sediments reaching the Gulf of Riga, and caused the deficit of sediment output feeding the foreshore and beaches. This deficit in its turn has enhanced the coastline retreat in the areas adjacent to the Daugava river mouth at the end of the 20th century.

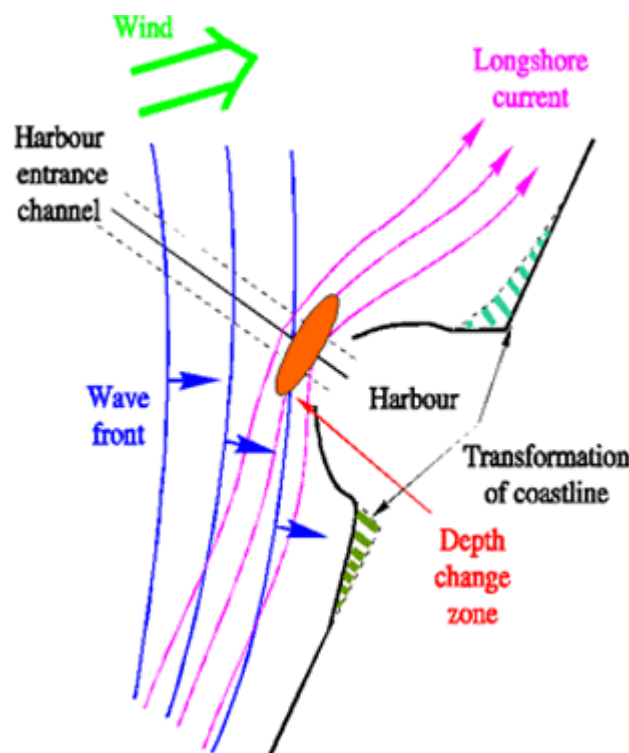


Fig. 1.5. Scenario of development of the coastal load transport processes.

The principal scheme of the processes related to the long-shore sediment transport and their interaction begins when the bed and suspended load transport is driven by the coastal hydrodynamics. The longshore and **wind** currents determine the velocity and orientation of mainly longshore load transports that have maximum values of depths of about 0 to 7 m. **The wave field**, especially in the zone of breaking waves, is most important in generating the shear stress and producing the suspension of the grain material in the water column. Wave-field is responsible also for the sediment transport to and from the shoreline. The bottom **shear stress** is dependent on the water depth (i.e.

the bathymetry and the actual water level), whilst the suspension rate as well as the bed load movement depend on the particle size distribution (grain size dispersion: typical mean of the distribution lies within range from 0.1 to 0.3 mm). Besides the bottom sediments, the load flow along the shoreline is being fed or diluted by, respectively, the erosion or growth of the coastline. These processes of coastal dynamics can result in changes of several hundred metres per half a century, and are driven mainly by the wave field action on the beach, which has a different impact for different water levels and size distributions of the sand particles.

The sinks (sedimentation) and sources (erosion) of the material load transport are dependent mainly on the bathymetry and the configuration of the natural and artificial (hydraulic constructions) obstacles, that, interfering with the hydrodynamics, results in the over- or undersaturation of suspended load, and inability or ability to move the bed load. The above conditions produce, respectively, sedimentation and erosion. These processes have a reversing influence on the depth redistribution as well as on the grain size dispersion of the bottom material (coarser particles in the erosion zones but smaller ones in the sedimentation regions). The superposition of the human influence on the depth distribution over the natural processes has to be carefully accounted for.

The processes of coastal hydrodynamics driving the load transport are :

- water level fluctuations in the synoptic time-scale, due to the action of mainly local winds and the overall atmospheric pressure field; in the cases of the location of the harbour in the river mouth (see Fig. 1..1) the river run-off (including its possible forcing by hydropower stations' regime) also may affect (enlarge) the water level in the regions of the vertical density stratification;
- wind wave field in the open sea and coastal wave transformation zone;
- longshore currents driven through the transformation of the wave field energy due to (i) non-orthogonality of the wave vector in respect to the coastline (energetic currents) and (ii) non-equal seaward depth profiles in different locations along the shoreline (gradient currents); longshore currents prevail in between the wave-breaking line and the coastline;
- wind-driven currents prevailing seawards from the wave breaking zone.
- One has to note also the interrelation of the above four elements of the coastal hydrodynamics and their structural dependence on the depth distribution and bottom material. The whole hydrodynamic process is forced by the local (river run-off, wind velocity and direction) and the global (cyclonic and anticyclonic atmosphere structures, non-homogeneous wind field over the whole Sea or Gulf, etc.) meteorological conditions.
- the fronts of the wind waves transforming in shallow zones reach the wave-breaking line non-parallel to the isobaths;
- energy transformation - after breaking, the waves produce the long-shore currents with the maximum discharge at the depths of 6 to 7 m

along the coast of the Baltic Proper or 3 to 5 m along the coast of the Gulf of Riga;

- the currents carrying the material load incline seawards (to the greater depths) before the wave breakers; here, mainly due to the greater depths, they become oversaturated and the sedimentation occurs;
- the long-shore current becomes even more oversaturated crossing the border of the channel. Due to the rapid increase in depth the bed load transport stops here, whilst the sedimentation of the suspended load depends on the width of the channel;
- passing the seaport, the longshore current is undersaturated; it restores the load transport up to pre-harbour transport capability continuously. This process causes the prolonged erosion of the bottom downwind from the harbour;
- the decrease of depth in the upwind side of the harbour shifts the wave-breaking zone seawards. The load transport to and from the coastline tends to support the growth of the beach (and vice-versa for the downwind region).

Some types of technical measures employed on Riga's beach have been foredune and forestry maintenance (see §3.3b), revetment and submerged nourishment.

- *Revetment:*

The revetment of Daugavgriva was built in 1960s in order to protect the adjacent port facilities from erosion. There was a dyke (a storm surge barrier) established and a concrete revetment was built in front of it. In 1999 the revetment has been reconstructed by applying geotextile technology. The length of the revetment in Daugavgriva was ca. 600 m.

Year	Amount in m3
1998	43000
1999	36000
2000	22000
2001	18000

Tab.2.1. Amount of dredged material in the mouth of Lielupe river. Source: EUROSION Case Study Gulf of Riga.

- *Submerged nourishment:*

Sand material dredged from the Lielupe river has been applied for the submerged nourishment of the coastal zone in 1990s in the foreshore adjacent to the river mouth. The amount of dredged material (fine sand and silt) applied for the submerged nourishment at Jurmala foreshore is given in Table 2.3. The depth at which the dredged sediments were dumped is 4 m.

The main objective for which the submerged nourishment has been performed in Riga is the stabilisation of the coast, particularly in recreational beaches where there are tourist facilities.

1.3c THIRD Application: *Dziwnow case study*

1.3.1. Description of the site

In **Dziwnow** (West Pomeranian Province, Poland) beach and dunes should protect the coast in the event of the “100 years storm” (this means that the min top of the dunes should be at the +4,80 m and the min dunes width should be 10 m; the seaside slope 1:3).

1.3.2. Previous interventions

The first protecting constructions (groynes) were built in 1918. Development of this municipality as well as progressive erosion of the coast caused by natural processes and hydro-technical constructions (link – side effect) requires continuous coast protection. Since 1956 to 1996 the range of protection has been successively increased. In 1956 and 1960 seawalls were constructed, but in the following years these structures deteriorated or were destroyed and from 1984 onwards the new, hard seawalls were constructed in the same place but much closer to residential buildings. The remains of old seawalls were removed lately in the interests of the safety of the people using the beach. The protected area was also expanded by means of groynes constructed to follow the link – side effect and the beach nourishment was applied.

The final intervention has been to protect a few residential buildings situated on Dziwnow Spit at the cost of narrowing the beach in front of seawall as well as at the cost of successive erosion of coast in the vicinity of protected sections. This situation necessitates the protection of longer and longer sections of the coast (in 1918 – 3.5 km, in 2004 – 8.5 km).

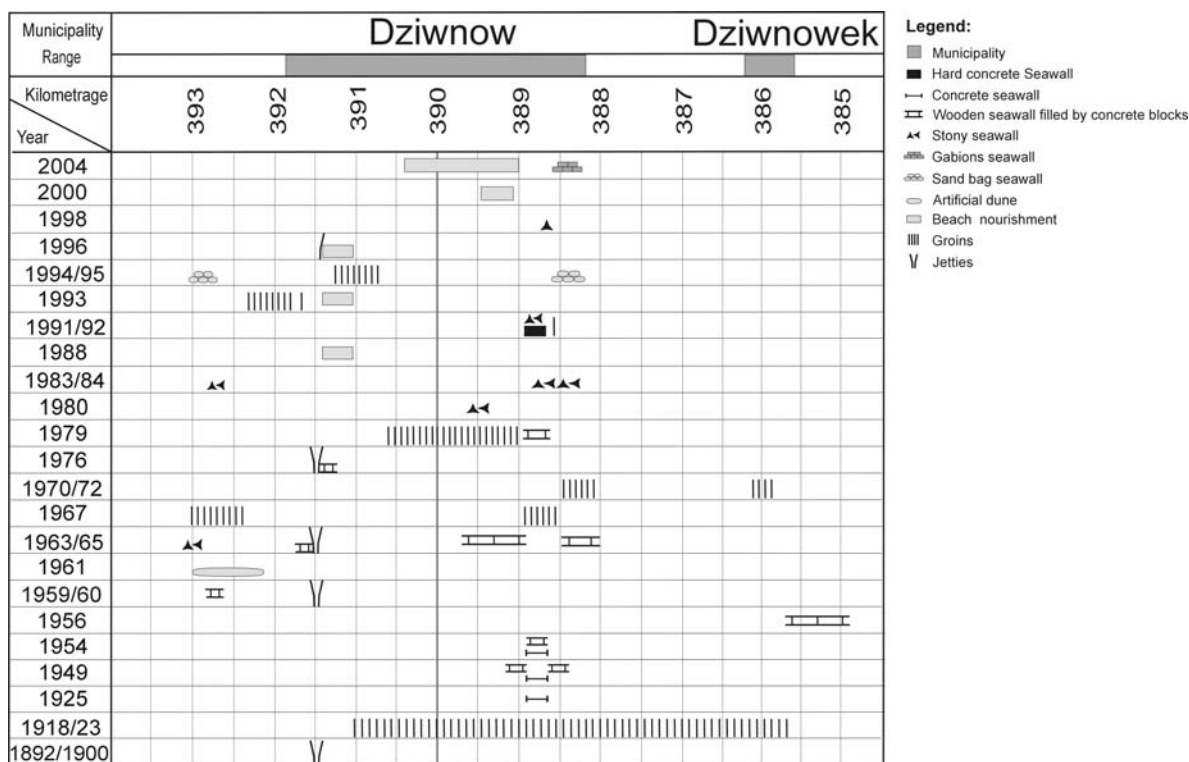


Fig. 1..6. Historical evaluation of hydro-technical constructions in Dziwnow region (based on the Maritime Office Materials)

Beach and dunes were measured in profile every 100 m in 1997; morphological parameters were calculated including “coefficient of feeling” and their changes along the coast.

Bathymetrical profile measurements were done in 1995-97 in the range of 1400 m from the coast every 500 m.

On the coast designated for beach nourishment several preliminary studies were carried out:

- Levelling measurement of the sea-side slope of the forehead dune in cross-section, every 100 m up to 0.2 m depth between 386.0 km and 394.0 km of the beach (80 profiles)
- Bathymetrical measurement in cross-section, every 500 m for about 1,5 km (17 profiles)
- Seismo-acoustic measurement in cross-section, at 386.0 km, 388.0 km, 390.0 km, 392.0 km, 394.0 km and in 2 profiles parallel to the coast (located 600 and 1200 m far from the water line)
- Sampling of the 8 drill core and surface sediment in characteristic places of the levelling and bathymetrical profiles, in cross-section, every 500 m.

On the potential area of collection the sand for beach nourishment the following studies were carried out:

- Bathymetrical measurement of 6 parallel profiles every 500 m.
- Seismo-acoustic measurement of 6 parallel cross-sections every 500 m (echo sounder and sub-bottom profiler)
- 16 drill core in a potential area for collection of the sand for beach nourishment



Fig. 1.7. Beach nourishment in the investigated site

Main features: Geographic coordinates: 54°02'N - 14°46'E.

Authors of Coastal defence Project or Plan H. Boniecka, A. Cieslak, R. Dubrawski, W. Gawlik, R. Leśny, h. Metlicka, E. Niemkiewicz, W. Potylicki, J. Warda, E. Zawadzka Maritime Institute, (Laboratory of the Marine Hydrotechnik); M. Budzisz, L. Gajewski, L. Gajewski, P. Iwen, E. Jezionek, M. Kałas, K. Lubomirski, J. Nowak, K. Szafler Maritime Institute (Laboratory of the Operational Oceanography); M. Masłowska, P. Przędziecki, J. Zachowicz Polish Geological Institute (Marine Geology Branch)

The performance of Dziwnow beach nourishment in 1996 is shown (Fig. 1.4). It consisted of a sand filling of about 67000 m³ dredged from the water path of the Dziwnow harbor. The sand was shaped into beaches about 300 m long. The nourishment was repeated 4 years later (in 2000), in beaches 450 m long at the western side of hard seawall. And currently (2004) the sand is applied to beaches over about 1400 m. The beach nourishment started from the hard seawall in a westerly direction (225 000 m³).

Groynes were constructed perpendicular (occasionally obliquely) to the beach, singly or as a system, only where longshore sediment transport is very high. These structures have as their primary aims the formation of a beach and the avoidance or slowing down of the existing beach erosion. However, the effect that they have on coastal dynamics is evidenced by the sand accumulation up-drift during the calm weather and the erosion down-drift during the storm.

Along the Polish coast single/ double groynes, double groynes with concrete plates (Fig. 1.8) and T–shape groynes (Fig. 1.9) were frequently present.



Fig. 1.8. Groynes localized in Dziwnow



Fig. 1.9. Filling of the T – shape groyne in Dziwnow

The groynes, however, did not have the expected result, making the beach return to the previous degraded situation or deep coastal erosion processes. This is why nowadays Maritime Offices avoid this type of protection and eliminate destroyed groynes.

Seawalls have been the oldest and most widely used type of Polish coast defence. This type of construction is parallel to the coastline and situated directly at the foot of a dune or cliff. The main task of the seawall is dune or cliff foot protection against the effects of erosion. Their main effect is to receive, reflect and disperse incident wave energy (when the wall is parallel to the coastline). The final result of seawall use is beach loss in front of it. They are constructed generally in front of the urban coastal zone.

Light seawalls were applied instead of hard seawall in Dziwnow (see Fig. 1.10). They are the softest form of this technical construction (Fig. 1.10) and so applied very often to preserve the widest, gentle beaches from storm waves. These seawalls are made of concrete blocks of different shapes arranged in few rows along the protected coast. They do not cause sand loss, but violent storms can completely destroy them.

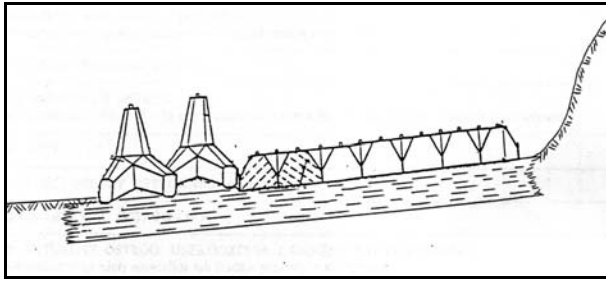


Fig. 1.10. Typical cross section of the seawall made of concrete tetrapods and pyramids lying on sticks

Medium seawalls (Fig.1.11) were very often applied in the 50's and 60's, but today we can see only remains in Dziwnow, because they were not very useful along open sea beaches.

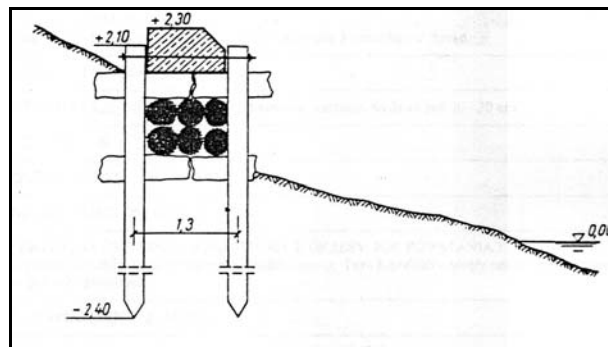


Fig. 1.11. Typical cross section of the bulkhead filled with concrete blocks

Hard seawalls are the hardest and more expensive coastal protection. Their main function is the reflection of the incident waves during the most violent storms, but they have a negative result in the sand loss seawards. In Dziwnow (Fig 1.12. and 1.13) this construction was undertaken in order to protect the buildings which are located on the very narrow Dziwnow Spit.

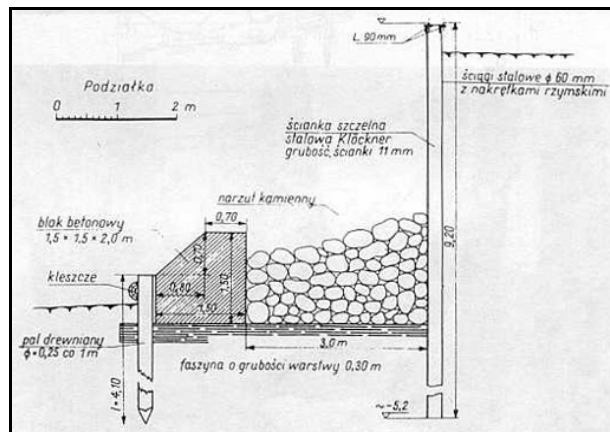


Fig. 1.12. Cross section of the old seawall in Dziwnow



Fig. 1.13. New seawall in Dziwnow

Monitoring the beach through bathymetric measurements and levelling measurements as an integral part of the coastal protection programme should be done every year after the storm season at the same cross-sections, every 500 m between 386,0-394,0 km, and every 100 m between 388.5-389.1 km.

Some useful information on the site follows:

- Total length of soft (sand, gravel) coastline (km), LS = all coastline
- Total length of coastline subject to nourishment (km), LN = 2,5 km (2) year – length (m)
 - 300m
 - 320m
 - 1995/6 – 300m
 - 450m
 - 2004 – 1400m

Total fill volume (mc):

year	– volume (mc)	
1988	– 30 000 m ³	(391.1-391.4 km)
1993	– 32 000 m ³	(391.08-391.4 km)
1995/6	– 60 000 m ³	(391.1-391.4 km)
2000	- 323.000 m ³	(389.05-389.5 km)
2004	- 225 000 m ³	(389.0-390.4 km)

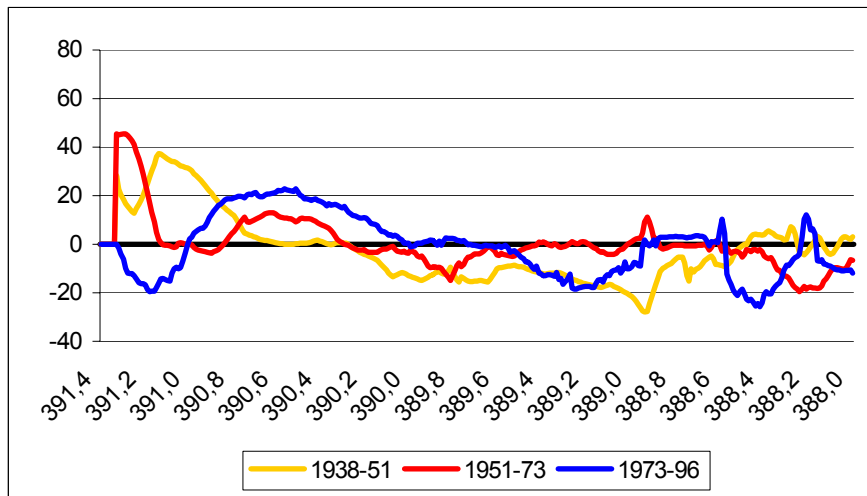


Fig. 1.14. Dune base line changes in particular time intervals on the Dziwnow Spit.

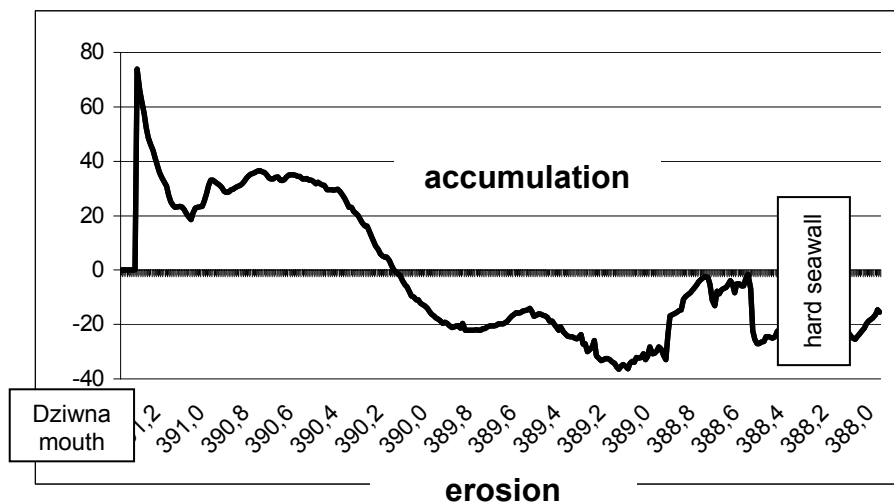


Fig. 1.15. Dune base line changes from 1938-96 on the Dziwnow Spit.

The application of protection methods to assure the safety of the coast however did not stop the erosion processes at all, and did not change trends of coast development. This trend has been established on the grounds of dune base line changes in the years 1938-96 (research done by Laboratory of Remote Sensing and Marine Cartography in the framework of the State Committee for Scientific Research project No 3P0405023). Most of the Dziwna Spit area lying eastward from the jetty of the Dziwna mouth has an erosive character. The place where the coast is more or less stable or erosion is much less than on nearby sections is at kilometre 388.7-388.9 – because here the hard seawall is located. Changes of the dune base line in years 1938-96 is seen in fig.1.14. In this we can also see the “link-side effect” existing on both sides of hard seawall. Here the erosion is greatest and these places are protected by rock filling and gabion seawall (east side) and beach nourishment (west side). The section of coast directly behind the east jetty has currently an accumulative character, but this accumulation is artificial, coming from beach nourishment (see Fig.1.14). However we can see, that here there exists an abrasive bay, which is seen also on the Fig.1.13, where the dune base line changes in particular time intervals are shown.

Thus, the stabilisation of the situation that has been currently reached on the Dziwna Spit is temporary. The erosive trend will continue here but the coast will be in danger of erosion again as the sea takes nourishment material or storm events destroy the seawalls.

Field	Core	Number of probes	Length of the core (m)	Mediana (mm)	Percentage of the fraction [%]			
					0.5-0.25	0.25-0.125	0.125-0.063	< 0.063
I	R 16	5	2.15	0.200	31.4	50.0	16.3	1.08
	R 17	7	3.20	0.246	45.4	40.8	8.6	1.28
	R 20	3	0.85	0.192	15.6	47.4	5.7	0.80
II	R 24	2	0.85	0.235	32.4	54.3	3.8	0.61

Tab.2.2. Granulometric characteristics of borrow material.

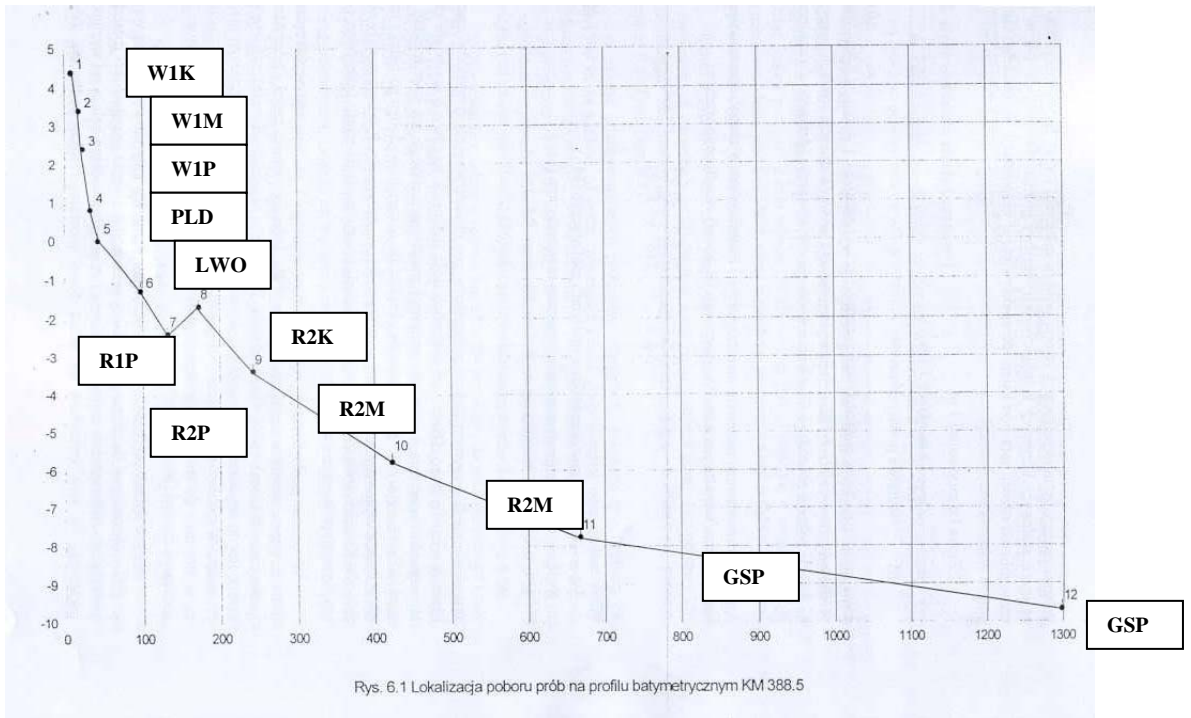


Fig. 1.16. Probes location on the profile KM 388,5

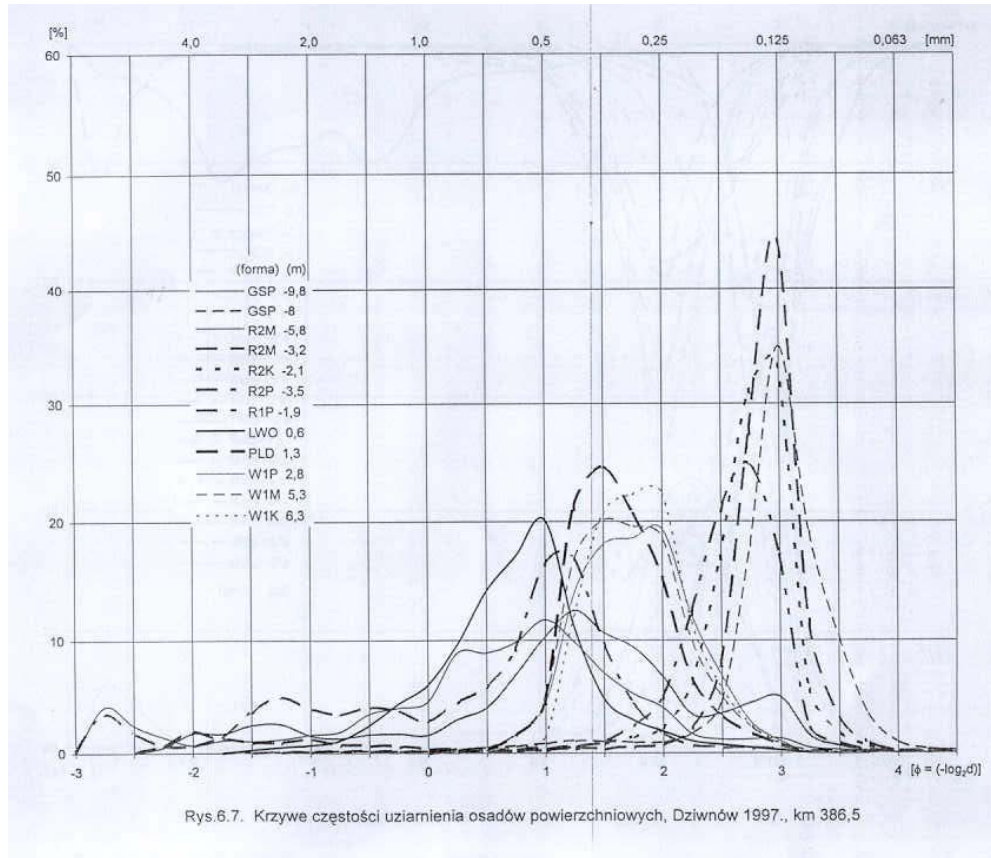


Fig. 1.17. Probes characteristics at profile 386,5 km

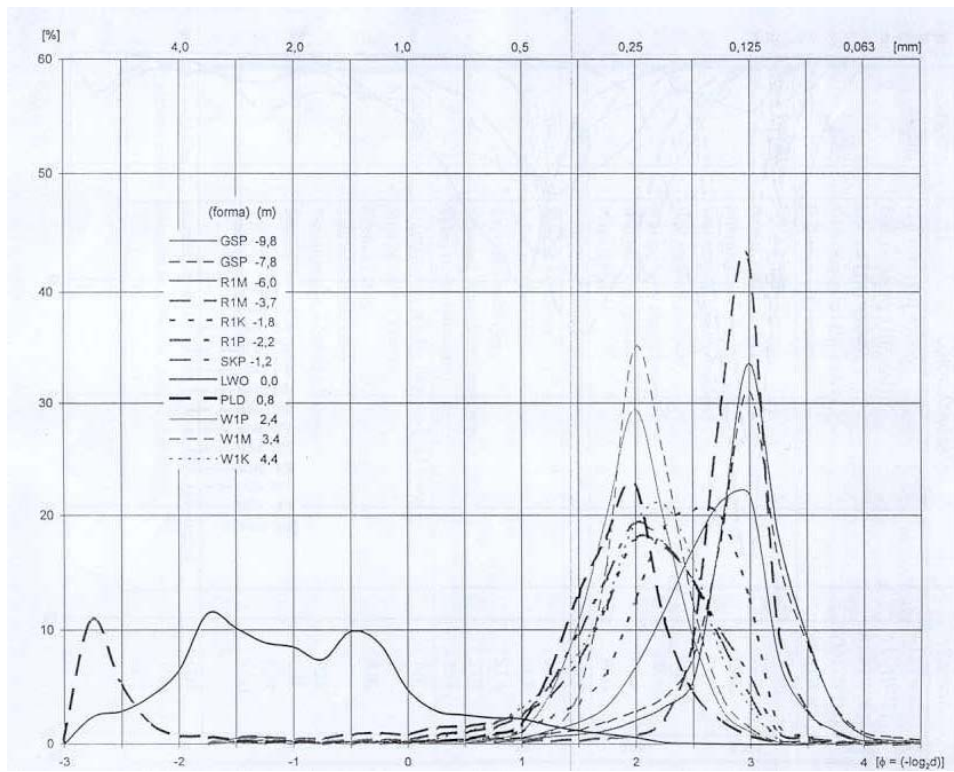


Fig. 1.18. Probes characteristics at profile 388,5 km

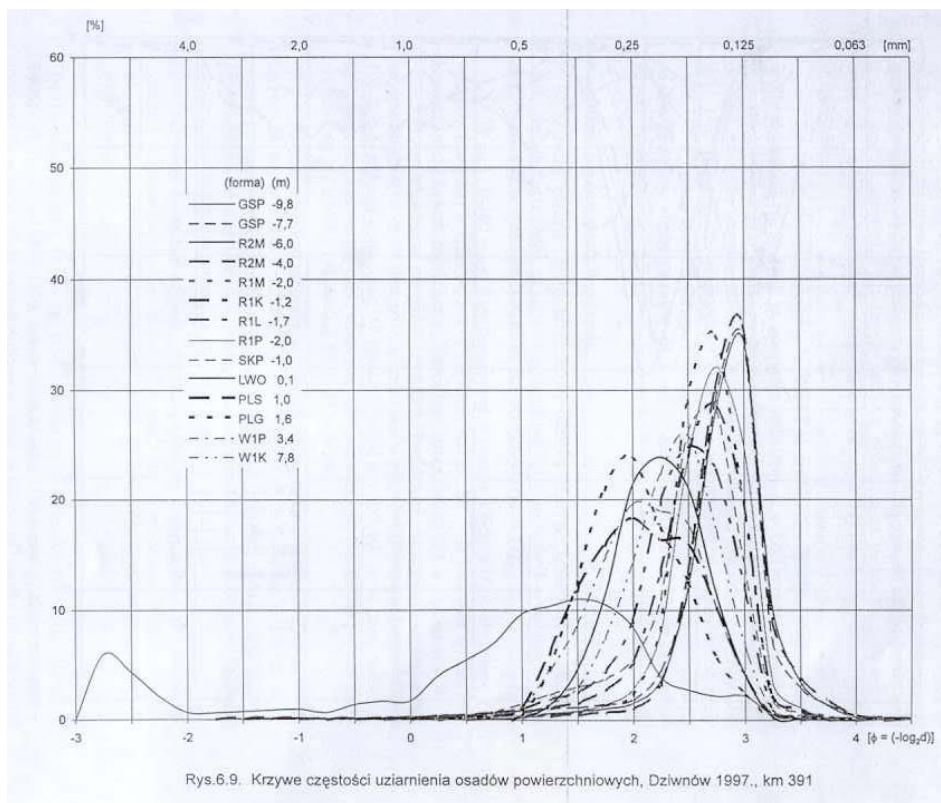


Fig. 1.19. Probes characteristics at profile 391 km

Year	Dziwnow region	
	all expenses	mean per year
1985 – 95	820 kE	82 kE
1995 – 02	300 kE	43 kE
plan 2003 – 22	15 000 kE	750 kE

Tab.2.3. Breakdown of expenses for the coastal protection in Dziwnow

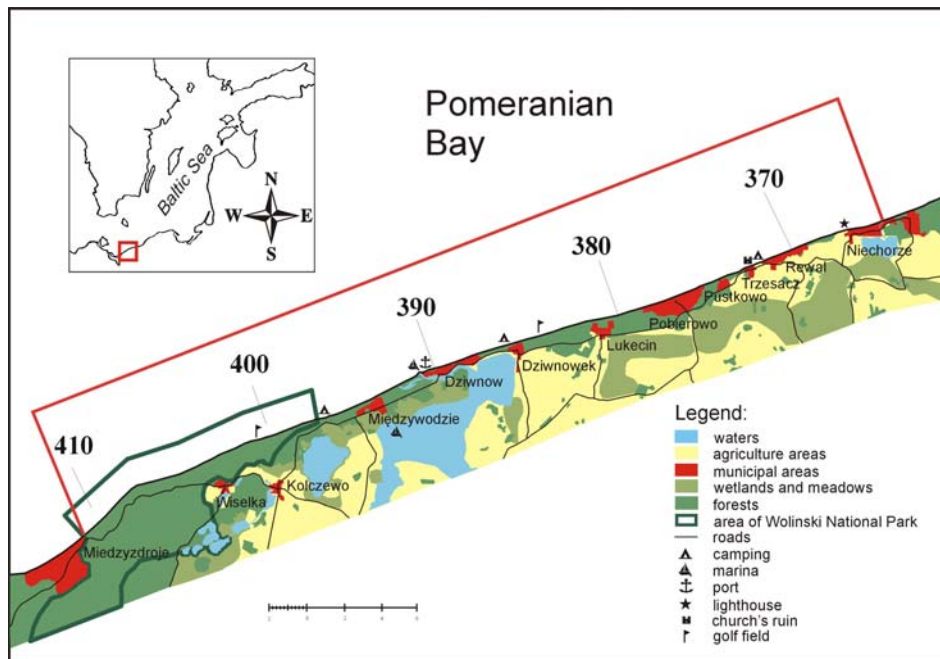


Fig. 1.20. Land use of surrounding area

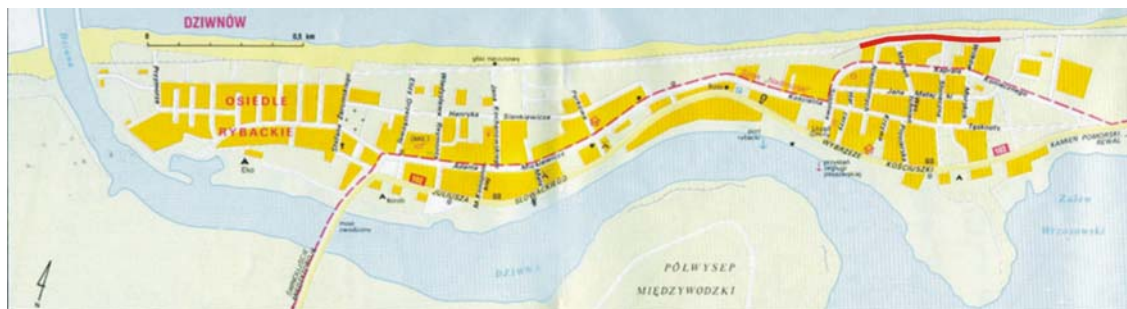


Fig. 1.21. Map of Dziwnow

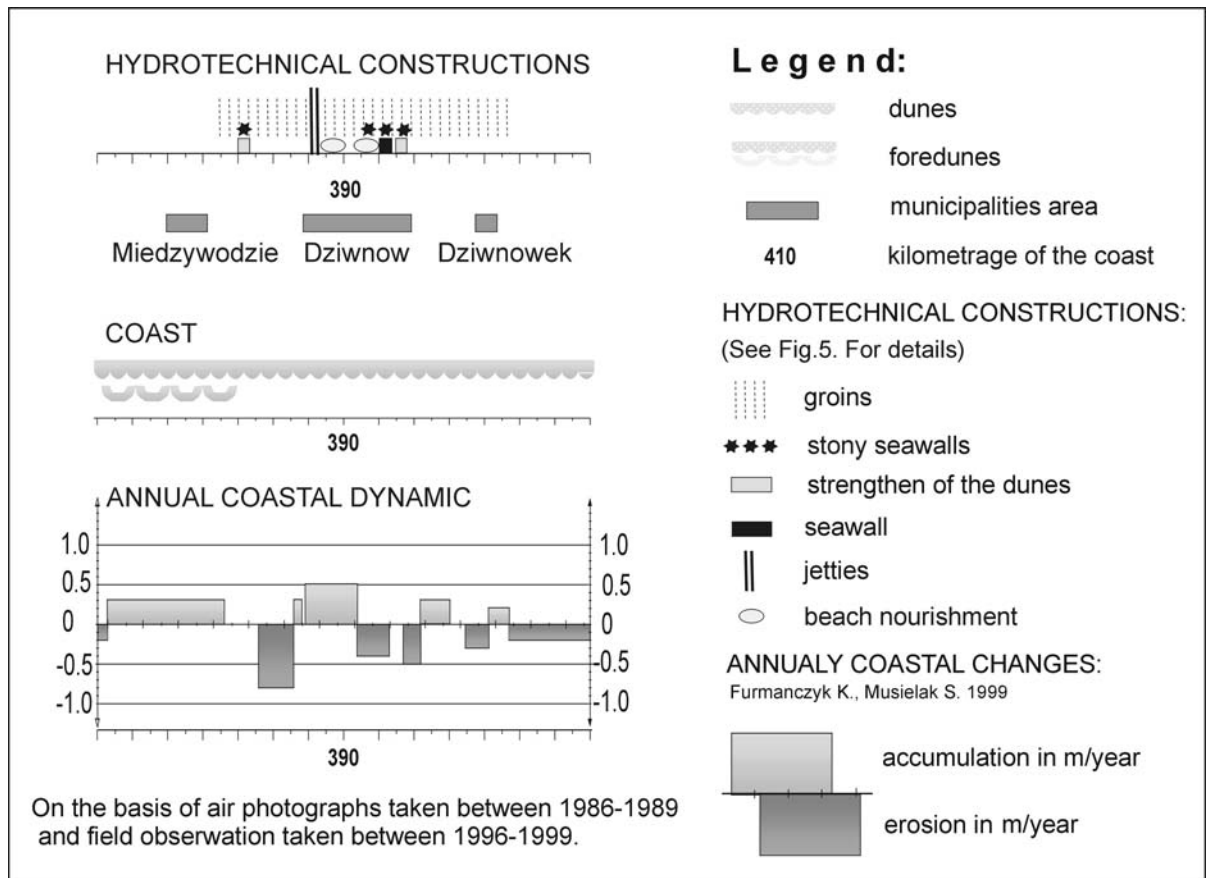


Fig. 1.22. Characteristic of the coast of Dziwnow

1.3.3. Applied methodology

All hydrotechnical constructions built in the area of Dziwnow Spit are now in good condition. The hard concrete seawall as well as the jetties have been repaired and we can expect that this kind of protection will have long-term effectiveness. Combined and medium seawalls are working and protecting the dune and the shore behind them effectively. Regarding these constructions, we can expect that the protection which they provide will have a temporary character dependent on the hydrometeorological situation in coming years. The last hydrotechnical works took place in 2005, replacing the geo-textile bags (used as the dune's core) with gabions – so now, the coast in Dziwnow area is well protected. The last beach nourishment was done in 2004, so there is no immediate need to supply the beach at the moment. Historical development of hydrotechnical construction on Dziwnow Spit is shown in Fig.1.25 and the present situation in Fig. 1.26.

