A spatial multi criteria analysis methodology for the development of sustainable flood risk management in the Ebro Delta

A FLOOD*site* case study

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Department Water
Engineering
and Management

August 2006

UPC

FLOOD*site*

University of Twente
Enschede - The Netherlands

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Preface

This research is a Master Thesis for the University of Twente (UT). It is part of the FLOOD*site* project, herein the university works together with three institutions: UPC (Universitat Politèchnica de Catalunya) and UniLund (Lunds Universitet). The work for this report was realized due to the collaboration of the UPC and the UT. This report wouldn't have been realized without help of many people. Firstly, I want to thank Joerg Krywkow and Anne van der Veen for their large support and advice here at the University and their pleasant accompanying on the trip to Barcelona. Secondly, but not less important I want to thank Vicenç Gràcia and José Jiménez for the warm welcome in Barcelona, patiently answering all my questions and the translation of the questionnaires into Catalan. A special thanks to Blanca Perez-Lapena for implementing the storm scenarios into GIS. For answering the questionnaires which provided me with a lot of information I want to thank:

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The research done for this report was very interesting. In this past months I learned a lot and made wonderful contacts withing the *young* FLOOD*site* network. The problems for Ebro Delta coast cover every aspect of civil engineering and working on so such problems is very challenging for a young civil engineer.

Enschede, August 2006

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Management summary

This report derives a methodology which combines spatial multi criteria analysis with risk assessment in order to support decision making for sustainable flood risk management of coastal zones. A trade-off is made between the reduction of tangible and intangible damage and the conservation of commodity (CO) and non-commodity output (NCO), for risk management strategies. In this case these strategies are land use changes. This is a trade-off between risk and benefit, where a reduction of risk often implies a reduction of benefit. This trade-off is often influenced by the perception of risk, which influences the preference for one of the opposing interests. Flood risk management policy scenarios are judged on the criteria, reduction of tangible and intangible damage and conservation of COs and NCOs in a spatial multi criteria analysis. Worry, awareness and preparedness, three parameters for risk perception are used to determine the weighting of the first two criteria versus the last two. Afterward pairwise comparison can be used to fine tune the weighting. The methodology should guide a policy maker toward sustainable flood risk management but not make the decision for the best flood risk management policy alternative itself.

The methodology is applied as an example on the Marquesa coast of the Ebro Delta. The Ebro Delta is Spain is frequently impacted by storm induced coastal erosion and flooding. The Delta is only protected by the coast itself and so flooding and coastal erosion often have consequences for the socio-economic functions of the coastal zone. Due to sea level rise and subsidence of the Delta, it is expected that the problems will further aggravate for the years to come. The functions of the Delta coastal are all closely connected; the main functions are rice cultivation, nature conservation, aquaculture, tourism, salt industry and living. Two land use scenarios are presented: (1) the baseline scenario; Business As Usual in which the construction of houses in the town of Riumar is included, and (2) the policy scenario; nature development in which the large parts of the Marquesa coast are converted from rice cultivation into salt steppes. The construction of housing in Ruimar proves to be negative for flood risk management; the situation deteriorates in comparison to 2001. In the contrary, the nature development scenario proves to be a risk management option worthy taken into consideration (with possible modifications).

Chapter 1

Introduction

1.1 Managing an increasing flood risk

Worldwide a trend is observed for an increasing flood risk. Research on the frequency of river floods with discharges exceeding 100-year levels from river basins in the world larger than 200.000 km, by Milly et al. [2002], shows that the frequency of floods in these basins has increased over the years. There is a large concern about the increasing flood risk due to river floods in the 21st century. Recent research contributes to the claim that sea levels will rise due to rapid meltdown of ice-sheets around the world. Surveys in Alaska [Meier and Dyurgerov, 2002], West Antartica [Thomas et al., 2004] and Greenland [Overpeck et al., 2006] indicate a rapid melting of ice sheets at those locations. On top of that coastal zones and river basins become more and more densely populated. There is a strong scientific base, which justifies the increasing worry about the increase of flood risk in both coastal areas and riverine areas.

Flooding which still occur, like recent flooding of the Elbe river (April 2006) indicate, that there is need of an integrated flood risk methodology, that guides the management of these flood risks. Therefor the European Commission started the FLOOD*site* project, in which an integrated approach to flood risk management is chosen.

1.2 The FLOOD*site* project and the role of task 26

The FLOOD*site* project is part of the first round of the Sixth Framework Programme of the European Commission. This is an 'Integrated Project' on flood risk management. The goal of the FLOOD*site* project is to create an integrated flood risk management framework and network [www.floodsite.net, 2006]. In an integrated project, works of various disciplines are combined into an analytical framework [Rotmans, 1998]. The framework is designed to analyse and manage flood risks problems in an integrated way. As shown in figure 1.1, the FLOOD*site* project is divided into seven themes. The first three themes cover

