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"Coastal erosion – Evaluation of the need for action"
Directorate General Environment
European Commission

Living with coastal erosion in Europe: Sediment and Space for Sustainability

Guidelines for incorporating cost benefit analysis into the implementation of shoreline management measures

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National Institute for Coastal and Marine Management of the Netherlands (RIKZ)
EUCC – The Coastal Union
IGN France International
Autonomous University of Barcelona (UAB)
French Geological Survey (BRGM)
French Institute of Environment (IFEN)
EADS Systems & Defence Electronics

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1. INTRODUCTION

1.1 Scope

The information reported in this document has been gathered in the framework of the EUROSION project (service contract B4-3301/2001/329175/MAR/B3: "Coastal erosion – Evaluation of the need for action"). EUROSION is a two-year study undertaken commissioned by the Directorate General Environment of European Commission upon the request of the European Parliament.
The aim of EUROSION was precisely to provide quantified evidence that coastal erosion in Europe is a problem of growing magnitude and that the current efforts undertaken by public authorities does not succeed in containing. This study also aimed at formulating a set of proposals to better mainstream coastal erosion in the future at the European, national, regional and local levels.

Over the past 50 years, the population living in European coastal municipalities has more than doubled to reach 70 millions inhabitants in 2001 and the total value of economical assets located within 500 meters from the coastline has decupled to reach in 2000 an estimated 300 billions Euros. A significant part of these assets is nowadays challenged by coastal erosion, which each year, devours 15 km^2 of coastal lands and undermines the defence of another 1000 km2 against coastal flooding. Within the period 1999-2002, between 250 and 300 houses had to be abandoned in Europe as a result of imminent coastal erosion risk and another 3,000 houses saw their market value decrease of at least 10%. But these losses are nothing compared to the value of assets including industrial facilities, agricultural lands, recreational areas and natural habitats – at risk of coastal flooding.

The EUROSION policy recommendations relate to several aspect to be taken into account when investments in the coastal zone are considered; 1) the importance of sound knowledge on coastal dynamics; 2) the incorporation of existing costs and risks in the planning development and investing decisions; 3) make shoreline management accountable; 4) strengthen the knowledge base of coastal erosion management and planning.

From recommendation 2 and 4 follows that the **impact, cost and risk** of human induced coastal erosion should be controlled through a better internalisation of coastal erosion concerns in planning and investment decisions.
EUROSION has made three guidelines for a better implementation of the recommendations:

- The integration of coastal erosion concerns within **Environmental Assessment** (both EIA and SEA), see part 5 of the Eurosion reports,
- Hazards should be monitored and mapped, evaluated and incorporated into planning and investment policies in a **Hazard Assessment** what is part 7 of the Eurosion reports,
- **Cost benefit analysis** (this report) of shoreline management measures provides the basis for making technical solutions viable financially and bankable. When rigorously conducted and adopting a broad time horizon (e.g. 50 years) and spatial scale (the sediment cell), such analysis also helps identify external environmental costs which in turn may provide further incentives to prefer managed realignment or simply "doing nothing" instead of erosion control measures.

This document aims at describing steps and guidelines in the assessment of the costs and benefits when projects or investments related to coastal defence are to be decided. The cost benefit analyses has to inform and guide involved stakeholders in the process of shoreline management measures and includes non-material costs and benefits, a so-called Societal Cost Benefit Analysis. Societal Costs Benefit Analysis is an evaluation method in which an as much as possible quantified overview is provided from the societal monetary (expressed in money) and non- monetary (not expressed or expressible in money) costs and positive and negative effects (benefits) on a longer period regarding various (alternative) measures. Shoreline management measures can be built for two reasons: a.) a defence work for an area at risk of erosion or flooding and b.) a mitigation measure for adverse effects of erosion from another project in the coastal zone, like a harbour extension seaward.
Shoreline management measures are measures which defence the coast from erosion. A distinction is generally made between hard techniques, which rely on heavy and non-easily removable materials (such as concrete or rock armoured structures) and soft techniques, which build upon sand and natural processes, like beach nourishments, cliff toe protection or dune regeneration. An overview of coastal defence measures is given in Appendix A.

1.2 Use of the guidelines

The guidance is designed principally for use by competent authorities, developers and CBA practitioners in the coastal zone in the European Union Member States and Accession Countries, see Box 1-1. When investments are made, normally a cost-benefit analysis is made by the main investor, in the case of investments in coastal defences works this analysis mostly has a wide societal context. Regarding coastal defence measures in Europe almost all capital works undertaken by national, regional, or local authorities are effectively funded out of general taxation.
This guide sets out the principles that could be used in undertaking economic appraisals for such funded projects for coastal protection and other related purposes. It is hoped that it will also be of interest to academics and other organisations who participate in CBA training and education and to practitioners from around the world.

Box 1-1 Users of the Guidelines

Competent Authorities

- Competent authorities may be involved in CBA either as participants in a CBA process or in response to a request for a CBA opinion from a developer. Their role may be to actually undertake the CBA and issue the CBA to the developer or to comment on and agree a CBA Report prepared by the developer.
- The competent authority may undertake CBA on its own or an independent body such as a financial advisory board may advise it.

Developers and EIA Teams

- Like competent authorities, developers are involved in CBA either as part of their development process and/or as a mandatory EIA process. In this role they may either prepare a draft CBA Report for comment by the competent authority and consultees or they may just provide information to the competent authority for the authority to carry out CBA.
- However, good practice also requires that CBA should be an integral part of any EIA. Developers and their EIA Teams should undertake CBA at an early stage to ensure that the environmental studies address all the relevant issues, irrespective of any legal requirement to undertake CBA.

Consultants

- When CBA is carried out by a developer or a CBA Team, either under a legally established system or as part of good practice in CBA, environmental authorities and other interested parties and the public should also be consulted. The value of public participation in the CBA process is increasingly being recognised by competent authorities and other participants in the CBA process within Member States. Early consultation with interested parties can be very valuable in avoiding later delays if new issues emerge from consultation only after the EIS is submitted.
- When an EIA is required, the EIA Directive requires competent authorities to seek advice from relevant environmental authorities prior to giving a CBA Opinion. In many cases other interested parties and the general public are also given an opportunity to comment. Consultants will therefore be involved in commenting on issues to be addressed in CBA.

These guidelines are organized as follows:

- Chapter 1 provides an introduction to the use of a cost-benefit analyses and how these guidelines get connected to it,
- Chapter 2 provides an overview of the implementation of the analyses and some technical information of the principles of costs and benefits,
- Chapter 3 reviews the costs for a project investment in the coastal zone,
- Chapter 4 reviews the benefits of a project investment in the coastal zone and the value scaping of the environmental area of the project.
- Chapter 5 provides a short review of using the hazard mapping and benefits-value-mapping for a Risk Assessment.

2. IMPLEMENTATION OF COST BENEFIT ANALYSES (CBA)

2.1 Phases in a CBA for a coastal project

In the introduction towards a planning investment in the coastal zone and the actual cost-benefit analyses for the project, four phases can be distinguished. These phases are visualised in Figure 2-1and the distinct coloured phases are explained below.

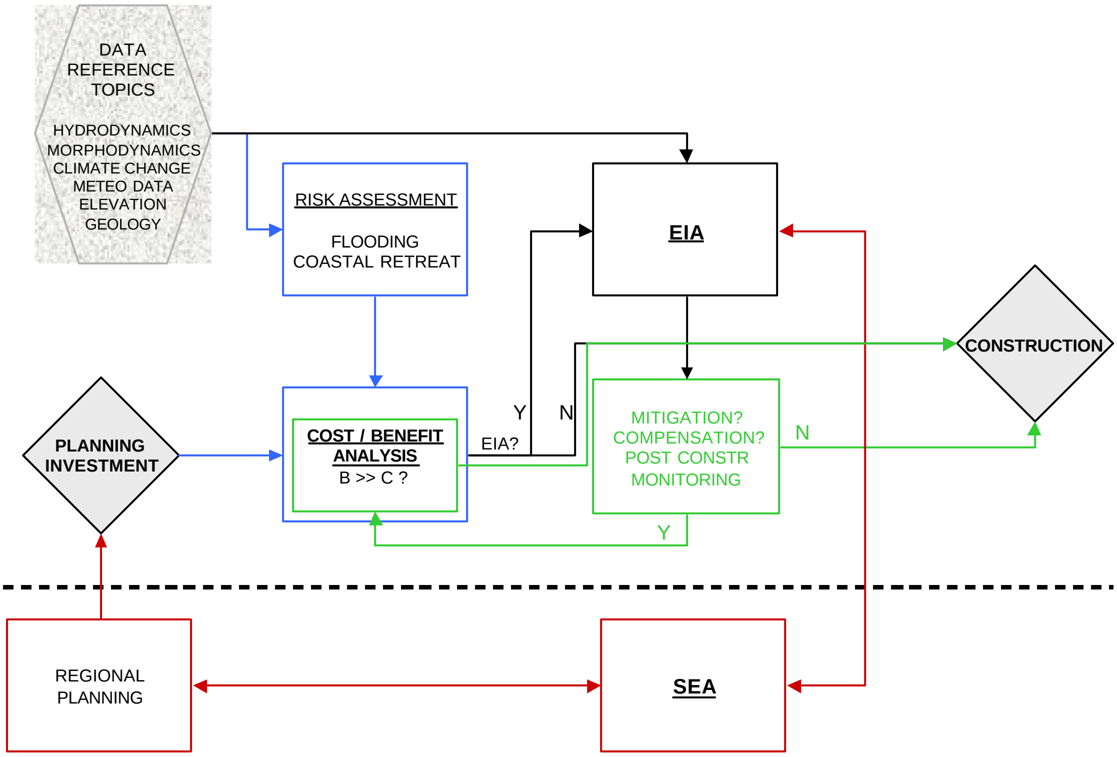


Figure 2-1. Overview of phases in project investment in relation to Planning, Hazard Assessment, CBA and EIA. Different phases in the process have different colours.

Step 1: Planning phase

The planning phase of a coastal project starts with a check of the regional planning. Measures to protect coastal areas can enforce or oppose existing and formulated policy on spatial development, nature and culture. Involving plans are for example Strategic Plans and Shoreline Management Plans.

The area to be protected can have tourism as main priority in existing policy plans. Coastal defence focusing at beach maintenance enforce this policy in such context. When the measures result in the loss of important ecologically designated areas, the responsible actors are legally obliged to compensate this through new nature compensation.

Strategic Environmental Assessment (SEA) procedures are also starting in the planning phase. Before acquiring the permits to develop the project the competent authority should have to check the integration into SEA.

Step 2: Technical design phase

This is the pure technical design related cost benefit analyse for the developer of the project. In the design phase the developer checks if the project is not in area at risk of flooding or acute erosion in a time span of about 10-50 years. Data required for this information is coming from the Hazard Assessment. In this first stage of development of the project, the developer or competent authority check if the benefits of the project are much higher than the costs, otherwise the development can be stopped in this phase, because an eventually EIA requirement brings extra costs with it.