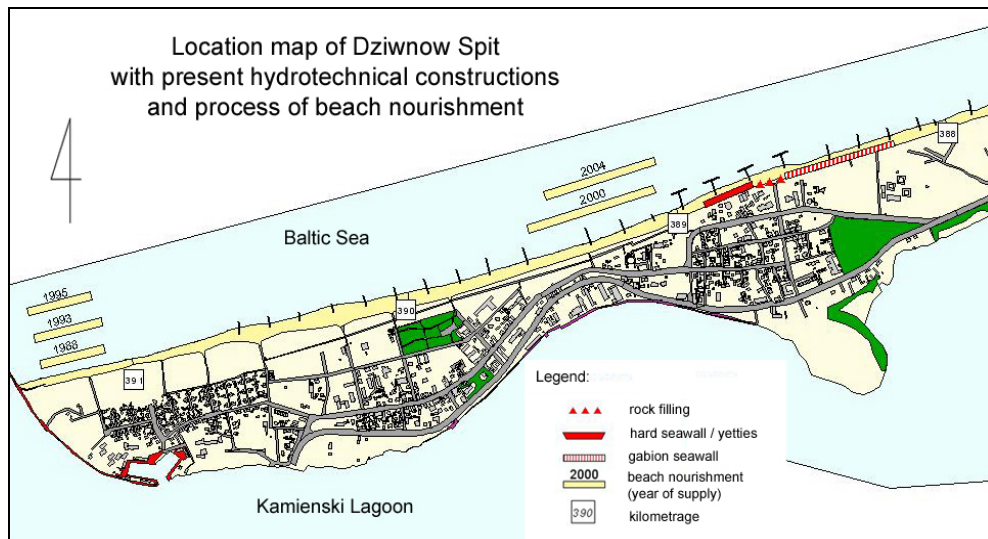


Fig. 1.23. Present location of hydrotechnical constructions and process of beach nourishment.



Fig. 1.24. Dziwnow: hard concrete seawall as well as rock filling seawall on the east side of hard seawall (left side of picture) are seen; on the first plan the roots of T-shaped groynes are visible; you can also see the protected property very close to the seawall.



Fig. 1.25. Dziwnow: hard concrete seawall and the narrow, but existing beach in front of the seawall are visible; in the background the T-shaped groynes are visible, too

1.3d FOURTH **Applicative examples: Maronti (Isle of Ischia) case study**

1.3.1. *Description of the site*

The Isle of Ischia is located 33 km SW of Napoli (Naples), Italy. It covers 46.3 km² and is the largest island in the gulf of Naples.

Ischia Island (fig. 1), located within the north-western sector of the Gulf of Naples, forms an active volcanic area together with the Phlegrean Fields, linked to the Plio-pleistocene evolution of the western margin of the Apennines chain, derived from progressive extensive tectonic phases related to the opening of Tyrrhenian Basin (Vezzoli, 1988).

The highest peak of the island is Monte Epomeo surrounded by several volcanic vents. Mount Epomeo, covers a surface of 16 km² or about 34.5% of the entire surface of the island. It is almost entirely made up of volcanic rocks locally called *Tufo Verde di Monte Epomeo* (Green Tuff of Mount Epomeo). The top part is covered by younger sedimentary and volcanic deposits (Tufite of Monte Epomeo and Colle Jetto formation). The central-eastern part of the island is occupied by a triangular-shaped depression called the Ischia Graben containing the villages of Casamicciola, Barano and Ischia Ponte. The southern border of the graben is limited by a fault system extending from Carta Romana to Maronti and to the west by Mount Epomeo. The depression is divided into two halves by a fault along the valley of Rio Corbore.

The volcanic activity of the island of Ischia is related to the same causes that produced the volcanic activity along the western margin of peninsular Italy. About 10 million years ago the areas now represented by the Italian peninsula and the islands of Corsica, Sardinia and Sicily, were bound together. A slow anticlockwise rotation of the Italian peninsula separated it from Corsica and Sardinia and caused the opening of the Tyrrhenian sea. The consequent stretching and thinning of the crust caused deep faults which favoured the formation and eruption of magmas.

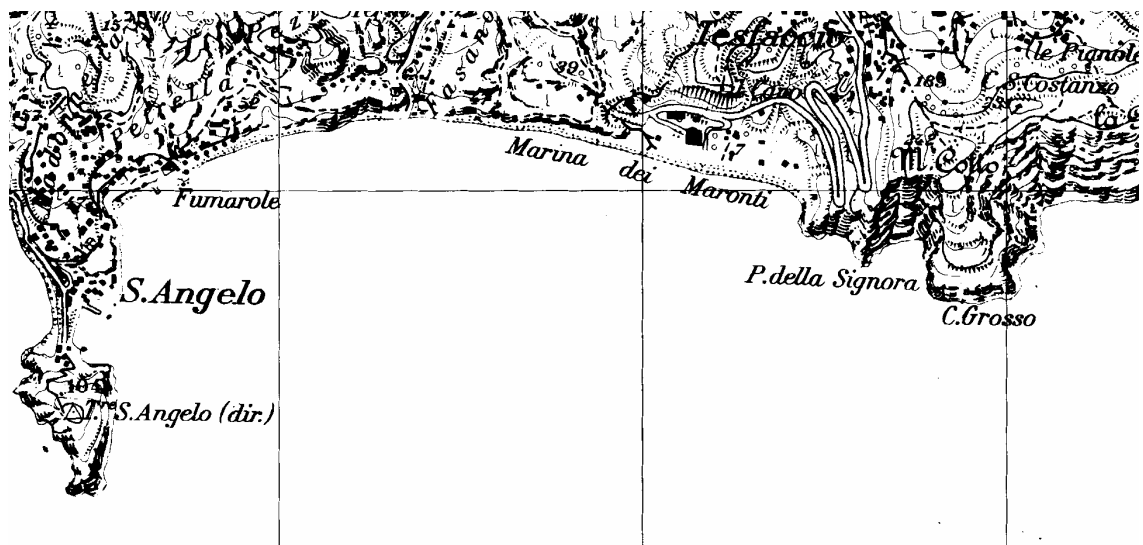


Fig. 1.26. Piece of the topographic map of Isle of Ischia showing Maronti Bay.

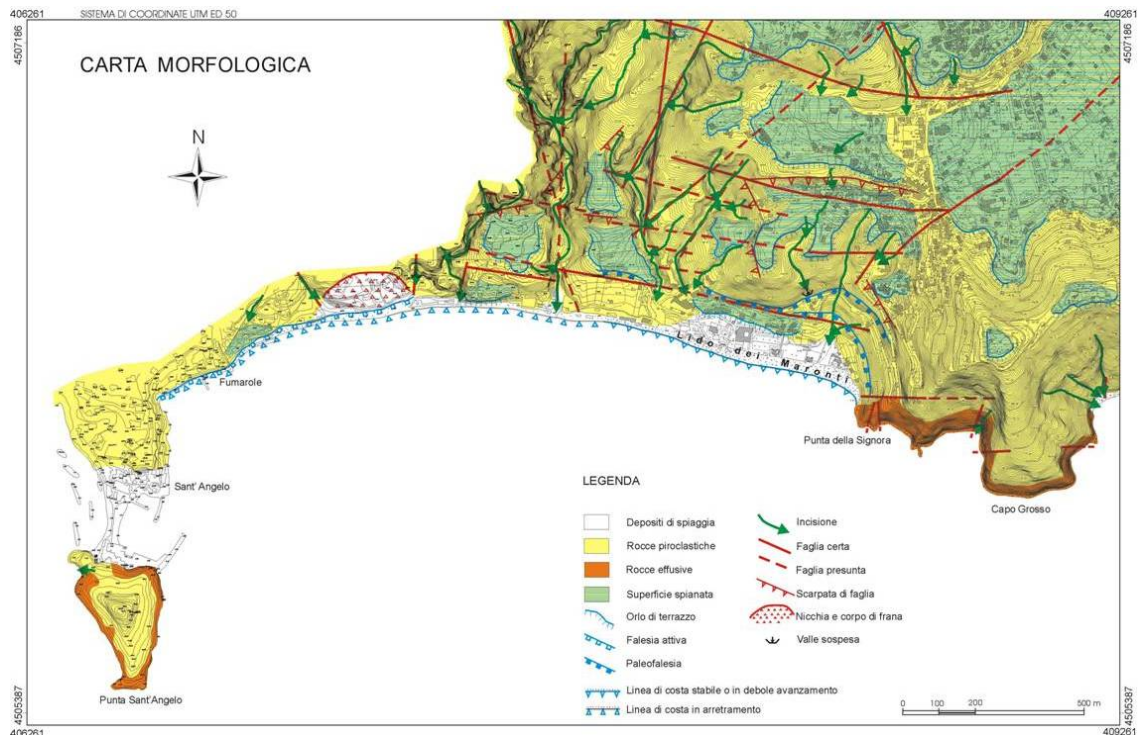


Fig. 1.27. Geomorphological map of the southern side of the Ischia Island. The western area of the Maronti Bay is subjected to high erosional processes with landslide on pyroclastic cliff. The eastern area, characterised by wide beaches, shows a steady equilibrium.

Ischia is one of the most important touristic locations in Italy both as a seaside and as a thermal resort. Over the last 30 years, it has undergone a radical environmental change due to population growth and the urban expansion on the coastal belt has also created a change in the coastal environment, thus increasing the risk factor. This is mainly due to the construction of various touristic and commercial harbours and the building of numerous coastal protection structures aimed at safeguarding tourist establishments and infrastructures located on the coast.

The intensification of the properties along the coasts of the island and the population growth of the towns on the waterfront have increased the vulnerability of the area.

Natural processes strongly influencing coastal erosion are linked to the wave motion and currents related to the river sediment supply and to the morphology of the coast and the continental shelf. Climatic changes, sea-level rises and subsidence phenomena of the coastal plains should also be considered.

Man-induced changes over the last 30 years, on the other hand, have also caused coastal erosion due to various interventions carried out in the hinterland. In particular, construction of hydroelectric and irrigation barrages, urbanisation of river banks and construction of check dams on these river beds, have caused the impoverishment of solid transport. The carrying away of inert materials from

the rivers and the excavation of coastal dunes in order to create urban and/or tourist recreational areas should be taken into consideration. Finally, coastal protection structures often result in more harm than good; commercial and tourist harbours and general urban growth should also be emphasised.

The expansion of touristic infrastructures (hotels, spas, harbours), as well as the interventions carried out in order to protect some coastal stretches, has created a strong disequilibrium along the coasts, initiating or amplifying the erosion phenomena which actually affect the island. These phenomena determine the regression of sandy coasts and/or the landslides along the slopes of high coasts, thus contributing to the augmentation of the risk factor in these areas and (considering the high population density) to the increased possibility of coastal hazards.



Fig. 1.28. Bay of Maronti (Isle of Ischia) view.

The coastal environment of the island of Ischia bears heavy signs of environmental degradation caused by a considerable increase in population and an indiscriminate urban expansion following the intense development of the tourist industry since the second half of the 1960s.

The climate, the unevenly distributed rainfall and the permeability of volcanic soil result in a reduced surface hydrography, caused also by reduced gathering ground due to urban expansion.

Hotels and restaurants are constructed directly on the beach, some on piles. In the 1980s, in the same area, also on the beach, a cement promenade which connects the public road to the various tourist structures has been built.

On the basis of various morphological and structural characteristics, the studied area could be subdivided into two sectors: the first one westward between S. Angelo and Cava Olmitello, the other one between Cava Olmitello and Grosso Cape. They both show evident signs of the effects caused by man, who drastically modified the environment; in fact, there are urban elements both at the top and on the slopes of the cliff that borders Maronti beach, where there are also numerous permanent tourist structures located directly on the beach.

The breakwaters at the entrance of the small harbour of S. Angelo, at the westernmost part of Maronti beach, derived from lava blocks taken from the seabed. This operation has removed the natural protection against the erosive effect of the sea and now the beaches along this coast suffer from heavy erosion phenomena which caused portions of land to disappear, such as the Fumaroles beach, which was of extreme environmental and scenic value. The disappearance of beach tracts near the subvertical cliffs has facilitated slipping and landslide phenomena which continuously change the features of the territory.

Furthermore, in December 1999, a violent storm battered Maronti beach causing the complete loss of the beach, and attacking the rocky cliff behind. As a result a beach nourishment intervention was proposed: 500,000 m³ of sand completed by two partly submerged protective breakwaters: one westward to keep sea from submerging the nearby S. Angelo harbour; the other one to avoid sand dispersion towards the seabed around *Punta della Signora*. It utilised sand from nearby areas. Rock breakwaters were not considered suitable because of their environmental impact, especially in an area with great landscape value, and for the negative effects which often result.



Fig. 1.29. Beach of Maronti narrowed by sea storm.

1.3.2. *Applied methodology*

The sea bottom morphology, sediment character and sedimentary dynamics of Maronti Bay allow the definition of the phenomena working along the littoral, enhancing the landscape value of Ischia Island.

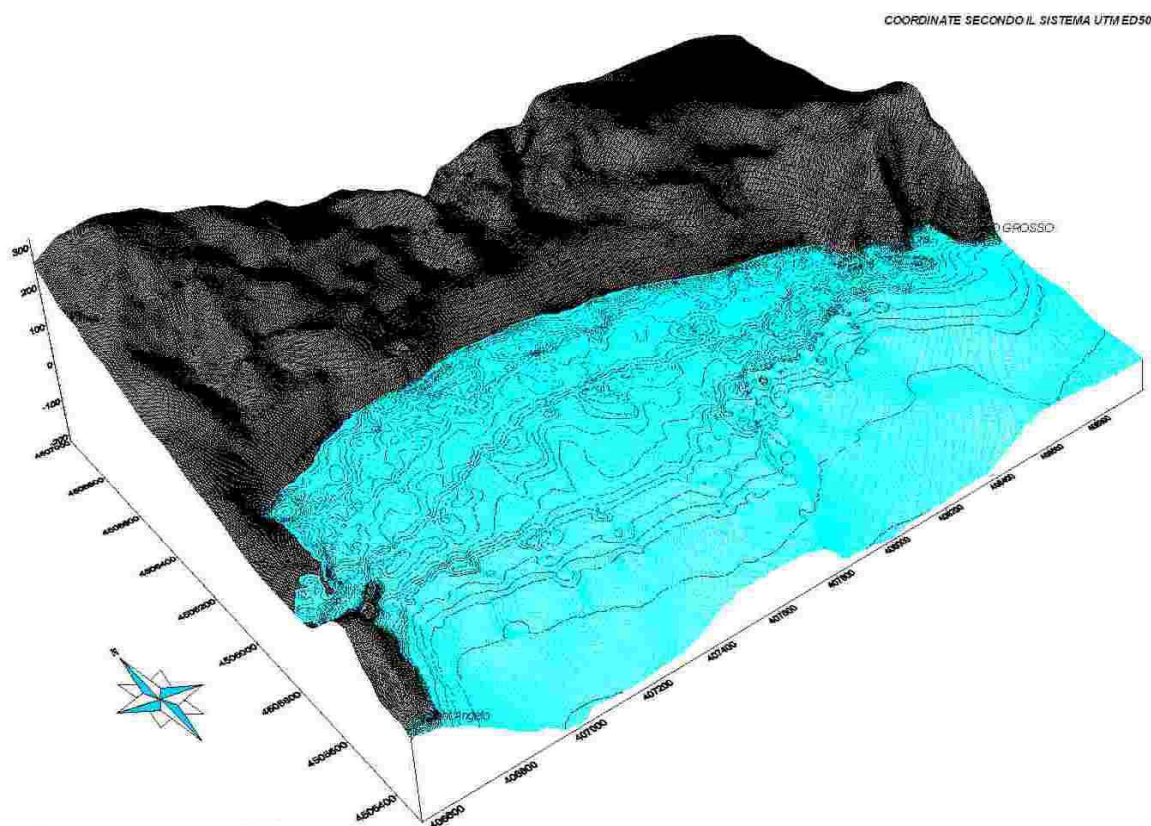


Fig. 1.30. Bathimetric and morphological map of the investigated area. Within the depth of 5 m, the map indicates a large sedimentary stockpile, especially in front of the tuffaceous cliff, with by ravitative phenomena. The eastern area, between 10 and 50 m deep, is characterized by lava rocks remnants. In the western area, the morphology testifies to the removal of some lava rocks. The removal exposes the coast to the waves, amplifying the erosional phenomena on the shore.

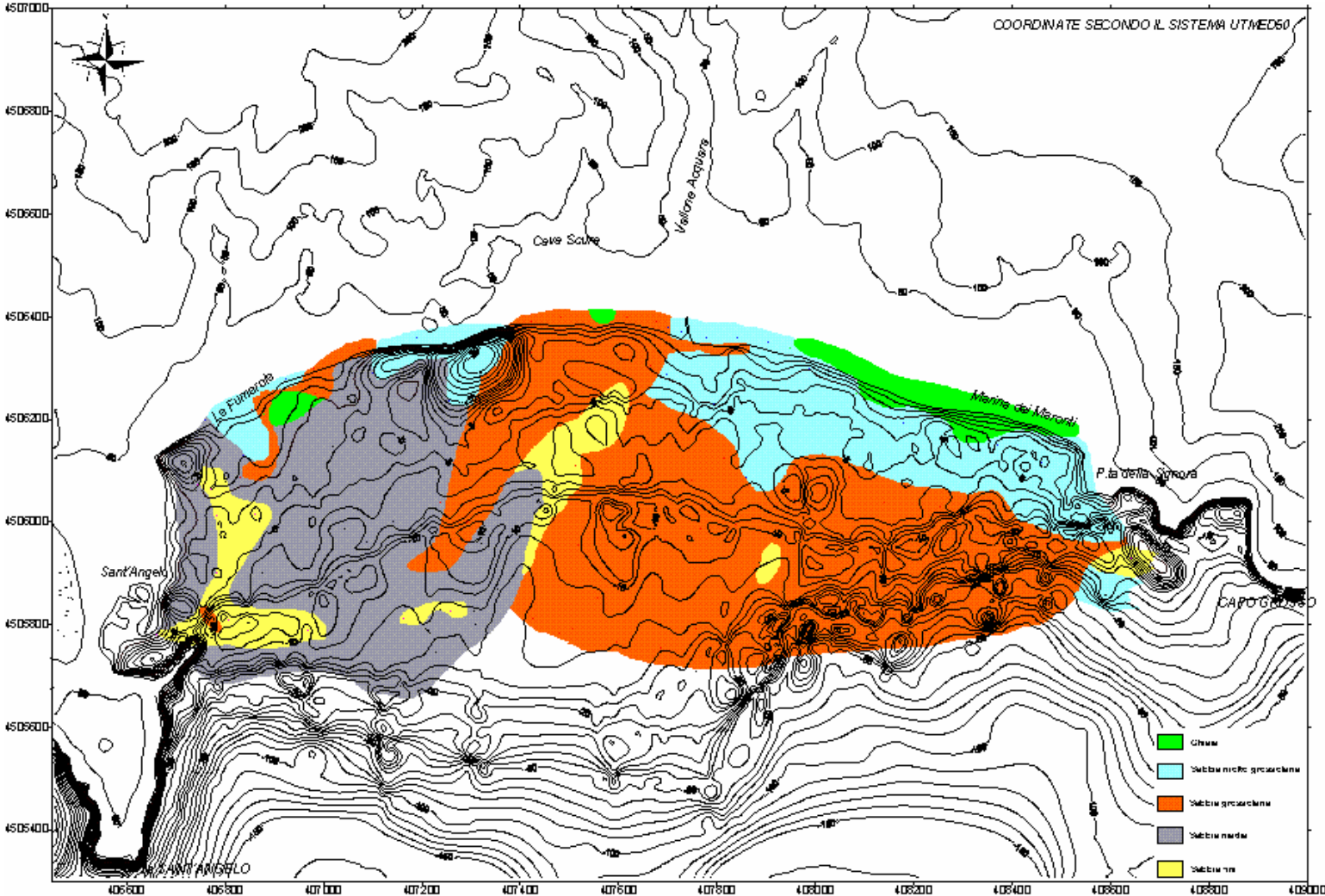


Fig. 1.31. Map of the distribution of sediments in Maronti Bay

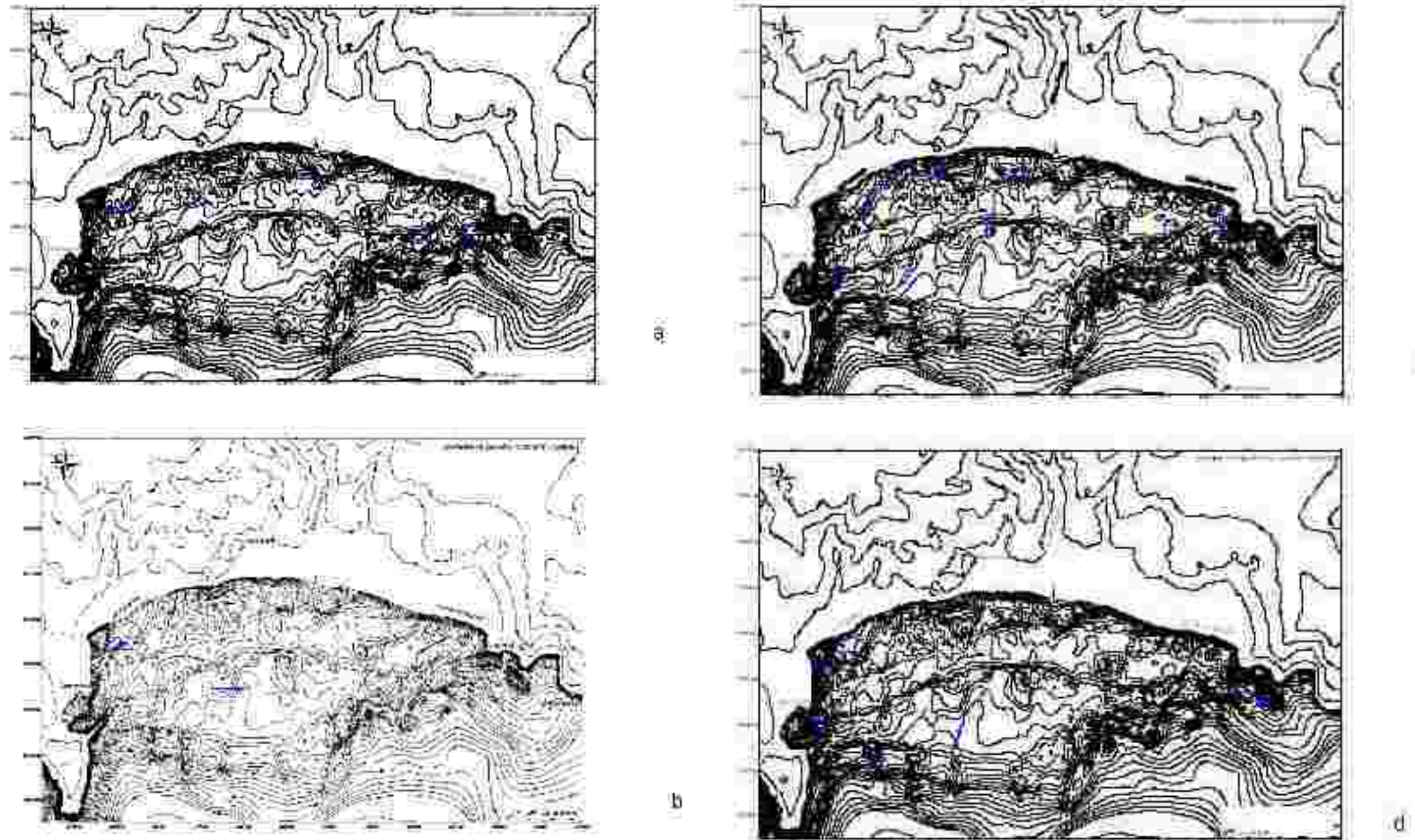


Fig. 1.32. Sedimentary transit. a) Very coarse sands show an eastward and seaward movement, due to longshore and rip currents; b) coarse sands move seaward along NE-SW and NW-SE direction; c) circulation of the medium sands points out a main movement due to rip currents removing the sediments towards the lower depths; d) the movement of fine sands points out the presence of a secondary cell in the western area of Bay with a seaward movement of sediments.

After the last beach nourishment in Maronti Bay, a morphological step is evident. The causes of this particular structure are multiple and related to each other: a poor re-distribution of the sand used for the nourishment; the nourishment has not been preceded by a correct re-shaping of the sea bottom; and finally, the transported sands were not of the same physical properties (granulometry, size, geology, etc) as the endemic sand.



Fig. 1.33. Recent image of Maronti Bay showing the morphological step.

The erosional processes that act on the beaches of Maronti Bay are mainly due to the anthropic action. The littoral dynamics allow the deposition of a stockpile of sediments on the sea bed, moving through deep channels after being eroded from the beaches.

The researches carried out allow the planning, for the environmental readjustment of the littoral, of artificial nourishment, using the sediments present on the sea bottom in front of the beaches. They are certainly in equilibrium with the coastal environment, in their sedimentary characteristics as well as the lithological. To prolong the retention of sediments on the reconstructed beaches submerged breakwaters could be built. They would be prefabricated and subjected to laboratory tests to avoid environmental damage.

Because of their environmental impact, rock breakwaters were not suitable, especially in an area with great landscape value. The latter sometimes produce negative effects along the coastal areas where they are built.

1.3e FIFTH **Applicative examples: Ferrara case study**

Subject to an intense touristic-recreational overuse, the littoral stretch between *Lido degli Estensi* (southward from Porto Garibaldi dock, near Ferrara, on the north-eastern coast of Italy) and *Lido di Volano* northward presents an increase in the south and decrease of the beach in the central-north.



Fig. 1.34. Aerophoto showing littoral stretch between *Lido degli Estensi* (southward from *Porto Garibaldi* dock) and *Lido di Volano* northward

In this site the installation of a sand-duct has been carried out. This is a system based on the creation of a duct to transport the sand from the zone where the sand accumulates (at north of Porto Garibaldi locality) to south.



Fig. 2.35. Evolution of the coastline of *Lido degli Estensi* from 1978 to 1998 (fount Arpa 2002)

Lido degli Estensi represents the *on loan area*: the area from which the accumulated sand is transported toward Lido di Volano.

The next images show the initial works for the installation of the sand-duct:



Fig. 2.36. Location of the excavation area on the beach of Lido degli Estensi, close to the docks of Porto Garibaldi



Fig. 2.37. Sand-duct trace in Ferrara.



Fig. 1.38. Work in progress in Ferrara for the installation of the sand-duct.



Fig. 1.39. Deposition and remodelling of sand on the nourishable beach.



Fig. 1.40. Lido degli Estensi after the nourishment in May 2004



Fig. 1.41. Lido di Volano: the image shows the narrow beach and dune instability

1.4. Expected benefits

1.4.1. Environmental benefits

The immediate measures of success that should be quantified and reported are dry beach width, volume of sand remaining after storms and flood protection capability. Subaqueous sand volumes should also be measured because they contribute to protection from storm waves and to recreational value. The great diversity of conditions, the mix of coastal processes and the resulting major regional differences make it neither practical nor desirable to establish a standard design for beach nourishment projects. Each project must therefore be designed to satisfy the conditions of its location.

In terms of environmental benefit, beach nourishment reduces erosion by modifying the slope of the shoreface and by diminishing the wave energy (especially in stormy periods). Furthermore, coastal forests and dunes can be conserved by using soft methodologies.

As regards the Gulf of Riga, this has benefits of erosion control, modifying the slope of the shoreface and thus affecting the incident wave trains by diminishing their energy (especially in stormy periods).

1.4.2. Social and economical benefits

As mentioned before, the purpose of this method was to protect the beaches along the nourished sector from storm wave attacks, protecting the facilities in the foredune. From the social point of view, the measure provided security for human assets.

Tourism and recreation play the principal role in the development of Riga and it is very important to conserve the cultural and historical monuments. The coastal forests and dunes of the study area, being an integral part of the coastal protective belt, enjoy protection within the general nature conservation framework.

On the other hand, five thousand inhabitants are potentially threatened, being particularly vulnerable to the flooding during the storm surge events.

Other important factors are the fisheries and aquaculture (the Lielupe river mouth provides port facilities for small-scale fisheries and there is no aquaculture of an industrial scale in the study area), and agriculture and forestry (there is small-scale market gardening, while forests mainly serve for recreational and conservation purposes).

As an example, some benefits deriving from the beach nourishment of the Latvian coastline are summarised below. MESSINA future activities include the monetary conversion of such benefits in order to obtain the Net Present Value related to each single examined case study.

- Protection of the facilities in the foredune.
- Improved security for human assets (5 thousand inhabitants are potentially threatened and particularly vulnerable).
- Conservation of cultural and historical monuments
- Development of tourism and recreation.
- Protection of fisheries and aquaculture.
- Protection of agriculture and forestry (in particular, small-scale gardening colonies).

Regarding the costs, these include, among the others:

- Nourishment costs
- Revetment reconstruction costs
- Annual maintenance cost for coastal pine forests (EUR per hectare)
- Annual maintenance costs for coastal foredune (EUR per hectare)

1.5. Determining adequate sediment characteristics

Beach nourishment requires large volumes of beach-quality sand. The initial nourishment project typically requires thousands of cubic metres of sand, and most beaches need periodic re-nourishment.

One of the most important characteristics of sediment is its granular size. The range of grain sizes of practical interest to coastal engineers is enormous. A particle's size is usually defined in terms of its *diameter*. However, since grains are irregularly shaped, the term diameter can be ambiguous. When performed in a standard manner, sieving provides repeatable results, although there is some uncertainty about how the size of a sieve opening relates to the physical size of the particle passing through the opening.

Another way to define a grain's diameter is by its *fall velocity*. The problem is that fall velocity is dependent on size, shape, and density. A grain's sedimentation diameter is the diameter of a sphere having the same density and fall velocity. This definition has the advantage of relating a grain's diameter to its fluid behaviour. However, a settling tube analysis is somewhat less reproducible than a sieve analysis, and testing procedures have not been standardised. *Fall velocity* can be considered as an indicator of the *capacity* of sediment to remain in suspension and be transported. The problem is that density can also be a significant parameter when mixing different types of sand (and it is normally overlooked). In general, the performance of a beach fill, in terms of the resulting gain in dry beach width relative to the volume of sand placed on the beach, is a function of the compatibility of the fill sand with the native sand. Profiles composed of coarser sediments assume steeper profiles; thus, beach fills using coarser sand require less sediment to provide the same equilibrium dry beach width than fills using sediment that is finer than the native sand. The difficulty of nourishment design consists of calculating the volume of

borrow with a given size distribution that will produce a required volume of (beach) fill. Ideally, the median size of the borrow sand should not be less than the median size of the native sand, and the spread of the sizes in the borrow size distribution should not exceed the spread of sizes in the native sand. Often it is impossible to meet these ideal conditions because suitable borrow material does not exist in adequate volume at a reasonable cost. Furthermore, on severely eroded beaches, the native sand may be skewed to coarser size ranges because the fines have eroded out, producing unrealistic requirements for borrow sand size distribution. Nourishment design aims to compensate for the differences between borrow sand and native sand, usually by overfilling with borrow sand and assuming preferential loss of the fine fractions. A favourable feature of beach fill technology is the accidental, partial loss of the fine fraction during the dredging and handling between borrow site and beach.

The shore protection and the recreational qualities of a beach fill conflict when coarser sediment sizes are used. Usually, a beach provides more protection against erosion when its particles are coarser (also when they are more angular and more easily compacted). However, fill material larger than sand size (about 2.0 mm) will reduce the recreational value of the beach.

Engineers pump sand from offshore or transport it in by barge. They prefer coarse sand because it stays on top of the old fine sand, stopping it from being blown away and giving the impression that it also remains there longer. But it does not feel as pleasant as the old sand and it disappears rapidly. Renourishment needs to be done every five to ten years, involving high costs. It puts more sand near the beach, creating sand bars and causing the beach to lie flatter, eventually no longer able to dry.

1.6. Identifying adequate sediment sources

Sand for nourishment projects is from a variety of environments. Terrestrial sources of sand include coastal dunes, coastal plains, and inland sand dunes. Offshore sources include dredge spoils from harbour maintenance, shallow-water sand fields, medium-depth sand channels, and deeper-water sand banks. Larger sources of sand must be hydraulically dredged with a suction dredge.

1.7. Selecting the adequate nourishment techniques

1.7.1. Establishing environmental mitigation strategies

No device *creates* sand in the surf zone. Any accumulation of sand produced by a structure is at the expense of an adjacent section of the shore. This fact distinguishes structures and other devices from beach nourishment, which addresses the basic problem in coastal erosion – the shortage of sand. Traditional structures are capable of providing effective shore protection and of mitigating the effects of erosion when appropriately designed, sited, and constructed. However, the use of traditional shore protection measures without

adequate attention to their effects on physical processes within local littoral cells has caused much damage.