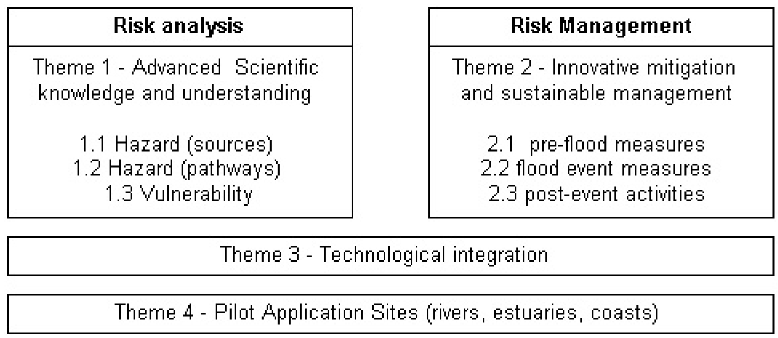


Figure 1.1: The structure of the FLOOD*site* project

the majority of the research, and are aimed at building the flood risk management framework. Theme 1 covers risk analysis and risk assessment and theme 2 covers risk management. Theme 3 is meant to integrate the scientific knowledge of the first two themes.

The themes are divided into sub-themes, and the sub-themes into tasks. Theme 1 covers sub-themes 1.1 Hazard (risk sources), 1.2 Hazard (risk pathways) and 1.3 vulnerability (receptors, consequences). Especially sub-theme 1.3 is important for this research. This theme consists of the tasks 9, 10 and 11. Task 9 describes guidelines for socio-economic flood damage evaluation. Task 10 describes socio-economic evaluation and modeling methodologies and task 11 covers risk perception, community behavior and social resilience. Theme two aims at finding innovative flood mitigation measures. The second theme is divided into sub-themes 2.1 Pre-flood measures, 2.2 Flood event measures and 2.3 post-event activities. The third theme covers the framework for integration of the last two themes.

Within theme 4 the FLOOD*site* methodology is tested for its applicability for specific test sites. Seven pilot sites are selected for a pilot study. These pilot sites are rivers, estuaries and coasts, and are covered by the tasks 21 to 27. One of these pilot sites selected for a pilot study is the the Ebro Delta Coast or task 26. A pilot study is part of a larger project or programme, undertaken to improve understanding of the main change or innovation being delivered by the project or programme, thereby reducing the risk and uncertainty associated with the change [Turner, 2005]. The specific objective of task 26 is to examine vulnerability, risk and defense needs against flooding at the Ebro Delta Coast applying the FLOOD*site* methodology [Jiménez, 2004]. The pilot study is supposed to provide feedback to theme 1, 2 and 3 of the FLOOD*site* project on applicability of the elements of the framework in 'reality'. Secondly, this project should provide a guide to end users; for example management action of policy makers.l

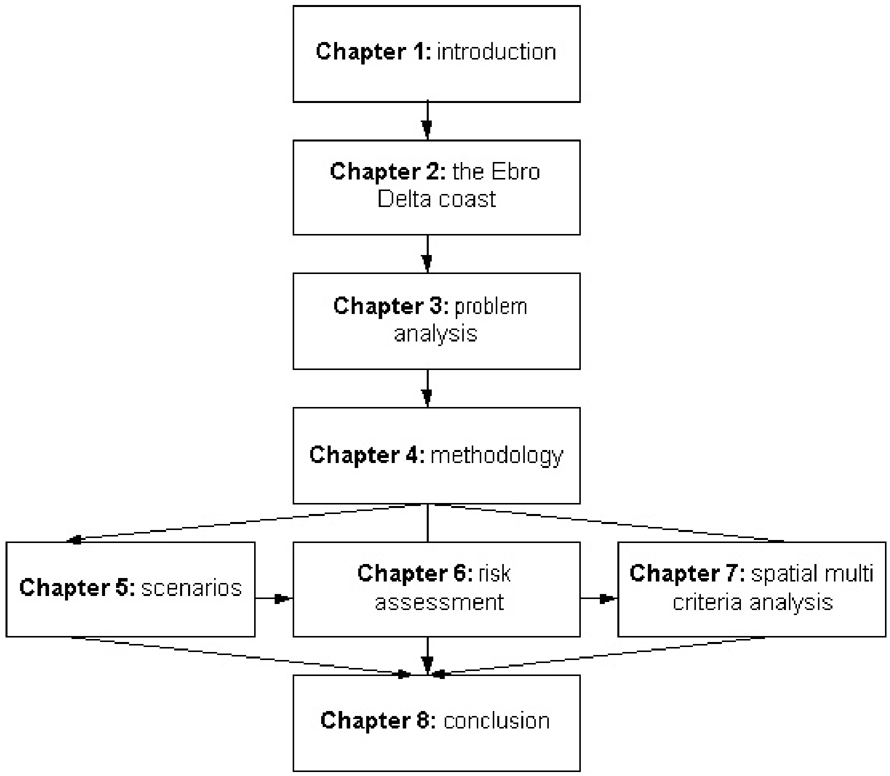


Figure 1.2: The structure of this report

1.3 Outline of the report

Figure 1.2 shows the structure of this report. After this introductory chapter, in the second chapter the reader is introduced into the problems and socio-economic background of and physical circumstances at the pilot site. This information forms the basis for the third chapter. The first part of this chapter describes the problem definition, the research objective and the research questions. In the second part of this chapter important definitions used in the problem analysis are described. Chapter four describes the methodology to answer the research questions. This methodology has three major components: (1) cenarios for the Ebro Delta, (2) risk assessment and (3) spatial multi criteria analysis. To each component of the methodology a chapter is devoted. The output of each successive chapter is used as input for the next one. The main conclusion can be drawn from the spatial multi criteria analysis which evaluates the future land-use scenarios on previously described criteria. Finally in chapter 7 the conclusion of this research is drawn.