Step 3: Phase of EIA

If, according to the size and impact of the project, an EIA is legally required, an Environmental Impact Study has to be implemented. Large size projects, such as harbour extension (e.g. Maasvlakte in

Holland coast, Aveiro in Portugal), land reclamation for creating wind parks (e.g. Wadden sea and Schleswig Holstein), or energy production plant (e.g. Paluel and Penly in Normandy) do address coastal erosion processes with the framework of their EIA. However, it is quite common that the cost of mitigation measures exceed the willingness - or the capacity - of the project developer to pay for it. This is best illustrated by the case of Aveiro where the cost of annual sand by-passing (5 millions euros) has been deemed excessive by the harbour authorities.
To determine these extremes **information** is needed regarding the **effects** per measure and the **risks** to which the measures will be subject. This list (database with information on separate measures) reflects information about costs, changes in sediment budgets, change in surface natural area, local extreme water levels etc. but the validity of the spatial boundaries (coastal cell?) within each situation needs to be established.
Taking into account that for measures separately these impacts are hard to estimate, the determination of the effects of combinations of measures the spatial impact on the existing situation is even more difficult. Therefore the "system boundaries" needs to be established under the lead of a panel of experts and the project team. This system boundaries need to support the information provision on both the **effects of** and the **risks to** which the measures will be subject

EUROSION proposes to execute these analyses at the level of the sediment cell
A good understanding of coastal sediment transport processes within the "sediment cell" the eroding area belongs to. A coastal sediment cell can be defined as a length of coastline and associated near-shore areas where movement of sediments is largely self-contained. In practice, this means that measures taken within a specific sediment cell may have an impact of other sections of the same sediment cell but will not significantly impact adjacent cells. This understanding may help reject some technical options and assess the impact of suitable options down-drift.

Step 4: Mitigation phase
From the EIS follows the requirement of mitigation and compensation measures to be taken to counteract the impact on physical and environmental processes. The execution of these measures brings again costs and maybe also benefits with them. Then a feedback has to be made to the original technical cost-benefit analyses. If the benefits are, after implementation of the mitigation and compensation measures in the project, still higher than the costs, the project can be constructed.

EUROSION Experience has shown that, at the present time, there is no miracle solution to counteract the adverse effects of coastal erosion, since any solution operates on the effect of erosion (e.g. coastline retreat, beach width) and not on its drivers. Best results have been achieved by combining different types of coastal defence including hard and soft solutions, taking advantage of their respective benefits though mitigating their respective drawbacks.

2.2 Net present benefits

The goal of a coastal defence work is of course the protection of a part of the coastline against erosion or flooding. The value of the area that has to be protected for loss, must be higher than the costs for a coastal defence work, otherwise it is not worthwhile to protect. The costs in a cost-benefit analysis for a coastal defence work are relatively easy to define, as they are the costs for construction, monitoring and mitigation. The benefits for a defence work are in fact the risk of loss due to erosion or flooding that is taken away for an area. The benefits become more clearly in figure 2-2. The first figure 1a is the situation at time zero. A valuable area (like a city or a natural area) is situated on a coastline, which is subjected to erosion due to wave processes and a net longshore drift of sediment to the east. In figure 1b the area at risk for a time span of 50 years is hatched. So when nothing is done, the valuable area will be partly lost. Therefore, a seawall is built to avoid this loss of the area. In figure 2a the situation is sketched of the impact of a seawall to the area updrift. In 50 years the coastline will draw back as predicted in 1b, but the erosion is stopped behind the seawall and increased in updrift direction of the seawall. The benefits of this seawall are now the value of the protected area minus the area that is extra lost due to the seawall in updrift direction.

In an equation form this will be (see Figure 2-2-2b):

$$\mathbf{T = (P - A_e) - C}$$

Whereby: T = Net present benefits in *t* years (here: 50 years)
P = Positive benefits of protected area
A_e = Negative benefits of area *extra* at risk
C = Costs

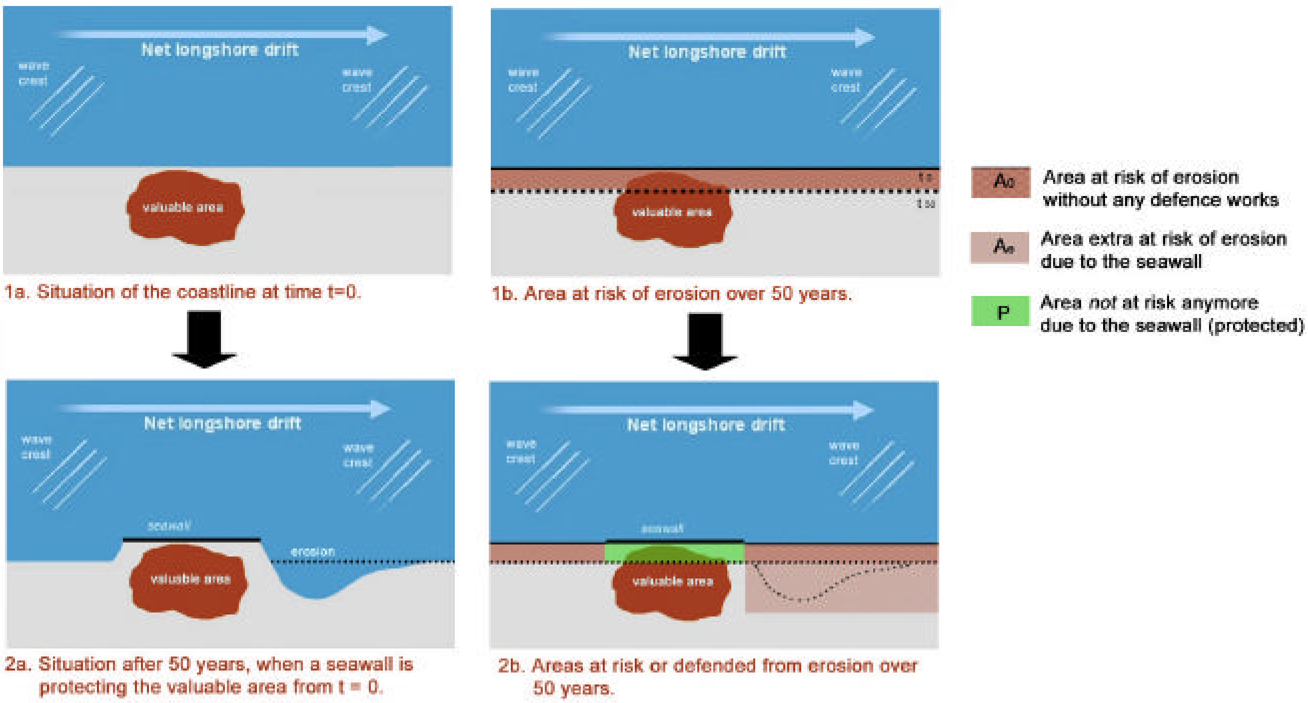


Figure 2-2.

A visualisation of the costs and benefits in time can be seen in figure 2-2. The costs of design and construction of the project are high in the first three years and after that the remaining costs are for maintenance, monitoring and possible compensation measures. The benefits are gradual increasing in time (not necessarily in a continue increase) and at one point in time the benefits become higher than the costs. Over a longer period the benefits become constant, dependent of the economical growth.

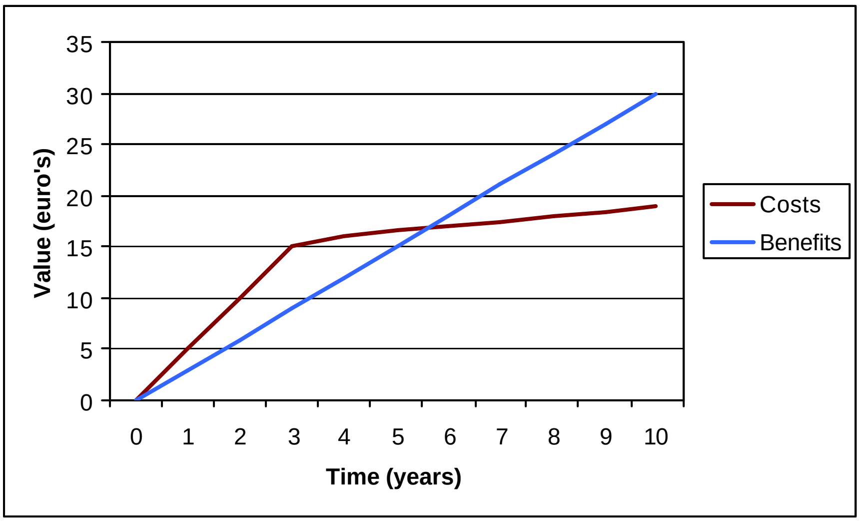


Figure 2-3. Development of costs and benefits for a project in a time span of 10 years.

Not all work is done simultaneously, but in different phases. Good phasing of execution becomes more important as knowledge is progressing during work execution. Uncertainties become clearer, this should be taken into account during selection of alternatives.
Coastal erosion measures are aimed to ensure the sustainable fulfilment of certain functions within or provided by the coastal zone. The lifetime expected of the measure is an important element in the cost benefit analysis. When different alternatives are to be weighed the time horizon should be the same.
When rigorously conducted and adopting a broad time horizon (e.g. 50 years) and a given spatial scale (the sediment cell), such analysis also helps to identify the internal and external costs.

3. COST ANALYSIS

In Europe, the cost of coastal erosion risk is mainly supported by the community and hardly by the owners of assets at risk or the party responsible for coastal erosion. This was observed within the majority of EUROSION technical case studies and the policy analysis. This is emphasized by the fact that coastal erosion Risk assessment is largely not included at level of local decision-making processes and Risk information to the public remains poor. The costs for a coastal defence work should be recovered from the causer of the erosion although most of the time it is not easy to define the exact cause of the erosion.