The performance of some beach nourishment projects can be substantially enhanced by the use of fixed (hard) structures when they are appropriately designed and placed at suitable locations: to anchor project ends, to protect specific locations (e.g., inlets), to provide a reserve capability to prevent flooding and wave attack where dunes cannot or do not exist, or to reduce wind-blown losses to the land. Structure design and associated beach fill need to be carefully planned and implemented because structures rearrange and control the movement of sand rather than increase the volume of sand within the littoral system.

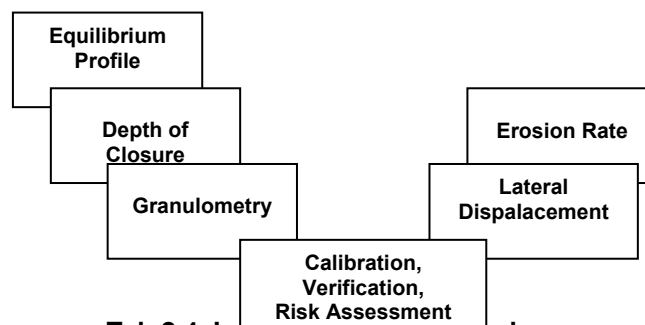
1.7.2. Designing long-term monitoring

Monitoring has been defined by the National Research Council, as “the systematic collection of physical, environmental, or economic data or a combination of these data on a beach nourishment project in order to make decisions regarding project operation or to evaluate project performance”. While this definition addresses beach nourishment, it is equally applicable to other types of shoreline protection projects (seawalls, revetments, cave filling, groins, etc.). In almost all situations, monitoring is a way to answer questions about project effectiveness and to identify project strengths and weaknesses.

Models can play a fundamental role while moving from nourishment projects to nourishment plans, i.e., when nourishment becomes an integral component of a coastal management strategy. Planning nourishment in the context of a multi-years management strategy requires more significant prediction skills than available in the past and an awareness of dealing with uncertainty. Technical issues include design frequency (frequency and redesign of sand fills) and life, pre- and post-fill erosion rates, post-fill profile equilibration, project length, volumetric requirements, grain size compatibility, protective dunes, long-term sand resources, placement location, “hybrid” projects, and downdrift impacts. Public policy issues include monitoring, periodic renourishment, maintenance, rehabilitation, and environmental regulations. Some issues, such as renourishment frequency, have both technical and public policy implications, reflecting the fact that beach nourishment is far from being only a technical exercise. An evaluation of a coastal system without the use of models is not systematic in that it may not include all pertinent factors in an equally weighted manner. One result may be that it is not possible to discriminate between the influences of natural variations and human impact, respectively. Finally, models provide a methodology or criteria to summarise the available knowledge and optimise project design.

A variety of modelling approaches for the evaluation of the evolution of coastal morphology has been developed over the last decades. The resulting models have proven to be quite powerful in representing the dominant physical processes with respect to the longshore and/or cross-shore behaviour of beach fills. Whether or not they can be used to fully tackle all or part of the relevant nourishment technical issues is, however, still to be decided. A lot of models are

now available which cover not only different processes but also different temporal and spatial scales. The role of numerical models in the design of shore nourishment is primarily to assist in assessing the pre-fill and post-fill volume loss rates and erosion rates working in concert with field observations.



Tab.2.4. Issues to be considered

The adoption of simulation models represents a technique to answer “*what if*” type of questions. They are used most appropriately when a problem under analysis is too complex to be solved by analytical models. Simulation (through models) is a quantitative procedure that describes morphodynamic processes by constructing a model and then observing how the model behaves over a series of iterations in order to learn how the process itself might behave. Models should be used with minimum data input better to define the problem, to provide a deeper understanding of the predominant processes, to identify potential project alternatives, and to offer guidance on the required quality and type of input data needed to understand the particular problem. Models should also be used to evaluate existing uncertainties and their effects, particularly while dealing with aspects that are not fully monitored or are not fully known. Models also provide the basis for Risk Assessment to be undertaken. The general approach to models of shoreline change involves the division of the coastline into a large number of individual cells or compartments. Equations relating the alongshore sediment transport rate to the wave parameters and to velocities of alongshore currents are employed to calculate the shift of sand from one cell to another. The application of a continuity equation allows for the conversion of volumes of sand entering or exiting a particular cell into the resulting shoreline changes. A geometric assumption is that sand is transported alongshore between two well-defined limiting elevations on the profile. The shoreward limit is located at the top of the active berm, and the seaward limit is located where no significant depth changes occur, the so-called depth of (profile) closure. Restriction of profile movement between these two limits provides the simplest

way to specify the perimeter of a beach cross-sectional area by which changes in volume, leading to shoreline change, can be computed. Finally, it is assumed that there is a clear long-term trend in shoreline behaviour, ignoring the *noise* in the beach system produced by storms, seasonal changes in waves, tidal fluctuations and other cyclical and random events; in essence, the assumption of a clear trend implies that the wave action producing longshore sand transport and boundary conditions are the major factors controlling long-term beach change. This assumption is usually borne out by engineering projects involving groynes, jetties, and detached breakwaters. Process-based models tend to be appropriately used for short time-scales, while descriptive, equilibrium and behaviour-oriented models are more appropriately used for long time-scales. The essence of behaviour-oriented models, in particular, is the identification of simple parametric mathematical models which exhibit a similar dynamic behaviour to the actual coastal morphology. The model equations are selected because their solution exhibits the suitable behaviour in a certain class of applications. In the application to nourishment planning and evaluation the choice of model structure is led by the a priori knowledge about the behaviour of the morphological system subject to the nourishment intervention.

Many models of physical systems in nature are built upon the hypothesis that an “equilibrium state” can be defined and changes in the system properties depend on the deviation from this equilibrium configuration. The analysis of the cross-shore behaviour of a nourishment intervention consists of the analysis of the process of a “return to equilibrium” of the profile. Generally, observed properties of equilibrium profiles are as follows: they tend to be concave upward; the slopes are milder when composed of finer sediments; the slopes tend to be flatter for steeper waves; the sediments tend to be sorted with the coarser and finer sediments residing in the shallower and deeper waters, respectively. The effects of changes that induce cross-shore sediment transport can be deduced from these known general characteristics. A proper beach profile evolution model should predict out-of-equilibrium states. In addition to the basic properties, many beaches in nature have one or more longshore bars present. At some locations, these bars are seasonal and at some they are more or less permanent. The presence of bars depends on wave and sediment conditions, and they may form or move further seaward during storms. At some beaches with more than one bar, the inner bar will exhibit more rapid response to changing wave conditions than those further offshore. When applying “equilibrium profile” concepts to problems requiring an estimate of profile retreat or advance, a related important concept is the principle of conservation of sand across the profile: under conditions where no longshore gradients exist in the longshore transport, onshore-offshore transport causes a redistribution of sand across the profile but does not lead to net gain or loss of sediment. Most engineering methods applied to the prediction of profile change ensure that the total sand volume is conserved in the active profile, so that erosion of the exposed beach face requires a compensating deposition offshore, whereas deposition on the exposed beach face must be accompanied by erosion of sediment in the surf zone. For cases where longshore gradients in longshore transport exist, the profile commonly advances or retreats uniformly at all active

elevations while maintaining its shape across the profile. In this way, sediment volume can be added to or removed from the profile without changing the shape of the active profile. As a result, most methods for predicting beach profile change treat the longshore and cross-shore components separately. An error in the definition of the equilibrium profile is immediately reflected in mismatches between the predicted nourishment behaviour and the actual nourishment behaviour.

Models can play a fundamental role when moving from nourishment projects to nourishment plans. Planning nourishment in time requires more significant prediction skills than available in the past and an attitude towards dealing with uncertainty and variability. The fundamental role of models is that of reducing as much as possible *surprise*. These surprises might be expressed in terms of failures and in terms of costs.

The continuous wave action on sandy coasts produces cross-shore sand transport by oscillatory velocities; longshore currents with maximum velocities and littoral longshore transport close to the wave-breaking line. The restructuring of the cross-shore profiles has a time-scale between the single storm period (wash out of the sand bar and/or beach) and the season (restoration of bar structure). The direction and magnitudes of longshore currents vary continuously. The analysis of the mean sand transport volumes along the coastline allows the specification of overall trends, accumulation and erosion zones, which on a longer time-scale will impact on the shoreline development. A simple one-dimensional model for predicting cross-shore distribution of the longshore littoral drift is developed. It accounts for wave generation (fetch model), transformation (include breaking), current distribution, formation of suspension, development of bed macroforms, bed and suspended load transport. The application of the model for the chain of cross-shore profiles along the Latvian coastline shows this. The prevalence of the southwestern winds is responsible for the significant (typically more than 1 million m³) northward load transport near the Latvian coast of the Baltic Proper. The combination of the fetch with the coastline orientation yields, generally results in southward sand transport (annual values below 100 thousand cubic meters) along the coasts of the Gulf of Riga.

The hydrodynamic processes become essentially two or three dimensional in the vicinity of harbours. Typical engineering constructions, which interact with wave fields, water flow patterns and load transport, are wave-breakers, jetties, sediment traps and sea entrance channels of harbours. A two-dimensional model is developed for applications in near-harbour regions (typically up to 10 km zones). It includes two-dimensional, time-dependent descriptions of wave-field, hydrodynamics, bed and suspended load transport, and morphodynamics (bed level changes). The operation of the model in a retrospective mode allows its calibration and verification.

The operation of the model in forecasting mode allows prediction of the siltation in sediment traps and sea entrance channels during typical and critical seasons; it helps to predict consequences of reconstruction efforts, and is useful for designing sediment traps and finding other engineering solutions such

as building additional wave-breakers. The application of the model described assisted in the reconstruction of Ventspils and Liepaja harbours.

1.7.3. Factors influencing the success of beach nourishment schemes

The methodology should establish procedures for innovative sand placement and corrective action to accommodate the significant spatial alongshore variation, high erosion or accretion, that routinely occurs in nourished beaches. The design profile should be based on natural profiles at the site that are suitably adjusted for nourishment grain size. Analytical and numerical models should be used to estimate sand losses that will be caused by spreading of sand to adjacent beaches. Fill volumes should be adjusted in order to provide sufficient volume to nourish the entire profile from the berm or dune to the seaward limit of the active profile and to avoid underestimating fill requirements. Sediment performance characteristics should be included in the design analysis. The first renourishment time interval could be shortened to allow for uncertainties in alongshore erosion rates; erosional hot spots can then be corrected before the design performance criteria are violated, and overbuilding of those areas in which the beach is widening through accretion can be avoided.

Careful consideration needs to be given to the effects of borrow sites located within the closure depth (the water depth at which no appreciable movement of sediment by wave action occurs) of the beach profile or at a site on adjacent beaches that normally feed the downdrift beaches and are critical to the success of the nourishment efforts. The impacts of creating a local depression in the sea bottom on offshore sand movement from the nourished beach and the quality and quantity of sand are particularly important.

Nowadays, the developed harbour industry in Latvia (the location of 10 seaports) disturbs the natural load transport processes through the hydrotechnical constructs such as the wave-breakers and sea entrance channels. The redistribution of the seabed topography, sedimentation in the sea entrance channels, and the dynamic response (growth or erosion) of the coastline are the cost of the operating seaports. In addition, the sedimentation in the sea entrance channels increases the expenses of shipping, requiring regular dredging works to ensure safe navigation depths. Thus, the methods for the forecast of the integral sedimentation/erosion volumes, their spatial and temporal distribution, and dynamics of the coastline, are very necessary. Besides this, engineering solutions for the optimum wave breaker configuration, the overdredging of the sea entrance channels, the configuration and depth of the additional (safety) overdredged areas, and the location of the load material discharge areas, are needed to minimise regular dredgeworks, allow their planning, ensure continuous navigation conditions, and reduce the erosion of the coastline.

The most distinct manifestation of the littoral transport occurs in its interaction with hydroengineering constructions of seaports (wave breakers, jetties, and sea entrance channels). Main qualitative features are beach growth in upwind

side of harbours while downwind areas suffer from erosion. Siltation in sea entrance channels is a real problem for navigation safety requiring annual planning for carrying out dredging works. The optimisation of the measures to ensure safe navigation at minimum cost is especially important for Liepaja and Ventspils harbours, exposed as they are to the Baltic winds and waves.

As nourished beaches undergo erosion, they must be maintained through beach re-nourishment. The re-nourishment process consists of restoring the beach to its initial conditions and usually has less time and cost associated with the project when compared to the initial nourishment. The time between re-nourishment projects, called the re-nourishment cycle, is dependent upon the severity of annual erosion of the beach and is usually several years.

1.8. Assessing and monitoring the environmental and social indicators for beach nourishment schemes

Monitoring beach conditions after a beach is nourished normally requires some baseline information of the beach conditions prior to the nourishment project. Beach width and slope should be measured prior to the nourishment project at various identifiable locations, spaced regularly along the beach, at the nourishment location and at downcoast locations. The pre-project measurements should be similar to, or more extensive, than the post-project measurements.

Most beach nourishment projects are inadequately monitored following construction; monitoring of the physical environment and the performance of the fill material is often too limited and of insufficient duration to quantify project performance adequately. Consideration of beach nourishment effects on biological resources has been limited, especially at sand borrow sites. Beach restoration projects should be planned so as to avoid significant long-term degradation of the biological resources that are effected by construction activities, with emphasis on monitoring resources and habitats of greatest concern, including borrow areas.

Timing for monitoring should take into consideration the expected performance of the nourishment project. For a project where all the material has been placed on the beach, it would be reasonable to expect that a lot of material will move offshore as soon as it is attacked by waves, because the underwater portion of the beach would be greatly out of balance with the portion of the beach that is above the water (see the Ischia case study).

Once this initial shift of material has occurred, it would be reasonable to expect that the beach would change at a rate similar to neighbouring areas. For such situations, it may be useful to undertake rather frequent monitoring initially and reduce the frequency as the changes become more gradual. For nourishment undertaken as a nearshore berm, there may be no changes to the beach until wave action has worked the berm and moved sediment shoreward. It may be enough to monitor the berm every few months and monitor the beach twice a year to establish a seasonal pattern and be able to separate beach changes caused by the new material from those caused by seasonal changes.

Risk assessment is a fundamental action in dealing with decision-making processes; both risk for not undertaking and risk for undertaking actions. Risk assessment is carried out to enable a risk management decision to be made. When actions are undertaken, risk assessment of the type of action should be made. If such actions are nourishment interventions, risk assessment of nourishment should be undertaken and should eventually be part of the accreditation process.

Risk management is the decision-making process through which choices can be made between a range of options to achieve the “required outcome”. The “required outcome” may be specified by legislation by way of environmental standards, may be determined by a formalised risk-cost-benefit analysis, or may be determined by another process for instance industry norms or good practice. It should result in risks being reduced to an *acceptable* level within the constraints of the available resources (both economic and non-economic).

A *risk assessment* will characterise the risk posed by a situation and then the process of risk management will eventually lead to a choice of action that will achieve the desired level of *safety*.

Where no acceptable risk standards exist or have been preliminarily defined, the risk management process should attempt to derive *acceptable* or *tolerable* risk on a case-by-case basis. This will always raise the question of “*Acceptable to whom?*” When Risk Assessment and management procedures are carried out by regulators or government, the aim is to produce societally acceptable risk levels.

Decision-making to determine *acceptable* or *tolerable* risk uses a number of approaches. The three major approaches to acceptable risk decisions are: (i) use historical precedent to guide decision-making, (ii) professional judgement where technical experts devise solutions, and (iii) formal analyses where theory-based procedures for modelling problems and calculating the *best decision* are used. The third approach allows for the quantitative measurement of the *probability, or frequency, of occurrence of a defined hazard* (such as a storm event) *and the magnitude of the consequences of the occurrence* (the morphological response).

If dry beach area is a concern, the measurements can be made using a tape measure, measuring from a stable location such as the base of a bluff, a seawall, the seaward extent of vegetation, or other easily identified location, to a seaward limit such as the tideline. The same locations should be measured regularly, every few months, for a given period of time (for example, four or six times a year for five or ten years, until the area is re-nourished or possibly for as long as there is some evidence of nourishment material at the beach site). It is important that the year to year measurements be taken in the same way, at the same shoreline locations and during the same time period, such as always during the same season, month, or two week period.

If there is concern about overall long-shore transport, the beach measurements should provide profiles from the back beach to a near-shore point. The critical elements that should be described in the monitoring plan would be the locations of the surveys, timing of the surveys, and their frequency.

Timing for monitoring should take into consideration the expected performance of the nourishment project. For a project where all the material has been placed on the beach, it would be reasonable to expect that a lot of material will move off shore as soon as it is attacked by waves, since the underwater portion of the beach would be greatly out of balance with the portion of the beach that is above the water. Once this initial shift of material has occurred, it would be reasonable to expect that the beach would change at a rate similar to neighbouring areas. For such situations, it may be useful to undertake rather frequent monitoring initially and reduce the frequency as the changes become more gradual. For nourishment undertaken as a nearshore berm, there may be no changes to the beach until wave action has worked the berm and moved sediment shoreward. It may be enough to monitor the berm every few months and monitor the beach twice a year to establish a seasonal pattern and be able to separate beach changes caused by the new material from those caused by seasonal changes.

1.8.1. Impact on shoreline stability

In the long term the major threat caused by erosion is related to the degradation of the beach and the foredune on a relatively wide coastal span. Coastal erosion already poses a threat to the houses adjacent to the foredune in Jurmala and, eventually, to the harbour facilities at 'Ziemas osta' in Daugavgriva. In other districts of Jurmala and Riga only some property or infrastructure is threatened directly by coastal erosion (Fig. 1.28). However since the study area is very important for recreation, the increasing erosion of the beach and the foredune might eventually threaten leisure facilities, which are closest to the sea coast (Fig. 1.29).



Fig. 1.42. Temporary defence measures in the place of the eroded foredune. Jurmala, November 2001



Fig. 1.43. Exposed recreation facilities after the storm surge erased the foredune. Jurmala, November 2001.

1.8.2. Impact on natural habitats

Dredging sand for nourishment from the sea bottom may cause direct mortality to sessile organisms, modification of seafloor habitats and the sedimentary burial of plants and organisms (shellfish), blockage of light from water (coral reefs), and toxicity of sediments. Furthermore, dredging too close to the shore can cause erosion.

1.8.3. Impact on water quality

Turbidity concerns may require regular water quality testing or water quality testing during times when turbidity might be a critical concern, such as during the lobster season, during times that the beach is used by sight-feeding birds, etc.

1.8.4. Social perception

Beach nourishment projects are often undertaken without due consideration of their relationship to and impact on other portions of the littoral cells that often cross political boundaries. Furthermore, most projects encompass only a portion of an area that can be considered a littoral geographic region or littoral sediment cell; yet actions within a littoral cell generally affect other areas in the cell and sometimes in adjacent littoral cells.

1.9. Budgeting for beach nourishment schemes

1.9.1. Feasibility costs

The costs of the previous studies of feasibility for Riga's beach drainage system were around 40.000€ for each of the phases (System 1 and System 2). Total feasibility costs are 80.000€.

1.9.2. Investment and engineering costs

For Riga's beach drainage system, costs of installation were around 400.000€ for the first phase and 290.000€ for the second. For *foredune and forestry maintenance* annual maintenance cost for coastal pine forests is 3,0 thousand EUR per hectare; for coastal foredune annual maintenance costs is 1,5 thousand EUR per hectare. For *revetment*, building costs from the Soviet period are incomparable with modern market-related costs of material, labour and technologies. The revetment reconstruction costs in 1999 were in the range of 100 – 200 thousand EUR. For *submerged nourishment* the costs were in the range of 2 – 2.5 EUR per cub. M of dredged and nourished material, which made the total cost of this measure 240 – 300 thousand EUR during the period of 1998 – 2001.

1.9.3. Maintenance and monitoring costs

Regarding Riga's beach drainage system, costs of maintenance are solely those related to the electricity used for water pumps and maintenance of the pump machine. For the first system, the energy bill is around 10.000€ / year and maintenance is not more than 300€ / year. For the second system, the two pumps cost around 15.000€ / year of electricity, as well as 600€ / year for machine care.

Overall, the total cost for the whole protected beach, including previous studies and installation, was around 760.000€ (excluding maintenance). The calculated cost for 10 years of running is around 916.000€ and 1.072.000€ for 20 years. Compared with the maintenance of the seawall (60.000€ / year), the beach drainage system is less costly in the long term.

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An example of the costs for the mitigation of losses inflicted by the November 2001 storm to the coastal zone of Jurmala municipality (Gulf of Riga) is:

Item	Unit	Quantity Costs (EUR)
Handling of beaches	km 22	2,180
Restoration of access roads gateways	7	1,340
Restoration of drainage network outlets	7	120
Revegetation of foredunes	km 16	22,460
TOTAL		26,100

Tab.2.5. Application costs in Riga.

1.10. Limitations

To fight coastal erosion, all forests and foredune ridges of Riga coastal zone in the case study area have been classified as protected and preserved. The Forestry Department (Ministry of Agriculture) is responsible for policy making, legislation, and coordination of practical efforts. However, there is a lack of financial resources available. The Law on Protected Belts (1997) includes several restrictions on land use in the coastal zone. It defines a protection belt of 300 m, starting from the permanent vegetation line, and also extending 300 m seaward from the permanent vegetation line including the beach. If the dune or other coastal formation exceeds 300 m, the protected zone is extended to its natural boundaries. In this zone any new construction is prohibited. The law also defines a belt of 5-7 km with limited economical activities. Unfortunately, the law is not always respected, particularly, in Jurmala municipality.

Local authorities have to maintain protected natural areas. They have rights to expand the regulations on the use of protected coastal territories in coordination with Regional Environmental Boards. The National Programme for Biological Diversity (1999) considers EUROSION Case Study problems of environmental protection – including ecosystems like the Baltic Sea, Gulf of Riga, beaches, dunes and coastal lakes – together with potential economic solutions.

2. Beach drainage

2.1. Purpose of beach drainage and expected results

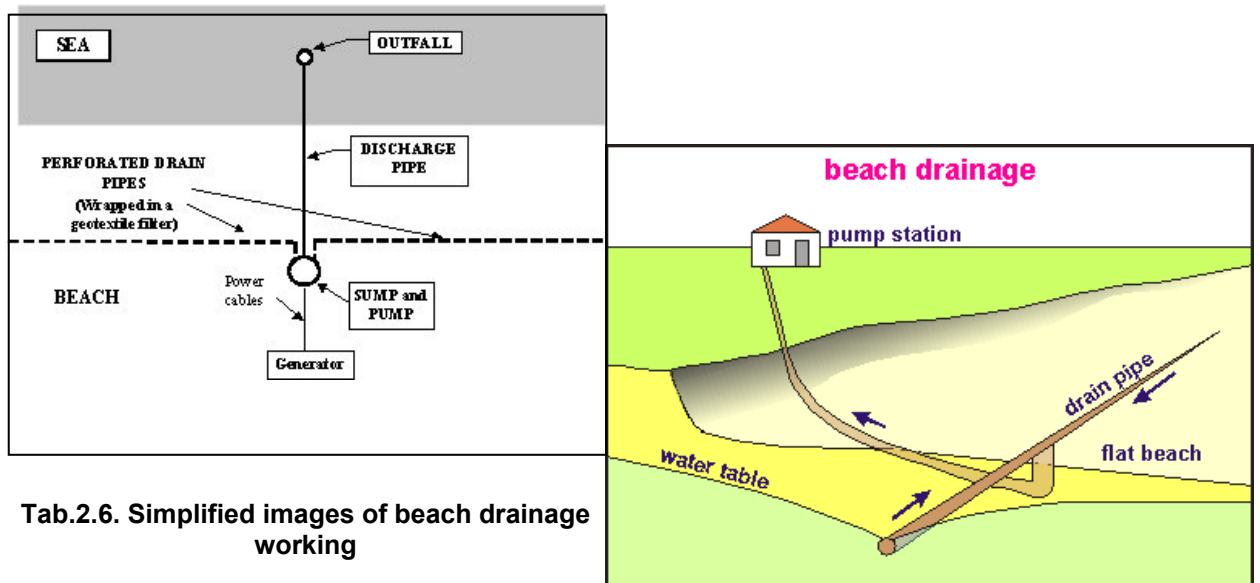
Sandy beach preservation is an important component of coastline management, since the beach is an effective means of wave energy dissipation. However, many beaches are subject to erosion due to reduced sediment supply (due to human or natural causes), sea level rise, and increased storm action due to climate change.

Previous studies have shown that a sandy beach may be stabilised by artificially lowering the beach water table using a simple sub-surface drainage system (e.g. Chappell et al., 1979; Vesterby, 1997).

The origins of beach drainage lie in several earlier studies which showed a relationship between the beach water table elevation and the rate of erosion. It was later demonstrated that artificially lowering the water table can lead to increased beach stability and in some cases accretion.

The most commonly used drainage system consists of collector pipes running parallel to the shoreline, buried at a depth of approximately two metres below the beach surface, and located between the high water and low water marks. Water is fed by gravity to a sump whence it is removed using a submersible pump, and the outlet is directed either back to the sea, a lagoon or recreational pool. This system is sometimes referred to as the Danish *Beach Management System (BMS)*. Now it has been improved by Italian engineers and planned for other sites.

A schematic diagram of a typical beach drainage system follows:



Tab.2.6. Simplified images of beach drainage working



Fig. 2.44. The beach drains may be installed during low water by digging a trench using a backhoe

The idea is to place a drainage pipe under the sand below the high tide level.



Fig. 2.45. Beach drain ready for installation

2.2. Basic principles

The drainage pipe conducts water to a collection point from where it is pumped out. The water is then led back to the sea. This method recognises that many beaches are sick because their sand cannot dry. These beaches usually lie too flat. By draining the high tide region, the water table is lowered and the sand has a better chance to dry. The sea wind completes the renourishment.

The method is quite simple to implement, requires no visible structures or mechanical transportation of sand, and the sand that is already in the sea is used. Energy can be saved by pumping only during the low tide and by day when the sand can dry.

For beaches with other problems such as sea wind obstruction or crusting, this method may be less successful.

The origins of beach drainage lie in several earlier studies which showed a relationship between the beach water table elevation and the rate of erosion (e.g. Emery and Foster, 1948; Grant, 1948). It was later demonstrated that artificially lowering the water table can lead to increased beach stability and in some cases accretion (e.g. Chappell et al., 1979; Davis et al., 1992; Vesterby, 1997; Turner and Leatherman, 1997).

A particularly effective means of beach stabilisation is the Beach Management System (BMS), which was developed by the Danish Geotechnical Institute in Lyngby, Denmark. The BMS design was based on a water collection system. The pipes are installed approximately 2m beneath the beach in the swash zone to collect water that had soaked into the beach and filtered through the overlying sand. Thus drained, there had been a considerable increase in beach width and sand depth.

Despite a number of successful installations, full scale results are varied and a number of studies have reported only limited success. This suggests that although beach drainage can offer an option for coastal stabilisation, its performance depends on local characteristics, and site-specific conditions must be taken into account in system design. Performance prediction is complex due to the number of potential influencing factors.

Several previous studies (Weisman et al., 1995; Briere, 1999; Mulvaney, 2001) have been carried out to investigate the phenomenon of beach stabilisation through drainage. Model experiments have inevitably been subject to scale effects, and previous results are thought to have provided an underestimate (Weisman et al., 1995) or overestimate (in the case of lightweight models) of beach drainage system performance (Mulvaney, 2001).

The swash/backwash motion, i.e., wave run-up and run-down in the swash zone, provides the driving force for swash sediment transport. The upwash moves sand on-shore while the backwash transports it offshore. The hydrodynamics of these processes are very complicated, involving highly non-linear transformations of broken and unbroken waves on a sloping beach. Moreover, the wave motion interacts with the beach groundwater flow. Seawater may infiltrate into the sand at the upper part of the beach (around the shoreline) during swash wave motion if the beach groundwater table is low. In contrast, groundwater exfiltration may occur across a beach with a high water table. Seawater infiltration under a low water table was found to enhance on-shore sediment transport, whereas groundwater exfiltration under a high water table promote offshore sediment transport. Sediment size influences the transport process of sand indirectly through the groundwater. A large sediment size results in a large permeability and hydraulic conductivity of the porous medium. This will increase the infiltration/exfiltration rate and hence affect wave motion that provides the driving force for sediment transport.

2.3a. FIRST Application: *Les Sables d'Olonne case study*

2.3.1. *Description of the site*

An example of beach drainage application is Les Sables d'Olonne, one of the most famous seaside resorts of the Atlantic coast, known for its fine sand and protected beach. Situated on the Atlantic coast of France, it stretches along the bottom of a bay open to the south.

On the west, the bay is closed by a headland and by the west pier of the harbour. They both protect the bay from the west dominant swells. On the ESE, the bay is closed by another headland. The length of the beach is approximately 1500m between the pier of the harbour in the west and the rocks of the red lighthouse in the east. A continuous seawall from west to east is built on the upper shore aimed at protection from flooding. The slope of the upper shore is around 4-7% and the slope of the shore face is around 2%. The seepage point is between these two parts of the beach. The seepage of the water table, significantly, is due to the clay layers located one meter below the shoreface.

The site is on the south of the British Massif. This region of the littoral is a metamorphic plateau plunging into the Atlantic Ocean, notched by several rivers. The littorals have evolved during the quaternary with the sea level variations. The estuaries of the rivers and the marshlands were filled up with fine sand and mud. In the downstream side of the rocky headlands, the sandy spits had progressively closed the estuaries and marshes. This could explain the presence of clay layers one metre below the shore face. The sediment characteristics of the beach are fine sand: $150\mu\text{m} < D_{50} < 250\mu\text{m}$ and very homogeneous.

The marine bottoms are shallow due to the continental shelf which extends 100 km to the west of the coast. Offshore, some rocky shoals close the bay to the south swells. The entire bay is well protected from the most dominant swells, but the whole of the littoral drift of the Atlantic coast cannot bring sediments into the bay. The bay has to live with an autonomous stock of sediments.

The dominant winds are south-west to north-west. 10% of wind speeds are greater than 8 m/s. The spring tidal range is about 5,6 metres. The main driving current is the tidal current. The flood current is to the south-east with a speed of around 0,4 m/s and the ebb currents to the west-north-west with a speed of around 0,25 m/s. Only the swells from south-east to south-west could penetrate directly into the bay. The swells from the west to north-west are diffracted by the headland and the shoals.

The cross-shore and long shore transport is around 1.000 cubic metres per year. The main action of the transport is cross-shore, between the lower and the upper beach. The bay, closed by the headlands and the rocky shoals, is an homogeneous sedimentary cell where the input and output of sediment are possible but very weak. The stock of sediment on the beach is not being improved by the littoral drift, but only by the cross-shore transport.

The reflection of waves on the seawall, and the cross-shore transport due to the action of waves have increased erosion. In the 60's the beach disappeared at high tide. The foot of the seawall was regularly damaged.

2.3.3. *Applied methodology*

The beach drainage system installed in the beach of Les Sables d'Olonne is the one developed by the Danish Geotechnical Institute. The system consists of a gravity drain which forces the lowering of the water table under the beach. The beach is not saturated in water when the waves break on the shore. The infiltration of the water in the sand is improved. The water speed in the swash decreases and the sand transported lies on the shore face. As a great deal of the water washes down into the beach, the volume of sand in the backwash is less. The accumulation of sand increases and the erosion is stopped. The water flows by gravity from the drain to a pump. The water is then pumped and thrown into the sea or used as filtered water in a marine swimming-pool, aquaculture, fisheries, a marine therapeutic centre, an aquarium...

The engineering options chosen in the past to protect the seaside front of Les Sables d'Olonne were of a hard nature. All the southern shoreline of the city is already protected by a seawall and dykes which are unable to stop the lowering of beach profiles. The proposed strategy was to work as much possible with natural processes. The beach drainage system has been chosen for its respect for the environment and landscape, and its capacity to use the natural processes to accomplish the objectives for which it was designed.

In April 1999, with the aim of halting erosion and stabilising the beach profiles, a beach drainage system was installed on the eastern part of the beach, which was the most exposed to the swells and the most eroded. This first system consisted of a gravity drain of 300m in length, buried 70m in front of the seawall, at the line of the mid sea level. In March 2002, as the positive results of the first one became evident, the local public authority decided to improve the efficiency of the first system with a second one on the western part of the beach. A second drain of 300m length was installed 60 metres in front of the seawall, and a third drain of 700m in length placed 30m in front of the seawall, at the line of the high tide level.

The soundings made to ascertain the different layers of the subsoil have indicated the presence of some clay layers one metre below the shore-face. In order to improve the drainage system, some furrows have been dug to increase the drainage of the beach.

There follows a diagram of the system installed in the beach of Sables d'Olonne (Fig.2.3):

2.2.3b. SECOND Application: *Lido di Ostia case study*

2.3.3. Applied methodology

In Italy, thanks to a convention between Regione Lazio Administration and Impresub, a BMS pilot facility was built in the South Eastern part of the “Lido of Ostia”. Ostia beach has been prone for many years to severe erosion, probably caused by a progressive reduction in river input. It consists of three sections covering a length of approx. 400 m. The recent coastline evolution shows that BMS produced good effects on beach evolution. The evolution observed will be compared with the surrounding baseline area, and correlated with meteoric conditions occurring during the experimental period.

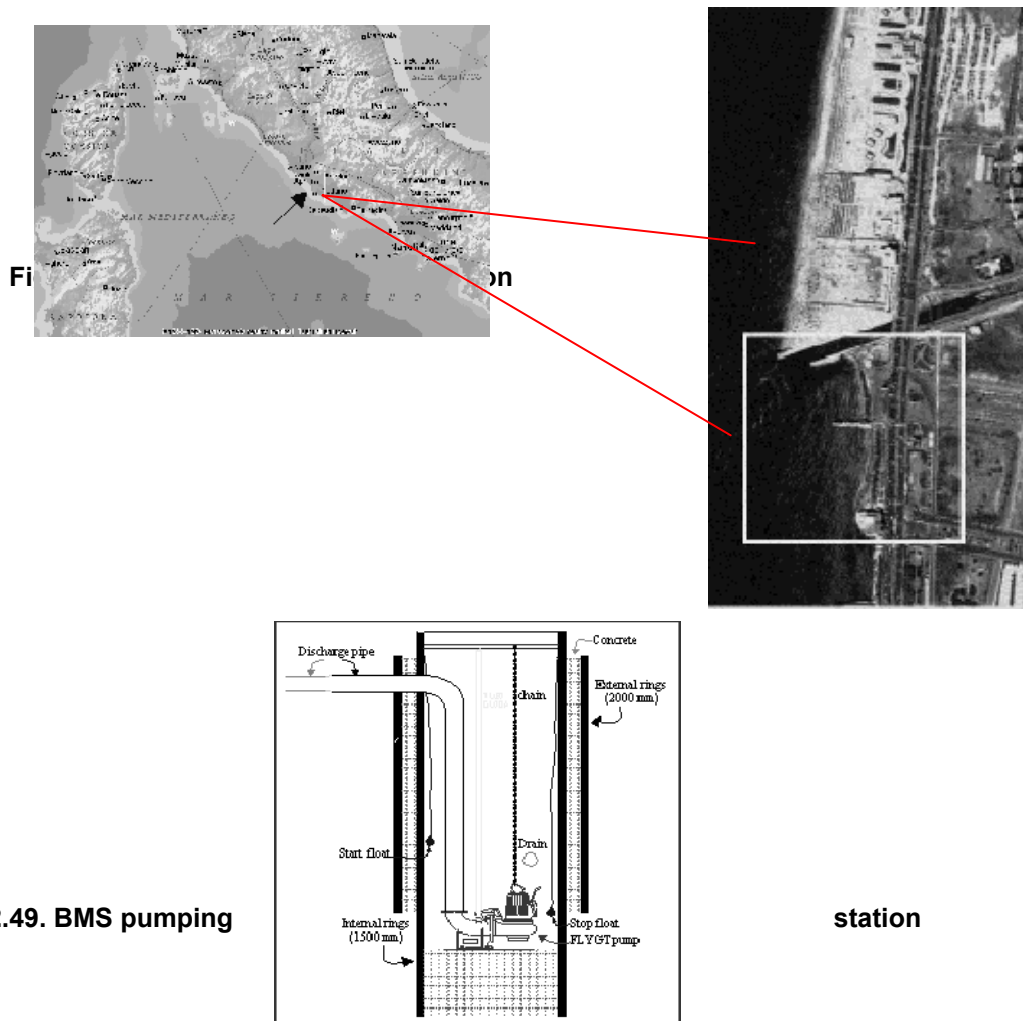


Fig. 2.49. BMS pumping

station

2.2.3b. THIRD Application: *Ferrara case study*

In Lido degli Estensi (Porto Garibaldi, Ferrara) a particular technique to safeguard the beach has been applied. It is the sand-duct, which has been described in the beach nourishment techniques (see §1.3e). In fact this methodology could be seen as a link between the two coastal defence techniques.



Fig.2.50. Installation of the sand-duct in Ferrara.