Chapter 2

The Ebro Delta coast

2.1 Geography

The Ebro Delta is a deltaic plain 200 kilometers south of the city Barcelona, in the region Catalunya. Figure 2.1 shows the Ebro Delta in its present state. The Delta has an emerged area of 320 km^2 and a submerged area of 1825 km^2 . The delta is the mouth of the river Ebro, a river with a total length of 910 kilometers and a catchment area of 85,362 km^2 [www.iberianature.com, 2006]. The last 28 kilometers of the river run through the delta plain [Santalla, 2002] The Ebro Delta has been formed due to the interaction between river and marine dynamics [Jiménez et al., 1997]. The Delta has been build up by the surplus of sediment discharge of the river Ebro [Galofré et al., 2002]. The surface of the Ebro Delta has expanded itself for several centuries. The coastline is 50 kilometers long and is made up of two spits, El Fangar, situated in the North-West and La Banya situated in the South-West. The La Baya spit is connected to the mainland by a bar, the Trabucador, this bar is 6 kilometers long and 250 meters wide [Santalla, 2002]. The beaches are named from north (Fangar) to south (La Banya): Marquesa, Pal, Riomar, Mitjorn, Serallo and Eucalitus. The river mouth is at Cap Tartosa, surrounded by the Buda and San Antonio islands (Catalan: Illa). About 10% of the delta lies under sea level and 45% of the Delta area has an elevation of less than 50 cm. [Jiménez et al., 1997, Day et al., 2004]. The Ebro Delta itself hardly knows elevation. Close to the beach there are some dunes, but these are not very high; the only protection against flooding is the beach itself. There are two villages in the coastal zone Riumar and Eucaliptus, which mainly consist out of secondary housing. The land use in the Ebro Delta categorized according to the CORINE (Coordination of Information on the Environment) biotopes classification is shown in figure 2.1 and listed in table 2.1.The CORINE biotopes classification is a geographic land cover/land use database encompassing most of the countries of the European Community.

No.	Habitat type	Surface [ha]
11	Coasts and seas	94,05
14	Mud flats and sand flats	1079,69
15	Salt marshes, salt steppes and gypsum scrubs	658,10
16	Coastal sand dunes and sand beaches	421,65
21	Saline or hypersaline lagoons	17,91
22	Standing fresh water	7,92
23	Standing brackish or saline water	686,00
24	Running waters	808
34	Dry calcareous grass-lands and steppes	110,42
37	Humid grassland and tall herb communities	-
44	Alluvial and very wet forests and brush	1,17
53	Water-fringe vegetation	715,86
82	Rice cultivation	4479,65
83	Orchards, groves and tree plantations	272,66
84	Tree lines, hedges, small woods, bocage, parkland, dehesa	-
85	Parcs and gardens	-
86	Urban and industrial areas	489,93
87	Abandoned fields, uncultivated lands and ruderal vegetation	1,32
89	Industrial lagoons and reservoirs, canals	940,62

Table 2.1: Land use in the Ebro Delta [www.nbn.org.uk/habitats/habitatInClass.asp, 2006]