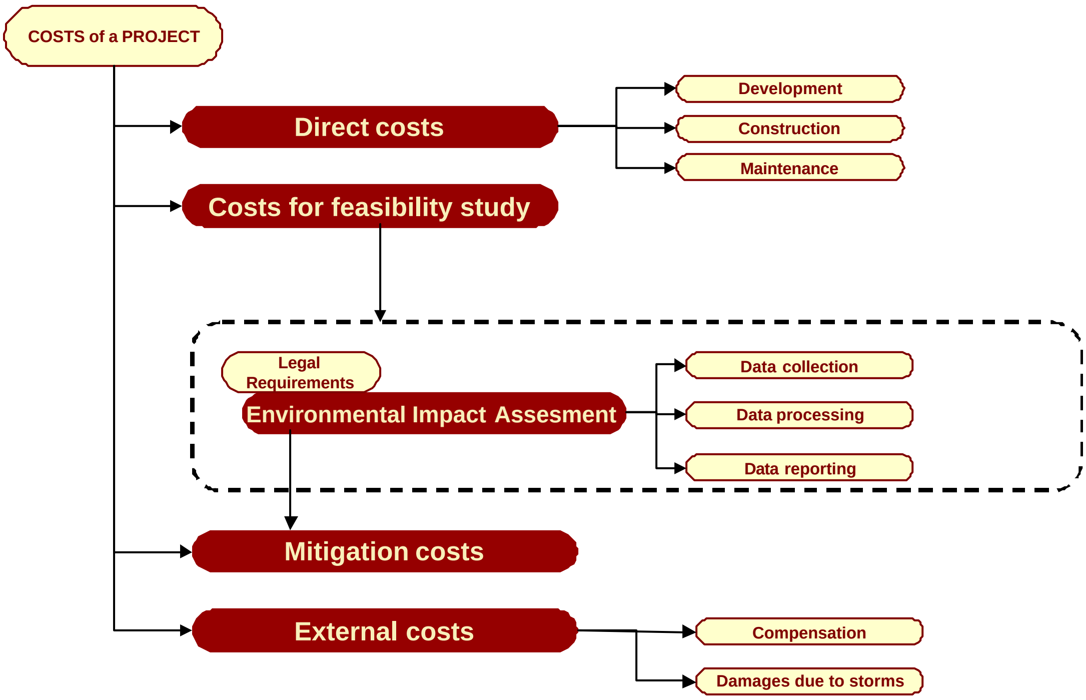


Figure 3-1. Overview of the types of costs for a project in the coastal zone.

A cost analyse for a project exist in fact of two decision steps, as can be seen in Figure 2-1. The first step is the practical project phase for the developer in terms of technical design, construction and maintenance costs and the opposite benefits are the economical benefits for the original goal of the project by the developer. The second step follows from the Environmental Impact Study (if legally necessary) and contains the costs for data requirements for the EIS and the EIS itself and from what follows the mitigation costs and compensation costs. An overview of these costs can be seen in Figure 3-1 and are further described below.

3.1 Direct costs

Several EUROSION case studies provided examples that the costs of coastal defence are quite significant. They range from a few thousands euros for localised protection through wooden pile breakwaters or geotextiles – such as along Estela beach (20,000 Euros) – to several of millions euros – for complete reshaping of the beach by combination of sand nourishment, rock armoured breakwaters, and design studies - such in Playa Gross (11 millions Euros). To these costs must be added maintenance and monitoring cost and, in the case of beach nourishment, the cost for repeating nourishment actions regularly.

<u>Project development costs</u>
These can be very significant and may include (depending on the project type/technology involved):

- Technical, legal and planning consultants' fees, and developer's own time, in negotiations with legal and statutory bodies (for example in obtaining planning permission and consulting the Environment Agency),
- Requirement of information from Hazard Assessment,

- Financing and legal costs, including the costs of arranging finance,
- Costs of licenses (for example, if imported food processing residues are used, a Waste Management License will be required, which will involve an initial charge and an annual fee).

Capital costs for construction
This is the main expense for most projects. It includes the costs associated with actually purchasing and installing the project hardware.

Operation and maintenance costs
The running costs vary enormously for different technologies and projects depending on variations in design and operating circumstances. Running costs will include:

- General maintenance and operating costs, of equipment, site, etc.
- Staff costs
- Insurance and administrative costs
- Transport costs
- Annual fees for licenses and pollution control measures

Training is an often forgotten or ignored part of the overall project cost. The people who run the project, of whatever size and technology, need to be fully trained in the safety, financial and environmental implications of the project. These skills will need to be updated as technology and knowledge develops.

3.2 Costs for feasibility study (if necessary)

If the project will have its effect on coastal processes above a certain threshold value, an Environmental Impact Assessment (EIA) is required. Within an EIA three implementation steps can be distinguished:

Data collection for the implementation of the study. Data requirements are for example:

- Near-shore bathymetry
- Terrestrial elevation
- Cross-shore profiles
- Coastline geomorphology and geology
- Sediment transport
- Near-shore wave regime
- Near-shore currents
- Tidal regime

Data processing trough the use of appropriate models to quantify the project effects on the shoreline stability. Costs are for the utilisation of the models and the engineers staff costs.

Data reporting is the writing and publishing of the final Environmental Impact Study. Also costs for Strategic Environmental Assessment (SEA) is included here. SEA will contribute to more transparent planning by involving the public and by integrating environmental considerations.

Detailed information is given in the *Guidelines for incorporating coastal erosion issues into Environmental Assessment (EA) procedures*, from the EUROSION project.

3.3 Mitigation costs

Following from the results of the EIA, mitigation measures have to be executed where the protection work tends to increase erosion in the updrift direction. This can be:

Primary mitigation measures. These are particular arrangements, which may be integrated directly in the project design the limit as much as possible the modification of the features, which are directly responsible for coastal erosion (the *pressure factors*). In that sense, these primary mitigation measures aim at preventing human induced coastal erosion to occur instead of combating it. These measures are expressed in different project alternatives related to financially cheapest alternative or environmental most friendly one. In order to 'weight' the different options of a project and provide objective comparison a kind of neutral reference situation is needed. The reference situation refers to a "business as usual" scenario, or a so-called *'status quo'* alternative**.** This has not to be confused with the "doing nothing" alternative. The CBA is comparing the differences of specific promising measures (alternatives) with the 'status quo' alternative, what provides an overview of the costs and benefits of all options. This can be extremes related to finances (cheapest), environmental extremes (less harm to nature) or space (quality of spatial environment) or a certain sector (maximum harbour extension). A specific item to take into account is the avoided costs, which would occur when the project is cancelled and the 'status quo' alternative takes place.

Additional mitigation measures. Unlike primary mitigation measures, additional mitigation measures are not meant to limit the factors responsible for coastal erosion, but to counteract their effects locally (i.e. coastal erosion). They should be considered only in those cases where primary mitigation measures fail to avoid coastal erosion. For a coastal defence work this will mainly be soft techniques, which build upon sand and natural processes, like beach nourishments.

The costs of mitigation actions
In 2001, public expenditures dedicated to coastline protection against the risk of erosion and flooding have reached an estimated 3,2 billions Euros compared to 2,5 billions in 1986 (+28%). With the current trends, the cost of coastal erosion mitigation measures would reach 4,3 billions Euros in 2020 and the extent of coastline protected by coastal defence would exceed 10,000 kilometres.
However, these expenditures mainly reflect the needs to protect assets at imminent risk of coastal erosion, and do not reflect the hidden costs induced by human activities on the long term.

The cost of habitat losses
It is highly predictable that in case of accelerated coastal erosion, fragile habitats not initially exposed to coastal erosion would disappear first and together with them, the societal, economical and ecological functions there are fulfilling now or may have fulfilled in the future. In that respect, a significant part of coastal dunes and wetlands would have irreversibly disappeared by 2100, which would generate in turn a deficit of several millions cubic meters of fresh water per year within coastal plains induced by salt water intrusion, a higher exposure to coastal flooding not necessarily compensated by coastal protection, and an increased eutrophication of coastal waters as the absorption capacities of salt marshes and mudflats decrease. Depletion of dunes, beaches and wetlands would also progressively deprive fauna species from appropriate sites dedicated to nesting and hatching, with long term unpredictable consequences for the ecological chain.

The cost of inappropriate measures
Finally, inappropriate measures to mitigate coastal erosion have also lead to significant losses as they have exacerbated coastal erosion processes at other locations or have generated new environmental problems.

3.4 External costs

During and after the project implementation monitoring of the impacts of the project is necessary. Although a good EIA is executed and mitigation measures are made, unpredicted impacts on the environment can occur. Therefore a good monitoring program should be included in the costs for a project. The impacts, which are monitored can be, as said before, not predicted and are external or unforeseen costs. In Europe, these costs are mainly supported by the community and hardly by the beneficiary of the project or the owners of assets at risk. EUROSION proposes that in the future the responsible beneficiary or developer contribute proportionally for environmental impacts due to their project.

Emergency damages due to storms can also be seen as external costs.

4. BENEFIT ANALYSIS

The benefits of a shoreline management measure are the value of the area that is defended from erosion.
are sometimes hard to predict, because not all benefits can be expressed in a direct economic value, as the produce of a fish catch or the turnover of a beach pavilion.
Economic value is determined by individual preferences and, where there is a market in the good or service in question, can generally be taken as the market price, at least as a first approximation. Many goods and services, however, have no market price, either because they are provided 'freely' by the state, such as defence, law enforcement and street lighting, or are otherwise freely available to all, such as a panoramic view or access to a beach. However, such goods still have an economic value. In the appraisal of flood and coastal defence schemes it is the valuation of environmental or recreational assets for which there is no readily available market price that is likely to prove problematic. On top of the economic value deriving from the direct use of an un-priced asset, such as a beach, there are other components of economic value, which might arise in some cases. These are:

• a ***functional value***, where an asset serves a number of functions and yields benefits other than those deriving from its direct use by 'consumers'; for example, where wetlands provide the functions of flood storage and wastewater treatment in addition to other use values, such as for recreation;

• an ***option value*** given to maintaining the option of being able to use the asset in the future, although it is not currently used; for example, a young but currently childless couple may have no interest in visiting the beach, and hence no use value for it, but may place an option value on it because of the possibility that they would wish to use it in the future should they have a family;

• an ***existence*** (often termed a 'non-use' or 'passive use') value representing a value which people attach to the continued existence of an asset for the benefit of current or future generations, even though they make no direct use of it themselves. If people derive some benefit from the knowledge that the beach is there and available for the enjoyment of others now or in the future, then this represents an existence value placed on that asset. Care always needs to be taken to avoid double counting by estimating total economic value in one way and then adding on some components, which have already been implicitly included within the calculation.

The most important values of the coastal zone to consider are the economic and functional value of a coastal area. The benefits of a natural coastal environment and the interaction with human activities can be categorised into four environmental functions:

<u>Regulation function</u>. This group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential physical and ecological processes and life support systems that, in turn, contributes to the maintenance of a healthy environment by providing clean air, water and soil and a protection of the hinterland from erosion and flooding.

<u>Ecological function</u>. A coastal ecosystem must have the capacity to maintain a certain biological balance through biological control of biotic processes. There are an almost infinite number of interactions between the species within food chains and food webs, whereby the ecosystem is the habitat of a diversity of flora and fauna species.

<u>Economical function</u>. Natural and semi-natural ecosystems provide space and a suitable substrate or medium for many human activities such as habitation, cultivation and recreation. Nature also provides many resources, ranging from food and raw material for industrial use to energy resources and genetic material. The economical function includes thus a carrier function for human activities and a production function for resources.

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

An overview of the four environmental functions of a coastal ecosystem can be seen in Figure 4-1.