2.2.4b. FOURTH Application: *Chiaiolella case study*

In June 2002 a BMS system module was installed in Chiaiolella (Isle of Procida, Naples). Specifically, the intervention involved Ciraccio beach (in the north-eastern part) and Ciracciello beach (south-western part). The system has three BMS modules, respectively 200, 300 and 380 meters long.

Chiaiolella beach (Fig. 2.8) comprises Ciraccio and Ciracciello beaches and is about 1.5 Km long to the west of Procida, between Punta Serra Cape and the volcanic little islet of Vivara.

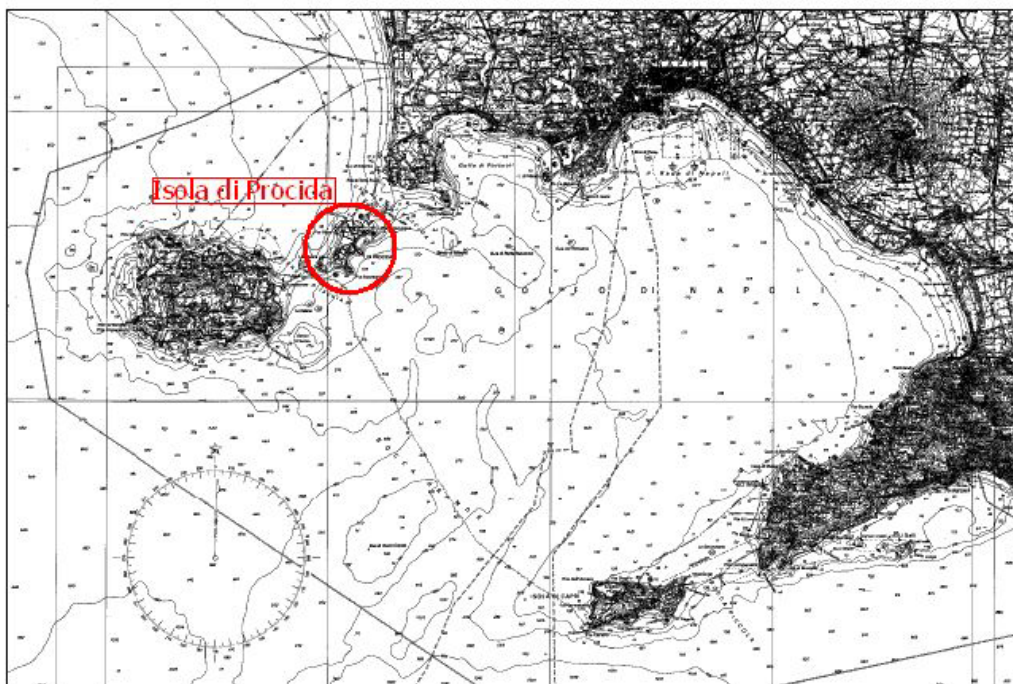


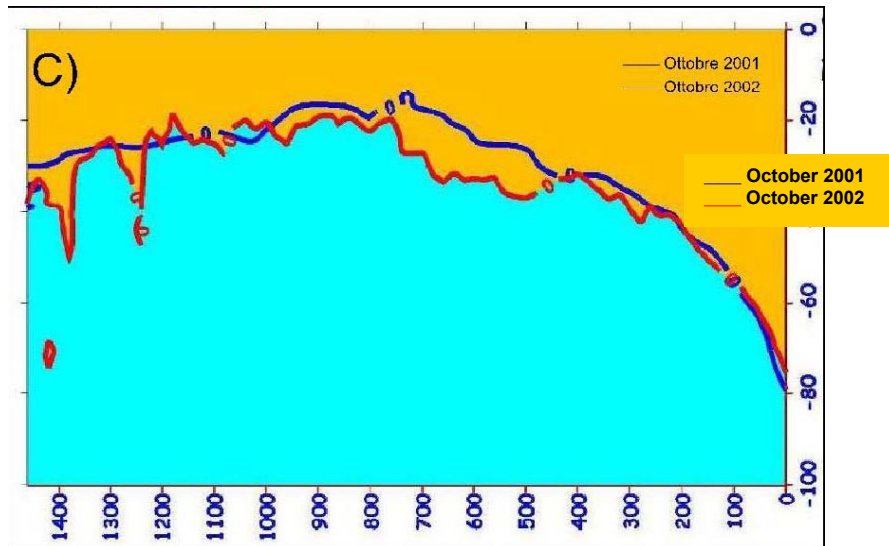
Fig. 2.51. Morphological map of the investigated site.

The coastal belt is classified as a short sandy beach, protected landward by a rocky mountain belt.

The beach is geomorphologically defined as a pocket-beach and its sea bed up to 10 m u.s.l. is only about 2%. The bathymetric profile is almost parallel to the coastline and granulometric analyses demonstrate the submerged beach is made up of medium size sands with a low presence of pebbles.

The installation of the drainage system followed various analyses of the different parameters of the coastal area. The installation of the system showed an evolutionary trend of increase and a simultaneous rise of the accumulation power and retention of the beach sediments.

This phenomenon can be seen in the following image (Fig. 2.9):



The in situ results show a notable enlargement of Chiaiolella beach with an advancement of the coastline of more than 6 metres, with a rise of the emerged beach of 5300 m square.

2.4. Expected benefits

The principal findings are that beach drainage results in a significant reduction in pore water pressure in the swash zone, even with waves operating; it can promote accretion in an otherwise erosive wave climate (in the swash zone); when beach drainage causes accretion, the volume of material gained in the swash zone (on account of the drainage system) is proportional to system discharge; when conditions change from calm to erosive conditions, material will inevitably be lost, even with the drain in operation (although the total beach volume will remain greater with the drain in). The system will begin to re-stabilise the beach after a length of time.

For non-tidal conditions, the drainage system is most effective when the upper section of the swash runs up over the zone of maximum influence of the beach drain.

2.5. Selecting the adequate nourishment beach drainage methods

One of the newest beach drainage technologies is the so-called *Beach Management System* (BMS).

BMS is a new method regarded as being between a soft approach and a beach management one. In 1999 *Impresub, Diving and Marine Contractor s.r.l.* bought BMS rights for Italy. This system was patented in 1985 by the Danish Geotechnical Institute.

When breaking waves impact on a beach, they reach beyond the point where the water table intersects the beach face and run up to a height controlled by excess wave energy, beach permeability, beach slope and roughness.

In the run-up phase the suspended sediment load tends to deposit on the beach face. The subsequent backwash flow accelerates the beach face down-slope and transports the sand sediment offshore. The net result can be beach erosion or accretion, according to the specific site and environmental conditions and wave nature.

In this process the level of the ground water table plays an important role. When the water table level is high in the beach, due to flow from the hinterland, tidal level or percolated water from the swash zone, the backwash flow is increased on the beach face, thus also the potential erosion of the retreating wave is increased. Moreover, the seepage flow occurring between the water table level and the mean sea level is mainly directed off-shore, thus contributing to the instability of the sand in the run up region.

On the contrary, when the water table level is low compared to mean sea level, a seepage flow will occur towards the beach during the run-up process. This seepage flow does not affect the run-up height, but reduces the backwash

flow, reducing its erosive potential. Moreover, the sub-vertical seepage flow helps to stabilise the sand in the run-up region.

On most sandy beaches these conditions occur naturally in summertime, when natural drainage will keep the water table level low and waves usually have a nourishing nature. On the other hand, during winter, the large amount of ground water occurring on the beach produces a natural elevation of the water table and the natural drainage is not effective enough to reduce the backwash flow produced by storm waves; in these conditions the beach face erosion is more likely to occur. The Beach Management System attempts to interplay with these natural phenomena by favouring deposition of sediment transported by waves during the up-rush and opposing its offshore movements during the backwash, thus tipping the balance of erosion; so in a sense, by recreating all year the conditions naturally occurring in summer.

The system is based on the principle of the artificial drainage of the beach to keep the water table level low. A drainage pipe is buried under the beach almost parallel to the shoreline, removing the excess pore water, which is driven by gravity to a collector pump station located further on-shore. The pumps discharge the drained water back to the sea or – as it is salt water – to places that can make productive use of it, such as seawater swimming pools, marine aquaria or fish farms.

The BMS system constitutes an innovative solution to the erosion with many advantages over traditional coastal protection systems, such as negligible environmental impact, low installation and maintenance costs, and no negative secondary effects on the nearby beaches.

2.6. Assessing and monitoring the environmental and social impact of beach drainage methods

A special survey of the first installation of a beach drainage system on the Gulf of Riga's beach has been carried out where methodologies to safeguard the beach and dunar system have been employed. This survey aims to understand the running of the system and the effects on the environment. The comity for the survey is composed of the "Ministère d'Équipement" (CETMEF), and the University of Nantes (IGARUN), as well as the regional and local public authorities. After the initial installation of the beach drainage system, in 1999, the survey carried out by the public authorities (Service Maritime DDE VENDEE) and the University of Nantes has shown that on the treated beach:

- The beach profiles are stabilised
- The erosion is quasi-stopped
- The beach is dry
- An accumulation of sand is gradually visible above the drain area
- The system is able to recover quickly the sand lost after a storm event

- No negative impact has been recorded either on the upstream or on the downstream side

The study of the results of the first installation has shown a problem in the drainage on the upper-shore due to the presence of clay layers. So to optimise the upper beach and improve the sediment deposition in this area, an upper drain connected to the same pumping station has been installed, 30 metres in front of the seawall. After the second installation of a beach drainage system in March 2002, the survey by the public authorities (Service Maritime DDE VENDEE) and the University of Nantes has shown that the positive effects visible on the first installation are visible on the second as well. The improvement brought by the second installation with the upper drain has been established by the comity for the survey (December 2002). The upper drain is able to conserve the summer upper-beach till December, even though some severe storm events occur.

After the installation of the first drain system, the tourist capacity of the beach has been improved, due to the drying of the foreshore and condition of the beach during high tide. Since the installation of the system, no damage to the seawall has been recorded, the beach profiles were stabilised and the erosion has stopped.

2.6.1. Impact on shoreline stability

The effectiveness of the beach drainage system for the Gulf of Riga can only be evaluated after a longer period. The beach drainage system has shown to be effective in stabilising the beach profiles and stopping the erosion. The improvements provided by the upper beach drain show the success of the system in this regard, even it is too early to ascertain the efficiency of the system in increasing the beach width. A better knowledge of the system in a greater tidal range is necessary for a successful application of the system

2.6.2. Impact on natural habitats

No impacts on natural habitats are found in the application of beach drainage systems.

2.6.3. Impact on water quality

The beach drainage system installed at Riga on the upstream side of the long-shore current has no negative impact on it. The system does not block the littoral drift, as happens with groynes. The treated beach is stabilised and the untreated beach continues to be eroded. The consequences of the system are only visible on the bay due to its closed morphology.

2.6.4. Social perception

Before the installation of the drainage system at Riga, the impacts on the environment, the landscape, the quality of sand and water, and the impacts on the neighbouring areas were assessed in the "Impacts study". Some public meetings were organised to debate and explain the different effects of the operation in the region.

3. Wetland creation and restoration

3.1. Purpose of wetland creation and restoration and expected results (protection vs. nourishment)

Riparian ecosystems generally form a minor proportion of surrounding areas, but typically are more structurally diverse and more productive in plant and animal biomass than adjacent upland areas. Riparian areas supply food, cover, and water (especially important in the arid regions) for a large diversity of animals, and serve as migration routes and forest connectors between habitats for a variety of wildlife, particularly ungulates and birds.

Wetlands generally occupy relatively small areas, and their occurrence along waterways makes them vulnerable to severe alteration caused by a variety of development activities. Impacts include expanding agriculture; canalisation projects; reservoir and dam construction; heavy livestock grazing; road, bridge, and pipeline construction; and flood control projects.

Riparian ecosystems generally are more structurally diverse and more productive in terms of plant and animal biomass than surrounding areas.

A number of difficulties are encountered when attempting to restore riparian zones to their original condition: (1) the historical condition of rivers might not be well known; (2) ecological means of returning to a known prior condition are not understood, nor is it certain that this is possible; and (3) presence of man-caused phenomena for long periods of time may genetically alter a species to the extent that restoration may affect it unfavourably.

Successful planning will benefit from an investigation of various functions of riparian wetlands (including wildlife and fish habitat, hydrologic flow, erosion control, water quality improvement, and recreational use).

Because riparian ecosystems often are relatively small areas and occur in conjunction with waterways, they are vulnerable to severe alteration. Wetlands throughout the World have been heavily impacted by man's activities. Riparian ecosystem creation and restoration have been used as mitigation for project impacts from highway, bridge, and pipeline construction; water development; flood control channel modifications; industrial and residential development; agriculture; irrigation; livestock grazing; mining; and accidental habitat loss.

Creation of a riparian ecosystem requires appropriate water supply and grading the topography to suitable elevations to support plantings of riparian vegetation. Restoration involves returning the ecosystem to pre-disturbance conditions and typically implies re-vegetation. Removing exotic vegetation or restoring water supplies to pre-disturbance level also may be involved.

Enhancement of riparian ecosystems commonly refers to improving existing conditions to increase habitat value, usually by increasing plant or community diversity to increase value for wildlife. Managing a riparian ecosystem typically involves enhancement techniques. However, creation and restoration projects often involve use of techniques considered more management-oriented (e.g., fencing to prevent cattle grazing until planted vegetation of a created or restored wetland is established).

Protection of an existing riparian ecosystem from impact should be of utmost importance during planning and construction phases of development projects. If

loss or damage is unavoidable, wetland creation or restoration can be used as mitigation.

The sediment control, bank stabilisation, and flood attenuation functions of riparian wetlands have been documented to some degree.



Fig. 3.52. View of the lagoons and marshlands of the Hersey Nature Reserve.

3.2. Basic principles

Two factors are especially important before one can either identify a problem or begin recovery processes in riparian ecosystems: (1) knowledge of the management objectives and (2) knowledge of the physical environment and biotic communities occupying the site, including the hydrologic regime, physical and chemical characteristics of the soils and substrates, potential for the site to support particular species and plant communities, and vegetation successional patterns.

There are six basic ingredients for adequate riparian ecosystem mitigation planning: (1) a solid base of data concerning wildlife in the project area and in the area set aside for mitigation; (2) a thorough analysis of the data; (3) creation of predictive models with which to create, in theory, a design for the mitigation; (4) design of required modifications, including site preparation (e.g., clearing, installing an irrigation system), equipment needs, costs, and a careful analysis of probable delays; (5) design implementation, including labour requirements and labour sources; and (6) monitoring, including methods of gathering information, analytical and interpretive techniques, and staff requirements.

When planning a creation or restoration project, close proximity to existing high quality riparian ecosystems is advantageous for the added benefit of recolonisation.

3.3. FIRST Application: *the Seaview Duver (Isle of Wight) case study*

A recently completed coast protection scheme has been carried out at Seaview Duver. This scheme includes an excellent example of wetland restoration.



a

b



Fig. 3.53 a-b. Seaview Duver: general overview of the Duver site, showing construction work on the outfalls for Barnsley Brook watercourse.



Fig. 3.54. General overview of the Duver site, showing construction work along the beach on the outfalls for Barnsley Brook watercourse.

A £4.5 million coast protection scheme for the Seaview Duver frontage between Oakhill Road and Springvale was completed in April 2004. Constructed over a period of one year by Van Oord ACZ the project was commissioned by the Isle of Wight Council's Centre for the Coastal Environment and designed by its coastal consulting engineers, Posford Haskoning. The scheme was grant-aided by the Department for Environment, Food and Rural Affairs (Defra).

The scheme provides the required standard of protection against coastal erosion and sea flooding for at least the next fifty years taking full account of the predicted impacts of climate change. The scheme comprises a 550m length of stone-faced reinforced concrete seawall protected on the seaward side by a rock armourstone revetment.

Additional facilities include an upgraded slipway and pedestrian walkways on the seaward and landward sides of the wall together with seating. In order to optimise the appearance of the final scheme the Council appointed John Maine RA, a sculptor and artist, to contribute to the aesthetic qualities of the design.

The foreshore and intertidal area along this part of the Seaview coast are designated as a Special Protection Area under the European Birds Directive. In

order to mitigate any impacts arising from the civil engineering works on this European site the Council has acquired, for a peppercorn rent for the next fifty years, 20 acres of marshland and reedbeds on the landward side of the former toll road from the Ball family. With the assistance of English Nature, the Environment Agency, local residents, and environmental specialist consultants ECOSA, a nature reserve has been developed which includes public access and the provision of a hide for bird watching. The area has been improved in order to optimise the environmental quality, particularly for wading birds, ducks and geese.

The nature reserve has been named after Alan Hersey, who was for many years a Parish, Borough and County Councillor who had a great interest in the history and environment of the village of Seaview. A formal opening of the coast protection scheme took place in August 2004. The scheme has recently been awarded a special prize by the Isle of Wight Society for the quality of the conservation and landscaping work.



Fig. 3.55. Construction work on an outfall at the western end of the frontage.



Fig. 3.56. Seaward view of the works looking towards Seaview.



Fig. 3.57. Seaward view of the works looking towards Ryde.



Fig. 3.58. Granite block seating on the raised footway.

3.3b SECOND Application: *Riga case study*

The Gulf of Riga has been described in detail in §1.3b. In this section we examine foredune and forestry maintenance.

The technical measures employed on Riga's beach are foredune and forestry maintenance, revetment and submerged nourishment.

- *Foredune and forestry maintenance:*

As mentioned, maintenance of coastal foredune and forest plantations is the principal technical coastal stabilisation measure within the study area. In the central part of Jurmala there was a concrete seawall erected as a base for a newly raised foredune after the storm of 1969 (Fig.3.8)



Fig. 359 The concrete base of the foredune, erected after the storm of 1969 and exposed again after the erasure of the foredune in November 2001 (photo: G. Eberhards).

Pine forest plantations are managed through clearing, selective cutting and replanting. The foredune is maintained by stabilisation and revegetation techniques. The marram grass and the willow are the most commonly applied plant species for the foredune revegetation.

3.4. Expected benefits

3.4.1. Environmental benefits

Wise management of remaining riparian ecosystems or replacement of these communities is extremely important because of their high value as fish and wildlife habitat. Riparian ecosystems generally are characterised by increased structural diversity of vegetation compared to surrounding plant communities and a defined boundary of the area.

Direct openings to the sea permit water exchange that can prevent stagnation and oxygen depletion, renew organic material and nutrients, and allow export of materials such as detritus, plankton, and aquatic invertebrates to the sea. Fish are known to enter backwaters readily, especially for spawning, and the free movement of fish into and out of these areas in response to changing conditions is important for maintaining healthy populations.

In general, cover increases habitat complexity, which can lead to a richer species complex. Cover provides hiding places for both adults and fry to escape predation. Its slowing effect on water velocity provides a metabolic resting place.

Improvement of riparian ecosystems also may increase groundwater storage

Vegetation influences soil erosion in several ways: foliage and leaf residues intercept rainfall and dissipate energy, root systems physically bind or restrain soil particles, residues increase surface roughness and slow velocity of runoff, roots and residues increase infiltration by maintaining soil porosity and permeability, and plants deplete soil moisture through transpiration, giving the ground a “*sponge effect*” to allow it to absorb water.

Loss of riparian vegetation in the channel has little effect on bank erosion, but loss of riparian vegetation in the floodplain zone does have a major impact on bank erosion. Revegetation in this zone can provide significant resistance to bank scouring because lower velocities permit plant establishment on most of the streambank. If not carefully planned and implemented, stream channel alteration (e.g., narrowing, straightening, diverting) also can greatly increase bank erosion.

3.5. Selecting adequate wetland creation and restoration techniques

3.5.1. Establishing environmental mitigation strategies

A general goal is to reverse (or mitigate) the damage that has or will occur to a wetland, and to answer regulatory concerns. Goals are usually broad and not site-specific. Goals direct the project to restore and improve wetland functions, such as flood storage, sediment trapping, food chain support, community diversity, biological productivity, and fish and wildlife habitat. Objectives, on the other hand, are more site-specific and direct the actions of the project (e.g., to revegetate disturbed areas with native trees and shrubs to provide wildlife food, cover, and nest sites; to provide an additional 1 acre-foot of storage capacity within the wetland to function as a storm water retention/detention basin).

The goal of a project may not be to re-establish the former riparian situation, if that situation is degraded. The goal should be to establish a new equilibrium condition that supports a viable riparian zone. The overriding consideration in planning a riparian ecosystem rehabilitation program may be to determine the rehabilitation potential of the target area and identify the root causes of the degraded condition. Causes must be resolved before an improvement project is initiated. Riparian zone rehabilitation should not circumvent the real causes of stream degradation. Natural recovery processes must be understood and incorporated in the rehabilitation. Objectives of the rehabilitation program should consider existing and future watershed condition, hydrologic regime, and the desired rate of recovery.

A comprehensive set of methods used for evaluating riparian habitats. Topics include sampling schemes, measuring vegetation, classifying riparian zone communities, determining various features of the soil, remote sensing, water column measurements, streambank morphology, measuring and mapping organic debris, historical evaluations, and use of benthic macroinvertebrates to evaluate stream riparian zone conditions.

In degraded situations where historical information is insufficient to formulate a design format, the use of comparable areas that have been little disturbed and managed as natural areas may be necessary to guide the revegetation plan. Techniques for assessing vegetative distribution patterns for formulating a working planting design involve a review of historical context and the selection of comparable areas to inventory for distribution, community and soil patterns, canopy heights, and elevational transects in relation to stream flow.

Knowledge of the geologic variability and geomorphological characteristics of drainage patterns can help predict water storage capacity for streams being reclaimed for riparian zone values.

Both site characteristics and the biological aspects of target species need to be considered in the management of riparian systems. Site characteristics include the climate (precipitation cycle, temperature ranges, length of growing season), soils (structure, fertility, topography, residual pesticides), water control potential (water supply/source, levees, control structures, pumps), plants (composition, structure and maturity, seedbank), and disturbance (man-induced perturbations, public use, research and management activities). Biological aspects of target species include chronology (migration, breeding, moult), nutritional requirements (population size, migration, breeding, moult), social behaviour (foraging modes, breeding strategies), significance of location (local, regional, continental), status (endangered or rare, recreational value), and multi-species benefits.

Preliminary efforts should entail classification, inventory, and evaluations from which critical aspects of the project design can be determined.

In the past, governmental reclamation agencies have relied heavily on planting design techniques dependent on exotic plant materials to achieve simplistic goals of erosion control, environmental tolerance (e.g., drought or flooding tolerance, soil tolerance, browsing tolerance), and aesthetic improvement. Today, use of exotic plant materials is still entrenched in riparian projects. But the use of native riparian plants should be expected to increase as

more managers realise the value and ecological diversity that native riparian systems offer.

Topics include matching original channel length, slope, meander pattern, depth, and width; sloping banks; stabilizing banks with riprap and vegetation; planting trees and shrubs; fencing; using suitable substrates; installing culverts and stream crossings; and using instream structures (boulders, low rock and stone dams, deflectors).

Many techniques involve planting or seeding either as the main technique used or to supplement other techniques (e.g., seeding grasses to accelerate vegetation recovery on fenced sites; planting trees or shrubs to accelerate establishment of riparian growth on banks of relocated streams).

Seeding sites is less expensive than transplanting cuttings or seedlings. Direct seeding eliminates costs associated with growing seedlings in a nursery and is less time-consuming than transplanting seedlings. However, seeding of shrubs and trees is generally less successful than transplanting cuttings or seedlings.

Covering seeds is essential to most germination and seedling establishment. Various methods can be used to enhance success rate of the simple hand broadcast method of seeding, including seed drilling, hydroseeding, or cyclone seeders.

Erosion control matting/blankets of dead plant materials or organic material provide temporary cover for exposed soils and moderate the effects of rainfall impact, runoff velocity, and blowing winds, and are particularly important when seeding slopes to provide protective cover for seedbeds, reduce evaporative losses, and stabilise seed location until germination. Matting made of straw, wood or coconut fibres, or synthetic materials costs more than simple layers of straw, but is more efficient.

Fertilization and irrigation often are used to enhance initial seedling establishment. Fencing may be necessary to protect seedlings from wildlife (e.g., rabbits, deer) or cattle grazing.

Time of planting is important (winter is the best time for planting desert riparian areas due to lower evaporation rates and thus greater saturation of soil from surface to water table). Certain precautions are necessary when using this method, including fencing the area from livestock, avoiding flooding for periods longer than 3 weeks, and controlling beaver activity.

Creation of riparian ecosystems, or restoration of severe channel damage, typically involves some type of landforming. Landforming can consist of relocating a stream, recontouring a channel by sloping banks, building meanders, creating pools, or creating marshes or ponds within the stream.

In urban areas, stream restoration is an alternative to conventional channelization involving stream straightening and deepening with heavily riprapped banks. A channelized stream may be restored by removing brush, debris, and dead trees that blocked water flow; sloping banks to less than vertical inclination; sloping meander bends to produce sandbars; seeding banks; and sparingly using riprap along highly erosive slopes. The result is an aesthetically pleasing urban stream with greater wildlife habitat potential and lower flood hazard.

Several studies have used instream devices in conjunction with efforts to restore riparian ecosystems. Instream devices are primarily used to enhance fish habitat by increasing flow, creating riffles and pools, restoring gravel spawning beds, and increasing fish access. Instream devices also can provide bank stability, thereby aiding in restoration of riparian vegetation.

3.5.2. Factors influencing the success of wetland creation and restoration schemes

Knowledge of particular combinations of substrate, microclimate, nutrient and water level regime, and the dynamics of riparian plant communities in both time and space, will greatly aid in riparian ecosystem creation or restoration.

Selection of plants for re-vegetation may involve not only consideration of native wildlife species, but also of plants that provide necessary resistance to erosive stream flows in heavily eroded areas.

Sediment texture also can influence establishment of riparian seedlings. On gravel bars willow establishment was higher on bars where surface sediment size was less than 0.2. Cottonwood (*Populus fremontii*) established more densely on areas of intermediate and large-sized sediments (0.2-1.0 cm), and mule fat (*Baccharis viminea*) dominated on larger sediments. Changes in gravel bar landforms can result in significant losses of established trees as well as young seedlings and saplings. Areas protected from swiftest currents are best suited to withstand high winter flows that can occur in this area.

A number of limiting factors may affect the success of bottomland hardwood: drought during the growing season or a late freeze following plantings; standing water and high temperature on sites with young seedlings; flooding on sites where the species planted are not adapted for the duration or depth of flooding; damage or destruction of seeds or seedlings by rodents, rabbits, or deer; and poor seed viability or poor quality of nursery stock.

Field and experimental studies have demonstrated the influence of various environmental conditions on the species composition of bottomland hardwoods. Study on the tolerance of various bottomland hardwoods to water-saturated soil indicated that occurrence of continuously saturated soil conditions for long, but varying, periods in bottomlands results in a competitive advantage for certain species (e.g., green ash [*Fraxinus pennsylvanica*], willows) and subsequently affects species composition of bottomland stands. Amount of exposure to direct sunlight and amount of litter and ground cover also can affect species composition, with cottonwood and willow seedlings preferring direct sunlight and lack of litter.

Selection of plant species for re-vegetation can be complicated by the fact that riparian communities are not always a distinct **climax** biotic community.

A properly designed monitoring system is vital to determining success of riparian ecosystem creation/restoration efforts. Equally important is that project objectives be stated in quantifiable and measurable terms. Meeting an objective of returning a riparian site to "original conditions" or a close approximation thereof, may be difficult because those conditions may not be known due to the site's long history of human impacts. Collection of historical data on the site can greatly aid the development of a restoration site plan and success criteria.

Several studies have used historical regional lists to determine desired plant or animal diversity of the completed scheme.

Many techniques used to document and monitor riparian habitats are untested, and some are designed to optimise time rather than accuracy. The value of information obtained from monitoring wetland creation/restoration projects depends on the precision, accuracy, and comprehensiveness of the data used for interpretation and decision-making. Because past measurements can seldom be verified for quality, data must be collected with tested methods using a valid sampling design, followed by proper analysis and interpretation.

Guidelines useful for monitoring wetland creation/restoration efforts are included in sections concerning sampling schemes, measuring vegetation, classifying riparian communities, determining various features of the soil, remote sensing, water column measurements, streambank morphology, measuring and mapping organic debris, and use of benthic macro-invertebrates to evaluate stream riparian conditions.

Determination of parameters to be monitored should be based on project goals and objectives and may include both independent (i.e., habitat) and dependent (i.e., population) parameters. Examples of independent parameters include frequency and duration of flooding; groundwater dynamics; channel morphology; streambank stability; streamflow characteristics; water quality; vegetative composition, cover, and production; and stream shading. Dependent parameters may include density and diversity of fish and wildlife populations. Frequency of monitoring is based on project goals and deadlines. Monitoring can be conducted frequently in the beginning and less frequently after rates of trends are determined. By far the most common monitoring method has been to evaluate plant growth and survival over time. Monitoring plant species distribution below the level of community dominants provides superior benchmark information as well as a more sensitive scale to detect changes in water level, substrate type, and nutrient status.

4. Dune rehabilitation

4.1. Purpose of dune rehabilitation and expected results

Dunes and sand sheets develop under a range of climatic and environmental controls, including wind speed and direction, and moisture and sediment availability. In the case of coastal dunes, sea-level change and beach and nearshore conditions are important factors. Organised dune systems and sheets in continental environments form from sediment transported or optimised by wind action. New generations of dunes may form from sediment optimised by climatic change and/or human disturbances. Coastal dunes are important determinants of coastal stability, supplying, storing and receiving sand blown from adjacent beaches. They play an important role by providing morphological and hydrological controls on biological gradients.

Removal of, or damage to, dune vegetation exposes sand dunes to high coastal winds and wave action which eventually cause dune blowouts and sand drifts.

A vegetated and stable frontal dune acts as a buffer, providing an erodible reservoir of sand that circulates between the front dune, the beach, the surf zone and seabed according to sea and wind conditions. Loss of protective vegetation through pressure from grazing, foot and vehicular traffic, fires and building exposes sand to high-velocity coastal winds and wave action, often resulting in erosion.

Dune erosion has two types: wind and wave. Wind erosion moves sand grains in a series of hopping movements (saltation) or by rolling them along the surface of the dune (soil creep). The larger grain size prevents the long-term suspension that occurs with finer soil particles. In this way sand from dunes is mobilised and forms transgressive dunes that creep inland, covering roads, vegetation and buildings. Within the dune itself blowouts may occur. These usually follow disruption to vegetation on the frontal or primary dune. They are aligned with the prevailing wind and form a U-shape in a lower section of the dune, which funnels wind, raising its velocity and increasing the loss of sand.

Wave energy plays a key role in beach formation, periodically depositing and removing beach materials. The wash of the waves carries material onto the beach while the backwash carries material away. During calm periods the material forms a beach, while during storms beaches may be eroded by the destructive backwash of the waves. Construction of buildings and roads on front dunes interrupts the buffering role the dune plays in the wider beach zone. Vegetation removal associated with construction and traffic reduces the dune's ability to trap wind-blown sand that would replenish sand removed by waves in storms.

Transgressive (mobilised) dunes cause major problems for land-owners inland from the original dune system as sand covers roads, property or farming land. Similarly they can limit access and recreation. The creation of reflective rock walls, groynes and breakwaters to protect property on frontal dunes interrupts natural beach processes, sometimes increasing erosion risk and beach scour, which often necessitates artificial replacement of sand. In severe situations dwellings close to the beach or cliff may be undermined by wave activity, causing property damage.

Look for disruption to vegetation on frontal or primary dunes. Removal of vegetation through grazing, fire or building works will ultimately cause erosion problems. Similarly, tracks caused by recreational vehicles such as motor bikes, cars or even horses and people often trigger sand drift and dune blowouts.

Dunes help prevent loss of life and property; absorb the impact of storm surge and high waves; stop or delay the intrusion of water inland; store sand that slows shoreline erosion and replenishes eroded beaches after storms; enhance the beauty of the coast; serve unique biological and ecological functions and are habitat for flora and fauna (including threatened and endangered species).

The main thing to do is to re-establish protective vegetation, control or restrict foot traffic, vehicles and fires, and construct sand traps or wind barriers. The most sensible scenario is not to disturb the dune and coast system; locate building development and infrastructure behind the dune system.

As a resilient natural barrier to the destructive forces of wind and waves, sand dunes are the least expensive and most efficient defence against storm-surge flooding and beach erosion.

Dunes absorb the impact of storm surge and high waves, preventing or delaying intrusion of waters into inland areas. Dunes hold sand that replaces eroded beaches after storms and buffer windblown sand and salt spray. This natural defence can be strengthened by increasing the height and stability of existing dunes and by building new dunes.

The growth of mainland coastal population centres and the increasing development and recreational use of the barrier islands can impact the stability of the dune environment.

Construction and heavy recreational use of the beaches can contribute to fragmentation of the beach/dune system and deterioration of dunes. The vegetation that secures sand is destroyed, sand is lost, and the dune line is breached by roads, trails, and storm runoff. Dune damage that results from human activities accelerates the damage caused by wind and wave erosion.

Inland areas become more vulnerable to hurricanes and tropical storms when the dune line is weakened. Protecting dunes helps prevent loss of life and property during storms and safeguards the sand supply that slows shoreline erosion. Protecting dunes also preserves and enhances the beauty of the coast and coastal ecosystems.

4.2. Basic principles

Duneguard is a dune protection system, similar in appearance to typical dune fencing, that works with the natural beach system to reduce the erosive impact of wave run-up on the base of dunes during storms. It is particularly suitable for narrow beach situations and scaped dune facings. It is also very effective at capturing both wind-born sand and even sand that is suspended in the wash. This sand build-up acts as a reservoir, giving further protection to the dune during following high water events. The dune itself is, of course, both a barrier

and a sand reservoir, providing protection to landward infrastructure, making dune protection extremely worthwhile.

Duneguard seems to be a very cost-effective way of preventing erosion and damage to beachfront property during storms. It is a flexible system that blends nicely with the seascape and allows for dune shifting. This approach contrasts with inflexible structures such as bulkheading which eliminate the natural dune environment, leave a harsh appearance and are much more expensive than duneguard.

This dune rehabilitation structures is made of materials which are UV and salt resistant and long-lasting. Its anchor system is deep and remains stable under extreme beach conditions. It does not require extensive planning permission in most states since it is usually considered as part of the normal dune maintenance program of a township, homeowners' association or individual private property owner.

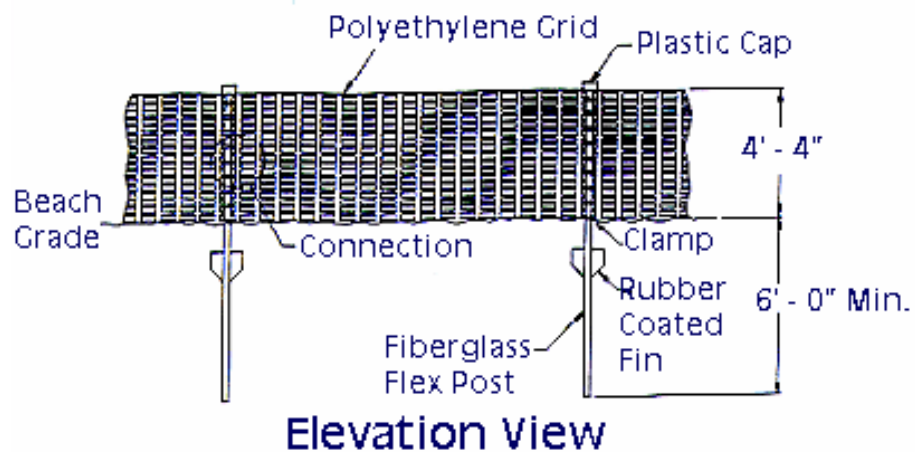


Fig. 4.60.

Elevation View

Duneguard scheme

Fig. 4.61. Installation of duneguard



4.3a FIRST Application : *the Estela case study*

4.3.1. Description of the site

Among our study cases, dune rehabilitation techniques are employed in **Estela**. The Estela Golf course is located in Estela, municipality of Póvoa do Varzim, approximately 9 km North from the city harbour and right away South of the Protected Area of the Littoral Park of Esposende. It lies along the North Western coast of Portugal in a dunar system approximately 3 km long (see Fig. 4.3).



Fig. 4.62. Location of Estela golf course in Portugal.

Coastal morphology and dynamics. The Estela golf course shoreline stretch is a Coastal Plain of about 3km in length characterised by sandy beaches with sand dunes. The wave climate ranges from 2 to 3m of medium significant wave heights, with periods of 8 to 12s and storm significant wave heights exceeding 8m, with periods reaching 16 to 18s. Almost all waves come from the N-W quadrant and the dominant wave direction is NW (~ 50%). Very occasionally there are waves coming from SW. The local wave conditions differ from the offshore ones due to the effect of the bathymetry and local phenomena, especially refraction, diffraction and shoaling. These local

phenomena affect mainly the direction and height of the waves. The tides on the Portuguese North Western coast are of the semidiurnal type, reaching a medium range of 2m and a maximum of 4m. The average tides in Leixões near Porto are + 2.00 m (HZ). The tide and wave values indicate that this is a macro-mesotidal tide-dominated coast. Meteorological tides are not significant outside enclosed waterbodies but they can contribute to increase onshore consequences when occurring simultaneously with spring astronomical tides or severe storms.