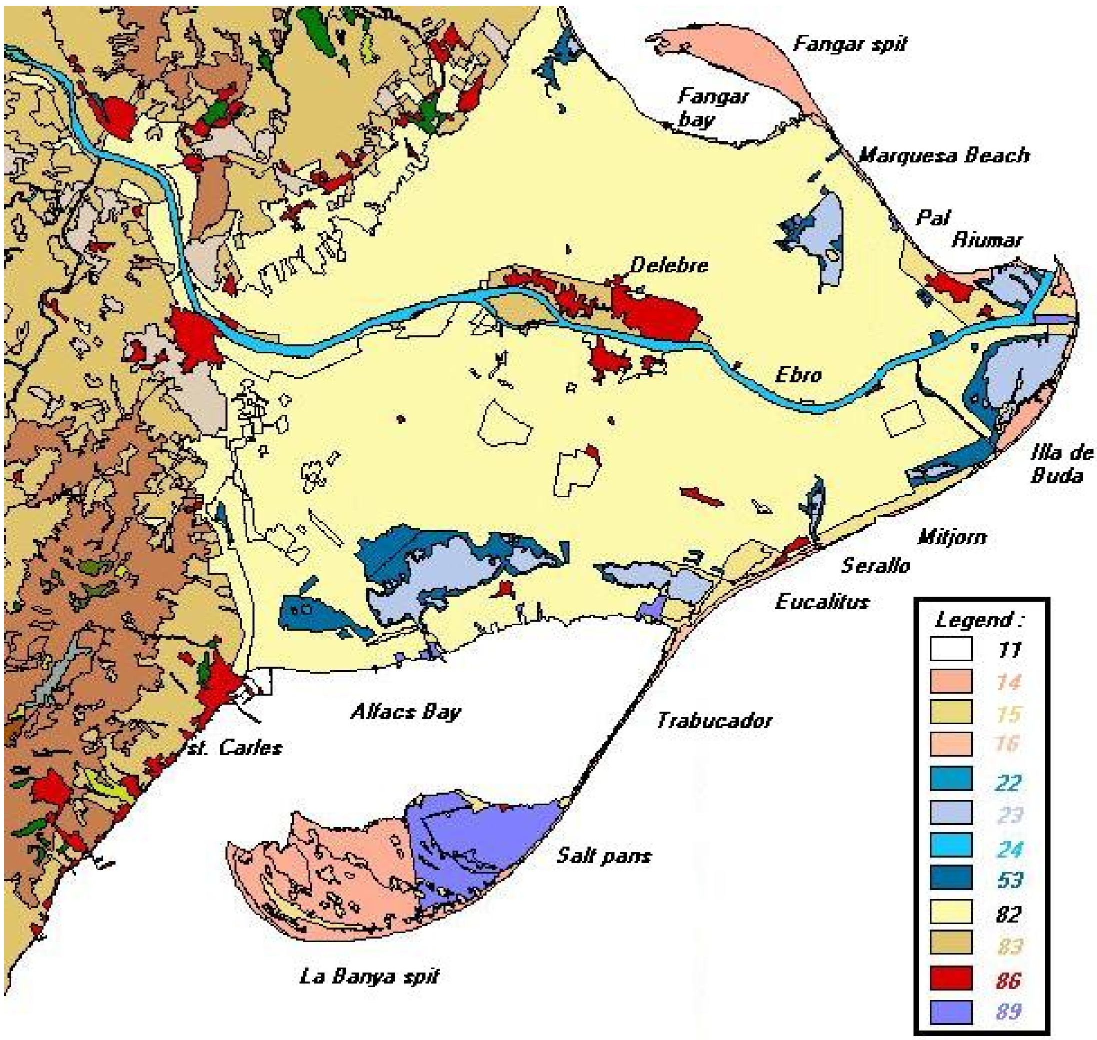


Figure 2.1: The Ebro Delta [Jiménez et al., 1999]

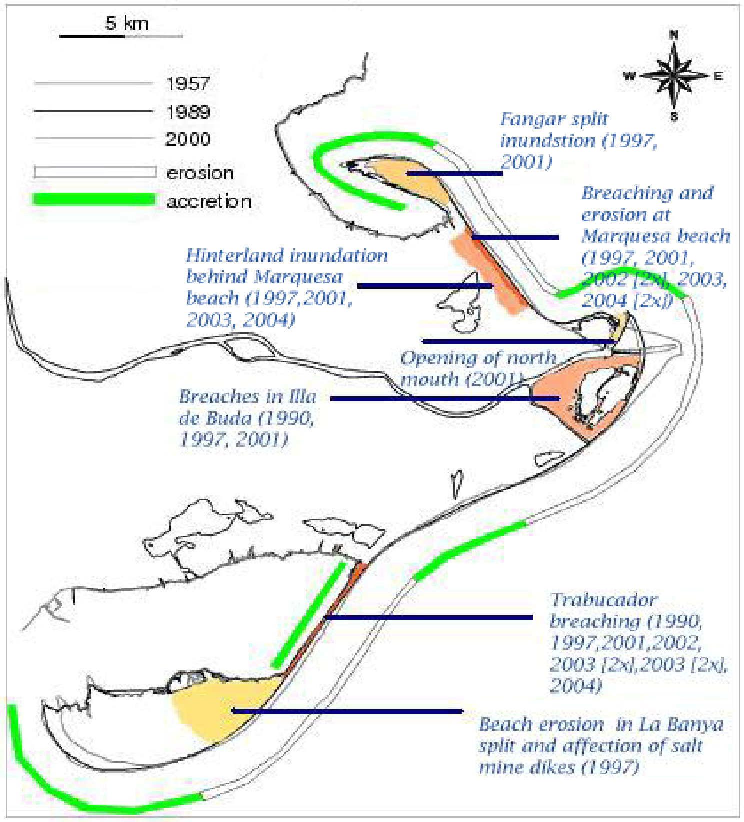


Figure 2.2: Impacts of storms 1990-2004 on the Ebro Delta Coast. *Adapted from:* [Jiménez and Sánchez-Arcilla, 1993]

2.2 Physical Processes

2.2.1 Storm events

From 1990 until 2004 there have been nine storms that have been defined as harmful, these storms have caused damages to or have had consequences for different systems in the Delta. Figure 2.2 shows the consequences these storms had for different areas in the Delta.

Table 2.2 shows the recorded storm events from 1990 - 2004 and their characteristics. In this table H_s is the significant wave height in meters , t is the time of duration of the storms estimated by the time the significant wave height exceeds 2 meters and T_r is the return period in years, obtained by using a Weibull distribution [Jiménez, 2005].