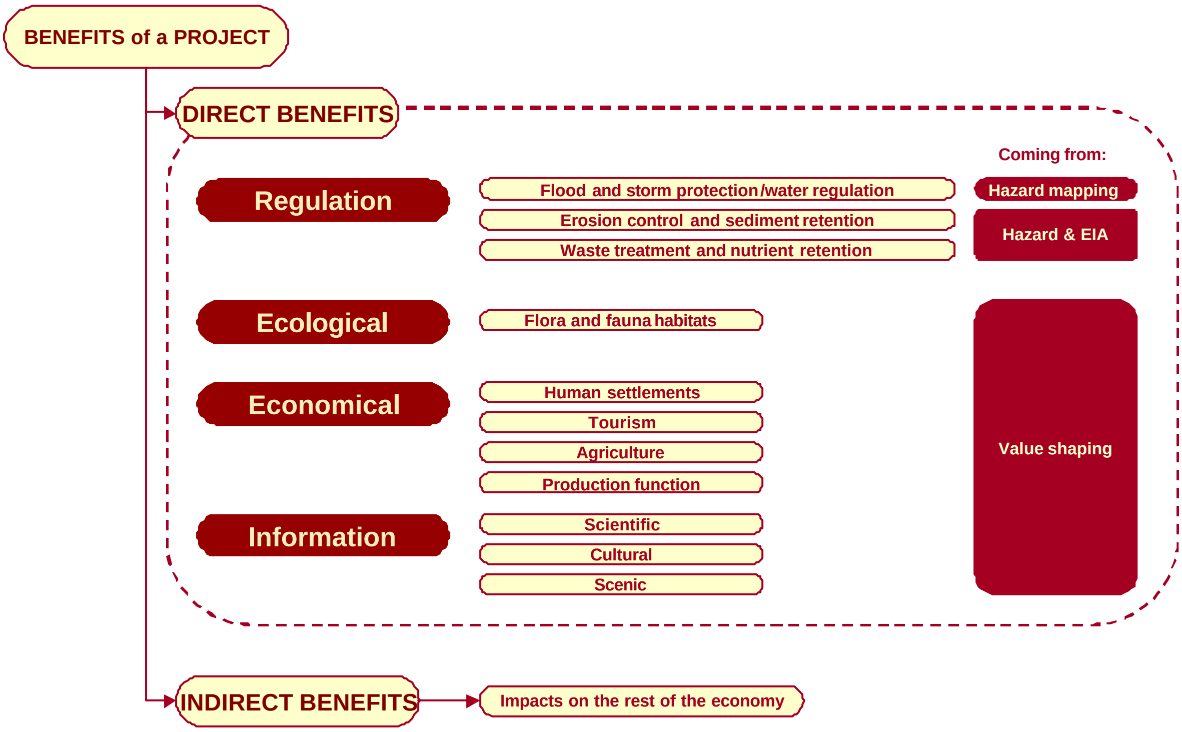


Figure 4-1. Overview of the benefits of a project in a coastal ecosystem, defined as four environmental functions.

Almost 30 % of the European coastline is subject to erosion due to climate change, with its effect on sea level rise and higher storm intensities, and the impact of human activities in the coastal zone. This implicates that the **regulation function** of the coastal zones for erosion and sedimentation processes is lacking. Coastal defence measures have to avoid the loss of coastal areas to the sea. The value of the coastal area whereby the regulation function is lacking can be expressed in terms of the **ecological**, **economical** and **information functions** of that area.

The present assets (ecological, economical and information) and their value to be considered in the cost benefit analysis depend on the outcome of the **hazard mapping** exercise, in which the potential areas of investment subject to erosion and/or flooding are defined and classified.
In order to know what assets are at risk differentiation between population, economy, ecology and cultural aspects are made to come to quantitative (and comparable) valuation at local level. Combining valuation and exposure to hazards provides **Risk mapping.**

The second step is the determination of the influence of the investment on present coastal dynamics, especially the ecological valuable areas. This is done in the environmental impact assessment (EIA) in which the potential areas of investment causing or contributing to erosion and/or flooding are defined and classified. The outcome of the **Hazard mapping** exercise **and** the **EIA exercise** provide essential and necessary input for the total CBA. Data requirements for the Hazard mapping, EIA study and this cost benefit analyses are coming from the **Information Database**. In the table with data requirements for each criterion, the acquisition of the topic refers to this database.

The combination of maps to come to a total **'value map'** would require a detailed combination of the different ecological, economical and information value present in the concerned coastal area. This could be done through a raster map in which each of the cells contains a kind of "scoring" information about the valuated assets. This results in a so-called multi criteria analyses what is visualised in Figure 4-2. Valuating the different functions of a coastal area is described in the next chapters.

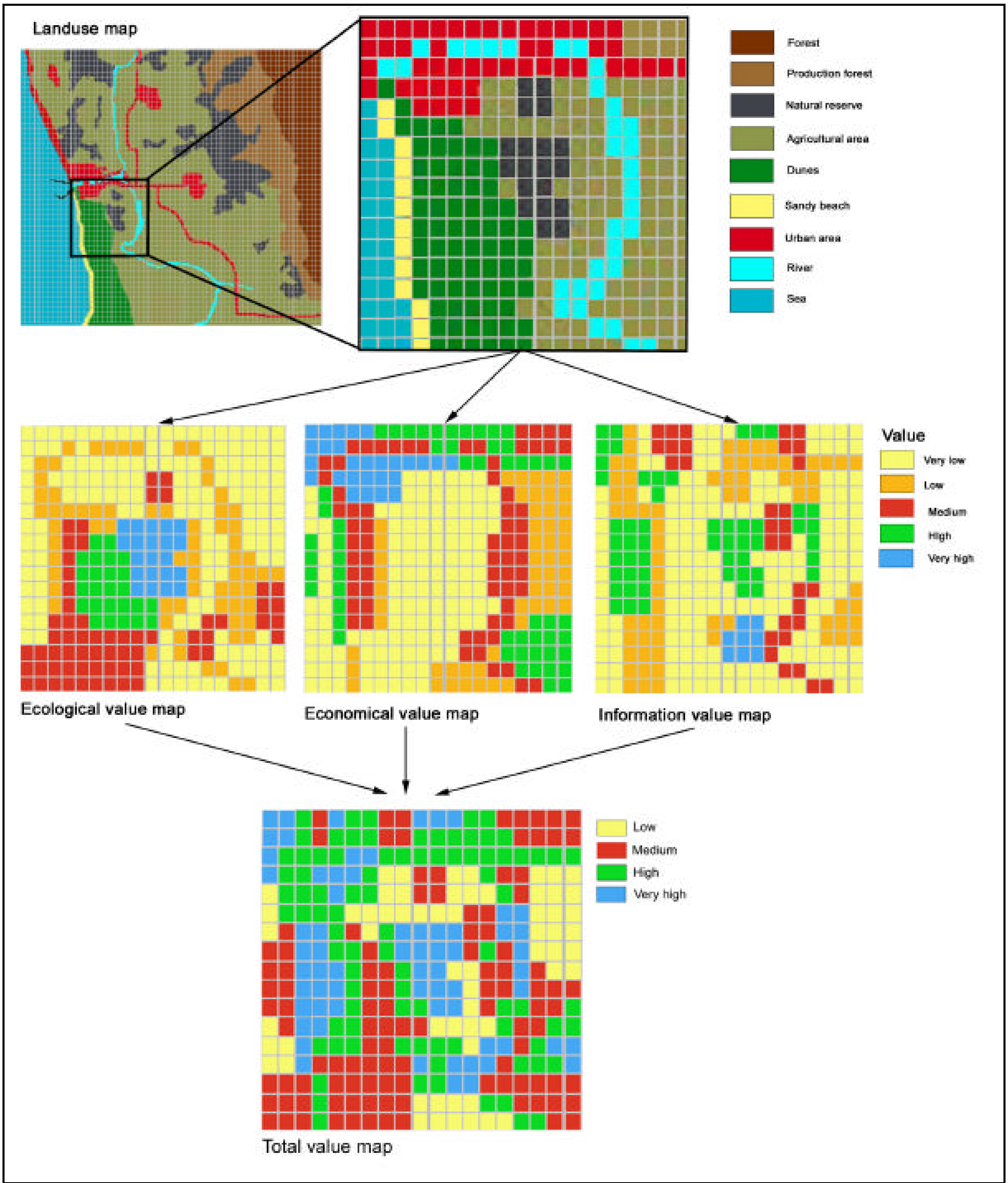
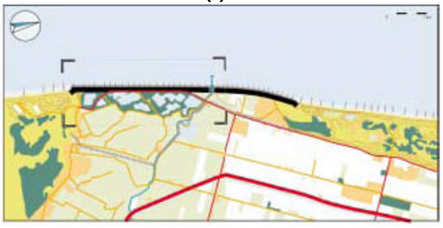
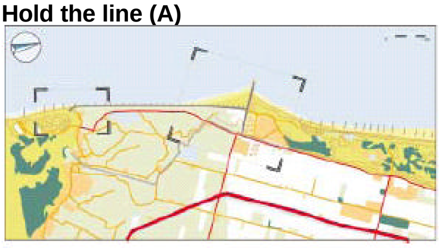


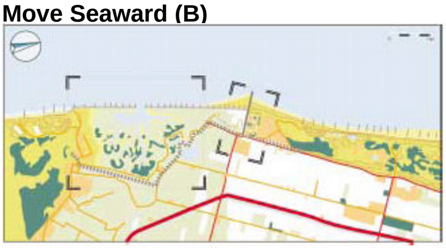
Figure 4-2. Method of value shaping of the different functions of an area by means of raster-data. Following from the rasterized landuse map, the area is valuated for the functions *Ecology*, *Economy* and *Information*. These three maps together (summed values) give the Total Value Map, which forms the total benefits of the coastal area.

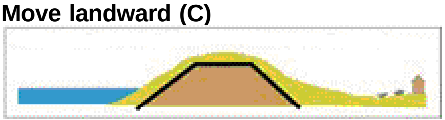
Example Cost-Benefit Analysis: Hondsbossche Sea Dike in the Netherlands

Current Situation (i)


Hold the line (A)


Move Seaward (B)


Move landward (C)


Drive: sandy variations (multifunctional)

The old Hondsbossche Sea Dike or "Hondsbossche zeewering" (1880, length: 5 km) shows currently several problems amongst which sea level rise, increasing erosion, instability and inflexibility (compared to a sandy coastline retreat) and consequently it sticks out by approximately 200m.

3 types of possible solutions are proposed, summarised by hold the line (A), move seaward (B) and move landward (C). Before deciding on measures a balanced cost-benefit analysis has to be made where all interests have to be incorporated. In (A) the current policy will be continued (maintenance with nourishments), in (B) the dike will be dismantled and a dune area will be raised. This alternative is primarily focused at recreational purposes. In (C), the dike will be dismantled without replacing it, an alternative for more ecological value. This example focuses more on the **benefits** of the different options and gives some illustrative approaches. The **costs** can be assessed in the more traditional way:

Costs \ Option	Hold the line (A)	Seaward (B)	Landward (C)
Investment (M €)	137,5	227,4	4,5
Maintenance (M € / 30yr)	20,7	4,0	144,5

The process of qualifying and quantifying the benefits of these separate options was done following a certain method where the distinction was made between three different aspects: (1) Money (economical); (2) Green (Ecological); and (3) Feeling (socio-cultural), after which an integrated approach was made to prioritise the different judgement criteria.