Spring tides:	Neap tides:
Maximum high tide: + 3.88 m (HZ)	High tide: + 2.5 m (HZ)
Minimum low tide: + 0.12 m (HZ)	Low tide: + 1.5 m (HZ)
High tide: + 3.55 m (HZ)	
Low tide: + 0.45 m (HZ)	

Tab. 4. 7. Spring and neap tides

Longshore transport is dominant along the shoreline and is mainly wave induced. The dominant direction is from North to South. The sedimentary cell is about 20km long from Cávado River to Póvoa do Varzim harbour and the main source of sediments is Cávado River. Another possible source of sediments is the one provided by beaches under process of erosion.

4.3.2. Previous interventions

The first documented intervention, made during the period of 1st to 12th April 1999, consisted of located reinforcement of the dune toe through mechanical ripping of sand from the frontal beach and consolidation of this sand deposit with wood piles and small sand bags of 5 kg weight (see Fig. 4.4). This intervention was simultaneously made in the critical zone 1 (CZ1), near the 5th hole and in critical zone 2 (CZ2), near the 13th hole.

Also in 1999, during October, a new intervention of reinforcement and dune consolidation was made in the CZ1, again using mechanical sand ripping and woodpiles and small sand bags. The aspect of the dune before this intervention

was of an advanced state of erosion with the erosion cliff very close to the golf fence. Before the 1999/2000 winter two more interventions were needed, one in January and the other in March. In addition to this technique, some traps (fences) were installed transversely to the shoreline to enhance the sediment trapping on the dune.

The 5th intervention near hole number 5 was made in October 2000 (see Fig. 4.5.), after the spring tides occurred on 28th and 29th September. They had partially destroyed the dunar system in that area, thus requiring further dune renourishment works.



Fig. 4.63: Dune consolidation with wood piles and small sand bags, April 1999.



Fig. 4.64. Sand ripping works near the 5th hole, October 2000.

The 2nd intervention at the 13th hole – still using the same dune consolidation technique -, was only needed in November 2000 after 5 previous interventions on the CZ1 near the 5th hole. In fact, it was only a year after the first intervention that the dune in this area exhibited erosion signals. This fact leads us to conclude that the erosion phenomenon is significantly more severe on the Northern extreme than on the Southern.

The winter of 2000/2001 was particularly severe with a high sequence of storm episodes happening very close one to another. In fact, even though in general wave heights with a return period higher than 10 years were not reached, the persistence of the storms generated a very unusual case of consecutive storm events in a way that made it necessary to carry on with emergency works of dune repositioning several times in the period from November 2000 to January 2001, both in the North and South limits of the golf course. In this period, the 6th, 7th and 8th interventions in the adjacent area of the 5th hole, and the 3rd intervention near the 13th hole, were carried out.

The 6th intervention on the Northern extreme limit of the golf course was carried out during the period of 14th to 27th November 2000, following the spring tides that occurred in November in which the dune was significantly affected. The emergency intervention consisted of mechanical sand ripping from the frontal beach to the dune.

4.3.3. Actual applied methodology

December 2000 marks the beginning of the use of a new technique of coastal defence in association with the sand ripping. The severe spring tides and storms that affected this area since October, causing a series of dune destruction events, were responsible for the decision to make use of a more solid reinforcement technique that consisted of a slope protection of the dune with a geotextile filter cloth underlay and sand containers of 1m³ (see Figure 4). The intervention was carried out in 3 stretches with 350, 70 and 50m and consisted of the placing of a geotextile filter cloth and sand containers along a 45° slope. During October and December 2001 and May 2002 new sand containers were placed on the dune slope, but this time the geotextile filter cloth underlay was not placed.

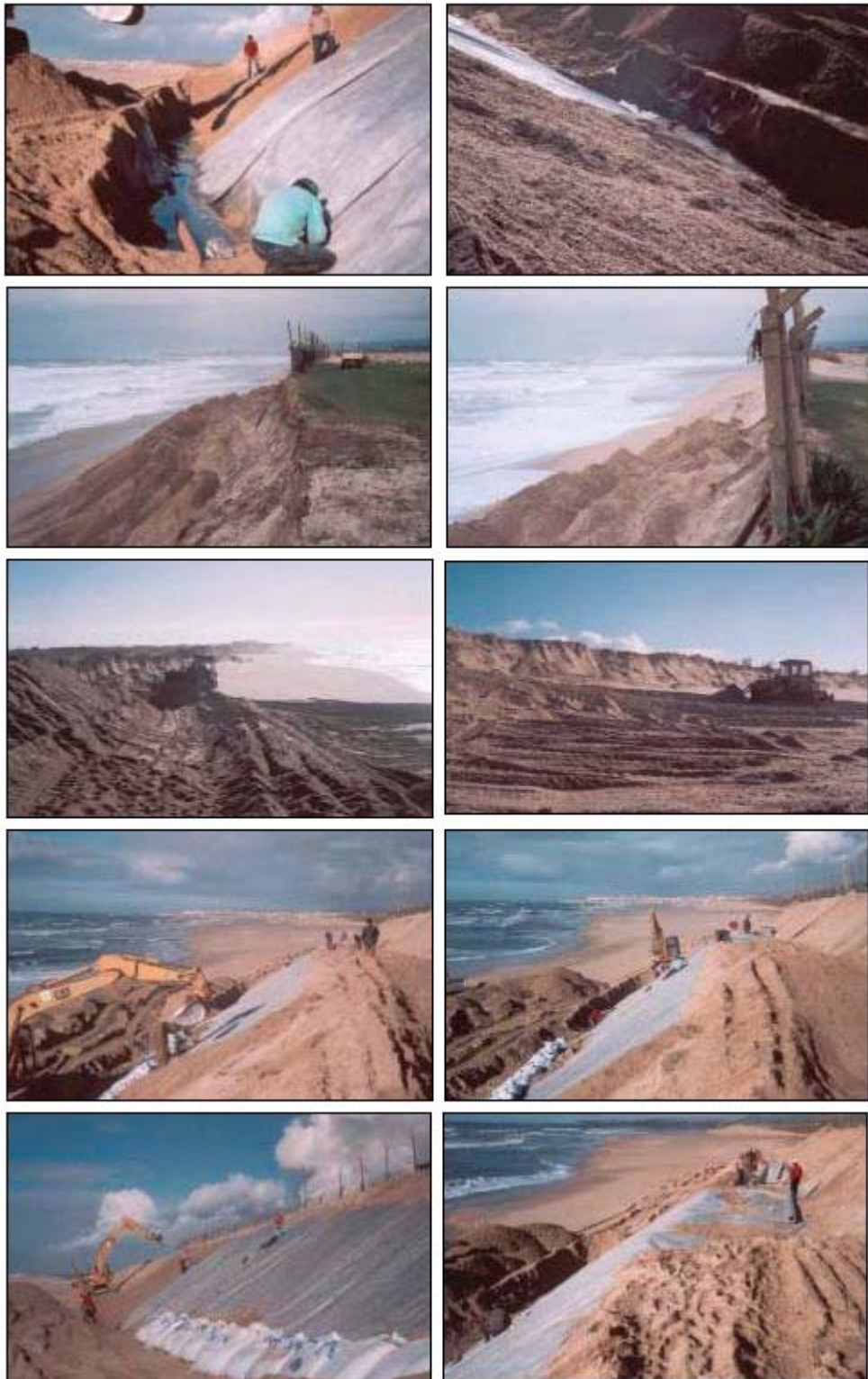


Fig. 4.65. Aspects of the execution of the technical solution using geotextile sand containers, December 2000.

Due to the decrease in the volume of sediments transported by the North/South littoral drift currents caused by dredging activities at the Cávado River and morphological changes on its basin, as well as other natural causes, the dunar system of Estela is being further affected by to the direct action of wave run-up (IHRH, 1997). As a consequence of this direct wave action, the dune ridge is becoming more and more fragile, with a decrease of the beach width and dunes. The frontal dune has been shaped into a dune erosion cliff with a tendency to migrate inland. This migration today is being stopped through dune restoration interventions.

The basic purpose of the IHRH's study of 1997 was to assess the state-of-the-art of the dune system, which serves as a barrier for the golf course against storm attacks, and to make proposals on how to mitigate the strong and rapid erosion that affected this coastal sector. The proposed solution, and the chosen one, was to restore the lost volume of sand of the dune ridge through mechanical sand ripping from the beach outside. The first intervention was followed by several more. Due to the fact that the interventions made in Estela are short-term solutions, the owner of golf course is considering, as suggested by the research team of the IHRH, the acquisition of adjacent fields and the re-location of the golf course to a position further inland. These interventions are therefore considered as being rather ineffective for dune consolidation even though they mitigate the sea invasion effects.

4.3b. SECOND Application : *the Sète case study*

4.3.1. Description of the site

Another site where dune rehabilitation is employed is **Sète**. The town of Sète is located on the coast of the French region of Languedoc-Roussillon, near the city of Montpellier. The coastal area is characterised by the presence of several lagoons, the most important of which is the Thau lagoon. The lido of Sète to Merseillan can be defined as the narrow sand spit which separate the Thau lagoon from the Mediterranean Sea, between Sète to the east and Merseillan to the west. The referred perimeter extends through 12km, between the Grau du Xvème to the west (Municipality of Marseillan) and the channel of Quilles to the east (Municipality of Sète).

Coastal morphology and dynamics. The Gulf of Lion forms a vast stretch of the French coast to the Mediterranean sea, of 200km linear coast in which a large variety of morphologies and environments occur. Its littoral is characterised by long sandy bodies (barrier islands) interconnected by rocky capes. These barrier islands, through the effects of longshore currents, are responsible for the formation of the many coastal lagoons present. The gulf can be divided into 5 independent transport cells (from the Rhone delta to Cape Creus), the second of which corresponds mostly to Sète's coastal front. In this cell the overall sediment transport is done from NE to SW.

From a geological point of view, the study area is formed by three sedimentary series recently constituted (from the BRGM geological chart):

- Mount St. Clair (rocky shores): Jurassic limestones.
- Thau lagoon (sedimentary shores): modern alluvial sediments, with a recent barrier spit, also known as lido.
- Cap d'Agde (rocky shores): basalt flows and tuffites.

After the last Pliocene orogenic stages in the region, the genesis of the coastal formations happened simultaneously to the Quaternary transgressive and regressive episodes. Then, the sand bodies were stretched between the rocky capes of Cap d'Agde and Mount St. Clair. The last transgressive event (Versilian, 5000BP) caused the closing of Mediterranean bays. The total isolation of the Thau lagoon from the sea by a barrier spit took place in the late XIVth century. The emerged body (barrier spit) is formed by 20m of sand and silt, which lie over a conglomeratic basement. The upper fraction of the sedimentary body is constituted by muddy sands and silt 1-2m thick, lying over brown sands and under a thin layer of fine sand, which can be easily transported by wind. The submerged sediments are characterised by fine sands, of approximately 1m thick in the submerged sandbars.

The data from tide gauges and satellite observations show that the mean sea level raised 15cm since the beginning of the XXth century, at a mean speed of 1.5mm/yr. The most frequent predictions (IPCC, 1998) considered an elevation of the sea level from 20 to 40cm (horizon 2050). The extreme values measured for Sète are about 1m, behind the storms of November 1982 and December

1997. The sea level variations depend on various factors, combinable between them, as seen:

- astronomical tide (mean level variation of 20cm),
- meteorological factors (wind),
- hydrodynamic factors (shoreline currents),
- atmospheric pressure,
- morphological factors (coastal shape).

The wind is an essential morphodynamic factor of the Mediterranean coastlines, responsible of the formation of dunes. In the area of the Thau lagoon, the most important wind directions are:

- NNW: 300° – 340°; wind from land, formerly known as *tramontane* or *cers*; represent 36% a year.
- NE: 20° - 30°; wind from land, known as *mistral*; represent 15%.
- SE: 120° - 140°; wind from the sea; represent 15%.

The transported volumes depend basically on the sediment characteristics (particle size) and on the wind speed, but also on the beach moisture, among others. The mean transport in the site of Sète is about 250m³/m/yr, based upon observations made in the period from 1978 to 1983. A typical Mediterranean sedimentary coastal system can be divided into three compartments working in close relation. The submerged part is limited in width by the breaking zone, whereas the “active beach” or emerged beach comprises the shoreface, foreshore and backshore. The terrestrial part is the single or multiple functional dune strips, a true barrier for marine stormwaves, which are separated from the fossil dunes by foredune basins. The functioning of these systems is based upon two dynamic factors: the south-eastern storms and the land winds. The former push the sediments held in the submerged system onto the backshore (or conversely, depending on the capacity of energy absorption of the beach), and the latter return the sediments to the beach, hence restoring the shoreline.

The nearshore bottom in front of the lido of Sète is characterised by the presence of a set of longshore bars, parallel to the shoreline. South of Marseillan, three longshore bars have been identified: a distal bar at –4m depth, a proximal bar at –2m and the shoreface. In front of the lido of Sète the sea bed presents only two bars: the distal one which is a prolongation of the aforementioned, and the proximal one, close to the shoreline. The progression of the bars is closely related to a sequential dynamic, by a succession of deposits over the bar slopes (E. Akouango, 1997).

The sedimentary movements which produce variations in the beach profiles are the resultant of the action of the hydrodynamic factors on the available sediments. These factors comprise the waves and wind, which are the most important, and with minor importance the tide-generated currents. These profile evolutions mean modifications of the beach and sea bottom levels, and hence of the distribution of sedimentary materials all along the profile. The resultant of the coastal sediment transport is a longshore drift which runs from north-east to south-west, with an average volume of carried load of 20,000 – 40,000m³/yr. The evolution of the coastal strip between Sète and Cap d’Agde has been

analysed using aerial photographs, comparing them with the topo-bathymetric profiles done by the Service Maritime during 15 years. A generalised loss of beach surface has been observed, around 23.5ha in places without engineering protection, and a maximum shoreline retreat of 50m for the period 1954 – 2000 (like Plage de la Corniche – breakwaters). For this reference period, the central part of the lido presents a stable configuration of the shoreline, with little accretion, whereas the north and south sectors suffer strong erosion, particularly off protected areas. In the central part a positive variation of volume (accretion) has been noted.

The object of the “*Étude générale pour la protection et l’aménagement durable du lido de Sète à Marseillan*” consists of defining a strategy for protection against marine erosion, efficient in the long term, and the opportunities arising from sustainable management with respect to the following objectives:

- Define a strategy of protection against erosion using techniques as soft as possible,
- Maintain the natural conditions and behaviour of the beach,
- Propose solutions of sustainable management compatible with the existing protection techniques.

4.3.3. Actual applied methodology

The scheme for protection and sustainable management of the lido from Sète to Marseillan has been based upon several advantages, some of which are:

- Restore the normal behaviour of the beach and assure a durable protection against erosion,
- Assure an efficient protection of the inner wetlands,
- ...among others.

The actions to restore the natural conditions of the beach and dunes are the reshaping of the beach profile (to 70 – 80m width), as well as the reconstruction of the dune cordon (3m high per 20m width) behind the backshore.

4.3c. THIRD Application : *the Vero Beach case study*

Actual applied methodology

This 600 foot length of beach in Vero Beach, Florida (Fig. 4.7a-b) uses an open grid pattern to provide protection from the predominate direction of storms while still allowing access for nesting sea turtles. Duneguard meets the environmental regulations of the State and local government.



Fig. 4.66 a –b. Duneguards in Vero beach (Florida)

4.3d. FOURTH Application: *the Avalon case study*

Actual applied methodology

In Avalon, New Jersey, a *duneguard* system was put in place in June of 1995 (Fig. 4.8 a-b). It was placed under and adjacent to the town fishing pier in front of existing dunes. This had always been a location where the dunes were weak and subject to overtopping by water during storms and flooding in the streets. This was due to a focusing of wave energy under the pier which had scoured down the bottom into a channel for incoming waves. As a result, the dunes to each side of the pier were smaller and farther back. In the spring of 1995, three rows of duneguard were placed in a V under and immediately adjacent to the pier, parallel to the shore. Within six months the system had accumulated sand half burying itself and mounds extending 20 feet away from the grid. The system had completely buried itself within one year, forming new dunes in front of the old ones. In fact, Avalon's public works director decided to plant dune grass over the system to further anchor the new sand. He was quite pleased to see dunes established in a place where nothing else tried before had ever allowed dunes to take hold and grow. This area is quite stable today, despite significant storms of the last two years (see Fig. Below).



Fig.

Avalon, June 1995

4.67 a-b.
Duneguards in
Avalon (New Jersey)



Avalon, June 1996

4.4. Expected benefits

4.4.1. *Environmental benefit*

In response to beach erosion, people plant deep rooting plant varieties, believing that their root systems will halt erosion. But the force of moving water is rather unforgiving. Water is 800 times heavier than air and once it moves by waves, is very destructive. Only sand that keeps moving, can remain. But fixed roots can stall erosion temporarily. Furthermore, salt water is fatal to any tree, except the mangrove tree (*Avicennia resinifera*), which thrives only in very sheltered, muddy bottoms.

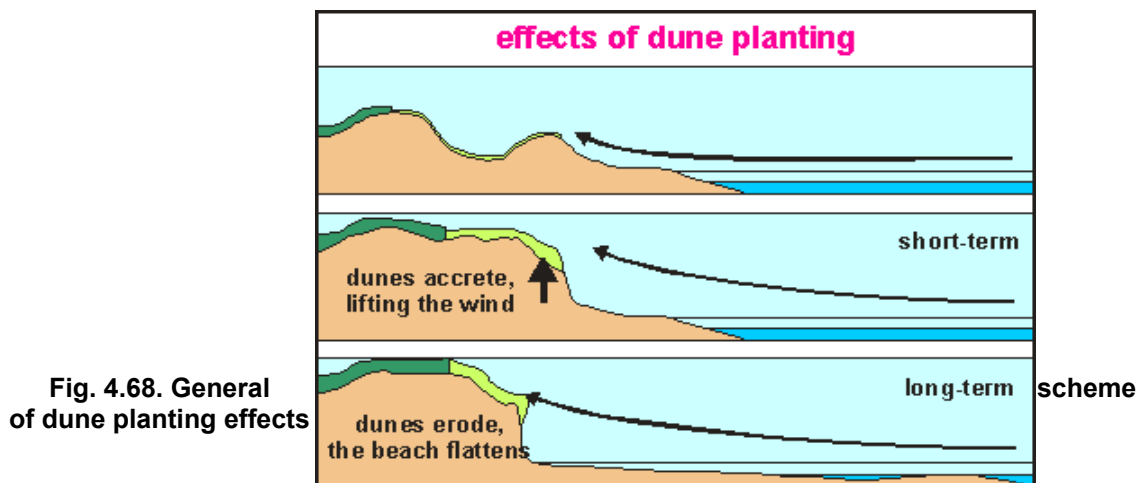


Fig. 4.68. General of dune planting effects

The first drawing shows a healthy situation with a steep wet beach, an area of dry beach, low fore dunes and rolling dunes further inland. The dune vegetation is sparse. Sand moves.

Once dunes have been planted for stabilisation, the dense vegetation starts to trap the sand. Once trapped, the sand can no longer move. The dunes grow and become a single large dune (second drawing). The plan appears to work. But once the dune has grown sufficiently tall, it lifts the sea wind from the beach, impairing its self-repair mechanism. The sea starts to eat into the tall dune, carving a steep bank (scarp). Sand can no longer saltate up this bank and the dune stops growing. With every storm the dune erodes further (third drawing). The massive amounts of sand from this process cause sand banks further into the sea and the beach to lay flatter. There is no more dry beach and the wet beach will no longer dry. The system's self-repair mechanism is now permanently damaged: the beach won't dry, the sand won't blow, the dunes won't roll and erosion becomes permanent.



Fig. 4.69. Dziwnow: uncovered by storm event part of the artificial dune with geotextile bags core, east from hard concrete seawall



Fig. 4.70. Dziwnow: hard concrete seawall and hollow in the beach tetrapods in front of it

In the case of Estela, the soft protection structure using geotextile sand-filled containers seems to have the potential to solve, in the short term, the erosion problems existing in Estela but its effectiveness is not yet proven. At the moment, this case is the subject of a research study and in the near future a pilot study station will be created using an improved solution of geotextile sand-filled containers.

As regards Sète, the BCEOM assessment estimates that there will be some good impacts from the measures planned. These are outlined in the different sectors defined below. The environmental benefits found are the increase in the capacity to soften incident waves (breaking and storm waves), and the upgrading of the biodiversity, as well as enrichment of landscape quality.

4.5. Designing a wetland creation and restoration scheme step-by-step

*4.5.1. Assessing the “do nothing” scenario (in reference to **comp 3**)*

Different options emerge from the several studies consulted, as well as from expert opinions, interviews and focus groups with local stakeholders (Report of Sète for Component 3 Messina). The main objective of the options is to produce a strategy to protect the lido from the long-standing coastal erosion. The displacement of the road is a key component of the different approaches. On this basis, four main possibilities have been suggested:

- Do nothing and maintain the current situation,
- Hard-engineering coastal defences on the shoreline and reduced intervention on the lido,
- Move the road backward to the limit west of the ancient dunes,
- Move the road backward up to the railway.

The “do nothing” alternative implies remaining in the current situation. Coastal erosion carries a high monetary cost, necessitating emergency procedures like repairing the road when it is damaged by a storm, maintaining the breakwaters in front of the Lazaret beaches and cleaning the road and dunes periodically. This option involves maintenance costs every year and does not achieve the objective of long term and sustainable protection of the lido.

4.6. Selecting the adequate dune rehabilitation techniques

4.6.1. Establishing environmental mitigation strategies

Several methods may be used to increase the height and stability of existing dunes, repair damaged dunes, encourage sand accumulation closer to the beach, or establish dunes where a low sand supply has inhibited dune formation or where dunes have been destroyed.

Where fresh sand deposits around obstructions such as grass clumps show conditions conducive to natural dune formation, plantings of native vegetation or structural barriers can be used to start and accelerate sand accumulation. Plantings of native vegetation should be the primary method for dune construction, improvement, and repair. Planting vegetation on gradients in the backshore and close to the line of vegetation, structures such as *slatted wood* or *plastic sand fencing* can help trap sand and stabilise dunes, but they should be used as a last resort and removed when vegetation is established for aesthetic reasons, for safety, and to avoid interference with public access (*temporary fences*).

Standard slatted wood sand fencing is ideal for dune-building structures because it is inexpensive, readily available, easy to handle, and can be erected quickly.

Plastic fencing has the advantage of being strong, durable, and reusable, and it won't be taken for campfire fuel. Plastic fencing, however, is about three times as expensive as wooden sand fencing.

A height of four feet, measured from the ground surface after installation, is recommended for dune-building structures. In areas where sand conditions are poor for dune building, a height of two feet is appropriate.

The fencing can be supported with wooden posts or metal poles at 10-foot intervals. Wooden posts should be black locust, red cedar, white cedar, or other wood of equal life and strength. Treated pine may be used as well. The minimum practical length for posts is 6.5 feet; a length of 7 to 8 feet is optimum. Wooden posts should be no larger than three inches in diameter. If the base of a sand fence is placed at ground level, dunes will build over the structure. If the base is elevated four to six inches above the ground, dunes will build on the downwind side of the structure, and the fencing can be retrieved for reuse as the dunes are formed. Structures should be placed no more than 20 feet seaward of the vegetation line. In most cases, structures should be oriented perpendicular to prevailing winds.

Dunes can be stabilised with success by using *porous jute netting* as sand fencing and as protective ground cover.

Inorganic debris such as automobile bodies, concrete, wire, or tyres must not be used for dune building. These materials are not biodegradable and are safety hazards.

In areas where the local sand supply is insufficient for these two sand-trapping methods to be effective, dunes can be artificially constructed with *imported sand*. All dune improvement project sites must be vegetated to maintain stability.

The *planting of native vegetation* to trap sand is always preferable to the use of man-made structures. Planting native vegetation is the best method for dune construction, improvement, and repair. Transplants from the vicinity of the dune project are more likely to survive than plants brought in from a distance.

Generally, mid-winter to late spring is the best time to plant coastwide. Plants should come from only healthy, dense stands in areas that are not subject to erosion but not from coppice mounds or from foredunes that are sparsely vegetated. Planted areas should be protected from vehicles, pedestrians, and grazing animals with fencing.

Elevated walkways can prevent damage to dunes from pedestrian traffic. If walkways are conveniently placed near access roads, parking areas, beachfront subdivisions, and public facilities, pedestrians will be less likely to cut foot paths through the dunes to the beach. The presence of walkways may increase public awareness of the value and fragility of sand dunes.

A walkway should begin landward of the foredune and extend 10 to 15 feet seaward of the vegetation line. It should be oriented at an angle to the prevailing wind direction. Otherwise, wind blowing up the path of the walkway may impede the growth of vegetation beneath it, erode sand from the seaward end, and increase the possibility of washout or blow-out development. Sand fencing can help restrict pedestrian traffic to the walkway.

Sand for dune construction must not be taken from the beach. Doing so robs donor areas of the material necessary for maintenance of the beach and dunes, and may increase erosion. Removal of sand and other materials from barrier islands and peninsulas is sometimes strictly regulated by state laws (see "Beach Access and Dune Protection Laws"). Sand for dune construction can be obtained from construction-material suppliers or cement companies.

The salt content of sand used to construct dunes should not exceed four parts per thousand (ppt). Higher salt concentrations will inhibit plant growth. For this reason, freshly dredged spoil material is usually not a good source of sand for dune construction projects. Imported sand should be similar in colour, grain size, and mineral content to the sand at the dune-building site. If native sand is topped with imported finer sediment, the finer sediment will quickly erode.

Man-made dunes should be of the same general height, slope, width, and shape as the natural dunes in the vicinity. Generally, they should be no less than four feet high with a slope of no more than 45 degrees.

The initial width of the dune base should be at least 20 feet. A dune with a smaller base will not build to a height sufficient to provide storm protection.

Where there is an ample supply of sand, dunes should be constructed slightly landward of the location where foredunes would naturally occur to allow for natural seaward expansion. Dunes built too close to the Gulf can be destroyed by wave action during even minor storms and may interfere with public access along the beach.

The town of Sète, after analysing the fourth option drawn up by the assessment, decided upon the third proposal of creating a "sanctuary" in the lido between the reconfigured Castellas campsite and the Villeroy bottling company. This proposed system depended on the principle of strategic realignment for sustainable protection of the lido, that is to say, moving the coastal road close to the railway. One of the techniques proposed in this hypothesis is the reconfiguration of the dune field between the 'Plage de la Corniche' and Marseillan.

The actions to be carried out were allocated to different sectors of the lido:

- *Lazaret beach between the Corniche point and 'le grau des Quilles'*

The dune of Lazaret will be reconfigured in order to create a dune formation simulating a natural morphology composed by a large beach, a first dune cordon (active) and some others (ancient). This reconfiguration will be made simultaneously with a new structure made with ganivelles, in order to keep the new dune in place. In the long term, the monitoring of these structures will on the one hand permit functional adaptations of this morphology to dynamic modifications, and on the other hand assure a background of experience. In addition, to limit the wind-blown inputs of sand on the dune of Lazaret, some ganivelles will be placed perpendicular to the shoreline and to the dominant winds as well.

- *La Corniche beach to PK¹ 30,25*

Among other actions to be carried out here is the creation of a dune with ganivelles at the height of 3m above NGF, with a beach slope of 2/1 and rear-dune slope of 5/1.

- *La Corniche beach from PK 30,25 to PK 30,75*

The reclamation of the upper beach and the creation of a dune cordon will also soften the effect of breaking waves which could overwhelm them, including storm waves. The management works can be divided into two phases, the first of which is the most important, consisting of the realignment of the coastal road and the reconstruction of a large beach and a dune ridge.

- *The coast between PK 30,75 (ZAC de Villeroy) and PK 32,5 (bottling company)*

The most important works to be carried out here are the moving of the coastal road close to the railway and the reconstruction of a large beach and a dune ridge.

- *The coast from PK 32 to PK 40*

The realignment of the road close to the railway will permit the linking of the ancient dunes with the active ones (those remaining), creating a vast dune field of about 150m long. At shoreline level, in order to recreate a coastal system in equilibrium in the long term, that is to say, capable of responding to the present hydrodynamic characteristics and of anticipating future trends (sea level rise, increasing storminess, ...), it will be necessary to reconfigure the beach profile according to the next criteria:

- a dune cordon of 2 or 3m height, and 30m long;
- an active beach of 70m width;
- a beach slope of 1/50 to 1/70 (mean grain size of 0.22mm).

The reconstitution of a large beach will be made possible by the backward placement of the dune baseline. The softening capacity of incoming waves and the sedimentary exchanges throughout the profile will be then increased, which is necessary for the maintenance of an active dune field. With efficient

¹ PK=kilometric point

management of the dunes, this new configuration better resists the assaults of the sea.

- *The coast from PK 32,5 to PK 37,2 (Camping Castellás)*

All along this 5km of coast, the system can be directly linked to the large dune field (20 to 80m) bordering the vineyards of the Listel Company. The realignment of the coastal road helps to recreate a coherent beach profile. At the time of the dune cordon creation, the places presently used as parking areas will be filled in to be incorporated in the new dunes, necessitating some sand input. These dunes, reinforced by a series of ganivelles, will be stabilised by vegetation, using, as much as possible, local species.

- *The camping of Castellás (PK 37,2 to PK 40)*

The area recovered will be used to reshape the active beach, much as the previous section, of about 70 to 80m width, using as much as possible the autochthonic material after the removal of the road pavement. The dunes will be equipped with ganivelles (with public pathways) and will be entirely vegetated, with the aim of increasing its stability and resistance in the face of marine attacks.

- *The coast from Camping Castellás (PK 40) to Port du Marseillan beach (PK 41,2)*

The solution is the same for that planned for the northern sector of the campsite.

- *The ancient dunes of the lido of Sète*

The displacement of the coastal road, which will be transformed into a beach restoration (80 to 100m width), allows the possibility of reconstructing a true dune system. Moving the dune baseline backwards, the ancient dunes will serve as a foundation to the new dune cordon. The beach width will assure a consequent softening of breaking and storm waves. The continuous dune cordon, maintained by ganivelles, will catch windblown sediments and will limit marine intrusion.

4.6.2. Designing long-term monitoring

For the different management strategies considered, it will be necessary to carry out a long term monitoring of the coastal zone (beaches and dunes). This monitoring will allow the observation of the evolution of the managed sectors, especially after storm events, and the assessment of the need to implement the measures prescribed in the second phase, in the area between ZAC de Villeroy and the bottling company in front of Castellás campsite.

- *Topo-bathymetric survey*

A series of topo-bathymetric profiles (one per kilometre), twice a year (end of winter and end of summer), will be done between Sète and Agde. These profiles will cover the edge dunes, the beach and shoreface up to a depth of 10m depth. After exceptional storm events, several profiles will be done immediately after the storm and 1 to 2 weeks afterwards, in order to evaluate the recovery speed. The same work will be done in foreshore areas.

The collected data will be analysed to compare sand volume variations, morphological changes of the berm, dune foot, dune ridge and beach slope.

- *Quality of the bordering dune*

A qualitative survey of the state of the edge dunes will be done twice for the comprehension of flora evolution as well as to assess the state of the measures taken (ganivelles). This survey will be made taking pictures along the same profiles mentioned before, between Sète and Marseillan-Plage.

- *Aerial photographs*

An aerial survey taking geo-referenced vertical pictures of the coast between Sète and Agde will be carried out following the same premise as the one made in 2000. The comparison between aerial flights will allow the assessment, in particular, of the evolution of beach width.

4.6.3. *Factors influencing the success of dune rehabilitation schemes*

One of the most important factors that influence the success or failure of a dune rehabilitation scheme is the wind. When planning dune action, the wind direction and average speed has to be taken into account for the successful design of dunar structures. Also, the type of sand, its grain size and moisture influences the rate of sediment transport in the zone.

This case is the object of an in-depth investigation of the evolution of the protection techniques applied, and the experience accumulated showed that some improvements have to be made in order to upgrade the level of protection and the effectiveness of dune rehabilitation. Concerning the characteristics of the solution used in the dunar system of Estela, the following improvements should be made:

- Use of non-woven geotextile sand container instead of a woven one;
- Careful design of the underlying geotextile sheet used as filter;
- The containers should be placed preferably with the long side perpendicular to the shoreline;
- The containers should be placed like bricks in layers with a beach slope of about 1:1;
- The lowest layer should be placed beneath the existing mean water level (at least one layer);
- The top layers should be placed above the maximum design water level (above 0.50 m freeboard);
- A sand trap fence should be placed again to keep the golf course free of sand.

Furthermore, during the research studies on the erosion control of the dunar system of Estela two basic solutions will be studied. These solutions can be combined to minimise the wave energy impact on the dune, which consists of:

- Passive coastal protection: a dune barrier made of stapled geotextile containers as a second line of defence and dune stabilisation, which is covered with sand;
- Active coastal protection: the construction of one or two temporary groynes made of geotextile containers (in addition the suitability of a submerged breakwater made of geotextile containers can also be investigated).

4.7. Assessing and monitoring the environmental and social impact of dune rehabilitation schemes

4.7.1. Impact on shoreline stability

In order to assess the efficiency of the management strategies proposed for Sète, and evaluate their impacts, (they consist of the slightly emerged detached breakwaters in front of ZAC de Villeroy and the bottling co. [PK 30,25 to PK 32,5] and the reconstruction of the dunes [PK 32,5 to PK 40],) two types of models have been developed using COSMOS 2D and BEACHPLAN (HR Wallingford).

COSMOS 2D is a software package using numerical modelling of physical processes acting on the breaking zone and beaches. This model simulates the following processes:

- transformation of the waves due to refraction, effect of shoaling, breaking and friction with the sea bottom,
- forces induced by waves and its formation,
- vertical dispersion of cross-shore currents,
- longshore transport of sediments,
- sea-floor modifications.

For the present example, the possibilities given by COSMOS 2D will permit the analysis of the behaviour of the beach after a storm event, in the present situation and after measures have been taken.

BEACHPLAN is an application for simulating the evolution of waves. It will help to predict the evolution of the shoreline after coastal protection works (placement of breakwaters, groynes or beach nourishments). The following processes are taken into account :

- transformation of waves due to refraction, effect of shoaling and diffraction,
- the artificial restoration of sediment transport around hard structures and the wave transmission through them,
- the solid transport (CERC formulae) and the allocation of shoreline transport along the beach profile,
- the techniques of beach maintenance such as beach nourishment or sand extraction.

In the present case, BEACHPLAN offers the possibility of illustrating effects of breakwater construction on shoreline evolution.

The results arising from the simulations of COSMOS 2D and BEACHPLAN confirm the effects of the management measures proposed for the lido. The creation of a wide beach, with a gentle slope (1/70 to 1/80), limited by a dune cordon, helps to soften the effects of storm waves. The erosion recorded in the profiles is important (foreshore retreat, full-length erosion) but markedly lower than in a backshore limited by longitudinal structures like rock revetments. The placement of breakwater-like structures lead to a regressive evolution of the shoreline between neighbouring structures. The subsequent nourishments could help to reduce the negative impacts but they must be done periodically.

4.8. Budgeting for dune rehabilitation schemes

4.8.1. Feasibility costs

The scheme for the protection and sustainable management of the lido from Sète to Marseillan is likely to include:

- the carrying out of the technical studies (topographic surveys, bathymetric surveys, preliminary geotechnical assessment) necessary for the proper definition of the project;
- the submission of the plans, by the Master of Works, of the pre-project, as well as the project, to inter-administrative evaluation and public announcement;
- the following of proper administrative procedures (Water Law, EIA, Public Inquiry) until the scheme's declaration of public utility or of general interest;
- Consultation processes before the beginning of works.

The following tables show the detailed budget plan for the feasibility stage:

Topographic surveys and dossiers, preliminary geotechnical assessment, EIA, Water Law study and dossier of public inquiry (Table 1A)	230 000 €
Juridical and technical assistance for setting-up a Syndicat Mixte	30 000 €
Assistance to Master of Works in the design phase (AMO ² principal and AMO specific) (Table 1B)	476 000 €
Archaeology	130 000 €
Design of works	1 538 811 €
TOTAL COSTS except various expenses and unanticipated	2 404 811 €
Various expenses and unanticipated (10%)	240 481 €
TOTAL COST	2 645 292 €

Tab. 4. 8. Estimations for the design phase.

Topographic survey	30 000 €
Preliminary geotechnical assessment	10 000 €
EIA	100 000 €
Water Law assessment	40 000 €
Dossier of public inquiry	50 000 €
TOTAL COST	230 000 €

Tab. 4.9. Detail of the estimated cost for technical studies.

² AMO: Assistance à Maîtrise d’Ouvrage (Assistance to Master of Works)

Principal AMO (60% in design phase)	246 000 €
AMO Communication council	50 000 €
AMO Juridical assistance	20 000 €
AMO Expertise salaries	30 000 €
AMO Geotechnics	100 000 €
AMO Coordinator Security & Health Protection	30 000 €
TOTAL COST	476 000 €

Tab. 4.10. Breakdown of Principal AMO and Specific AMO's.