Storm	H_s(m)	t(hours)	T_r (years)
Oct 1990 (1)	4.51	18	2.9
Oct 1990 (2)	3.57	28	<1
Oct 1997	4.91	39.5	5.2
Nov 2001 (1)	5.62	63	14.6
Nov 2001 (2)	5.95	38	23.5
Apr 2002 (1)	3.25	43	<1
Apr 2002 (2)	3.17	48	<1
Apr 2002 (3)	3.05	20	<1
May 2002	4.52	65	3
Feb 2003	2.90	51	<1
Oct 2003	4.11	94	1.6
Mar 2004	4.65	63	3.6
Apr 2004	4.12	37	1.7

Table 2.2: Main characteristics of the storms identified as harmful for the Ebro Delta [Jiménez, 2005]

2.2.2 Marine climate and coastal dynamics

Satellite measurements from January 1993 till December 1998, point out that in this period the sea level has risen mean rate of sea level rise is 7 ± 1.5 mm/year. However, the sea level rise is not uniform over the whole Mediterreanian, in some regions the level rises, while on other places a negative trend is detected [Cazenave et al., 2002]. Ibáñez et al. [1997] estimate that the rate of eustatic (relating to the world wide change in sea level) sea level rise for the Ebro Delta coastal zone is ca. 1 - 2 mm/yr. The maximum differences between low and high water levels recorded are approximately 0.4 meters. This mostly occurs under a combination in a drop of atmospheric pressures and the effects of an eastern wind [Jiménez et al., 1997]. The average annual significant wave height in deep water is about 0,7 m, and *storm conditions* are defined as the average annual significant wave height exceeds 1.5, approximately twice as the average. The highest storm surges occur from the months September till November [Jiménez et al., 1997]. The Ebro Delta Coast is not protected by dunes or dike, as for example the Dutch coast is. The only protection against flooding is the beach itself. Earlier research in this pilot study examines the impact on storms on the Ebro Delta Coast (for more information see Jiménez [2005]).

2.2.3 Erosion

The Ebro Delta formed due to interaction between river and marine dynamics. The surface of the Ebro Delta has expanded for several centuries. Mainly due to the construction of the dams Ribarroja and Mequinça dams (1964-1969) in the lower Ebro river course the sediment discharge has decreased [Day et al., 2004]. This means the deltaic continuum, the range in which delta morphologies are dominated by relative intensities of river, wave and tidal processes, has changed from river dominated to wave dominated. So the sediment on the Ebro delta coast is transported due to the waves. The transport of sediments predominantly takes place under storm conditions, where the long shore transport dominates over the cross shore transport [Jiménez et al., 1999]. Figure 2.2 shows the areas of erosion and accreditation. There are three coastal areas heavily influenced by erosion; The three main sites that are heavily influenced by erosion; (1) *La Marquesa beach* , (2) *Illa de Buda* and (3) *Trabucador*,'the artificial' connection from the mainland to *La Banya Spit*. The location of these areas is highlighted in figure 2.8. Deposition of the eroded sand, which is transported by long shore transport processes, takes place at the La Banya and the Fangar spit. This implies that the Ebro delta is mainly subjected to reshaping processes instead of formation processes [Jiménez et al., 1997]. There is a dominance of a net long shore transport form the river mouth (Illa de Buda) toward the north and the south. The most sediment transport occurs under eastern storm conditions, as it produces the highest waves with the most energy. The the maximal present regression of the coast at the Illa de Buda is in the order of 12 meters/year and the present coastal erosion of the Marquessa beach is in the order of 2 meters/year [CPIDE, 2002]. A photograph (figure 2.3), taken in April 2006 at the Marquesa beach, shows the erosion in this stretch of beach. It shows that the coastal defenses in this area are already weakened, and that there is a reasonable chance the hinterland is affected during a next storm. In contrast to the erosion at the Marquesa and the Illa de Buda, the Fangar and La Banya spit accreditate. From 1957 till 1998 the tip of the Fangar bay beach is advanced in the order of 1400 meters. Without human interference and when present trends are continued the closure of the bay is a matter of years. For the la Banya spit the average coastal progression (for the headland) was 22.5 m/yr in the last 132 years [Ibànez et al., 1997]. The reduced sediment transport of the river Ebro leads to lack of accreditation in the delta causing subsidence of the deltaic plain below sea level [Jiménez et al., 1997, 1999, Day et al., 2004]. Estimates of the rates of subsidence of the delta are between 2-5 mm per year [Ibànez et al., 1997]

2.2.4 Relative sea level rise

A large part of the Ebro Delta is below or near to sea level, so slight increases in sea levels or storm surge levels could have large consequences for the delta [Sánchez-Arcilla, 1996]. The relative sea level rise (RSLR) is defined as the added effect of sea level rise and subsidence of the Delta. The combined effect of an eustatic sea level rise of 1-2 mm per year and the subsidence of the delta, between 2-5 mm, results in a RSLR between 3-7 mm per year. The combined effect of subsidence of the Delta, coastal erosion and sea level rise, makes that the future flood risk within the Delta increases. The first effect will be the flooding of the low-lying areas; the inner coast near of the two spits and the marsh area near the river mouth . When storm surges are high enough, the

Figure 2.3: Erosion of the coastal defenses at the Marquesa beach

entire plain under sea level can be flooded [Jiménez et al., 1999]. All coastal lagoons and wetlands, and a large agricultural area is under flood risk [Otter et al., 1996]. Simple calculation shows that with a mean estimated RSLR of 3-7 mm/year the 45% of the delta area, that has an elevation of less than 50 cm will be below sea level, will be below sea level in about 71 - 166 years. Ten percent of the delta is allready below sea level, thus in with present estimates more than half of the delta will be under sea level within the given years. How large the excact RSLR will be remains uncertain. This is illustrated in figure 2.4 which shows the range of uncertainty for the relative sea level rise for the Ebro Delta.