Part of: Benefit Assessment **"Money"**:

Type of benefit	Effect	Assessment method
Returns agriculture	Push out production Change productivity	Market values
Safety perception	Change perception	Contingent Valuation Method
Recreation	Change number of tourists Change perception	Travel cost approach
Fresh water storage / extraction	Production	Market prices
Fishery benefits	Creation breeding ground	Production function method
Economical activity	Mitigated flood damage	Risk assessment
Property value	Change house prices Change number of houses	Hedonic prices Market value

Part of: Benefit Assessment **"Green"**:
Ecological benefits are quantified and assessed according to the envisaged changing aspects of ecological diversity. The table below shows a *relative* scoring which may give an indication of different political visions on nature.

Score \ Option	Hold the line (A)	Seaward (B)	Landward (C)
Ecosystem diversity	0,12	0,31	0,46
Species diversity	0,21	0,21	0,22
Natural quality	0,16	0,50	0,73

Part of: Benefit Assessment **"Feeling"**:
The researcher involved in the *ex ante* assessment of socio / cultural benefits of certain management options may follow the following steps: (1) Reviewing of existing literature regarding comparable cases; (2) Examination of existing maps on the different reference topics and gathers information on notes, municipal guides and internet sites; (3) Makes an inventory of different stakeholders and their interests; (4) Consults one or more boards of stakeholders for advise on the necessary steps towards decision, supported by expert opinions; and (5) Bundles the obtained information and requests additional research on sensitive topics.

Focus on the latter two:
A simple method to quantify feeling is to let the stakeholders give a score of 100 to their main project goal, and percentages of 100 to other project goals, this to make the differences between stakeholders transparent: In the table below for 2 groups (G1 and G2):

Project goals	Most preferable outcome	Least preferable outcome	Rough weights	
			G1	G2
Preserving safety culture	Responsibility government	Appear to be left to nature	100	100
Increase tourism	Unique identity	No distinction with others	60	60
Increase amenity	Keeping polders	Removing polders	60	30
"Authentic" nature	Recovery sea inlet	No sea inlet	0	60
Limiting lasting congestion	No intensive constructions	Intensive constructions	20	20
Keeping flexibility	Lasting options	No options	20	20

The next step is to score the project goals relative to the 3 different management options by the groups, e.g. from 0 to 1. Multiplying the two scorings a weighed total score can be achieved.

The final step involves an **integrated assessment** of the three aspects on the three management options to get a complete overview of the project. This is essential for both the presentation and communication towards stakeholders and local citizens. Also, this overview is needed to give the decision – and policy makers some grip to balance the respective management options between the aspects of Money, Green and Feeling (Source: Baten van Water, zoute case studies, 2002 – in Dutch).

4.1 Regulation function

Flood and storm protection and water regulation

Benefits of a coastal defence work, cliff or a dune system against flooding can be measured as the difference between damages without and damages with the (natural) prevention measures. Valuation of this function is in fact the risk mapping of the area that is protected from flooding by the beach, dunes or cliffs. Information needs to determine the benefits of a coastal protection work or natural defence system are then:

- the analysis of the history of natural flooding to determine the probability of re-occurrence;
- the history of damages in terms of economic losses traceable to natural flooding to determine the estimated probable value of damages;
- the assessment of the present condition/situation of the areas under study to determine their percentage of vulnerability to flooding, the so-called **flood-hazard-mapping**;
- an estimate of the existing **ecological value** of coastal areas in order to estimate the environmental losses. This is done in chapter 4.2.
- an estimate of the existing **economical value** of investments/facilities in the sectors industry, housing & infrastructure, tourism and agriculture in order to determine the economic losses in the hinterland. This is done in chapter 4.3.
- an estimate of the **information value** of a coastal area what is done in chapter 4.4.

Hazard mapping is done in a Hazard Assessment (see Figure 2-1). Data requirements for a Hazard Assessment are:

- Predictions of climate change parameters effective at the coastal zone, which include data of sea level rise and increased storm frequency and wave heights,
- Terrestrial data what includes bathymetry of the nearshore and terrestrial elevation of the coastal zone, existing of beach, cliffs, dunes and the hinterland.

The method for estimating losses in existing human investments or natural areas is explained in chapter 4.2 and 4.3.

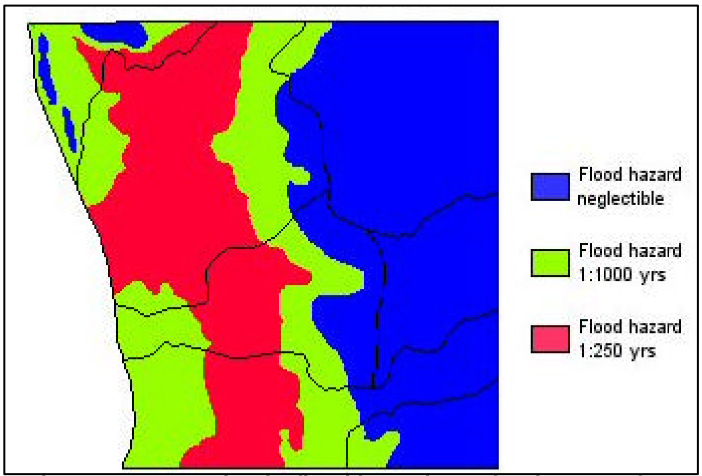


Figure 4-3. Example of a flood hazard map for the area of figure 4-2.

Erosion control and sediment retention

Similar to the flood prevention function, the economic value of protective coastal areas can be deduced from the amount of money that would be needed to protect the backshore and the coast from *chronic* erosion through coastal defence works. Data requirement from hazard mapping what should be used here is the map of mean erosion trends. An example of an erosion hazard map is given in figure 4-4. Valuating this function of the coastal zone can only be done when the whole sediment cell is valuated, because the sediment cell are zones where movement of sediments is largely self-contained, with areas of sediment sources and sinks.

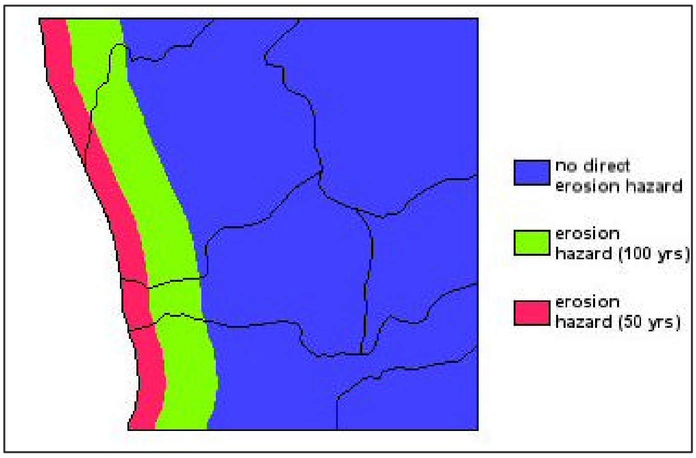


Figure 4-4. Example of an erosion hazard map for the area of Figure 4-2.

Information about erosion control and sediment retention is coming from an Environmental Impact Study and from the Hazard Assessment. A fully overview of the European coastlines are the maps of the CORINE Coastal Erosion-layer with trends up to 1990, updated in the EUROSION GIS-Database.

<u>Waste treatment and nutrient retention</u>
Coastal ecosystems receive large amounts of various kinds of human waste, such as oil, heavy materials, pesticides and PCB's. This waste is mainly produced outside the coastal area and enters it by means of rivers, sewage systems and air currents. To a certain extent, aquatic ecosystems are able to reduce the concentration of some of these elements to levels below which no permanent ecological damage occurs. For example, the concentration of dissolved metals can be reduces by means of co-agulation with hydrated iron- and magnesium oxides and clay-minerals in the sediment.

Due to industrial fertilizer production and use of these nutrients, in the form of nitrogen and phosphates, for agricultural soils, a large amount of these nutrients ends up in rivers and is transported to the sea. Tidal flats, salt marshes and estuaries have an important function in the removal and recycling of these inorganic nutrients. Tidal waters carry nutrients to the marsh surface where they diffuse through a thin layer of oxidized sediment to the anaerobic zone below and are removed from the water system.

The preventive nature of this function saves much money in the sense of non-inflicted damage that would result from polluted water for many sectors such as fishery, aquaculture and recreation. If the amount of removed polluted material by coastal ecosystems can be determined, then an estimation of the damage to the sectors can be calculated as a value shaping of the ecosystems. Especially tidal flats, (salt) marshes and estuaries have a high value shaping for waste treatment.

The *Averting Behaviour Method* can be a method for value shaping for the environmental qualities of an area. It is based on the assumption that people show averting behaviour with regard to a deteriorating environment. The money people spend to avoid pollution of the environment is a criteria for value shaping of a coastal area.

4.2 Ecological function

Important criteria that determine the conservation value of a given natural area are naturalness, uniqueness, species richness and diversity. The value of ecological important areas is (national or European designated areas) needs to be incorporated in the cost benefit analysis, both from a presence valuation, but also from a compensation obligation when measures are affecting certain designated areas. Areas designated from a legislative point of view can only be economically defined when the investment environmental impact has been defined, as here the costs for compensation will define the economical value.

The needed information to estimate the economical value of an area requires for:

- Naturalness: detailed information of the degree of human presence or impact, either in terms of physical, chemical or biological disturbance,
- Uniqueness: detailed information on the presence of ecological highly valuated areas, which are to be protected or compensated for in case of loss or damage induced by human activities,
- Species richness: detailed information on the population values in terms of quantity of birds is using the site for breeding or feeding purposes and the quantity of fish,
- Species diversity: detailed information on the occurrence of specific endangered species present in the ecological important areas has to be provided. The importance for special areas or habitats for coastal biodiversity should be mapped,
- Size of the area.

Economic valuation of a natural area is difficult, but some often-used methods are mentioned below:

- A mainly used criteria in ecological terms is the species diversity times the size of the area or the uniqueness of the area. The uniqueness of the area can be ordered with the environmental importance of the area at international, European, national and regional level:
  - UNESCO Biosphere Reserves
  - Wetlands of international importance (Ramsar convention)
  - Habitat Directive: Special areas of conservation
  - Bird Directive: special areas of protection of birds
  - National and regional parks
  - Nature reserves
  - Environmentally sensitive areas
  - National scenic areas

- A good indication of the socio-economic importance of an area is that part of the money donated to organisations that strive to conserve the natural area in its natural state, or the amount of daily visitors to the area.
- Another method to estimate economic values for ecosystems is the H*edonic Pricing Method*. It can estimate benefits associated with environmental quality (air pollution, water pollution and noise) and environmental amenities, such as aesthetic views or recreational use. The idea of the method is to estimate the value of preserving open space by looking at how the value of the average houses changes when the amount and quality of open space nearby changes.
- A last method that can be used is the *Contingent Valuation Method*. This is a survey-method whereby respondents are asked how much money they are willing to pay for the conservation of a coastal environmental area under hypothetically created market-circumstances.