4.8.2. Investment and engineering costs

Taking into account the imprecision of some of the available data (topography, geology,...), the financial estimates for this phase of the lido from Sète to Marseillan protection scheme are approximate. An error margin has been logically integrated into the estimations, to allow for uncertainties.

There follows the financial estimate for the different actions required:

Land acquisition	630 000
SUB TOTAL	630 000
Strategic realignment and protection against erosion Preliminary works	410 000

Reallocation of the coastal road	13 050 000
Demolition of the road close to the beach	810 000
Restoration of dune cordon and beach	6 230 000
Creation of rear dune fields	730 000
Reorganisation of the local residents network linked with the coastal road reallocation	1 115 000
Partially emerged detached breakwaters in suitable areas	8 000 000
SUB TOTAL	30 345 000
Parking, bicycle paths and TCSP way	
Reorganisation of parking areas through integrated parking areas management	3 190 000
Bicycle paths	1 900 000
Transport road between neighbouring communities; a shuttle vehicle along the beach	1 470 000
SUB TOTAL	6 560 000
Creation and restoration of natural spaces and habitats	
Creation of access at the salt pans of Xvème	100 000
Reclamation of the dykes of Villeroy and Xvème salt pans	200 000
SUB TOTAL	300 000
Reception and public sensitisation equipment	
Infrastructures of reception and interpretation	520 000
Rehabilitation of the Redoute du Castellas	50 000
Signals	50 000
Aid stations	80 000
SUB TOTAL	700 000
Private works	
Rebuilding of Castellas campsite	2 500 000
SUB TOTAL	2 500 000
TOTAL	41 035 000
Various expenses and unanticipated (11,9%)	4 888 894
Assistance to Master of Works (AMO's), Master of Works, works of communication phase	570 225
Mastery of Works phase works (3,75%)	1 538 813
TOTAL COSTS IN €	48 032 932

Tab. 4.11. Financial estimations per action to carry out.

4.8.3. Maintenance and monitoring costs

As mentioned before, this is not a definitive solution to the erosion problem, so periodic interventions have to be made in order to maintain the level of protection that the dune system offers to the golf course.

Regarding the maintenance costs of dune spaces for the lido from Sète to Marseillan, the *Communauté d'Agglomération du Bassin de Thau* expected an estimated cost of 38 500€ per year for diverse works of dune maintenance and restoration of ganivelles. In Marseillan, these costs are estimated around 10%,

being 3 850€ / year. The relative costs of dune maintenance will increase in the coming years due to increase in the number of ganivelles installed, which will usually be maintained, repaired and changed. Some predictions give the hypothesis of a cost multiplication of 4, being 168 000€ per year.

4.9. Limitations

For the first time, in Portugal, a coastal erosion problem is being addressed with a coastal defence solution using geotextile containers. The fact that the incident waves on the West Portuguese coast are among the most vigorous in the world leads people to underestimate the potentialities of this kind of solution, especially in cases like Estela. Nevertheless, this type of solution can effectively control some coastal erosion problems, in the short term, but needs to have a design procedure similar to any other coastal defence structure. At the moment, there is still a significant lack of information regarding the design and behaviour of these defence techniques.

5. Artificial reef creation

5.1. Purposes of artificial reef creation and expected results (protection vs. recreation)

Artificial reefs are generally defined as submerged structures placed in selected marine areas, on the substratum (sea bottom), deliberately to mimic some of the characteristics of natural reefs for beach stabilization.

Artificial reefs around the world have been built from a considerable range of materials and design. Usually created from man-made or natural objects, usually with various sized stones, steel or concrete material or some heavy-duty plastics, once put in place, an artificial reef acts in the same way that naturally occurring rock outcroppings do in providing the hard substrate necessary in the basic formation of a live-bottom reef community. Termed “reef breakwaters”, these structures are defined as a rubble mound of single-sized stones with a crest at or below sea level which is allowed to be (re)shaped by the waves.

Their use in coastal management includes fishery yield and production, recreational diving and the prevention of trawling. Their strength lies in protecting the local beach sediment budget, improving the water quality and enhancing the hard-bottom habitat. More recent applications of artificial reefs mainly involve shoreline stabilisation and coastal protection. Designed reef habitat units of various shapes and sizes are currently being tested at many nearshore and offshore locations.

5.2. Basic principles

Reef breakwaters are coast-parallel, long or short submerged structures built with the objective of reducing wave action on the beach by inducing waves to break over them; in addition, the construction of an artificial reef could provide a natural habitat for marine biodiversity and opportunities for recreational activities.

Emerged offshore breakwaters are usually built to a height above high tide and are made of stone or concrete units. These emergent breakwaters are protective structures of a rigid type but with active replenishing effects; they have the function of damping down the energy of the waves and therefore of creating on their landward side an area of “shadow” or “calm waters”. These measures are not without their risks: there is the risk of downdrift erosion; of the formation of fine-grained sediment banks, obstructing littoral flows and so causing the phenomena of clouding; and the relative problems, for the environment and for exploitation, of stagnation of the waters between the barrier and the shore, with a corresponding risk of pollution and eutrophication, and of deterioration of the landscape. All of these risks can be avoided, or significantly reduced, if the barriers are of the submerged type.

The emergent barrier, moreover, although suitable in theory for preventing erosive processes already under way, must be rejected for its very high negative impact on the landscape. It would indeed make it possible to achieve the functional objectives (of protecting houses and the road) but it would do so while destroying in a virtually permanent way all the attractiveness of the beach

for tourists and holiday-makers; it would also increase the use of stone material, adding to the impact on the environment “transferred” to the quarry areas and those deriving from its transport, with a considerable increase in costs.

The submerged barrier acts as a physical operator, dissipating and damping down the energy of the wave movement, respecting the shape of the local shoreline in its pre-erosive form and protecting the addition of granular material suitable for reconstructing the emerged and submerged beach.

The presence of such a barrier is a physical support to the beach profile, enabling it to reform with a more moderate gradient than that naturally assumed; it also leads granulometric fractions, which otherwise would have been lost out at sea, to become stable in water. It does not create any negative visual impact on the coastal landscape, and it may enhance habitat for local marine fauna.

There are many types of longshore structures protecting beach. They vary according to the type of site, the erosive process, the availability of space and funds.

Not all materials are suitable for the creation of artificial reefs. Some, which may be suitable for one site may not be so for another. The materials for reef creation need to be durable and have a large multi-dimensional surface area for the colonisation of sessile organisms, and several entrance and exit holes for mobile organisms, water flow and light penetration. The reef components should be designed for long-term stability and be suitably weighted so they cannot move around on the sea floor. All materials need to be free of noxious substances and residues.

Many materials such as concrete pipe, concrete pilings, steel highway bridges and a variety of other bulky structures are often re-utilised as substrate in the construction of artificial reefs, but the most favoured reef materials are concrete (including cubes, blocks and pipes) and rock stones (also with boulders).

In the last years, the artificial reef construction has been developed in many coastal sites of the world, with different materials used, and different designs tested; so that many private companies take out a patent on their products.

Some Japanese private companies are world leaders in the artificial reef technology for commercial fishery enhancement and have been creating artificial reefs since the 18th century. Materials used are of high quality – for example concrete grass and reinforced glass.

For example, the Japanese Nishimatsu company has developed a new type of submerged breakwater called the Wave Trapping Artificial Reef (WATAR). It is a subsurface wave neutralisation structure, consisting of a first-stage reef, made of rubble mounds and jackets where wave energies are magnified by the sudden slope, and a second-stage reef made of an upper-level concrete slit structure, where waves are broken. Finally the broken waves pass through the slit of the second-stage concrete reef and the resulting internal disruption reduces their energy.

In the USA, the artificial reef programmes of many maritime states are run for the benefit of recreational sports fishing, diving, commercial fishing, waste disposal, and environmental mitigation. Materials used are mostly waste

including concrete, rocks, construction rubble, cars, railway carriages, ships and reef balls.

In Great Lakes (Wisconsin, USA), reef breakwater structures provide nesting and roosting sites for waterfowl, as well as supporting many human recreational activities. The structures are constructed of rock of varying sizes, construction and demolition materials (concrete), and sheet pilings. Many structures use a combination of materials, often in different segments. These structures attract fish, intercept seasonal movements, and provide shore anglers with access to deeper water. The economic value of the area has been improved by designing a marina as well as improving public access for fishing (a boat ramp and fishing access from the breakwater) and hiking (observation platform, footpath, and boardwalk). Concurrently, the ecology of the area has been greatly enhanced by creating a vegetated breakwater.

Innovative longshore structures are the so-called “*beachsavers*”, *Forte*, the *P.E.P.* (prefabricated erosion prevention) *reefs* and also the *geotextile* structures (such as the *undercurrent stabilizers*), too.

Breakwaters International Inc. has developed a new type of submerged breakwater called the *beachsaver reef* that works more effectively with the natural beach system and improves a beach’s equilibrium. As their name implies, the breakwaters break the waves and create a shadow of calmer water in their lee which allows suspended sand to settle out of the water and deposit in the near shore area and on the emergent beach.

The beachsaver reef system works with sand nourishment and ocean forces to protect and extend the life of beaches. The reef reduces the volume of sand required for a nourishment project, retains replenished sand as it is pumped onto the beach, and keeps added sand on the beach longer by slowing the rate of erosion.

The reef works to enhance the long-term performance of beach fills in two ways. First, the reef forms a partial barrier, preventing suspended sand from moving out to sea in the return wave. This sand resettles instead in the nearshore zone or emergent beach. Second, the energy of incoming waves is reduced by 20 to 30 % as they cross the reef and as they break farther offshore, taking less of a toll on the beach front (Fig. 5.1.).

An important patented design feature of the reef is the “backwash flume” (circled in the Fig. 5.1). The flume consists of three slotted openings which are wider on the curved beachward face and become narrower as they arc upward to the top of the structure. As a storm wave recedes, the flume projects a high velocity curtain of water and suspended sand upward off the reef so that the next incoming wave cycles the sand back towards the beach. This inhibition of the offshore movement of sand is key in erosion control during storm events.

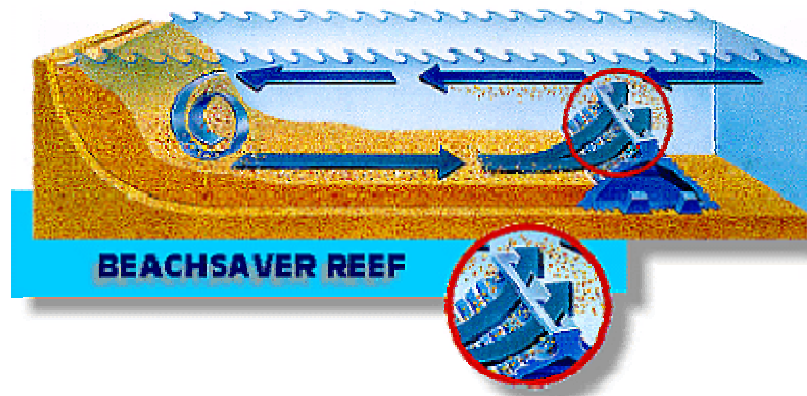


Fig. 5.71. Beachsaver reef scheme.

A unique shore protection system has shown great promise in stabilising previously eroding shorelines. *Undercurrent Stabilizers* (as patented and installed by Holmberg Technologies of Whitehall, Michigan) have been placed in a large number of locations over the last two decades. Monitoring surveys at these installations indicate that the traditional shortcomings of shore protection systems can be overcome. The survey data shows that gains in beach width and height are achievable, and that such gains are maintained over time.

Undercurrent Stabilisers are shore-perpendicular low-profile structures that are placed in configurations similar to that of traditional groynes. However, the differences between stabilisers and groynes are profound in both geometry and effect. Stabilisers consist of concrete filled, geotextile tubes. The rounded shape of stabilisers reduces the amount of wave reflection and turbulence created when significant waves reach the shore. Wave reflection and turbulence are primary reasons that structures such as walls, groynes and revetments damage adjacent property and scour their own foundations. The other unique geometric aspect of stabilisers is that they follow the bottom profile and taper down in size as they extend into the water. Their low profile minimises aggravation of the wave climate during storm events, especially when compared to other conventional shore protection options. The effect is to create a low energy beach which reduces sediment entrainment and encourages deposition. Stabilisers encourage retention of the natural beach slope reducing the severity of scour during large storm events and indicate that beach and bluff protection can be achieved over the long-term.

Interesting application of artificial reefs as recreational structures are present along some coasts of the USA (Texas, Seattle, Florida, South Carolina, etc.).

In Texas (USA) artificial reefs enhance fishery resources as well as fishing and diving opportunities. These rise like oases in the desert - dotting the vast expanses of mud and sand covering the floor of the Gulf of Mexico - with innovative recycling of obsolete petroleum platforms into permanent artificial reefs.

In South Carolina (USA) marine artificial reefs have been constructed from a wide variety of materials ranging from various forms of suitable scrap to

specifically designed and constructed reef habitat structures. These more temperate reef communities occur only in specific locations on the ocean bottom where nature has provided a suitable hard substrate, which serve as a point of attachment and colonisation for sponges, corals and a wide assortment of other invertebrates.

In the Marriott beach (Caribbean Sea), particularly susceptible to erosion especially during storm events, artificial reefs have been used for the protection of natural and existing coral reef. Materials largely used are “reef balls”.

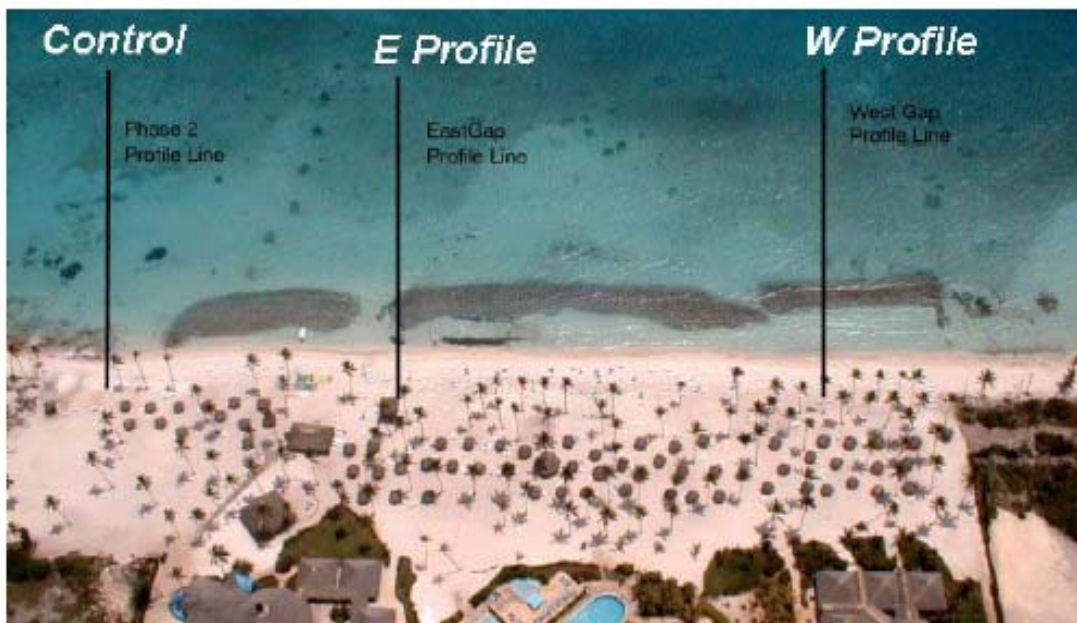


Fig. 5.2. Artificial reef beach stabilisation project for the Grand Cayman Marriott.

Another important application of artificial reefs is for surfing activity, mainly on Australian coasts, where special authorisation by the Department of the Environment and Heritage is required to create an artificial reef. Authorisation is necessary to ensure that appropriate sites are selected, the materials are suitable and prepared properly, no significant adverse impact on the marine environment occurs, and the reef does not pose a danger to navigation, fishermen or divers.

In Europe, artificial reefs were pioneered along the Mediterranean coast in the late 1960's. Italy, France and Spain have been the most active reef building countries since 1970. Spain is placing more artificial reefs into its coastal waters than other EU countries. Current initiatives include a network of European artificial-reef research to establish a co-ordinated direction for artificial reefs within the EU.

5.3 FIRST Application : *the Giardini Naxos case study*

5.3.1. Description of the site

The example given for this technique is the shore protection intervention in **Giardini Naxos** Bay, where the first stage of a coastal project, with the creation of an artificial reef breakwater associated with beach nourishment in the same protected area, has been completed. The second (and final) stage is planned to include an advanced monitoring program with installation of buoys in Giardini Bay and the enlargement of the nourished beach, protected by an artificial reef-barrier. Assessment studies of the environmental and social impact of the artificial reef in Giardini Bay in the first stage are useful for the second stage of the coastal project in collaboration with the local Administration, stakeholders and engineering designer.

The bay of Giardini Naxos (Fig. 5.3) is a typical Mediterranean tourist coastal site, situated in the Northern sector of the Ionian coast of Sicily, between the towns of Messina and Catania.



Fig. 5.3. Location of the coastline of Giardini Bay.

The Giardini Bay is governed by two municipalities: Taormina and Giardini Naxos. These were only one municipality until 1847 and Giardini-Naxos was an old fishing port with small, humble buildings (Fig. 5.4).



Fig. 5.4. Historical photos with a southern view of the Giardini Bay in the period 1850 – 1900.

At present, the town of Giardini Naxos has about 10,000 inhabitants and it is the most important tourist area in the eastern Sicily with more than 1 million tourists per year. With its 34 hotels and 46 restaurants, the bay of Giardini is typical of coastal tourism development around the Mediterranean sea. In summer, the promenade may be frequented by more than 20,000 tourists a day, i.e. twice the population of Giardini Naxos.

The beach enclosed by the bay is considered as a “relict” beach or pocket beach; its length is 5 km and is oriented to the east, between two rocky headlands: Capo Taormina in the north of the bay and Capo Schisò in the south. It has an average orientation of 34° E, morphologically regulated by a regional fault system.

5.3.2. *Previous interventions*

Many places in Giardini Bay are affected by erosion exacerbated by a general reduction in longshore sediment transport, due to the destruction of ridge dunes and the removal of inert material from riverbeds and sandy backshore areas.

The coastal stretch between San Pancrazio's church and lido Sirenetta is mainly affected by erosion and has required continuous protection since the 1970s. In fact some hard structures were built, such as groynes and breakwaters. However, evidence has shown that these structures were rarely placed at a sufficient distance from the shore to be effective; in consequence they had limited efficiency, causing further erosion problems downdrift.

5.3.3. *Previous interventions*

Regional Authorities have recently grown aware that the current erosion management practices along the Bay of Giardini-Naxos are not sustainable and so it has been decided to intervene with a new shore protection scheme. In particular, the aim of this investment programme is the "removal of the causes of deterioration and/or erosion in the coastal areas, by means of the restoration of the natural conditions which led originally to the formation of the shoreline, with particular reference also to building activities inland, to the recovery and restitution to their natural state of the wet and dry river courses and the restoration of the solid littoral transport. Particular attention is to be paid also to the effects on an increase in tourist potential, the recovery of state property and the protection of private and public goods from sea storms". This investment programme is still in progress.

Therefore, an intervention has been planned in a protected beach area (Macine area in southern sector of Giardini Bay), artificially nourished for about 250 metres with the use of sand material coming from two different marine borrow areas: the sand deposit adjacent to the sea bottoms at 12 – 15 m b.s.l. to the north of Capo Schisò and the adjacent sea-bottoms of the filled harbour of Giardini Naxos (Fig. 5.5).



Fig. 5.5. Aerial photo of Giardini Bay with photo references on artificial reef project.

From an environmental point of view this is also a good choice, as the material used is taken from the erosion of the central area of the same bay and therefore borrow and native materials have similar textural and compositional characteristics.

The beach-fill design has been stabilised by a single nearshore submerged reef-breakwater (top submergence at 0,5 m. b.s.l.; crest width: 15.00 m.; length: 330 m. in phase B.1 and 1000 m. in phase B.2) with selective placement of volcanic stones. The aim of this natural reef-barrier is to reduce the effects of wave action on the beach, minimising the loss of sand to the sea. Structural combinations, similar to those of Giardini-Naxos Bay, mitigate downdrift impacts, increase the fill life of the re-nourished beach and reduce their environmental impact more than if selectively implemented. These would also eliminate the unacceptable appearance of hard protective structures such as transversal groynes and sub-parallel reefs.

In this coastal area there is also a conflict between previous protection measures (breakwaters and groynes) present inside the bay and the need to create one or two marinas inside the bay. This case study should be part of a wider SEA, but at the moment the local coastal conflicts appear to take place at a political level only, with no public participation.

To the south of the rocky headland of Schisò there is a stretch of sandy beach which links directly to the Alcantara river mouth. The western boundary is marked by the Peloritani Mountains and the southern by the North-Eastern slopes of Mount Etna. The continental area behind Giardini Bay is hilly, and the hills rise gradually in height moving inland, and form, as a whole, the range of the Peloritan Mountains.

The Bay of Giardini is bounded by Capo Taormina in the north and Capo Schisò in the south. According to the geomorphological features of the two headlands and considering the geological nature of the continental area, it is clear that the northern area is completely “isolated” by the contiguous physiographic units (coastal sedimentary cells), while the southern area shows a greater “permeability” with (in) respect to alongshore sediment transport from South.

In the southern sector, there is a wide beach with shallow bottoms and fine sediment circulation. In the northern sector, there is a narrow beach with deep bottoms and the presence of large boulders and pebbles.

The Bay of Giardini Naxos may be divided into several parts. These parts are characterised by the presence of a number of man-made structures created over the years: the quay of Schisò, five sub-perpendicular groynes, three sub-parallel breakwaters and the quay of Saia.

Using both man-made and natural landmarks it is possible to identify the following areas (Fig. 5.6):

- Schisò Harbour, from the quay built onto the extension of Capo Schisò to the first sub-perpendicular groyne built to the South of the *Lido della Sirenetta*: this represents today’s Giardini Naxos Harbour.
- Sirenetta, between the two southernmost sub-perpendicular groynes: this offers a widespread sandy area where the private lidos are situated.
- Macine: between the second and third sub-perpendicular groynes: this represents a flat rocky area, periodically free of sediment, where it is possible to see traces of the quarrying of millstones for oil-mills (“Macine” in Italian).
- San Pancrazio, between the third and fourth sub-perpendicular groynes: an area greatly degraded by the presence of the three sub-parallel breakwater barriers.
- San Giovanni, between the fourth and the fifth sub-perpendicular groynes, offering a stretch of beach varying in width, at the centre of which is the mouth of the San Giovanni stream.
- Municipio (“City Hall”), between the fifth sub-perpendicular groynes and the Saia quay: a barely developed stretch of beach, protected by a number of outcropping rocks.
- Villagonia, which falls almost entirely within the territory of the City of Taormina, between Saia Quay and Capo Taormina: a stretch of pebbly beach, running alongside the railway line, where at present bathing is forbidden.

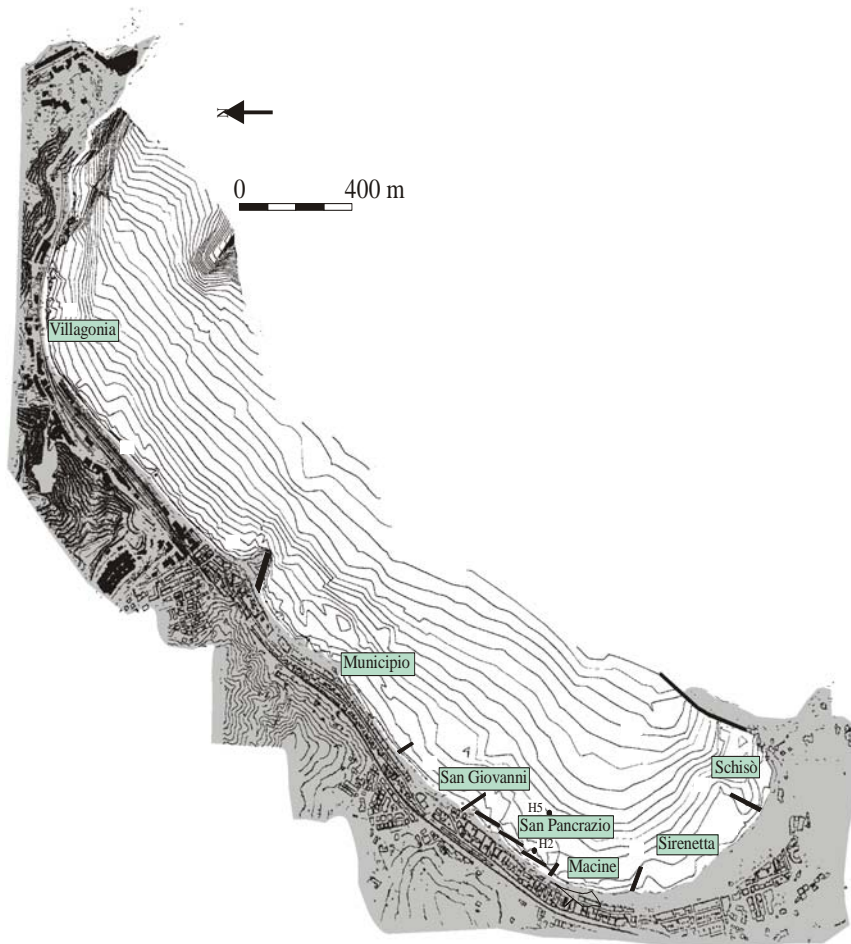


Fig. 5.6. Detailed map of Giardini Bay.

The detail of the bathymetric map, drawn in the summer 2000, of the Giardini Bay shows a fairly marked trend in the isobaths to the depth of -15m , generally increasing in gradient proceeding northwards. A regular distension could be seen, except lower isobaths (-1 and -2 m) close to the coast with the interdistances between isobaths present at depths between -2 and -14 m depth. This distension is marked in the Sirenetta area and does not appear in the Macine, San Pancrazio and San Giovanni areas.

In the nearshore areas, anomalies in the bottom morphology can be seen due to the shore protection interventions along the coast. In the Sirenetta area, under the total protection of the harbour quay, there occurs a wide area of sedimentation, which sometimes emerges; while in the sector adjacent to the Macine, it is possible to observe a steeper gradient of the coast, without a corresponding steepness in the more distal areas.

The regularisation of the distension could be done to coincide with the -5 m isobath which maintains a constant distance (about 150 m) from the shoreline,

and marks an irregular internal area (inland) and a regular external area (seaward) with uniform interdistancies.

Considering the orography of the area, the site proves to be well protected from north winds and to some extent from north-east winds, being sheltered from these by the headland of Capo Taormina. However, the area is exposed to south-easterly and easterly winds; the former are slightly broken by the headland of Capo Schisò, while the latter sweep into the Bay of Giardini without meeting the slightest impediment. Because of the orientation of the coastline between Capo Taormina and Capo Schisò, the dominant east and north-east winds tend to generate southward littoral currents within the bay, while the dominating south-west winds generate minor northward currents.

There are no specific studies of the area on eustacy vs. isostasy, while the entire coastline of Sicily is considered as a patchwork of pieces which show a differential movement related to the local tectonic activity. Tide range is not important, being less than 15 cm.

In the past, the dynamic equilibrium of the beach was determined by the alternative driving forces due to the SE winds, which moved the sediments northward along the beach, and to the NE winds, which moved the sediments southward.

The never-completed construction of Schisò Harbour has stopped the northward movement of the material, constricting the sediment transport to southward.

Underwashing activity, in the last decades, brought Giardini bay a sediment transport towards the southern area.

From a sedimentological view-point, in Giardini Bay the sediment distribution is abruptly interrupted opposite the Town Hall area, where there are very coarse sands; in fact, in the Northern sector the medium sands disappear almost completely. The coarse sands, present from the backshore area to a depth of – 5 m., give way, moving out to sea, to fine sands, to a depth of between 8 and 12 metres; beyond these, the coarse sands reappear. It may be that these fine sands had widely covered an area naturally occupied by coarse sands; only subsequently, following a change in the sediment distribution system, probably linked to the building of the harbour, they were transported further out to sea. From the Macine to the Municipio areas, the beach is characterised by coarse sands up to a depth of about –3 m, while medium sands are present up to the isobars of –5 and –6 m and fine sands are dominant offshore. In the southern sector, between Lido Sirenetta and Schisò Harbour, to a depth of about 6 metres, medium sands are present, while externally the sands are finer; in an isolated zone, corresponding to the sub-perpendicular groyne dividing the two sectors, there is a limited outcropping of coarse sands.

On the subject of weathering, it is interesting to mention the action of the discharge of the pluvial water through tubes located along the “promenade” (seawalk) which give rise to an eroding action concentrated on the emerged beaches. This water discharge action, concentrated, causes concentrated erosive processes in the few points in a good state along the beach (Fig. 5.7).



Fig. 5.7. White waste water tube.

At the beginning of the 1960's, the anthropisation of the bay area has reduced the amount of river sediments reaching Giardini's beach, causing the deficit of sediment output feeding the foreshore and beaches.

The main objective achieved is the stabilisation of the coast, particularly in recreational beaches where there are tourist facilities.

5.4. Expected benefits

5.4.1. Environmental benefits

In general, submerged reef structures are built with the following purpose:

1. To prevent beach erosion
2. Reduction of wave heights at the shore
3. Increasing the amount of hard bottom habitat
4. Reducing stresses on existing reefs
5. Acting as obstacles to provide a deterrent for ships and nets
6. Serving as guideposts for snorkel and diver trails
7. To provide scientific research opportunities
8. To improve water quality
9. To reduce illegal trawling

In the Giardini Bay, where there are significant coastal resorts and attractive natural resources, the environmental benefits of artificial reef creation are mainly as follows:

1. shore protection with dissipation of wave energy
2. beach restoration with regulation of sedimentation and deposition of littoral drift material behind the breakwater

These both improve erosion control, modifying the slope of the shoreface and thus acting over the incident wave trains by diminishing their energy (especially in stormy periods).

A favourable effect of the low-profile geometry of *undercurrent stabilisers* is that they force additional shoaling of waves before reaching the beach. This, along with their less reflective nature, creates a low energy strand of beach. Since fast water picks up sand and slow water drops its load, the low energy beach will be the most likely place for deposition of suspended sediment loads to occur. Importantly, *undercurrent stabilisers* are successful at retaining the natural slope of the beach platform. Scouring at and adjacent to traditional structures creates an artificially deepened nearshore, which subjects those areas to greater wave energy. Scouring also occurs on natural and artificially nourished beaches (see the Ischia case study). The material loss caused by wave action begins at the trough between shore and bar, progressing shoreward. If the storm duration is long enough for this deepening to reach the shore, losses of the beach platform and bluff occur. The orientation of stabilisers resists this deepening by helping retain the natural slope of the beach and nearshore.

5.4.2. Social and economical benefits

The Giardini Bay is a typical Mediterranean tourist resort centre and one of the most important in the island of Sicily. It is confirmed by a continuous positive trend of tourism in the last ten years in Sicily, either in hotels or in other tourist accommodation (Tab. 5.1 - 2).

Tab. 5.1. Presence of Italian and Foreign tourists in hotels (1990 – 2001).

Years	It. arrivals	It. presences	For. Arriv.	For. presences	Total arriv.	Total presences
1990	57795	229931	51538	311504	109333	541435
1991	59991	229188	59541	351622	119532	580810
1992	56659	205448	48400	246292	105059	451740
1993	60184	223932	32750	181289	92934	405221
1994	73317	262121	57643	286410	130960	548531
1995	81513	310055	84567	381924	166080	691979
1996	91002	379314	96184	483196	187186	862510
1997	92126	360773	102296	479922	194422	840695
1998	88885	347011	104512	467874	193397	814885
1999	88393	352975	102237	483730	190630	836705
2000	85387	338909	109227	509756	194614	848665
2001	96295	372635	126646	565302	222941	937937

Tab. 5.2. Presence of Italian and Foreign tourists in extra hotel structures (1990 – 2001).

Years	It. arrivals	It. presences	For. Arriv.	For. presences	Total arriv.	Total presences
1990	429	1934	249	1004	678	2938
1991	289	1123	427	2615	716	3738
1992	194	994	121	444	315	1438
1993	187	1019	66	1004	253	2023

1994	277	1367	70	359	347	1726
1995	252	1257	210	1157	462	2414
1996	326	1288	247	1438	573	2726
1997	270	1255	209	1161	479	2416
1998	282	1483	287	1611	569	3094
1999	239	1243	367	2422	606	3665
2000	3858	17289	4745	35558	8603	52847
2001	5225	19757	7768	55835	12993	75592

Two municipalities exist on Giardini Bay: Taormina and Giardini Naxos. Taormina is one of the most famous resorts of the Ionian sea, known for its archeological treasures (Greek theatre), night life, and its famous international film festival; Giardini-Naxos is the “beach” of Taormina (206 m a.s.l.) with its numerous hotels and restaurants which accommodate more than 1 million tourists per year.

Tourism is the most source of income for the area (Giardini-Naxos area holds 34 hotels and many attractions); consequently, its economy depends largely on the beach quality.

The aim of artificial reef creation in Giardini-Naxos is to remove the causes of deterioration and/or erosion in the Bay, by means of “the restoration of the natural conditions which have led to the formation of the sandy-gravelly beach, with particular reference also to building activities inland, to the recovery and restitution to their natural state of the adjacent torrential streams and channels and to the restoration of the solid littoral transport; particular attention is to be paid also to the effects on an increase in tourist potential, the recovery of state property and the protection of private and public goods from sea storms”.

5.4.3. Technical and financial benefits

In terms of technical benefits, the intervention in Giardini Bay of a long reef breakwater associated with moderate artificial nourishment aims to achieve an accretion in width of the beach of about 50 m for about 850 m. When the scheme is complete, there will be an unbroken public beach, instead of several little stretches of beaches interrupted by groynes.

5.5. Designing the artificial reef scheme step-by-step

To get a clear, integrated and complete idea of the entire protection intervention, it may be useful to go back over each stage of the realisation of a coastal defence construction, including also the stages prior to planning, those of execution (even if only in summary) and those of management.

It is possible to summarise the “order of procedures” as follows:

- defining the objectives of the project (non-technical as well as strictly technical);
- establishing the surrounding conditions and the limits imposed in planning;

- carrying out preliminary studies (determining the state of the coastal environment);
- defining all the possible planning options in conformity with the already defined objectives, surrounding conditions and limits;
- examining the various options and if possible ways to optimise them (with the help of models)
- comparing the options prior to making a choice (on the basis of a “costs-benefits” analysis involving such aspects as seaside tourism and sea-bathing, the landscape, as well as social and environmental considerations);
- executive planning of the works to be carried out and drawing up of a maintenance program (with the help of models)
- building (monitoring the building activity step by step); implementing the completed work and subsequently managing it (and by this management protecting the benefits of the scheme, through monitoring and maintenance of the protection works, in conformity with the pre-established parameters)

The adequate sediment characteristics were determined, in terms of granulometry, using the JAMES 1975 ratios, while the compositional compatibility was determined using the mineralogical analysis, performed counting 300 grains of sand under a binocular microscope, and comparing the data from the source of material and the sand present on the beach. Finally also the chromatic compatibility was determined using the Mansell’s table.

An adequate sediment source for beach nourishment was found in two parts of the southern sector of the Bay.

Potentially, if all sediment trapped in the southern part of the bay were available, there should be about 50.000 m³ of material; but not all material is available because part of this sediment now forms a landing beach for boats.

In the submerged area of the port there is about 150.000 m³ of available material to be dredged and placed on the beach. Another source of material for about 70.000 m³ is present to the north of the dam of the port in correspondence with the isobaths of – 8 and – 12 m. About 50,000 m³ of available material to be dredged are inside the port area.

5.6. Selecting suitable artificial reef techniques

5.6.1. Establishing environmental mitigation strategies

In many sites around the world, where these structures have been created for the protection, repair and mitigation of damaged reefs, environmental and eco-tourism has benefited.

For example, a *prefabricated erosion prevention* (P.E.P.) reef was installed during the summer months of 1992 and 1993, at the town of **Palm Beach** in Palm Beach County, Florida. The reef was constructed at the Midtown segment of the Palm Beach Shore Protection Project. The structure consists of 330 interlocking wedge-shaped concrete modules placed approximately 76 m

offshore, in 2.9 m of water. The total length of the structure is 1.2 m, including a 66 m gap near the north end for a submerged cable easement. The purpose of the structure was to reduce incident wave energy, allowing accretion of sediment in the lee of the structure, resulting in good environmental mitigation action.

In Giardini Bay, environmental mitigation strategy is limited to the artificial reef creation, with no other schemes planned.

5.6.2. Factors influencing the success of artificial reef creation schemes

Factors such as water depth, currents, substrate type, wave action and biota can have a bearing on the suitability of a site for the construction of an artificial reef.

5.7. Assessing and monitoring the environmental and social indicators for artificial reef creation schemes

Over recent years several stretches of the coast of Giardini have been the subject of intense erosive activity, caused and aggravated by a series of man-made constructions: within the hydrographical basin (check dams); along the coast (sub-parallel breakwater barriers); or directly at sea (harbour quays).