2.3 Socio-economic aspects

2.3.1 Major functions of the coastal zone

About 50,000 people are currently living within the area, of which 15,000 live inside the Delta and the rest on its inland edge. Main socio - economic functions of the coastal zones are agriculture, fisheries and aquaculture,(eco) tourism and recreation, nature conservation, salt production and transport [Otter et al., 1996, Santalla, 2002, Day et al., 2004].

- **Agriculture:** rice cultivation is the dominant human activity in the Ebro Delta. Rice, the main culture, covers 21,000 ha or 65% of the Delta area and 15% is devoted to other crops (vegetables and fruit trees)

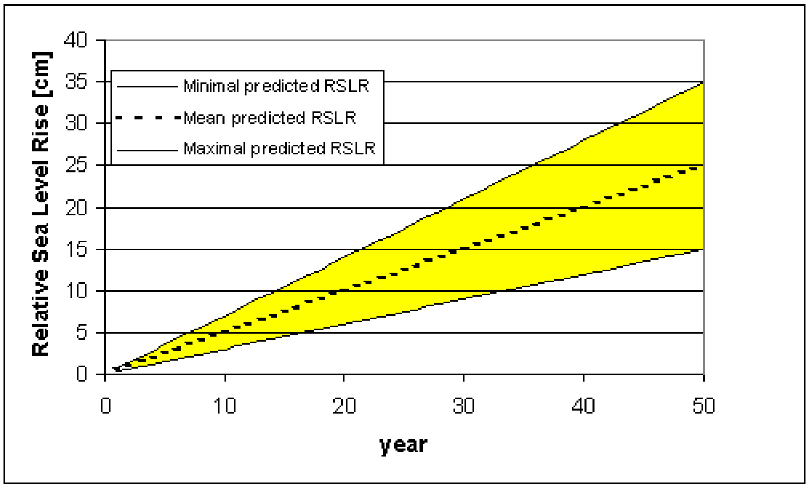


Figure 2.4: Range of uncertainty for the RSLR for the Ebro Delta

[www.ramsar.org, 2006]. To aid the production of rice an extensive network of irrigation channels has been constructed in the delta to deliver fresh water from the Ebro river. The rice production is the third most important of the European Union and represents 98% of the total production in Catalunya [Santalla, 2002, Day et al., 2004]. The rice-growers co-operatives are very important in the delta. Farmers are unified in the 'Arrosaires', the organization which processes the harversted rice and in the Comunidad regantes, the organization which makes sure irrigation water is distributed fairly over the fields of the farmers. The fresh water that is irrigated over farmland originates from the river Ebro and is discharged into the Alfacs and Fangar bays or into the wetlands. The rice fields link riverine environments with lagoon and marine environments. The wetlands and the rice fields naturally purify the water, they act as biological filters [Ibànez, 1998]. Side effects of agriculture are the distribution of nutrients and toxics into the aquatic enviroment. Pastor et al. [2003] measured concentrations chlorinated compounds (like PCB and DDT), in the Ebro Delta, formerly used in agriculture, being stored in sediments and brought into the water by desorption. The eutrophication of the bays due to excess use of fertilizer poses a problem for the aquacultural industry in the bays, which relies on a good water quality within the bays. It is important to note that the natural area and the rice cultivation are closely interlinked and these systems wouldn't function well without each other. The agricultural surface has an important function for the ecology, as it provides a food source and habitat for birds in the area. Another good side effect of rice cultivation is the reduction of the salinity of the ground, because the irrigation water supresses the seepage of the salt sea water.

- **Fisheries:** fishing is an important activity in the Delta. It involves the two ports of Sant Charles de La Rapita and L'Ampolla within the delta. There are two sorts of fishing, commercial fishing in the open sea and recreative fishing in the lagoons. The people from the natural park ensure that there is a good water quality in the lagoons and therefor helps the fishing activity there. Sea fishing has a positive influence for many bird species, as sea gulls, as they eat the remains of fish thrown away by fishing boats.

- **Aquaculture:** the aquacultural production is aimed at producing mussels, bivalves and oysters for consumption purposes. The production in the area is divided over the two bays: the El Fangar and Alfacs bays. There have been experiments with aquaculural production on the land, however these have failed due to a shortage on of salt water with a sufficient water quality for the production of mussels. The production of bivalves, mussels and oysters in the Ebro Delta region is equivalent to 99% of the total production in Catalunya. Due to accreditation of the Fangar and La Banya spit, the Fangar and Alfacs bay are closing. When the bay is closed the water quality inside the bay will decrease due to phosphorus and pollution loads from agriculture which can not be transported to the open sea [CPIDE, 2002]. As a consequence of the closure the characteristics of the water will change which will make it unsuitable for exploitation for aquacultural activity.