Some global criteria for value shaping of the ecological function can be seen in the small ecological value map in Figure 4-2 and are for example:
- A sea and dune reserve have a high ecological value,
- A large natural reserve is more valuable than a smaller area,
- An natural area with endangered species is also valuable (like a Habitat Directive area),
- River banks with natural vegetation, wetlands and sand banks is more valuable than artificial river channels.

4.3 Economical functions

A global value scaping (and thus benefit rating) for the economical functions of a coastal ecosystem can be based on the land cover types of the CORINE database. Depending on the present land-use, the value of considered areas differ significantly.
Distinction is made from 44 land cover classes of the original categorisation into the valuation of the following 5 major land cover groups:
(i) urbanized areas,
(ii) agricultural areas,
(iii) natural and semi-natural areas,
(iv) wetlands, and
(v) water bodies.

The *land market value* is a financial aspect to be considered within the economical presence valuation. The needed information to estimate this is detailed, quantifiable information on present land market value based upon the location and facilities provided by the land and surroundings. This is related to land-use but is more refined, types of buildings, natural beauty etcetera.
The financial quantification of land-use types depends on the local values given to the different defined types distinguished. After determination of this by the competent authorities this can be quantified. Multiplying the calculated surface and types of land-use a quantity can be calculated, expressed in financial terms.
When combining the total financial presence valuated areas and the determined risk levels from the Hazard Assessment, the level of present finance at risk in the coastal zone can be established.

<u>Human settlements</u>
The most important item to be considered, not from an economical point of view, is the presence of population in the coastal area considered. Amounts of persons present (population at risk for flooding,

or trough retreating coastline) and the professional occupation of the population provide insight to the "value" and thus the benefits to be defended.

Correlating the numbers of present population with the urbanisation surface patterns (from e.g. CORINE layer i) allows the quantitative population assessment. The possibility of occurrence of flooding, undermining or other danger for the present population is provided through the Hazard Mapping component. The combination of these gives the most important indicator of the population at risk. This risk level is working in the same way for the other criteria.
Valuation of the urbanised area can be done through the prices or rental of houses and buildings.

<u>Secondary sector: agriculture, industry and infrastructure</u>
In order to assess the economical value in the considered area it is important to distinguish the presence value and the functionality value.
For the economical valuation of existing functions in the considered area an inventory needs to be made at the local level of the present companies. Main items reflecting the value of economical functions are:

- Name of the company and its economic activity
- Address for the coordinates on a map
- Initial capital
- Number of jobs
- Turnover
- Value of assets

These numbers can provide an overview of the value-importance of economic activity of a certain area. An example is given in Figure 4-5. A coastal strip of 5 by 10 km of the Holland coast is selected in an economical GIS-Database, with as a result the economical value of the companies operating in that area (see Table 4-1). With this data the benefits for protecting a coastal area are calculated. Extra benefits for different sectors due to a coastal project can be predicted. For example, when beach nourishment is done or a breakwater is constructed to enlarge the beach area, more people will come to that beach for recreation, what will probably increase the turnover over the beach pavilion.

For the functionality value the presence of infra-structural works (roads, tunnels, railways, high voltage lines, large jetties, large human constructions as harbours, airport and plants) and remarkable objects (e.g. lighthouse, geodetic benchmarks) are a main item. The financial quantification of infra-structural works depends on the local values given to the different defined assets distinguished (roads, houses, tunnels, etc.). Multiplying the surface and types of infra-structural assets provides a quantity present expressed in financial units at risk.

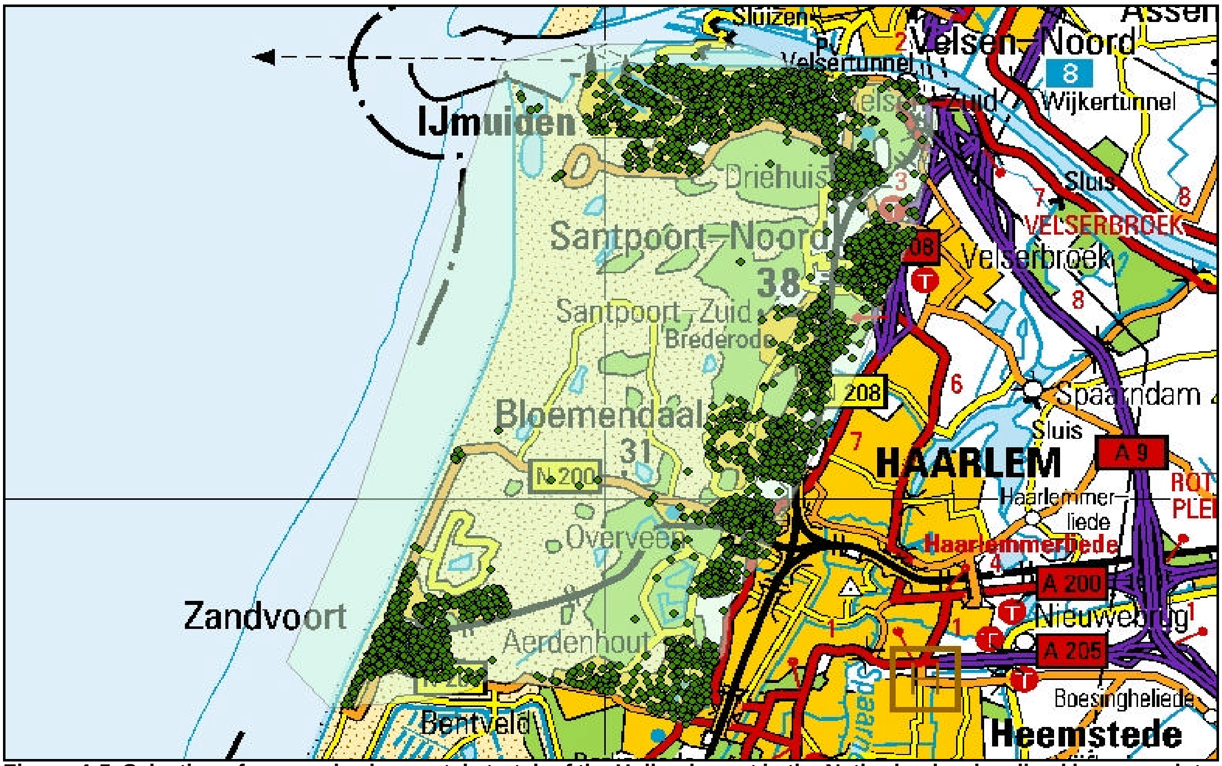


Figure 4-5. Selection of companies in coastal stretch of the Holland coast in the Netherlands, visualised by green dots (source CBS).

Number	Description of economic activity	Jobs (amount)	Production (*mln euro)	Added value (*mln euro)	Companies (numbers)
1	Agriculture, forestry and fishery	919	44	27	133
2	Mineral extraction	57	1	1	4
3	(Luxury) Food-industry	348	62	15	39
4	Textile and leather industry	56	12	3	23
5	Paper industry	6	1	0	1
6	Publishing and printer companies	136	30	11	40
7	Petroleum-industry	n.g.	n.g.	n.g.	n.g.
8	Chemical industry	66	6	2	7
9	Rubber- and synthetic industry	45	9	3	9
10	Basic metal industry	6	1	0	2
11	Metal products industry	461	54	23	42
12	Machine-industry	331	44	17	27
13	Electro-technical industry	127	13	5	13
14	Transport industry	164	12	4	17
15	Other industry	99	7	4	35
16	Energy - en Water Board companies	272	70	25	1
17	Conventional and utility construction	583	66	20	166
18	Soil-, water- en road construction	136	17	8	14
19	Other construction industry	657	44	20	168
20	Wholesale business	1687	141	81	490
21	Retail trade, auto trade and -repair	3108	113	69	789
22	Catering	1802	82	40	434
23	Transport over land	387	52	37	57
24	Transport over water and by air	322	50	22	21
25	Transport service	429	37	21	72
26	Post en telecommunication	386	46	29	22
27	Banks	875	36	22	454
28	Insurance business and pension funds	1	0	0	1
29	Financial assistance activities	179	17	12	94
30	Rental and trade in real estate	319	165	129	135
31	Commercial service sector	2660	269	137	975
32	Health- and welfare care	3251	110	83	369
33	Environmental service	22	7	3	4
34	Culture, sport and recreation	1033	82	37	264
35	Other goods and services	685	36	22	318
36	Government, defence en social insurance	1584	148	90	29
37	Subsidized education	2002	69	58	99
	TOTAL	**25201**	**1953**	**1080**	**5368**

Table 4-1. Description of activities and economical rates for companies in the selected green area from figure 4-5. (source: www.cbs.nl)

Tourism and recreation
An important sector in the coastal zone is tourism and recreation. In the summer time a lot of people spend their holiday along the coast or are daily visitors of the coast.
The economical value of this sector can be determined in the same way as described above with the economical GIS-Database. Activities what include this sector are hotels, bungalow-parks, camping-sites, catering, pavilions, sport- and leisure companies, local shops and more.
The functional and optional value of this sector is more difficult to valuate. People spend a lot of free time along the coastal zone, but do not pay direct money for their visit, like walkers, surfers, swimmers, horse riders and sport-fisherman. But the welfare and scenic value of the coastal zone is high.
Coming to a socio-economic value of the functional and optional value of the coastal zone a value can be given to the amount of daily visitors to an area, or the time they spend in the area, or the money they have to pay to come to the area.

Production
Natural and semi-natural ecosystems provide many resources, which range from oxygen, water, food, medicinal and genetic resources to sources of energy and materials for clothing and building. The most important products out of coastal areas and the sea can be split in two categories: renewable resources and non-renewable resources.

Renewable resources are:
- Fishery in the form of worms, shrimps, shellfish and fish,
- Natural or cultivated salt-loved plant species like seagrass, glasswort and sea aster,
- Agricultural crops in the coastal zone,
- Wind energy.

Non-renewable resources are extraction from the seafloor of:
- Shells
- Sand
- Oil
- Gas
- Minerals (salt)

Economical values of the production function of the coast can easily be valuated by the proceeds of the products. National Statistics or Economic Agency can provide these data. But the following should be taken into account: the positive economical benefits can have negative functional benefits. For example, extraction of resources from the seafloor can cause seafloor subsidence what have its effect on physical and environmental processes in the ecosystem. Mitigation measures have to compensate these negative effects in the extraction area or in adjacent areas.

Some global criteria for value shaping of the economical function can be seen in the small economical value map in Figure 4-2 and are for example:
- Sea reserves will have a low economical value because fishing is not allowed,
- Natural reserves will also have a low economical value because tourism and recreation is not allowed,
- A beach has a relative high value because of a high tourism and recreation rate,
- Rivers can be valuable for shipping but also for recreation,
- Value of the economical companies-areas is related to the value of the buildings, jobs and added value,
- Urban settlements like housing are more valuable along the beach where they have a wide and nice view than along industrial areas or agricultural areas,
- Large agricultural areas are more valuable than small areas because they have a higher production rate. Along rivers the soil can be more fertile what gives more production and thus a higher value.