The seafront has retreated considerably, with the result that important stretches of the coastal road have been damaged. These stretches of road have been replaced and temporarily protected with breakwater barriers and shoreline defences, which in turn have had a strongly negative environmental impact because, while protecting a few dozen metres of coastline, they have accelerated the erosion of neighbouring areas.

The erosive process is also favoured by a general reduction in transported solid load, due to a series of factors (some of them common to most of the shorelines of Italy).

5.7.1. Impact on shoreline stability

The present coastline situation is that in recent years, several stretches of coastal area in Giardini Bay have been exposed to intense erosive processes. This erosion is caused by the dominant east and north-east winds that tend to generate southward littoral currents which mainly erode the central-southern sector of the bay. It has been made worse by some man-made constructions along the shoreline (harbour quays, groynes and seawalls).

The man-made structures built all along the bay in order to protect the coast were: Schisò harbour (1958, with the most recent modifications made in September 1984), the quay of Saia (late 1960s), the Tyndaros sea-front from San Giovanni to Schisò (1970s), three sub-parallel breakwater barriers, built at the base of the Tyndaros sea-front, and five groynes sub-

perpendicular to the shoreline, variously oriented and built in the San Giovanni area (late 1970s).

Historically, in the northern sector of Giardini Bay, the seawall was built to protect the railway line. This initially led to a severe erosive phenomenon, later stabilising naturally, probably because the presence of natural rocks had created more protected areas.

At present, comparing the ancient and recent maps, it is possible to define an area stretching from south of the Sirina torrent to Capo Schisò where the increasing urbanisation and the realisation of a series of hard structures has led to the erosion of various zones of the Bay beach (San Pancrazio and Macine areas with a mean retreat of 10 m. and maximum of 35 m. between 1940 and 2002) as well as to the gradual advancing of the beach in the protected area of the harbour structure (southern sector with a mean retreat of 50 ÷ 70 m. between 1940 and 2002). This trend has led to the infilling of Schisò Harbour and to the reduction of the central part of Giardini Bay, so that it is no longer suitable for beach bathing (Fig. 5.8).

The seafront has withdrawn considerably, with the result that important stretches of the coastal road have been damaged. These stretches of road have been replaced and temporarily protected with breakwater barriers and shoreline defences, which in turn have had a strongly negative environmental impact because, while protecting a few dozen metres of coastline, they have accelerated the erosion of neighbouring areas.



Fig. 5.8. Before artificial reef construction in the Macine area (Giardini Bay), the beach is in retreat and threatened by eastern waves. It is a narrow beach with mixed sediment patterns. Photo (January-2004).

Estimation of coastline increase (in metres or square metres). After a reduction of 35,000 m² of sandy backshore area between 1940 and 2002 in central sector of Giardini Bay, the re-nourished beach in Macine area (southern sector of Giardini Bay) is in accretion with about 5,000 m² (after phase B.1; Fig. 5.9), while it will be about 50,000 m² after the completed shore protection intervention of phase B.2).



Fig. 5.9. In spite of a winter sea storm the beach is wide, and the seafront has not sustained damages. Photo (9-dec-2004) after intervention in Macine area (Giardini Bay).

Comparing the maps of 1938, 1967, 1972 and 1984 for Giardini, it is possible to define an area, stretching from south of the Sirina torrent as far as Capo Schisò, where the increase in urbanisation, seafront building and the new hard protection structures, have together led to the erosion of the Northern sector (San Pancrazio) and the progressive advancement of the beach in the area protected by the harbour structure.

For example, in the years between 1967 and 1972, the beach decreased by about 5 metres each year, along the northern sector of Sirina area.

In the more northern part, the seawall erected to protect the railway line initially led to severe erosion, later stabilising naturally, probably because of the characteristics of the seabed. In fact the beach initially found a new balance along the direction of the foot of the roadbed supporting the railway line, but

then it became more stable thanks to the presence of natural rocks which created more protected areas.

5.7.2. Impact on natural habitats

One of the major goals is to create artificial reefs that are as close to natural reefs as possible, thus reducing the impact on natural habitats.

In the Giardini area, agriculture is almost absent; only light cultivation of gardens for the very limited production of vegetables now takes place. In the past the entire area was given over to the cultivation of citrus fruits (lemons, oranges) from where the name of the town derives: Giardini indicates the place where the citrus fruits are cultivated. Woods are completely absent.

The distinctive characteristics of the study area have made necessary the choice of a plan which was able to solve the problem of coastal defence while at the same time allowing the structure itself to fit easily into the natural environment and landscape. This would eliminate the degraded appearance offered by the hard protective structures as transversal groynes and sub-parallel reefs.

The impact on natural habitats is not negative.

The current erosion management practices along the Bay of Giardini-Naxos are no longer sustainable and so it has been decided to intervene with a new shore protection scheme. The aim of this investment programme is the removal of the causes of deterioration and/or erosion in the coastal areas, by means of the restoration of the natural conditions which led originally to the formation of the shoreline, with particular reference also to building activities inland, to the recovery and restitution to their natural state of the wet and dry river courses and the restoration of the solid littoral transport. Particular attention is to be paid also to the effects on an increase in tourist potential, the recovery of state property and the protection of private and public goods from sea storms.

This investment programme is still in progress.

5.7.2.1. Impact on coastal fauna

The impact on coastal fauna is positive because the reef barrier should favour the nursery and growing of fish and mussels.

5.7.3. Impact on water quality

There is no special water management policy. The sewage is collected and treated.

After the intervention of phase B.1 (executive experimental plan) the beach is more stable and the water turbidity was absent only a week after the intervention (Fig. 5.10). It is a result of high quality compared with the effects of previous interventions in the municipality of Giardini.



Fig. 5.10. Water clarity after intervention in Macine area (Giardini Bay). Detail of previous photo (9-dec-2004).

No water pollution has been recorded in the Giardini study.

5.7.4. Social perception

To improve the quality of the Giardini bay, the soft protection of the beach and the reconstruction of a sustainable panorama (a long golden beach without groynes or breakwaters) is of primary importance. It will then also be necessary to include in the Bay system a rational port structure. It should be also possible to create two ports: in the northern area a tourist port and in the southern area a commercial one (where cruise boats can also dock); here there is a need for a synergetic development which should involve dialogue between the municipalities of Giardini – Naxos and Taormina. Here there is a local conflict.

During the peak tourist period (August 2005) the Bay of Giardini Naxos was involved in a field survey on the social perception at local level of artificial reef creation.

The enquiry into the habits and needs of beachgoers (beach users) was carried out by asking people on the beach to complete a questionnaire; in addition local stakeholders were interviewed during the same period, while the representatives of the local governments and public institutions were consulted during September 2005.

This activity was carried out using a questionnaire similar to the EUROSION questionnaire scheme on social perception, used in the Giardini Bay before the artificial reef creation project. Therefore, it has been possible to evaluate the difference in local perception before and after the artificial reef creation associated with sand nourishment.

Over five hundred beachgoers answered the questionnaires, as well as some economic operators and official representatives. The beachgoers interviewed

were for the most part habitual visitors to those beaches, although there were also some occasional tourists.

The questionnaire asked beachgoers to give their assessment of various aspects connected with the beach, divided into four categories: physical and geomorphological characteristics, environmental aspects, infrastructures and services, aesthetic aspects/design and comfort of the beaches.

The questionnaire also asked beachgoers to supply some personal information (sex, age, place of origin, type of accommodation chosen, number of hours per day/days per week spent on the beach, reasons for going to the beach) so that a social profile of beach users could be traced. Some questionnaires were discarded during the data processing phase, because they were incompletely or incorrectly filled in. The data are still being analysed and discussed.

The local stakeholders and economic operators interviewed included shopkeepers, hotel, bar and restaurant owners, managers of the lidos and people working in the port area. The activities of all these operators are in some way strictly connected with the presence of the beach and their work places are located in the immediate vicinity of it.

The local Administrators were interviewed in an informal way in the course of normal discussion. Further interviews took place with two free-lance professionals, both involved with the MESSINA project. Because all these interviews were held in a very informal and colloquial way, it has not been possible to represent the information exchanged in the form of diagrams or graphs.

From the results of the interviews it is easy to see that the vast majority of beachgoers go to the beach for the purpose of swimming and sunbathing; only some of them go to the beach for other purposes.

Visitors from different places of origin tend to view the physical aspects of the Bay in slightly different ways. The ones who appear to appreciate these aspects most are those from the north of Italy. Also foreign visitors appear to appreciate the climatic and geomorphological aspects of the Bay, but they tend to be more critical of the present rocky shoreline and the emergent rocky groynes. The most critical of all have been generally local and habitual beachgoers.

With regard to the environmental aspects of the beach it is easy to note here that the assessment of the various environmental components analysed tends to be less favourable among the higher social and economic categories and vice versa.

With regard to a general assessment, most of those interviewed have given a generally positive evaluation and only some of them gave the beach an low assessment.

All the people interviewed agreed that the local project for an artificial reef creation with sand nourishment has led to an improvement in the environmental situation. Design and aesthetic aspects of the area have generally been viewed positively.

5.8. Budgeting for artificial reef schemes

5.8.1. Feasibility costs

Intervention costs of the technique used. *The intervention cost of reef breakwaters increases considerably with water depth and wave climate severity, both environmental factors that heavily influence their design and positioning.*

The coastal defence plan for Giardini Bay is aimed at shoreline management along the coastal area of Giardini-Naxos and at the enhancement of beach restoration, where there are some ancient groynes made of volcanic black boulders.

The cost of coastal defence project consultancy was € 243,720.31, whereas the costs of used coastal defence techniques were: € 1,853,000 for the artificial reef (85% of total cost) and € 327,000 for artificial nourishment (15 % of total cost); therefore, the intervention cost in the executive experimental plan (period: Jul 2004- Dec 2004) was € 2,180,000. The total intervention cost was € 3,150,387 for completed Phase B.1 (Fig. 5.11-12).



Fig. 5.11. The shoreline in December 2004, two weeks after nourishment, at the end of the intervention. The barrier is completely submerged. Photo (5-dec-2004) of the Macine area (Giardini Bay).



Fig. 5.12. During the first winter sea storm, waves surfing (and breaking) on the submerged barrier. Photo (9-dec-2004) of the Macine area (Giardini Bay).

The calculated total intervention cost for completing the executive plan (the next phase B.2) is € 8,500,000. Phase B.2 of the Coastal Defence Project in Giardini Bay is enhancing phase B.1, for the model and intervention solution used (Tab. 5.3).

Tab. 5.3. Intervention costs in Giardini Bay.

Steps of Coastal Plan	Phase A	Phase B.1	Phase B.2
Type of Coastal Plan	Preliminary Plan	Executive experimental plan	Executive completed plan
Dates	May 2002	July – December 2004	In next future
a) Project Consultancy cost		€ 243,720	
b) Intervention total cost (b=b ₁ +b ₂)		€ 2,180,000	
b ₁) Artificial reef-breakwater cost		€ 1,853,000 (85% of total cost)	
b ₂) Artificial nourishment		€ 327,000 (15 % of total cost)	
c) Total intervention cost (c=a+b ₁ +b ₂)		€ 3,150,387	€ 8,500,000

Intervention costs of supposed techniques to be used (and their estimation of success). The calculated total intervention cost to complete the executive plan (the phase B.2) is € 8,500,000. Phase B.2 of the Coastal

Defence Project in Giardini Bay is planned to enhance phase B.1 for the model and intervention solution.

No environmental mitigation cost has been calculated for Giardini Naxos' defence work.

€ 243,720.31 is invested in Giardini Naxos' project.

5.8.2. Maintenance and monitoring costs

Costs for the maintenance and monitoring the defence work at Giardini Bay are about of 100.000 €.

5.9. Limitations

The intervention can be performed only after a study of the area and it has produced a very good result also because it was sited inside a closed bay.

SECTION III

III. COMPARISON WITH TRADITIONAL ENGINEERING STRATEGIES

1.1. Basic principles

Classical responses to an eroding beach used to be as follows.

A structural approach is simply to prevent upland loss and can be in the form of: revetments, seawalls, detached breakwaters, or groynes, etc. If well designed armouring in the form of shore-parallel structures (seawalls or revetments) is placed on an eroding shoreline, it would satisfy its intended function of preventing erosion of the upland; however, with continuing erosion, the beach would narrow and eventually no longer be present. Groynes trap sand from the littoral stream and may impact adjacent shorelines. Recognising that there are cycles of shoreline advancement and recession superimposed on the long-term shoreline change, the armouring would tend to occur during periods of erosional cycles. The time required before no fronting beach is present could be decades.

A second option is retreat as the shoreline erodes. Retreat would appear to be the most appropriate option in areas of high erosion and in the presence of a small economic revenue base.

1.2. Comparison schemes

1.2.1. Collecting baseline information

The other unique geometric aspect of stabilisers is that they follow the bottom profile and taper down in size as they extend into the water. This is the opposite of the geometry of groynes which become larger in size and follow the water surface as they extend seaward. The primary utility of tapering and hugging the bottom is that these structures are essentially permeable with respect to the littoral (longshore) movement of sediments. Traditional groynes are impermeable to littoral drift. The permeability of stabilisers is a reason that monitoring surveys have found no downdrift losses of beach or bluff. Also important is that stabilisers encourage retention of the natural beach slope, unlike walls and revetments, reducing the severity of scour during large storm events. Most importantly, undercurrent stabilisers indicate that beach and bluff protection can be achieved over the long term, unlike beach nourishment.

SECTION IV

IV. REFERENCE

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ANNEX

COST-BENEFIT ANALYSIS OF SOFT ENGINEERING TECHNIQUES FOR COASTAL DEFENCE

INTRODUCTION

Although proven engineered shore protection measures exist, there are no quick, simple, or inexpensive ways to protect the shore from natural forces, to mitigate the effects of beach erosion, or to restore beaches, regardless of the technology or approach selected. Available shore protection measures do not treat some of the underlying causes of erosion, such as relative rise in sea-level and interruption of sand transport in the littoral systems, because they necessarily address locale-specific erosion problems rather than their underlying systemic causes. Furthermore, all shore protection and beach restoration alternatives are controversial with respect to their effects on coastal processes, effectiveness of performance, and socio-economic value.

For these reasons, the MESSINA project pays particular attention to the balance of costs - including environmental costs - and benefits - including environmental benefits - related to the various technical solutions for the shoreline protection.

Such solutions, in fact, must always be “sustainable” by local communities either in financial or in socio-economic terms. In order to identify the relevance or irrelevance of certain solutions, it is best to carry out a cost-benefit analysis which can help to identify the optimal solution, including the “do nothing” option.

COST-BENEFIT ANALYSIS

General features

Carrying out a cost-benefit analysis is a technical exercise involving numerous choices and calculations. The more complicated the decision being addressed, the more care should be taken to identify and measure key variables and to analyse them appropriately. However, the technical nature of the analysis should not obscure the fact that the exercise is being carried out to inform the decision process. Each decision going into the analysis must be documented and described in a manner that will reassure those who are party to the decision process that the choices are sound.

Once a decision to carry out a cost-benefit analysis is made, the conceptual concerns raised above are set aside and the pragmatic business of specifying the overall framework to be used, the input variables to be included, how to

measure them, and many other decisions must be made. These decisions are not inconsequential, because seemingly innocuous choices, if arbitrarily made, can cause large swings in the outputs of the analysis.

Cost-Benefit Analysis and Time

The cost-benefit analysis must generally measure the net benefits of projects that generate costs and benefits over a period of time, with costs and benefits often occurring in different time periods. This increases the complexity of the analysis, because a euro of costs or benefits ten years from today is not directly comparable to a euro of costs or benefits today. Because comparisons require a common metric, cost-benefit analysis uses a process called discounting to express all future costs and benefits in their present value equivalent. This takes place by discounting costs and benefits in each future time period and adding them to arrive at a present value.

This gives rise to one of the weaknesses of cost-benefit analysis. Because the discounting process calculates its results from the present generation's perspective, one needs to be concerned about intertemporal equity issues, that is, to the fairness of the decision to future generations. In fact, costs that occur far into the future may be given little weight in traditional cost-benefit analysis.

Choice of Input Values

Carrying out the present value calculation is mechanical, but the choices of values for input variables will ultimately determine the results of the analysis. Choices may be divided into parameter values and benefit and cost values.

Parameter choices include:

- the discount rate
- future rates of economic growth
- future rates of population growth
- future rates of inflation
- future rates of technological change

Benefit and cost choices include:

Benefits

- monetary values for marketed goods
- monetary values for non-marketed directly used goods
- monetary values for non-marketed passively used goods
- goods for which monetary values cannot be measured

Costs

- monetary values for marketed input goods
- monetary values for non-marketed directly used goods that must be given up
- monetary values for non-marketed passively used goods that must be given up
- costs for which monetary values cannot be measured

Because the values chosen for these variables will significantly influence the final values calculated, the decision maker must satisfy herself that the values chosen are reasonable.

Methods for Determination of Value from Projects

Once estimates of benefits and costs associated with a project have been identified and estimated, they must be analysed to determine the capital value of the project. This value is derived from the stream of net benefits the project is expected to generate in the future. These net benefits are usually expressed in monetary terms and are generally referred to as cash flows, or to emphasise the inclusion of non-marketed benefits and costs, as cost-benefit flows. Net benefit implies that the benefits of any capital project are subtracted from the costs associated with that project in a given time period.

Once a capital value is determined for each project, projects under consideration (including the “do nothing” option) can be ranked according to that value. This process requires that the potential projects be compared using an unbiased measure. It should be recognized that any method chosen to aggregate values over time is a model, that is, an analytical tool that simplifies the analysis at hand. Several different models are commonly employed in government and industry to compare the capital values of projects. However, individual measures can lead to different rankings depending on the specific circumstances of the analysis. If the ranking can change arbitrarily depending upon the method chosen, the ranking is said to be biased. Although no single model is perfect, some are clearly better than others.

The goal of the capital project evaluation process is to ensure that, from a number of alternative choices, the project or set of projects chosen generates the greatest economic value to society. Because capital projects have economic lives that extend into the future, the value of time must be taken into account. This is commonly referred to as calculating the time value of money. Time influences value because by choosing to invest in a specific capital project, other choices are forgone.

In addition to the time value of money, several other factors must be incorporated into any acceptable measure of value. First, all future cost-benefit flows should be taken into account. Failure to consider all future cost-benefit flows could lead to the choice of a project with large initial benefits and larger, but unidentified, subsequent costs. Second, any measure of value should incorporate the risk associated with the stream of cost-benefit flows.

To summarise, any measure of value chosen should meet the following criteria:

1. Incorporate the value of time.
2. Reflect all future cost-benefit flows.
3. Incorporate risk into the calculation of the value.
4. By adhering to these criteria, the decision maker can be assured that the project(s) chosen will yield the greatest economic value.

Commonly Used Measures for Intertemporal Comparisons

Several measures are commonly employed to determine the value of a capital project. These are:

- the payback
- discounted payback
- internal rate of return (IRR)
- modified internal rate of return (MIRR)
- net present value (NPV).

Payback. The payback method is the simplest measure to calculate and the least consistent with the criteria listed above. The payback method simply calculates how many periods into the future it takes for a capital project to repay the initial investment.

The payback method for determining value does not meet the criteria established above. It fails to account for all cost and benefit flows. Furthermore, the payback method does not take into consideration the time value of money. Finally, risk is not considered.

Discounted Payback. The discounted payback method attempts to rectify one of the shortcomings of the payback method, the incorporation of the time value of money. The cost-benefit flows are discounted to reflect the value of time. For example, suppose the appropriate discount rate is 5%. The net benefit stream for projects A and B can be recalculated to reflect this new piece of information. The present value (the value of some future amount in today's euros given a discount rate) is calculated using the following formula:

$$PV = [FV/(1+r)]^t$$

The symbols represent present value (PV), future value (FV) and the discount rate (r) expressed as a percentage. The number of periods from the day (period 0) the net benefit accrues is the number of discounting periods, t .

Both the payback and discounted payback methods for determining value of capital projects are inconsistent with the criteria mentioned above. Although occasionally employed in industry as a thumbnail measure of a project's value, neither is consistent or fully acceptable for evaluating capital projects.

Net Present Value. Net present value (NPV) is similar to the discounted payback method in that the cost-benefit flows are discounted to reflect the time value of money. However, unlike the discounted payback method, NPV considers all future cost-benefit flows. The method yields one value that is easily interpreted. If the value is positive, the project yields benefits that exceed its costs. If the value is negative, costs exceed benefits. The discounting calculations are based on the same formula that is used to discount cost-benefit flows in the discounted payback method.

NPV easily allows us to compare projects and is also consistent with the identified criteria. The method accounts for the time value of money through discounting. It also considers all of the expected future cost-benefit flows.

Further, the discount rate can be adjusted on a project by project basis to reflect the inherent risk of each.

Internal Rate of Return. It is often difficult to determine the rate at which future benefits should be discounted to today's dollars. In addition, decision makers are often more comfortable with value expressed in percentage terms rather than some other metric. The internal rate of return (IRR) is a method for determining value that does not depend on the determination of a discount rate and that expresses value in terms of a percentage. Essentially, the method requires the calculation of a discount rate such that the discounted value of future cost-benefit flows exactly equal the initial investment. In other words, the present value of costs minus the present value of benefits equals zero.

To calculate the IRR it is necessary to find the discount rate that would equate the initial investment with the future cost-benefit flows.

IRR is based on the assumption that the cost-benefit flows are reinvested at the internal rate of return. If we are examining projects that are mutually exclusive, IRR may yield results that are inconsistent with a ranking based on the NPV method.

One should note the effect of the timing of the cost-benefit flows on the IRR calculation. Any project that has relatively large positive cost-benefit flows early in its life will generate a relatively large IRR.

Finally, the use of IRR as a measure for choosing between projects is inappropriate when capital rationing exists. This problem is again due to the assumption that the cost-benefit flows are reinvested at the internal rate of return rather than at the cost of capital as in NPV. What this implies for the decision maker is that the ranking of projects will depend as much on their relative size and the timing of their cost-benefit flows as it will on the actual cost-benefit flows, where the actual flows should be the only determinant of acceptance or rejection.

The inconsistency implies that the usefulness of the IRR method is limited. Furthermore, difficulty arises when calculating the IRR of a project that has negative cost-benefit flows after the first period. Due to the mathematics of the calculations, it is possible under these circumstances to calculate multiple IRR's that equate the net present value of costs with the net present value of benefits. This is clearly an undesirable situation.

Modified Internal Rate of Return. Modified internal rate of return is a technique that allows for the calculation of an internal rate of return when negative expected cost-benefit flows occur after the initial period. The method requires the compounding of all positive cost-benefit flows to the last period of project life and the discounting of all negative cost-benefit flows to the first period, at a given discount rate. The formula for compounding values forward is:

$$PV = [FV/(1+r)]^{T-t}$$

Again, FV is the future value, PV is present value, r is the appropriate discount rate, t is the number of compounding periods, and T is the final period. Once the positive cost-benefit flows have been compounded forward and the negative cost-benefit flows have been discounted back, the MIRR can be calculated.

Once the initial calculations have been completed, the final step is to determine a MIRR that equates the positive cost-benefit flows with the present value of the negative cost-benefit flows. The decision rule for utilising the MIRR method is similar to the decision rule employed for the IRR method. If the MIRR is greater than the hurdle rate, accept. If it is less than the hurdle rate, reject. While the MIRR method does eliminate the potential for calculating multiple IRR when projects have negative cost-benefit flows late in their useful lives, it does not eliminate the problems that arise from mutually exclusive projects or capital rationing.

Choosing the best Method

The preceding discussion of various methods commonly employed to determine the value of capital projects detailed many of the problems associated with each method. In general, the following table outlines under what circumstances any given method is consistent with the four indicated criteria.

<i>Method</i>	<i>Independent Projects</i>	<i>Mutually Exclusive Projects</i>	<i>Capital Rationing</i>	<i>Scale Differences</i>
IRR	Acceptable	Not Acceptable	Not Acceptable	Not Acceptable
MIRR	Acceptable	Not Acceptable	Not Acceptable	Not Acceptable
NPV	Acceptable	Acceptable	Acceptable	Acceptable
Payback	Not Acceptable	Not Acceptable	Not Acceptable	Not Acceptable
Discounted Payback	Not Acceptable	Not Acceptable	Not Acceptable	Not Acceptable

Table 1: Comparing Methods of Valuation under Various Scenarios

Scale differences refers to the relative size of the cost-benefit flows. When comparing projects that vary in size dramatically (i.e., thousand dollar cost-benefit flows versus million dollar cost-benefit flows) only NPV yields results consistent with our criteria.

The NPV is the only method that is both consistent with the above mentioned criteria and acceptable given any set of circumstances that affect the comparison of projects under consideration. While not as easy to calculate as the payback method, NPV is computationally easier than either the IRR or the MIRR. Finally, NPV provides a simple basis upon which to accept or reject projects and to compare across projects.

Measuring Benefits and Costs

A properly constructed cost-benefit analysis will attempt to measure the change in economic welfare associated with all costs and all benefits uniquely generated by a project. In general, these will fit into one of three categories: (1) marketed (direct) benefits and costs, (2) non-marketed direct benefits and costs, and (3) non-marketed indirect benefits and costs. For benefits, we attempt to measure the willingness to pay by all affected consumers for the relevant project benefits. The rationale for doing so derives from applied economic welfare analysis. This approach argues that economic welfare derives from preference satisfaction and that preference satisfaction is reflected by the consumer's willingness to pay.

More specifically, economists infer willingness to pay for direct benefits and costs by observing choices made in markets or by observing other choices to spend money to facilitate direct consumption of the resource. This is said to measure preferences revealed by choices, or simply to measure revealed preferences. For non-marketed, indirect benefits and costs, stated preference estimates derived from survey research are employed. For costs, we attempt to measure the opportunity costs using the economic resources (land, labor, materials, etc.) in the project rather than in some other use. For direct private costs, market prices of resources are used. Non-marketed costs, tend to be treated as benefits foregone, and are estimated exactly as are benefits.

1. Marketed Benefits and Costs

Marketed benefits, also referred to as private benefits, are measured as the sum of willingness to pay by consumers for the new quantity of product produced by the project being evaluated.

The private costs associated with the project, unlike the benefits, are typically measured at market prices. This reflects the fact that factor inputs, like land, labour and materials tend to be much more substitutable and therefore supplied at roughly constant prices. Few projects are by themselves large enough to cause changes in prices through project activities, and, hence, the assumption of constant prices is reasonable.

The issue of under-utilised resources is a bit more problematic, however. Local administrators are typically enthusiastic about new jobs created by economic development, private or public. National administrators, on the other hand, recognise that the benefits are not unique to the project, because they would occur anywhere a project was undertaken, and would be likely to be similar for quite different projects of roughly equal magnitude. The only question for a national decision maker would be whether special weight would be given to economic development in particular areas as a matter of policy.

2. Non-Marketed Direct Benefits and Costs

A large number of natural and environmental resources are consumed directly, but are not purchased in markets. Examples include fishing in a mountain

stream, enjoying a panoramic view, living in a community or neighbourhood with clean (or dirty) air, or working in an occupation that provides opportunities to enjoy increased (or decreased) health. We note that environmental "dis-amenities" as well as amenities can come into play.

Hedonic models are often used to measure the impacts of favourable or unfavourable environmental conditions on property values. For example, the impacts of a view could be isolated statistically, by controlling the size of house, size of lot, construction, and other features. In other cases, a travel cost approach is used to infer willingness to pay for an environmental amenity. For example, costs incurred by fishermen can be observed and related to stream attributes, such as beauty, isolation, average catch, average sized catch, and the like. By isolating other affects statistically, it is possible to infer the willingness to pay for attributes of many natural attractions, like national parks, seashores, lakes and mountains.

These approaches are referred to as revealed preference measures because they infer willingness to pay as revealed by consumer choices. From them, demand schedules can be estimated and consumer surplus measured.

3. Non-Marketed Indirect Benefits and Costs

Non-marketed indirect benefits and costs arise not because of direct use of a resource, but rather because individuals place value on the "existence" of the resources. For example, many people have never seen marine protection areas, but are willing to pay to see them preserved. This value is an indirect benefit. The challenge lies in measuring such value in meaningful scientific ways, that is, ways that can be validated and replicated.

In general, because there are no behavioural footprints from which to infer value survey-based approaches are used to derive indirect values. The most commonly applied approach is called contingent valuation analysis wherein a hypothetical, or "contingent," choice is made that is designed to reveal an individual's willingness to pay. Typically, these analyses present detailed scenarios to respondents that include information about the project under consideration, what it hopes to accomplish, how it will be paid for, and over what time period actions will take place. Various formats are then employed to obtain a contingent value that is an estimator of actual willingness to pay.

APPLICATION TO THE MESSINA CASE STUDIES

Selected coastal defence techniques

The cost-benefit analysis described above will be applied to some coastal sites in which innovative environmentally-friendly engineering techniques have been implemented.

In particular, MESSINA project will focus on the following techniques:

Beach nourishment

Artificial increase of sand volumes in the foreshore via the supply of exogenous sand. Sand supply may be achieved through the direct placement of sediment on the beach, through trickle charging (placing sediments at a single point), or through pumping. It can be also take place in the emerged part of the foreshore (“beach nourishment”) or under the water line (“underwater nourishment”) which is generally cheaper.

Beach drainage

Beach drainage decreases the volume of surface water during backwash by allowing water to percolate into the beach, thus reducing the seaward movement of sediment. Beach drainage also leads to drier and “gold” coloured sand, more appreciated for recreational activities.

Wetland creation and restoration

Wetlands provide effective natural storm defences, absorbing the energy of the waves and accumulating sediment that raises the level of the land.

Dune rehabilitation

Wind-blown accumulation of drifted sand located in the supra-tidal zone. Wind velocity is reduced by way of porous fences made of wood, geo-textiles, or plants, which encourage sand deposition

Artificial reef creation

Building an artificial reef which absorbs the wave energy (thus providing coastal defence), while providing a natural habitat for marine biodiversity and opportunities for recreational activities

The Net Present Value method for coastal defence techniques

The approach tested in the framework of MESSINA is based upon the concept of Net Present Value (NPV) estimated for each engineering technique among those taken into account.

The Net Present Value (NPV) is a key indicator to assess and compare the economical viability of different options, including the “do nothing” one which is systematically reviewed and constitutes the reference option.

The NPV is calculated using the formula:

$$NPV = \sum_{t=0}^{t=T} (BE_t - IC_t - EC_t) [1/(1+r)^t]$$

where:

- *BE* are the estimated benefits for year *t*
- *IC* are the estimated internal costs for year *t*
- *EC* are the estimated external costs for year *t*
- *T* is the life expectancy of the shoreline defence solution
- *r* is the annual capitalisation rate.

So, benefit-cost analysis, through the NPV method, reduces a complex problem down to one number. It's important to understand the assumptions and theory behind the calculation of that one number.

The analytical process requires inputs from models representing a variety of disciplines. Arbitrarily these models have been divided into three broad areas: models of beach behavior, environmental models and economic models. Figure 1 presents a schematic of the cost benefit process.

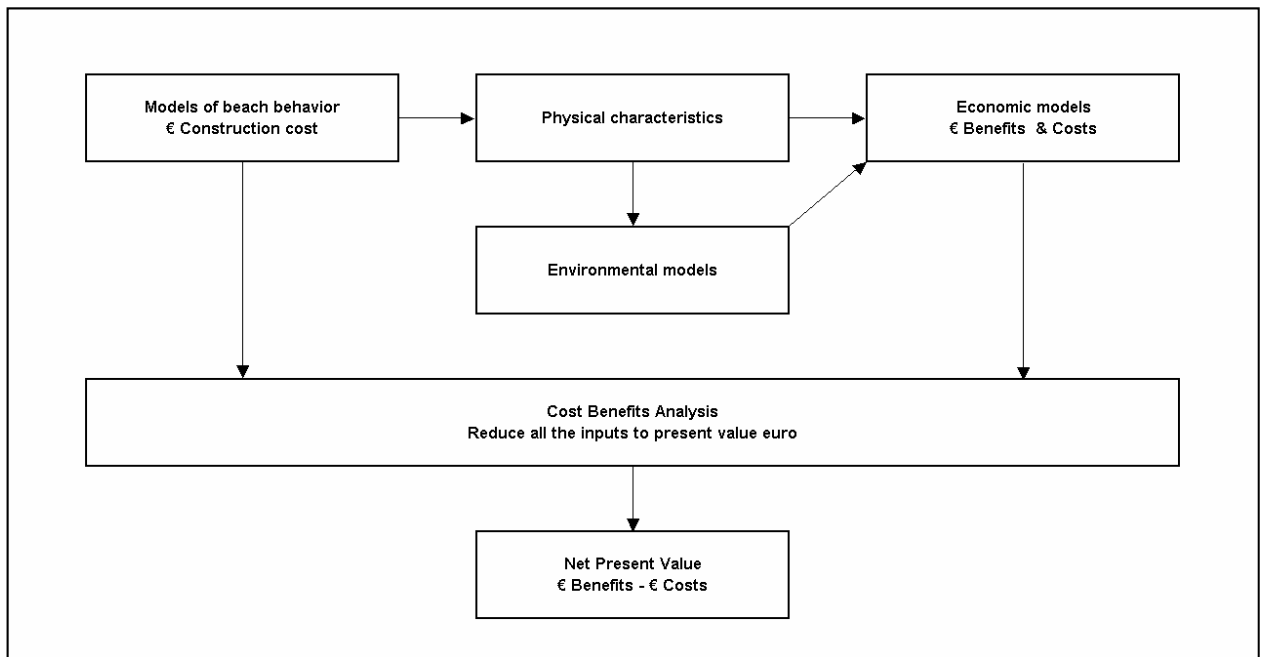


Fig. 1 – Cost benefit process

Although NPV is not always computable (and it does not usually reflect effects on income distribution), efforts to measure it can produce useful insights even when the monetary values of some benefits or costs cannot be determined. In these cases: a comprehensive enumeration of the different types of benefits and costs, monetized or not, can be helpful in identifying the full range of project effects.

Quantifying benefits and costs is worthwhile, even when it is not feasible to assign monetary values; physical measurements may be possible and useful.

Expected Costs and Benefits of coastal defence techniques

Internal costs

Internal costs are the investment and recurrent expenses relating to the implementation of the shoreline management scenarios. They include:

- the preliminary costs, which is to say the costs of preliminary studies including technical feasibility, environmental impact assessment, cost-benefit analysis, and social perception studies.
- the investment or capital costs necessary to implement the Shoreline management scenario. These costs include the collection and production of baseline data and indicators, consulting fees for shoreline modelling and technical design, expenditures related to input materials and field operations, and the costs of project management and administration.
- the operating and maintenance costs, which are the costs to be spent annually to maintain the effectiveness of the Shoreline management solution over its life expectancy. These costs should be capitalised at present bank interest rate.
- the operating cost of environmental monitoring procedures, which is to say the costs of measures and procedures to monitor and mitigate the adverse effects of the Shoreline management scenario, as defined by the environmental impact assessment study. These costs should be capitalised at present bank interest rate.

External costs and benefits

External costs and benefits respectively reflect a decrease or increase of values induced by the different scenarios. These values include:

- the human value (marketed benefits and costs), which is to say the value derived from goods (including land) which can be extracted from or built on in near-shore areas as a direct result of mitigated coastal erosion (such as new infrastructure built in areas less prone to coastal flooding, new hotel resorts built along waterfronts and to a lesser extent small scale mining activities of sea products). Once estimated, annual direct use benefits should be capitalised at present bank interest rate.
- the economical value (marketed benefits and costs), which is to say the value – mainly in monetary terms – that humans can extract from the sale

of products, services and/or rights derived from a land parcel or from assets built on this parcel (such as infrastructure). The economic value may be expressed in a variety of ways including in terms of capital invested, land market value, replacement costs, turnover, or jobs. It may concern a wide range of economic sectors: tourism, mining, agriculture, aquaculture, fisheries, services, etc. Once estimated, annual economical benefits should be capitalised at present bank interest rate.

- the ecological (or regulation) value (non marketed direct benefits and costs), which is to say the value derived from functions fulfilled “naturally” (i.e. without human intervention) by a coastal land parcel. This include for example dunes protecting freshwater lens and filtering waters, wetlands and local marine habitats providing suitable conditions for fisheries and aquaculture, marshes and flats absorbing nutrients and contaminants drained by rivers. Ecological value may be expressed in terms of replacement costs or willingness of the public to pay for protection. Once estimated, annual ecological benefits should be capitalised at present bank interest rate.
- the heritage (or existence or information) value (non-marketed indirect benefits and costs), which is to say the value derived from the benefits which do not involve using the site in any way, the value that people derive from the knowledge that the site exists, even if they may never actually visit the site. Heritage value may be estimated for designated buildings and monuments (e.g. churches), designated natural parks (national, regional parks, site of scientific interest), archaeological sites, historic gardens, parks, or battlefields, and remarkable sites. Annual budget spent for the conservation of heritage sites, or willingness to pay for their conservation can be taken as proxy of heritage value. Once estimated, this value should be capitalised at present bank interest rate.