- **Nature conservation:** the natural park within the area has an surface of 7800 ha. Natural areas remain on 20% of the Delta area, mainly along the coast, composed of sandy beaches; lagoons; fresh water, brackish and salt marshes; reedbeds; and associated coastal wetland habitats. The Delta is known for its high biodiversity; about 311 different bird species and about 515 different plant species can be found in the Ebro Delta. In figure 2.5 the number of species in the Ebro Delta per taxon is shown (a classification of species on the basis of structure or origin), which points out that the biodiversity in the Delta is very high.

  The natural park is protected by law. The Ebro Delta Nature Park (7,736 ha) was established by the Catalonian Government. After that the protected area was increased to 11,530 ha by the Plan for Natural Sites of Specific Interest. The total protected area (Natural Park and PEIN) was proposed by the Catalonian Government as a Site of Community Importance (LIC) for inclusion in the network of protected areas "Natura 2000" of the European Union (Habitats Directive 92/43/EEC) [www.ramsar.org, 2006]. The main goal of protecting the areas is the maintenance of the ecological character of the natural areas and the protection of birds and specific habitats of mayor importance (for the European union). The natural park is closed to visitors and in the combined

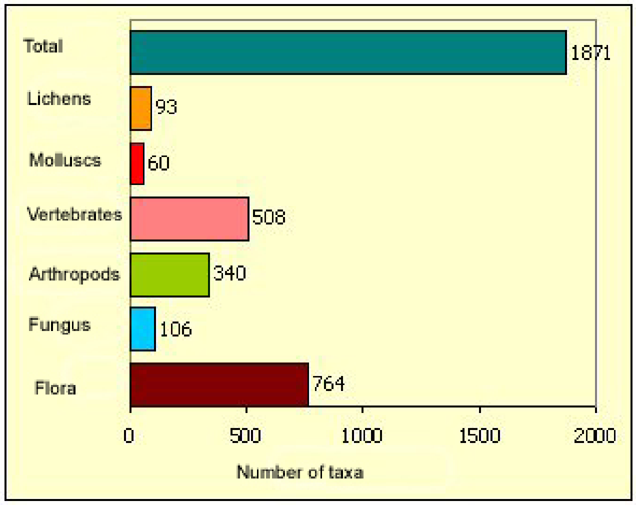


Figure 2.5: The number of taxa in the Ebro Delta [http://biodiver.bio.ub.es/biocat/homepage.html, 2006]

camping	**town**	**capacity (nr. of people)**
Riumar	Deltebre	45
La Tancada	Amposta	240
Mediterrani Blau	Amposta	185
Càmping Eucaliptus	Amposta	645
Total	*Coastal zone*	*1115*

Table 2.3: Campings in the coastal zone

area of PEIN and Natural Park it is subjected to a building prohibition. The protected areas are shown in figure 2.6

- **Tourism and recreation:** tourism is mostly aimed at eco-tourists attracted by the national park and tourists attracted to the beaches. The Ebro delta attracts more than half a million people per year [Orellana, 2005]. As shown in figure 2.7, the largest number of places for tourists are provided by the hotels (1243), and campings (1115). The rural tourism sector is rather small with only 263 places for staying [www.gencat.net/ctc, 2006]. The tourism in the coastal zone is limited to camping and secondary housing. The towns Eucalyptus and Riumar consist of secondary housing. There are four campings in the coastal zone, two situated near Riumar, one near Eucaliptus and one near la Tancada. The campings in the coastal zone are listed in table 2.3.

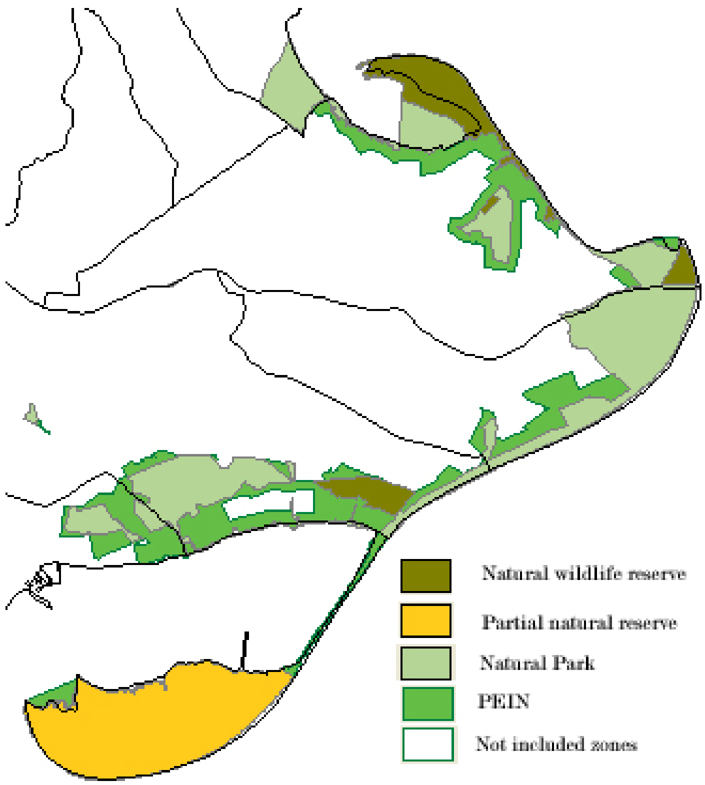


Figure 2.6: The areas in the Ebro Delta under protection by law [http://mediambient.gencat.net/cat/el_departament/cartografia/fitxes/inici.jsp, 2006]