4.4 Information function

Scientific or educational

The economical value of the opportunities for education and research in an area may be deduced from the amount of money spends on educational excursions and scientific studies. Scientific studies can be expressed in amount of scientists, their income or the profit of the project or published articles.

Heritage

Two types of heritage can be defined for coastal ecosystems: the *historical and cultural* heritage and the *environmental* heritage. A measure for the socio-economic importance of these heritages of an area, which should be protected from erosion, may be the time and money people spend (or are willing to spend) for the conservation of the area in its natural state. A value scaping can be done in order of significance of the area at international, European, national or regional scale. The table below lists the different types of designations encountered in Europe.

Level of designation	Historical & cultural heritage	Environmental heritage
Areas of international importance	▪ UNESCO World Heritage Sites	▪ UNESCO Biosphere Reserves ▪ Wetlands of international importance (Ramsar convention)
Areas of European importance	▪ European Community Treaty (Article 151) for safeguarding European important cultural heritage ▪ Areas with a high probability for archaeological treasures (e.g. Global Archaeological Map of the Continental Shelf with the probability of finding ship wrecks)	▪ Habitat Directive: Special areas of conservation ▪ Bird Directive: special areas of protection of birds
Areas of national importance	▪ National and regional heritage sites ▪ National sites of special scientific (archaeological) interest	▪ National and regional parks ▪ Nature reserves ▪ Environmentally sensitive areas ▪ National scenic areas

Scenic

Many people enjoy the special scenery of natural areas or (old) city landscapes. Although methods to analyse the aesthetic value of landscapes and scenic features exist, it is difficult to evaluate this function objectively since the appreciation of the scenery is a highly personal experience. A method that can be used here is the *Contingent Valuation Method*. This is a survey-method whereby respondents are asked how much money they are willing to pay for the conservation of a coastal environmental area or old city landscape under hypothetically created market-circumstances.

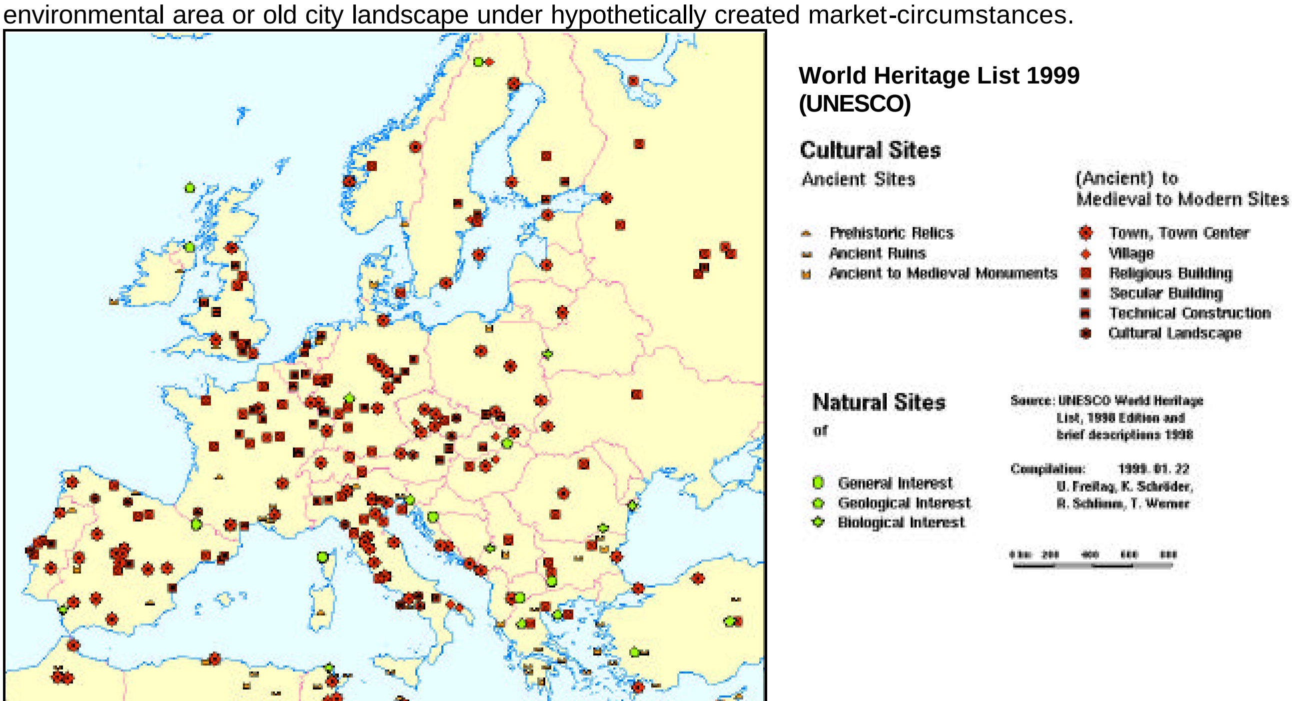


Figure 4-6. Map of World Heritage Monuments in Europe (from UNESCO).

Some global criteria for value shaping of the information function can be seen in the small information value map in Figure 4-2 and are for example:

- The level (international or regional) of importance of the cultural or environmental heritage is an indication of the value,
- Nature reserves are an object for educational purposes, just like old city-buildings or museum,
- Coastal areas (beach, dunes, river delta's or estuaries) can have a high research value when the areas are suitable for research,
- Beaches, rivers and (old) city views can have a high scenic value for people.

5. *RISK MAPPING*

5.1 Risk assessment

Risk assessment is defined as:

"A process of analysis to identify and measure risks from natural hazards that affect people, property and the environment. This process can also encompass the assessment of available resources to address the risks." (Vulnerability and Risk Assessment, UNDP, 1994)

Risk assessment is carried out in a series of related activities that builds up a picture of the hazards and vulnerabilities that explain disaster events. Information is first collected on the specific location, severity, duration and frequency of threats that are faced by a society. This is followed by an assessment of potential hazard impacts on the society's livelihoods, economy, infrastructure and key facilities, etc. Those processes that either increase or decrease vulnerability, which may be economic, social, political or environmental, will always condition the scale of these impacts.

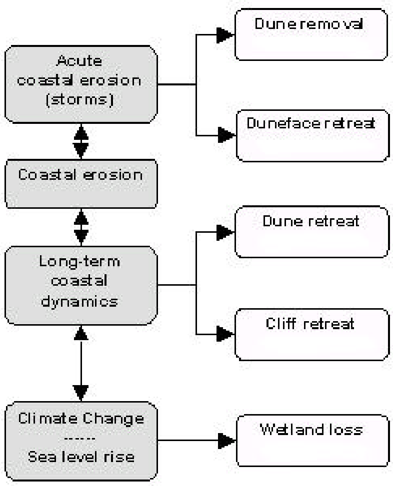
Risk assessment therefore has three central elements:

1. Collection of relevant data and information
2. Hazard analysis, understanding the scale, nature and characteristics of a hazard
3. Vulnerability analysis, the measuring of the extent to which people or buildings are likely to suffer from a hazard occurrence.

Any change in either of these last two components will correspondingly effect to it, the information has to be passed on in an appropriate format to decision makers to determine levels of acceptable risk and what actions should be taken to reduce it. Decisions will then be made as to whether risk reduction measures should be initiated, what level of protection is required and whether there are other more pressing risks to address with finite resources. Understanding risk and taking decisions is therefore a two part process involving both risk evaluation and risk assessment.
Hence, risk assessment refers to the scientific quantification of risk from data and an understanding of the nature of the hazards and the vulnerable elements to it, and is therefore a scientific quantification of risk from data and an understanding of the nature of the hazards and the vulnerable elements to it.

Coastal risk assessment comprises on the one hand side the determination of the failure probability $P_{failure}$ of coastal defenses and on the other hand the estimation of the loss (consequence) C_{damage} in case of failure using the following concept to determine the risk (see also Figure 5-2):

Risk $= P_{failure} \times C_{damage}$
= [probability of hazard] x [estimation of social/economical loss as a result of hazard]



The review of case studies conducted in the framework of EUROSION has demonstrated that there are basically two main types of erosion-related events that may potentially affect assets located in the coastal zone. These events and hazards are (see figure 5-1):

1. Acute coastal erosion and associated flooding
2. Long term coastal dynamics, such as structural coastline retreat and wetland loss (both related to accelerated sea level rise)

Figure 5-1 Acute and chronic erosion consequences.