The table below summarises the different value indicators which are expected to be used, as suggested by the *Guide for implementing Geographical Information Systems (GIS) dedicated to shoreline management*, prepared in the framework of MESSINA project.

Value indicators to assess benefits and external costs

Value types	Value indicators	Applicability	Interpretation
Human value	<u>Population at risk</u>	<ul style="list-style-type: none"> Population 	<ul style="list-style-type: none"> Decrease of population at risk induced by a scenario is a benefit Increase of population at risk induced by a scenario is an external cost
Economical value	<u>Capital invested or replacement costs</u>	<ul style="list-style-type: none"> Infrastructure (road, railways, harbours, airports) 	<ul style="list-style-type: none"> Protection of an infrastructure induced by a scenario is a benefit Loss of an infrastructure induced by a scenario is an external cost
	<u>Land market value</u>	<ul style="list-style-type: none"> Urban areas, agricultural areas, non-designated natural areas 	<ul style="list-style-type: none"> Rise of market value induced by a scenario is a benefit Fall of market value induced by a scenario is an external cost
	<u>Full time equivalent jobs</u>	<ul style="list-style-type: none"> All registered companies (tourism, agriculture, aquaculture, fishery, mining, industry, service, etc.) 	<ul style="list-style-type: none"> Creation of jobs induced by a scenario is a benefit Loss of jobs induced by a scenario is an external cost
	<u>Annual turnover</u>	<ul style="list-style-type: none"> All registered companies (tourism, agriculture, aquaculture, fishery, mining, industry, service, etc.) 	<ul style="list-style-type: none"> Increase of annual turnover induced by a scenario is a benefit Decrease of annual turnover induced by a scenario is an external cost
Ecological (or regulation) value	<u>Replacement costs or willingness-to-pay for protection</u>	<ul style="list-style-type: none"> Habitats stabilising slopes (e.g. forests) Habitats providing protection against storm surges (dunes, mudflats) Habitats providing protection against salt water intrusion (dunes) Habitats absorbing nutrients and contaminants (e.g. marshes, mudflats) Habitats provide suitable conditions for animal feeding, nesting and hatching (e.g. dunes, mudflats, marshes, beaches) 	<ul style="list-style-type: none"> Protection or improvement of an ecological function induced by a scenario is a benefit Loss of an ecological function induced by a scenario is an external cost
Heritage (or existence or information) value	<u>Conservation budget or willingness-to-pay for conservation</u>	<ul style="list-style-type: none"> Designated buildings and monuments (e.g. churches) Designated natural parks (national, regional parks, site of scientific interest) Archaeologic sites Historic gardens, parks, or battlefields Remarkable sites 	<ul style="list-style-type: none"> Protection of a heritage site induced by a scenario is a benefit Loss of a heritage site induced by a scenario is an external cost

Table 2

For each of the selected techniques, expected benefits will be identified, based on the case studies analysis. Such benefits will be classified as follows:

- Environmental benefits
- Social and economic benefits
- Technical and financial benefits

In budgeting for soft engineering techniques schemes, the following costs will be taken into account:

- Feasibility costs
- Environmental mitigation costs
- Investment and engineering costs
- Maintenance and monitoring costs

Test case n. 1: Beach nourishment - Ostia (Italy)

General description

The nourishment carried out in the Levant sector of the Ostia Beach is the most important in the Lazio Region and it is the first soft intervention (that is without any protection) created both in the Region and in Italy.

This kind of intervention was based on monitoring executed between 1990 and 1995 on the stretch near Ostia Centre, followed by a cost-benefit analysis, to choose between a sheltered nourishment (with a submerged barrier) and a soft one (sand only), which showed that the barrier's protective effect cannot justify its cost if the nourishment sand price is reasonable, beneath 7,50 Euro/m³.

The nourishment (made in **1999**), involves a **3,5 km** stretch of coast, with a **950.000 m³** sand dredging, that implies a total expense of **Euro 7.643.562**, without contemplating maintenance and monitoring.

The sand collection has been made adjacent to the Torvaianica-Anzio site, 7,4 km from the coast and about 45 km from Ostia, having a potential of over 2 billions m³.

The project involves 50.000 m³ sand for maintenance a year and a biennial monitoring consisting of measuring the shore-line and the transversal sections changes.

On the whole, the intervention showed a remarkable efficacy and a more than satisfactory meeting of the project's expectations, allowing a moderate advancement of the shore-line of about **44 m**.

6 years after the creation of the scheme, the available information relates to internal costs (Investment and engineering costs, Maintenance and monitoring costs) and external benefits (social and economical) based on the annual turnover indicator related to the beach activities of the lidos.

The economic value

The Ostia main economy is based on services linked to the tourism.

Regarding the "seasonal" tourism flows of summer, Ostia, with its own lidos, represents a natural resource, moreover; it is the nearest bathing resort to the capital. The structures that form the tourist facilities can be described in outline as follows:

- 68 lidos (bathing establishments);
- 1.496.596 m² of state concessions, for about the 80% of total;
- 206.284,62 m² covered surface;
- 196.951,4 covered surface with reference to the establishments, whose 159.131,11 covered surface of the 42 establishments with "free" entrance;
- hotels (2 cat. 4 stars, 5 cat. 3, 4 cat.2);
- 1265 hotel rooms;
- 1477 beds;
- 5 bed & breakfast;

- 7.000 available cabins;
- 15.000 dressing-rooms;
- 130.000 annual sub-subscriptions;
- 10.000.000 seasonal total population;
- over 280.000 m² occupied by campsites;
- 150 bungalows;
- Leisure harbour with 800 berths (of which 60% are already sold), with 72 internal shops and 20.000 estimated population in the holiday summer days, 6.000-8.000 on working days, and half that during winter.

A recent study (Nomisma, “La valutazione economica delle località balneari”, 2005) evaluated the medium turnover value of an Ostia lido, solely from beach activities (beach-umbrellas, sun-beds etc.) in 2003: that turnover, evaluated in 282.119 Euro, corresponds to 25,2 € per m² of state concession.

Cost-benefit analysis

The soft nourishment intervention carried out in 1999 cost 7.643.562 €: about 87 % was the cost of the sand purchase, while the rest was technical expenses. The monitoring in the following years emphasises that, due to the natural erosive process, not moderated by any protecting nourishment operation, it is necessary to nourish again the stretch of beach with about 120.000 m³ of sand in the first year and with 60.000 m³ yearly, on average, for the following years. For that reason, by restricting investment and maintenance costs, quantified by the attribution of 7 €/m³ cost to the nourishment sand, in the 25 years of the investment temporal horizon, it is expected to obtain the following internal costs table:

Year	Internal costs €	
1999	7.643.562	Investment and engineering costs
2000	3.322.200	Maintenance and monitoring costs
2001	553.700	“
2002	553.700	“
2003	553.700	“
2004	553.700	“
2005	553.700	“
2006	553.700	“
2007	553.700	“
2008	553.700	“
2009	553.700	“
2010	553.700	“
2011	553.700	“
2012	553.700	“
2013	553.700	“
2014	553.700	“
2015	553.700	“
2016	553.700	“

2017	553.700	“
2018	553.700	“
2019	553.700	“
2020	553.700	“
2021	553.700	“
2022	553.700	“
2023	553.700	“

Tab. 3

Regarding the benefits, on the other hand, only the economic value has been taken into account: this is the most important, considering the beach's purpose (bathing) and the economic market entity revolving around it.

As an economical value indicator, the annual turnover of the tourism industries has been used: in the interests of rigorousness, only the turnover coming from beach activities has been taken into account, even if the increase in the beach surface suggests an impact on the other economic activities (eg cafés, restaurants, hotels, etc.) that, in the case of Ostia, the bathing resort of Rome, is really remarkable.

By considering that the soft nourishment in Levant Ostia has increased the beach by 155.300 m² and that the state-subsidised surfaces represent 80% of the total beaches, and by using the above-mentioned medium value of 25,20 €/m², it is expected to obtain a constant annual benefit (external benefit - social and economical), of 3.130.848 €, as an increase of the annual turnover.

Thus, by applying the NPV formula, with an average capitalisation rate of 3,5% (medium value of the discount rate in the last 7 years in Italy), the present net benefit is of about 33 million € (ratio B/C = 2,78), with a unitary value of 9.440.200 €/km of shore and 212,75 €/m² of increased beach.

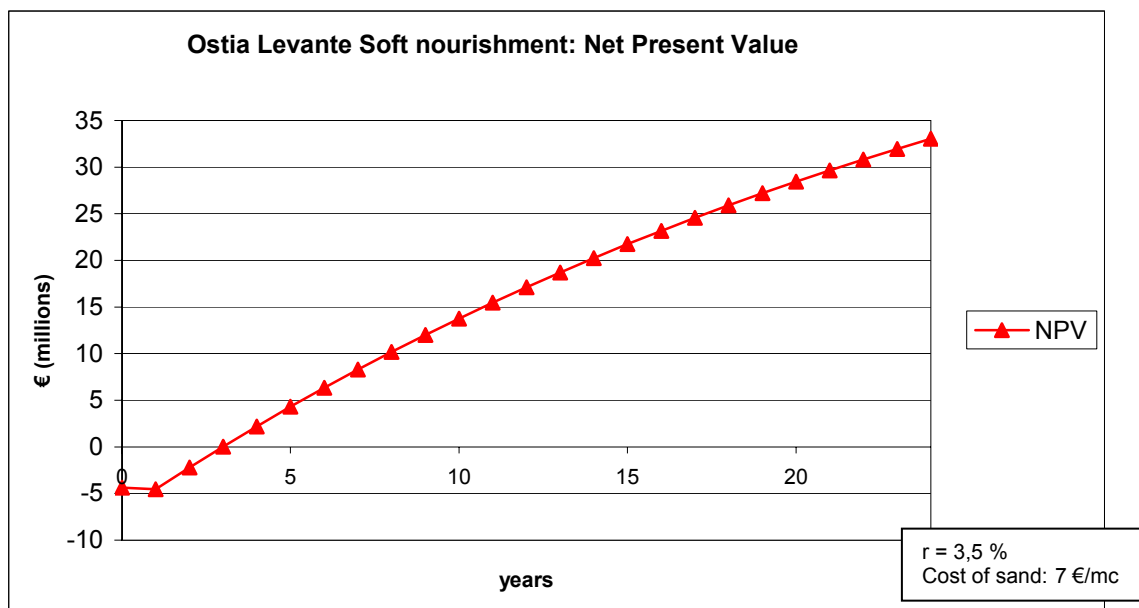


Fig. 2

The following tables and graphs show the sensitivity analysis made in respect of the capitalisation rate and of the sand cost:

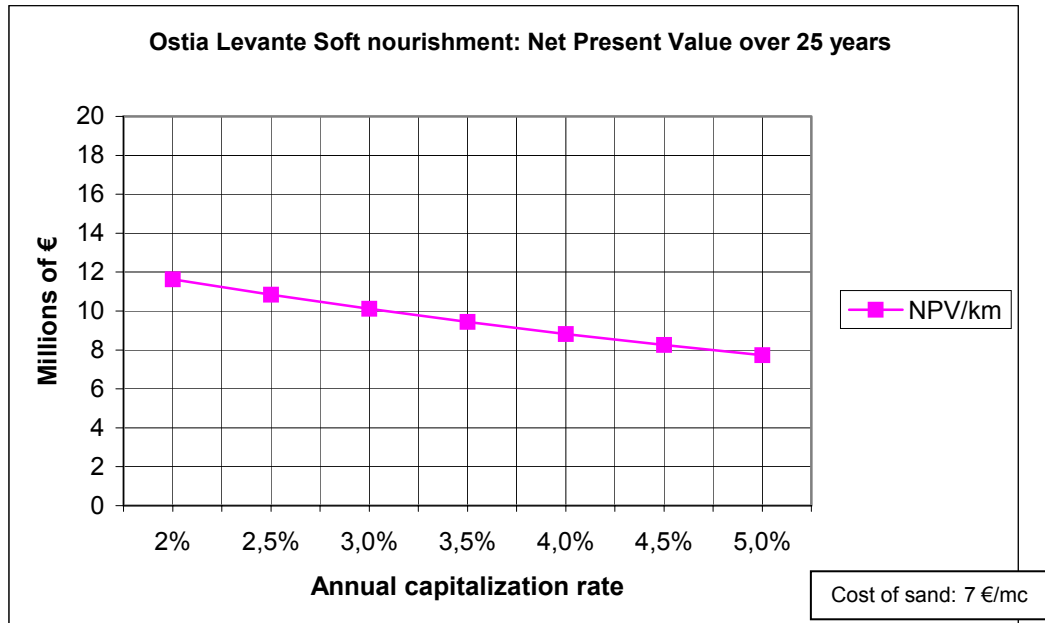


Fig. 3

	Annual capitalisation rate	
	2%	5%
NPV (millions of €)	€ 40,70	€ 27,06
NPV/km (millions of €)	€ 11,62	€ 7,73
NPV/mq (€)	€ 262,09	€ 174,24

Tab. 4

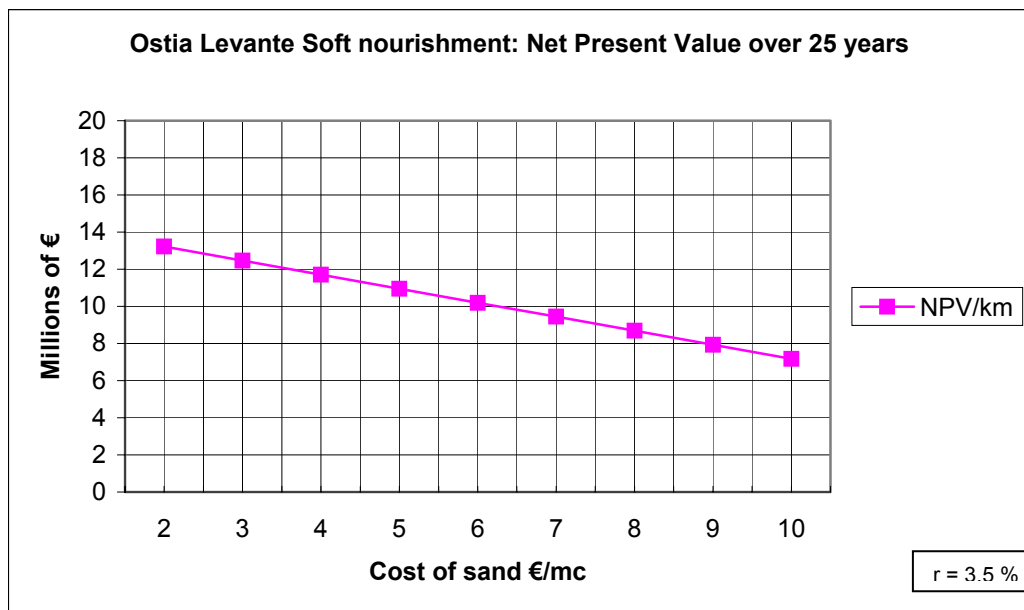


Fig. 4

	Cost of sand (€/m ³)	
	2	10
NPV (millions of €)	€ 46,30	€ 25,09
NPV/km (millions of €)	€ 13,23	€ 7,17
NPV/mq (€)	€ 298,16	€ 161,56

Tab. 5

As said above, the studies before the intervention showed that, keeping the sand cost under 7,50 €/m³, the soft nourishment is preferred, on the basis of the NPV calculation, over the nourishment interventions protected by hard structures (seawalls, groynes etc.).

Test case n. 2: Beach drainage (nourishment according to BMS) - Procida (Italy)

General description

Ciraccio and Ciracciello beaches, in the isle of Procida, have been the application sites of a beach drainage intervention made in 2002. They are sandy beaches, used for bathing tourism, not very extensive, and hardly suffering from erosive phenomena. The intervention choice (the first experience of BMS use for an island in the Mediterranean Sea) has been imposed by the desire of Procida Municipality to avoid the use of severe protection works.

The intervention has been carried out by placing 4 sections (one at Ciraccio beach and the others at Ciracciello beach), each of them provided with two pipe-drain parallel lines in the beach front, a little collecting well for the drained waters and a lifting pump for the discharge: two little wells release the water into the sea and another two, linked to each other, send out the water into Chiaiolella port, so facilitating the port's oxygenation.

In total, the intervention involved **1km** of coast, for a drain length of 850 m and a cost of about **1.000.000 €**, a sum inclusive of studies, planning, patent rights, and installation (included material and labour).

In June 2003, a year after the intervention, a survey was made of the shore-line that, compared with a similar investigation carried out before the intervention, revealed a moderate advancement of the beach of **8,11 m**. The beach surface increase was accompanied by a thicker layer of sand, estimated at **7987,30 m³**

The economic value

The most important economic activity in Procida is fishing. Because of the proximity of the island to Naples, many Procida inhabitants work in Naples and travel daily. The second economic activity is tourism, dependent on the delightful beaches of the island.

As already mentioned, the beaches are small: to estimate their economic value, one may refer to the study made of Italian beaches (Nomisma, "*La valutazione economica delle località balneari*", 2005) divided into dimensional classes of beach surfaces given by the National Authority.

That study assigns an annual turnover of 34,29 €/m² to the small beaches, solely from beach activities. The research has been carried out by examining central Italian bathing places. Another research, undertaken by the Italian Bathing Syndicate (*Rapporto sulle imprese balneari*, 2002), reveals that the average turnover of a southern Italian company is well below, at about 66% of the average turnover of a central Italian similar company. On the basis of such considerations, it is reasonable to use an annual turnover value of up to **22,64 €/m²** for Ciraccio and Ciracciello beaches.

Cost-benefit analysis

The beach drainage intervention requires very cheap maintenance costs, basically linked to the control system and to the work of checking and cleaning the draining pipe-lines: such costs can be estimated at just 6200 €/year.

Thus, regarding the 25 years of the investment temporal horizon, it is possible to obtain the internal costs shown in the table 6.

As regards the benefits, considering only the economic value, the annual turnover of the beach activities has been used, calculated at **8100 m²** (beach enlargement produced by BMS), assuming that only 60% of the shore on average is given consideration.

The obtained annual benefit (external benefit - social and economical) is constant and up to 107.908 €.

As a result, by applying the NPV formula, using an annual capitalization rate $r = 3,5\%$, the Net Present Benefit is positive and up to 716 thousands of Euro (B/C ratio = 1,67), with a unitary value up to 88,30 € for each m² of beach enlargement.

Year	Internal costs €	
2002	1.000.000	Investment and engineering costs
2003	6.200	Maintenance costs
2004	6.200	“
2005	6.200	“
2006	6.200	“
2007	6.200	“
2008	6.200	“
2009	6.200	“
2010	6.200	“
2011	6.200	“
2012	6.200	“
2013	6.200	“
2014	6.200	“
2015	6.200	“
2016	6.200	“
2017	6.200	“
2018	6.200	“
2019	6.200	“
2020	6.200	“
2021	6.200	“
2022	6.200	“
2023	6.200	“
2024	6.200	“
2025	6.200	“
2026	6.200	“

Tab. 6

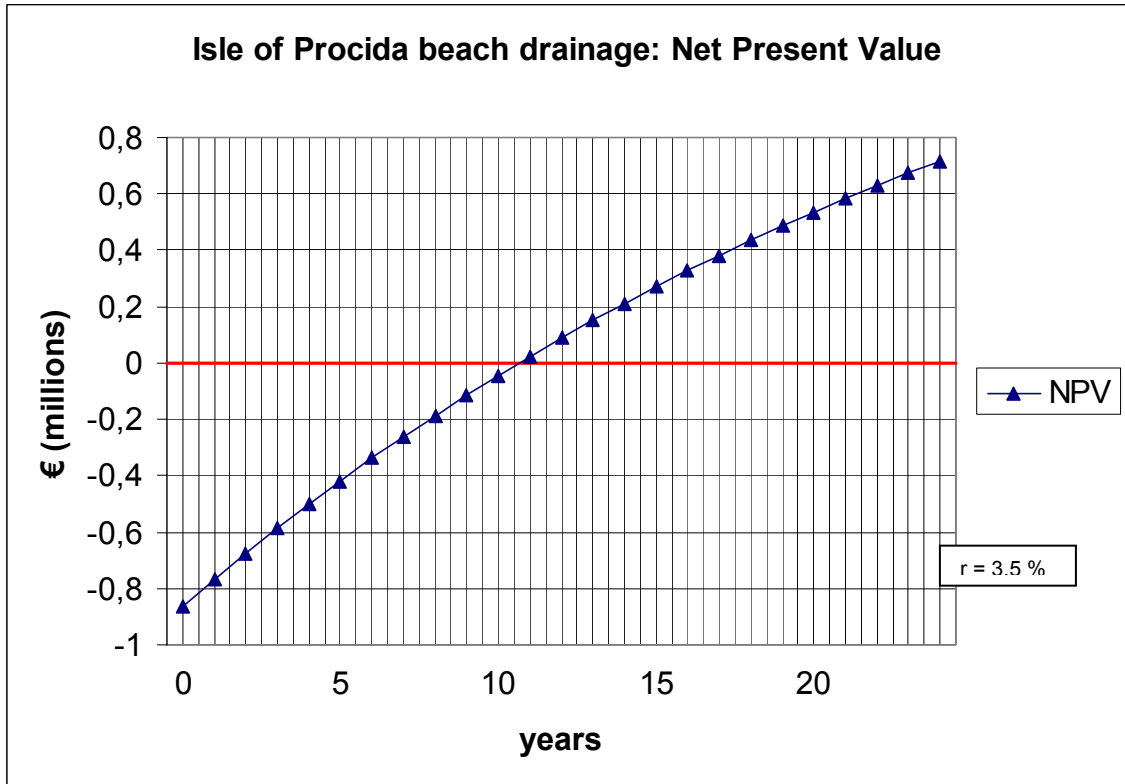


Fig. 5

The following graph and table show the sensitivity analysis, made in respect of the annual capitalisation rate:

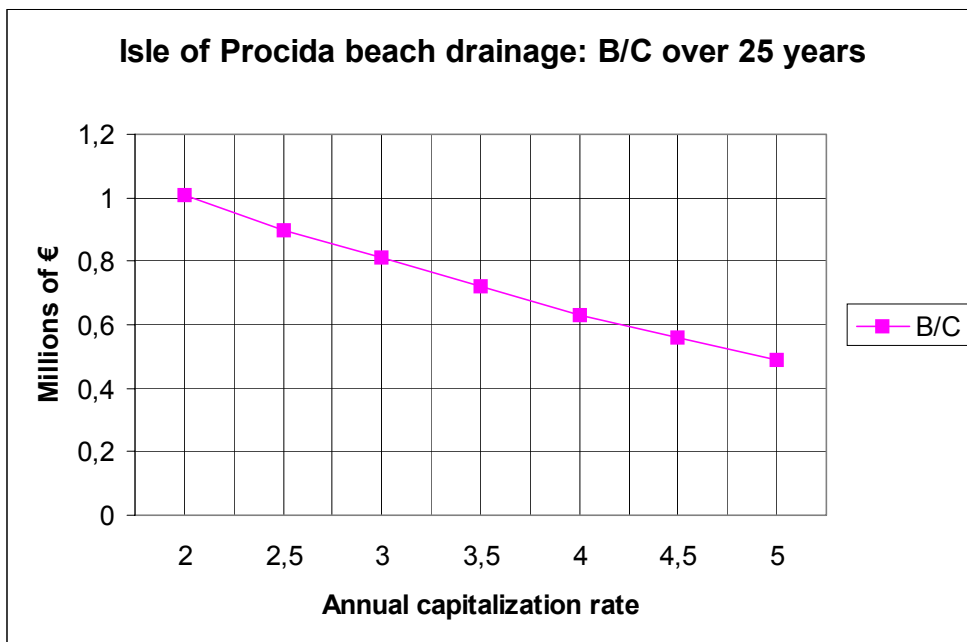


Fig. 6

	Annual capitalisation rate	
	2%	5%
NPV (millions of €)	€ 1,01	€ 0,49
NPV/km (millions of €)	€ 1,01	€ 0,49
NPV/mq (€)	€ 124,71	€ 60,05

Tab. 7

It is interesting to compare the BMS intervention to a pure nourishment one, aimed at producing the same result (7987 m³ more of sand). As the shoreline evolution is not known in quantitative terms, it is only possible to form the “extreme” hypothesis of a yearly total re-nourishment.

In respect of the BMS intervention, of course, only the costs differ, as they are strongly linked to the sand import cost and to the availability of a suitable submarine sediment extraction area, not too far from Procida.

The simulation shows that, by considering the influence of the engineering costs, the nourishment yearly carried out gives a net benefit higher than the BMS solution, as long as the sand cost is kept under of 6,00 €/m³. This is not realistically achievable in Italy; it corresponds to a distance from the sand extraction area of about 10 km (Mondini F., De Girolamo P., Contini P., Mino A. – *Analisi dei costi di coltivazione delle cave sottomarine di sabbia per i ripascimenti* – Giornate Italiane di Ingegneria Costiera).

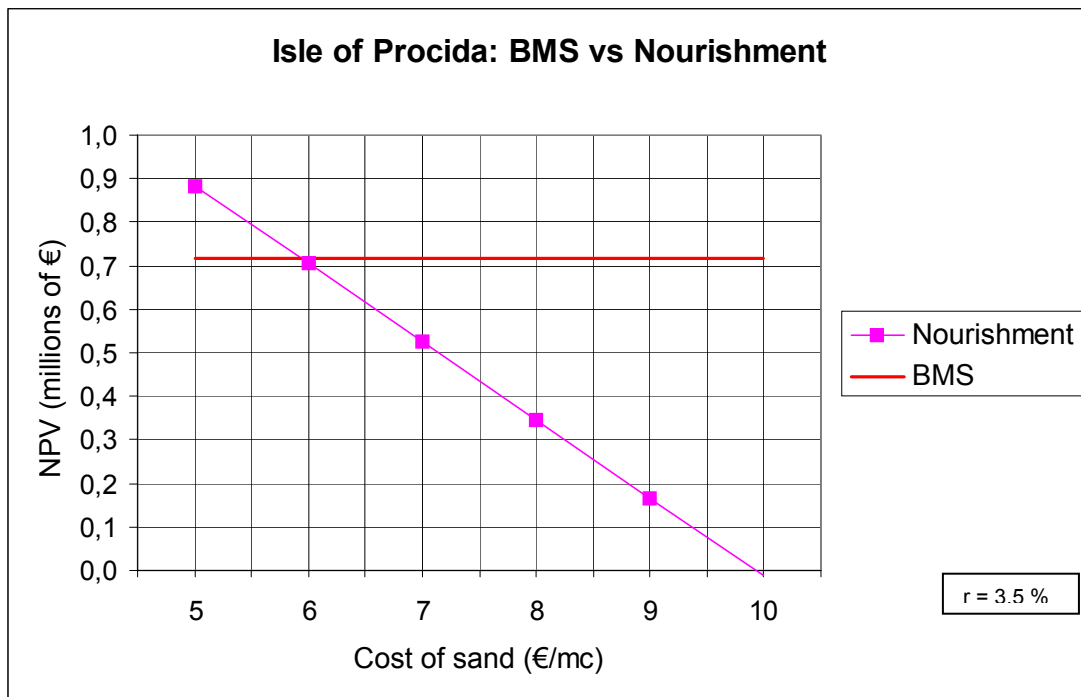


Fig. 7

Summary table

Test case	Ostia Levante (Italy)	Procida (Italy)
Beach typology	sandy beach	sandy beach
Defence technique	nourishment	Beach drainage (nourishment according to BMS)
Year of the intervention	1999	2002
Length of the intervention	3,5 km	1 km
Shoreline progress (average)	44 m	8 m
Investment and engineering costs	7.643.562 €	1.000.000 €
Maintenance and monitoring costs (yearly)	553.700 €	6.200 €
Type of benefit	External benefits: economic value	External benefits: economic value
Benefit value indicator	annual turnover from beach activities: 25,20 €/m ²	annual turnover from beach activities: 22,64 €/m ²
Net Present Value (over 25 years with r = 3,5%)	33 millions of Euro	0,716 millions of Euro
Net Present Value/km	9,4 millions of Euro	0,716 millions of Euro
Net Present Value/m²	212,75 €	88,30 €

Tab. 8

Test case n. 3: Protected Nourishment (submerged breakwaters) – Isle of Ischia - Maronti Beach, Italy.

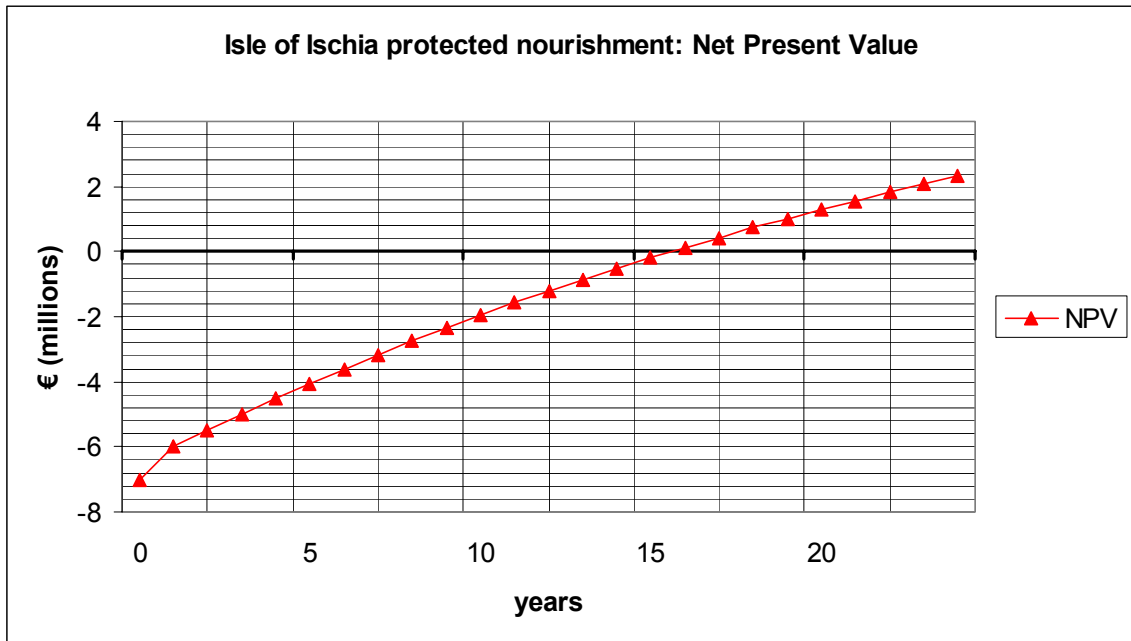


Fig. 8

Cost-Benefit Analysis

Project life (years)	25
Length (km)	2,0
Shoreline increase (m)	37
Volumetric increase (m ³)	445.000
Interest rate (%)	3,5
Initial Costs (€)	8.236.636
Annual Maintenance costs (€)	414.666
TOTAL ANNUAL BENEFITS (€)	
• Annual turnover from beach services	984.614
NET BENEFITS (€)	1.836.152
BENEFIT TO COST RATIO	1,16

Tab. 9

Test case n. 4: Soft Nourishment– Asbury Park to Manasquan Beach- New Jersey, U.S.A..

Existing problems

- Long-term erosion: 2.0 feet per year (average value of 1953-1987)
- Storm damage: 1962 storm →22,4 million \$; 1984 →2,6 million \$

Project Objectives

- Reduce the threat of potential future damage from storms, with an emphasis on wave attack and recession.
- Mitigate the effect of, or prevent, long term erosion.
- Enhance the recreation potential of the area.

Cost-benefit analysis of alternative solutions:

“The final solution must fulfill the three objectives at the most economical cost”

No Action	<i>fails to meet any of the objectives</i>
Buy-out Plan	<i>prohibitive costs</i>
Beach restoration	
Groynes	<i>no storm protection and further erosion of the near Sections</i>
Groynes with beach restoration	<i>high annualised initial costs</i>
Seawalls	<i>increase erosion of the near Sections</i>
Seawalls with beach restoration	<i>not supported by the State</i>
Revetments	<i>not supported by the State</i>
Revetments and beach restoration	<i>not supported by the State</i>
Breakwaters	<i>increase erosion of the near Sections</i>
Breakwaters with beach restoration	<i>very expensive and significant hazard to boating activity</i>
Perched beach with beach restoration	<i>technical infeasibility and high cost</i>

Tab. 10 – Alternative solutions and related evaluation

Cost-benefit analysis of the proposed solution

Project life (years)	50
----------------------	----

Interest rate (%)	8,5
Initial Costs (\$)	47.325.000
Annual Renourishment costs (\$)	3.233.000
Local cost (\$)	2.907.000
TOTAL ANNUAL COSTS (\$)	8.492.000
TOTAL ANNUAL BENEFITS (\$)	11.878.000
<ul style="list-style-type: none"> • damage prevention accomplishment • maintenance and enhancement of recreational opportunities 	
NET BENEFITS (\$)	3.386.000
BENEFIT TO COST RATIO	1,4

Tab. 11

Bradley Beach vs. Miami Beach

The Asbury Park to Manasquan Beach project can be compared with the famous nourishment of Miami Beach, often cited as the model to follow because of the enormous economic benefits which resulted. In order to do this, we focus on Bradley Beach, one of the four Municipalities involved.

The following table summarises the costs in both cases. Obviously, the cost of the Miami Beach nourishment has been converted from 1980 value to actual value in order to compare it with the Bradley Beach one.

		MIAMI BEACH	BRADLEY BEACH
Length	miles	10,5	1,0
Cost	\$	137.600.000	6.360.384
Sand replenished	yd ³	16.000.000	1.462.000
Shoreline increase	ft	300	100
Cost per mile	\$	13.104.762	6.360.384
Cost per cubic yard	\$	8,60	4,35
Cost per foot	\$	458.667	63.604
<i>Benefit to cost ratio</i>		1,4	500

Tab. 12

Unit costs paid by Miami beach are much higher, but the benefit to cost ratio, conversely, shows that the Miami Beach project realised enormous benefits compared to Bradley Beach.

Moreover, the value 1,4 refers to four towns, not only to Bradley Beach. Avon-by-the-Sea and Ocean Grove, for example, traditionally attract many more holiday-makers and have more restaurants and expensive private homes located close to the ocean.

We can reasonably state, therefore, that regarding Bradley Beach Municipality benefits are less than costs.

Some reasons for such failure are summarised in the table below, which show how some aspects constitute benefits for Miami Beach and not for Bradley Beach.

Bradley Beach	<i>Miami Beach</i>
The greenish tint of the sand is not aesthetically pleasing	Miami Beach was fortunate to dredge much whiter sand
Small population and a low per-capita income: Bradley Beach will suffer from an increase in property taxes	Having a larger population to distribute the burden is beneficial
Fishermen used to fish from the jetties: now they are situated only 30 yds from the beach	Fishermen in Florida more commonly prefer deep-sea fishing
Visitors to Bradley Beach arrive at weekends or make day trips, for 3 months/year only	Tourists from U.S. and foreign Countries alike vacation in Miami year-round and stay for longer periods
The additional area is not wide enough for entertainment events (100 ft)	The additional area (300 ft), with especially hard-packed sand, allows musical concerts and entertainment events
Smaller benefit from storm protection (fewer storms and low-value infrastructure)	Greater benefit from storm protection (frequent storms and high-value infrastructure)

Tab. 13

Test case n. 5: Artificial reef creation – Narrowneck – Gold Coast, Australia

General description

The Narrowneck reef is located on the Gold Coast, Australia, where there have been erosion problems for years. In the past, natural processes used sand from the beach to create protective sandbars offshore, but development has flattened the dunes and vegetation and consequently reduced the ability of nature to curb erosion. It was decided that an artificial reef could use nature to solve nature's problems, whilst providing amenity benefits to surfers and tourists.

The reef is the first of its kind in the world. It consists of 350 heavy geotextile sand bags and is situated about 500 feet offshore, with a northern section providing a right wave-break and a southern section a shorter left wave-break.

The sections are made out of three layers of geotextile bags, filling an area of 1,150 feet by 2,000 feet and ranging from 3 to 33 feet in depth.

Marine life is already well established on the reef and was said to have rapidly acclimatised.

There are no negative down-coast impacts, although there has been some concern about the quality of the surfing waves. The inside parts of the reef are working well even on small swells, but the outside two-thirds are still too deep and only work when waves are above six or seven foot.

Cost-benefit analysis

The reef cost \$1.5 million; however, it is estimated that just one surfing competition on the reef will bring \$2.2 million in to the Gold Coast economy.

The beach opposite the reef has been significantly widened, creating additional public open space and providing effective coastal protection.

Replenishment was carried out before the reef was built: as a result the reef has sunk lower than expected and the quality of the surfing waves has been affected.

The project is expected to generate 60 times more benefits (in terms of cost savings and direct revenues) than costs, which is a high rate.

The benefits would be derived through direct tourism revenue (\$1.6 million in taxes per annum) and savings from not having to repair beach erosion.

The Narrowneck reef has been awarded a Queensland environmental award which entailed evaluation in 17 categories including: Environmental Management, Environmental Impact, Project Management and Construction Practice.

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