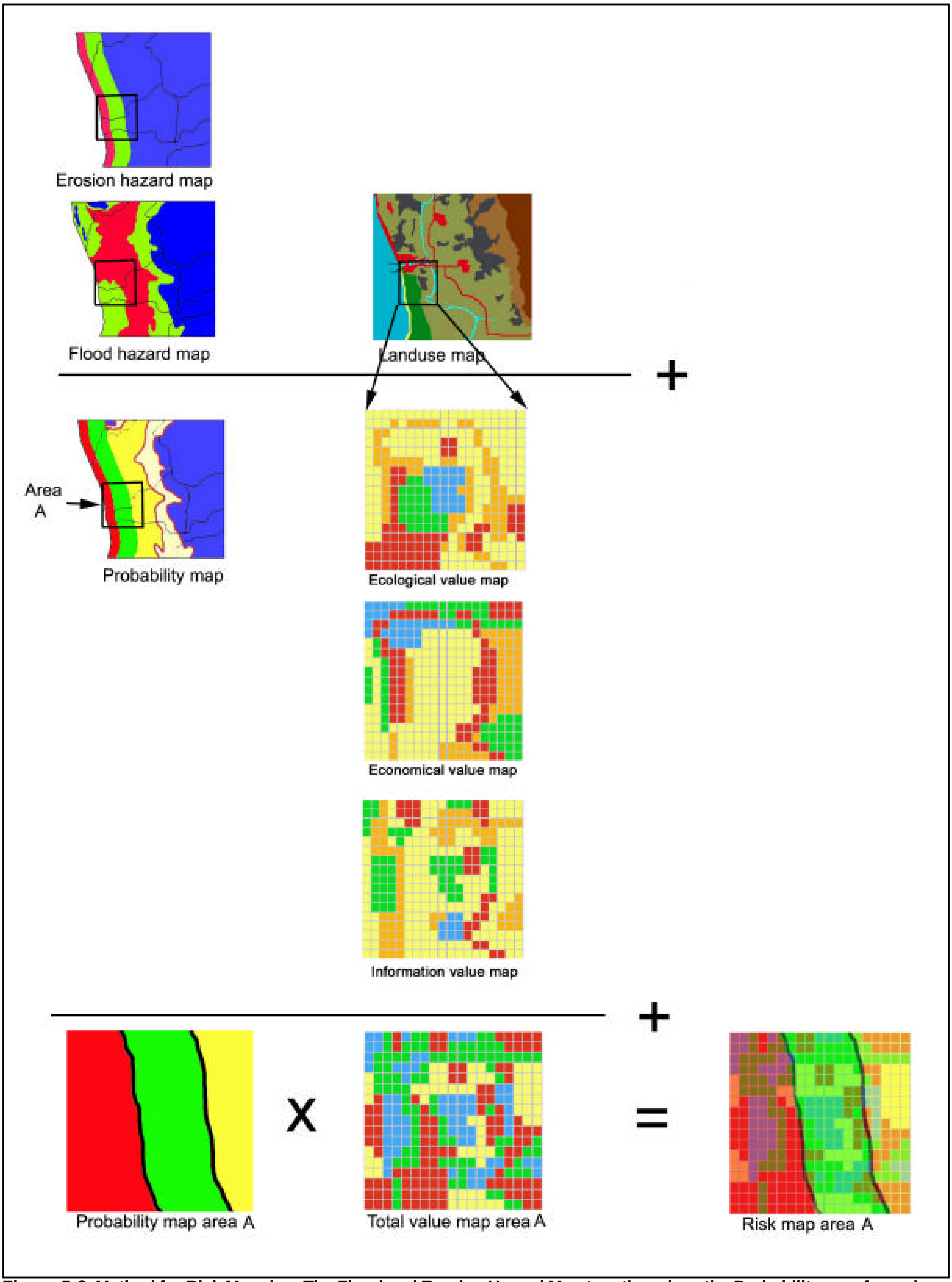


Figure 5-2. Method for Risk Mapping. The Flood and Erosion Hazard Map together gives the Probability map for a given area A. Valuation of the Landuse Map into Ecological, Economical and Information function of an area A gives the Total value map op area A. The Probability map times the Total value map gives the Risk Map of area A. Valuation of the probability map is explained in the text below.

5.2 Risk scoring approach

The ideal method for assigning priorities to the various hazard threats would be a scientific, quantifiable probability assessment. Unfortunately, probability data are not consistent among the different hazard types of coastal erosion and flooding, nor are they always available or useable at the local level. As an alternative, communities can develop a relative priority matrix to use as a general guide for addressing the different hazards. Designing such a matrix requires you to determine which factors are most critical to your community and assign weights accordingly.

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

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

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

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

Such as:

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

Within your risk consideration areas there could be additional boundaries representing varying degrees of risk. These varying degrees of risk should be represented in your risk consideration areas both graphically (additional boundaries on the maps) and through some type of relative scoring system (higher scores for higher risk areas).

When developing a relative priority scoring system for storm surge inundation, Category 1 storm surge areas would therefore have the highest risk of being flooded since they are at risk of inundation in all storm events.

The table below shows an example of a relative priority scoring system. The general concept is that locations with no consideration for risk will have a score of 0 and each incremental increase in risk adds 1 point.

	Risk score	Highest	Lowest
Flooding			
100 yr flood plain (Stillwater level)	4	4	1
250 yr flood plain	3		
500 yr flood plain	2		
Remainder of area	1		
Coastal erosion			
High	3	3	1
Medium	2		
Low	1		
Remainder of area	0		
(Etc.)		Σx	Σy
Natural Hazard Risk Potential Scores		7 + Σx	2 + Σy

Here, coastal erosion has locations where the risk consideration score = 0. The maximum extent of the hazard risk does not realistically include the entire county but is limited to proximity to coastal waters. Also, the minimum risk score for flood hazards is 1 since there is some to occur anywhere throughout the area.

Using a GIS, the risk consideration areas were combined and the scores were added together to create summary scores for every location in the area. These summary scores were used to develop a summary risk (here: coastal erosion and flooding) area map (see Figure 5-2).

The valuation of the function maps is described in the previous chapter and had a valuation of :

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

Combination of the three function maps with values between 1 and 5 gives a total value map of values between 3 and 10. If this total value map is multiplied with the risk score the risk map is born.

APPENDIX A. Overview of coastal defence works

TECHNIQUES	*PRINCIPLES*	*LIMITS OF APPLICATION*
HARD TECHNIQUES		
Breakwater	Breakwaters are protective structures placed offshore, generally in hard materials such as concrete or rocks, which aim at absorbing the wave energy before the waves reach the shore.	Breakwaters reflect or diffract wave energy in destructive ways or concentrate it in local hot spots. Erosion problems and the scouring effects of the misdirected energy lead to the loss of beach / coastline and undermine the structures that were meant to be protected.
Gabion	The gabion is a metal cage filled with rocks, about 1 metre by 1 metre square. Gabions are stacked to form a simple wall.	They are used to protect a cliff or area in the short term only, since they are easily damaged by powerful storm waves and the cages tend to rust quite quickly. Gabions have the advantage of ease of use and are relatively cheap but their life span is short.
Geotextiles	Geotextiles are permeable fabrics which are able to hold back materials while water flows through. Geosynthetic tubes are large tubes consisting of a woven geotextile material filled with a slurry-mix. The mix usually consists of dredged material (eg. sand) from the nearby area but can also be a mortar or concrete mix.	Geotextiles are relatively recent but provided good results to prevent beach from retreating. Plus they are very flexible and can be re-arranged if their configuration does not provide good results.
Groin fields	Groins are structures that extend perpendicularly from the shore. Usually constructed in groups called groin fields, their purpose is to trap and retain sand, nourishing the beach compartments between them. Groins may be made of wooden or rocky materials. They interrupt the longshore transport of littoral drift. When a well designed groin field fills to capacity with sand, longshore transport continues at about the same rate as before the groins were built, and a stable beach is maintained.	Sand accumulated between groins contributes to a sediment deficit down-drift. Coastal erosion problems are then shifted to other locations. Thus, to be effective, groins should be limited to those cases where longshore transport is predominantly in one direction, and where their action will not cause unacceptable erosion of the downdrift shore.
Revetments	Revetment is a sloping feature which breaks up or absorbs the energy of the waves but may let water and sediment pass through. The older wooden revetment consists of posts fixed into the beach with wooden slats between. Modern revetments have concrete or shaped blocks of stone laid on top of a layer of finer material. Rock armour or riprap consists of layers of very hard rock with the largest, often weighing several tonnes, on the top. Riprap has the advantage of good permeability and looks more natural.	Revetments are adapted to foreshore with a gentle slope. It has the same adverse effect as seawalls though with a reduced intensity. It also results in changing the nature of the sea frontage which may lead to further changes in the foreshore ecosystems.
Seawall	Bulkheads and seawalls protect banks and bluffs by completely separating land from water. Bulkheads act as retaining walls, keeping the earth or sand behind them from crumbling or slumping. Seawalls are primarily used to resist wave action. Design considerations for these types of structures are similar. These structures do not protect the shore in front of them, however.	When bulkheads and seawalls are used in areas where there is significant wave action, they may accelerate beach erosion (much of the energy of the waves breaking on the structure is redirected downward to the toe). Bulkheads and seawalls are most appropriate where fishing and boating are the primary uses of the shore, and gently sloping areas for sunbathing or shallow -water swimming are not essential. They are also critical when risks associated to coastal erosion are imminent.
SOFT TECHNIQUES		
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	Only few examples of artificial reef creation exist in Europe (in Sea Palling, UK mainly), but seems to provide good results.
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.	The technique is relatively new and experience lacks to assess its performance. It has to be noted however that beach drainage is adapted when erosion mainly occurs cross-shore (non significant long-shore drift)
Sand supply or 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	Beach and underwater nourishment as been very popular in the North because of the availability of sediments which has similar properties as the beach sediment. When

TECHNIQUES	*PRINCIPLES*	*LIMITS OF APPLICATION*
	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.	sediment is not available and has to be imported from another region, beach nourishment may not be the best decision. Nourishment schemes have also to be carefully designed as they may alter the biota (both on the beach and in the dredging area).
Beach scraping	Artificial re-profiling of the beach when sediment losses are not severe enough to warrant the importation of large volumes of sediments. Re-profiling is achieved using existing beach sediment	Beach scraping is among the cheapest techniques as it does not require importing sand. However, the process may have to be carried out several times before the right profile is found. It is also restricted to those beaches where cross-shore erosion is dominant and storms not heavy.
Cliff drainage	Reduction of pore pressure by piping water out of the cliff and therefore preventing accumulation of water at rock boundaries	May not be applicable for all types of cliffs.
Cliff profiling	Change of cliff face angle to increase cliff stability. The angle at which cliff become stable is a function of rock type, geologic structure and water content.	May not be applicable for all types of cliffs, and the techniques requires a fairly good knowledge of the cliff geologic structure and watering process.
Cliff toe protection	Protection of the cliff base by placing blocks at the foot of potential failure surface.	This technique is easy to achieved but do not stop erosion completely. It may therefore be adapted in those case where further loss of lands is still acceptable
Creation of stable bays	Increasing the length of the coastline to dilute wave energy per unit length of coast. While some coastline segments are protected, erosion continues between these hard points leading to the formation of embayments	This technique is almost not used in Europe and is still experimental. However, it has been envisaged for a number of sites (especially the Holland coast)
Dune regeneration	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-textile, plants, which encourages sand deposition	Adapted for those cases where wind plays an important role
Marsh creation	Planting of mudflats with pioneer marsh species, such as *Spartina sp*. Marsh vegetation increases the stability of sediment due to the binding effects of the roots, increasing shear strength and decreasing erodability. Marshes also provides cost-effective protection against flooding by absorbing wave energy.	Marsh creation is particularly popular in United Kingdom. However, the technique may be jeopardized by accelerated sea level rise. In this case, the accumulation of fine sediments necessary to the marsh creation may not occur in the proper way and the marsh finally collapse.
Mudflat recharge	Supply of existing mudflats with cohesive sediments. This is achieved via trickle charging (see beach feeding), rainbow charging, and polders	Such as marsh creation, mudflat recharge may be jeopardized by accelerated sea level rise.
Rock pinning	Prevention of slippage in seawards dipping rocks by bolting layers together to increase cohesion and stability. Does not prevent wave attack at the cliff base, but does reduce the threat of mass movement and thus reduces net erosion rates.	May not be applicable for all types of cliffs.
sand by-passing	Reactivation of sediment transport processes by pumping sediments accumulated up-drift by coastal infrastructure normal to the coastline and injecting them down-drift. A variant of sand by-passing is to use materials dredged for navigational purposes to reactivate the sediment transport.	This technique has been implemented by a number of harbour authorities (or dams authorities) in Europe as volumes of sand trapped by harbour breakwaters (resp. dams) are generally considerable. When sediments are trapped by a series of groins (or consecutive dams) the technique might not be cost effective anymore. It has to be noted that in the case of dams, accumulated sediment may be contaminated may not be re-injected in the sediment transport system.
Vegetation planting and/or stabilisation	Colonisation of coastal soils by vegetation whose roots bind sediment, making it more resistant to wind erosion. Vegetation also interrupts wind flow thus enhancing dune growth. As for cliffs, vegetation increases cohesion of surface soils on cliff slopes to prevent downhill slumping and sliding	Vegetation adapted to dune (eg. Marram grass) is generally very fragile and require integral protection and daily care to the dune system.