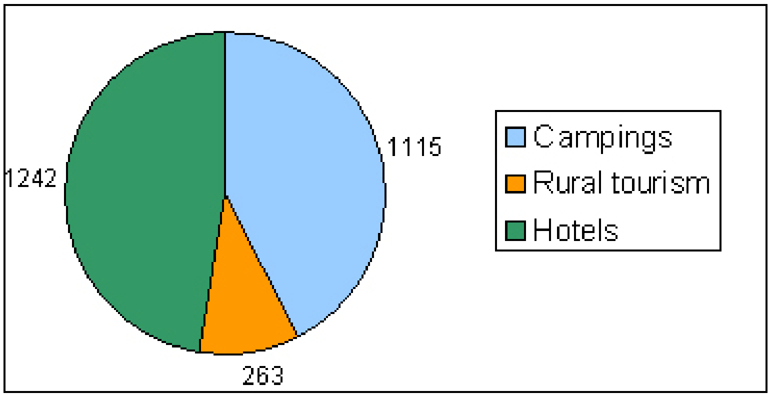


Figure 2.7: The division of residential modes [www.gencat.net/ctc, 2006]

A negative side effect of tourism to the coastal area (for example the Marquesa and Fangar beaches) is the deterioration of the natural defenses. For example the parking of cars among and unauthorized entry of the dunes have deteriorated the state of the dunes [Santalla, 2002]. Another negative side effect is the introduction of ships on the lower river courses of the river Ebro, which puts an additional stress on the area [Gràcia, 2006], for example due to the construction of a harbor near the Illa de Buda.

- **Salt extraction and transport:** this sector is of a very small and involves the salt extraction on the Trinidad Salt pans on the La Banya spit, and the transport of the extracted salt by lorries over the Trabucador bar. The salt is produced in basins on clay-limestone grounds, where the salt crystals are obtained by evaporation of sea water. The salt works of La Trinitat de la Punta de la Banya are exploited by the firm Infosa [www.ramsar.org, 2006]. The average production for a year is 60.000 tons, but in warm years (like 2005) the production can grow to about 85.000 to 90.000 tons [www.villaweb.cat, 2006]. The salt extraction on the La Banya spit is very important for the pink flamingo population in the natural park. The salt extraction industry has also taken responsibility for the repair of the Trabucador bar, after it partly disappeared after storms (for example in 2001) and there was an open connection between the Alfacs Bay and the open sea. This open connection had negative consequences for aquaculture.

The main threats for the delta are flooding of the Ebro Delta coast. This could lead to losses of wetlands and other natural habitats and damage to agriculture, assets (like the salt pans, residences and tourist facilities) and infrastructure. Due to agricultural activity fisheries decline and water quality in the Al-

Activity	**Estimated gross economic benefit Mil. Euro**	**Estimated production (metric tonnes/year)**
Agriculture	60	120.000
Fisheries	20	6000
Aquaculture	10	3000
Tourism and recreation	30	-
Salt extraction	1	60.000 tons

Table 2.4: Overview of economic activity and productivity in the Ebro Delta

facs and Fangar bays deteriorates, which has a negative impact on Aquaculture. Both aquaculture and agriculture are threatened by the coastal reshaping. Aquaculture due to the possible closure of the bays, agriculture due to the loss of natural defenses against flooding. Maintaining the current activities within the delta is questionable when present trends of are continued [Day et al., 2004]. The main threatened sites are (1) Illa de Buda (2) the Trabucador and La Banya spit and (3) La Marquesa. All three of these areas have their own specific land-use characteristics; the consequence is that the impact of a storm on the Delta system is of a different nature for all these three sites. Quoting J. Jiménez: ”The problem is not the flooding itself, but the flooding of land with a certain value for its user’. The storm impacts for the three sites are characterized (1) Ecological for Illa de Buda (2) Economic-ecological for Trabucador and La Banya spit and (3) Economic for La Marquesa. This means the impacts are either mainly economic, ecological or mixed, so not purely one of these sort of consequences.

1. **Illa de Buda (*Ecological*):** storm impacts have a main consequence for the natural system. The lagoon, *Els Calaixios*, behind the beach is characterized by both freshwater (from adjecant agriculture) and saltwater (from coastal overwash) inflows [Valdemoro et al., 2005]. The dominance of salt-tolerant species is expected to increase when the inflow of salt water becomes larger, due to an increase in overwashes induced by storm events.[Jiménez, 2005]

2. **Trabucador (*Economic/Ecological*):** firstly the Trabucador is used for the over land transport of the salt ’factory’ on the La Banya spit. The factory has a limited storage capacity of one week. When a storm destroys the Trabucador, the salt business on La Banya Spit is affected. The natural recovery of the Trabucador is too slow for the salt firm so it is often repaired artificially. Secondly the Alfacs Bay, behind the Trabucador is used for aquaculture (the production of mussels). The breaching of the Trabucador is associated with a loss in production for aquaculture. A loss in production of 15% was related to the storm events of spring 2004 [GdC]. Thirdly overwash of La Banya spit will have the same sort of ecological

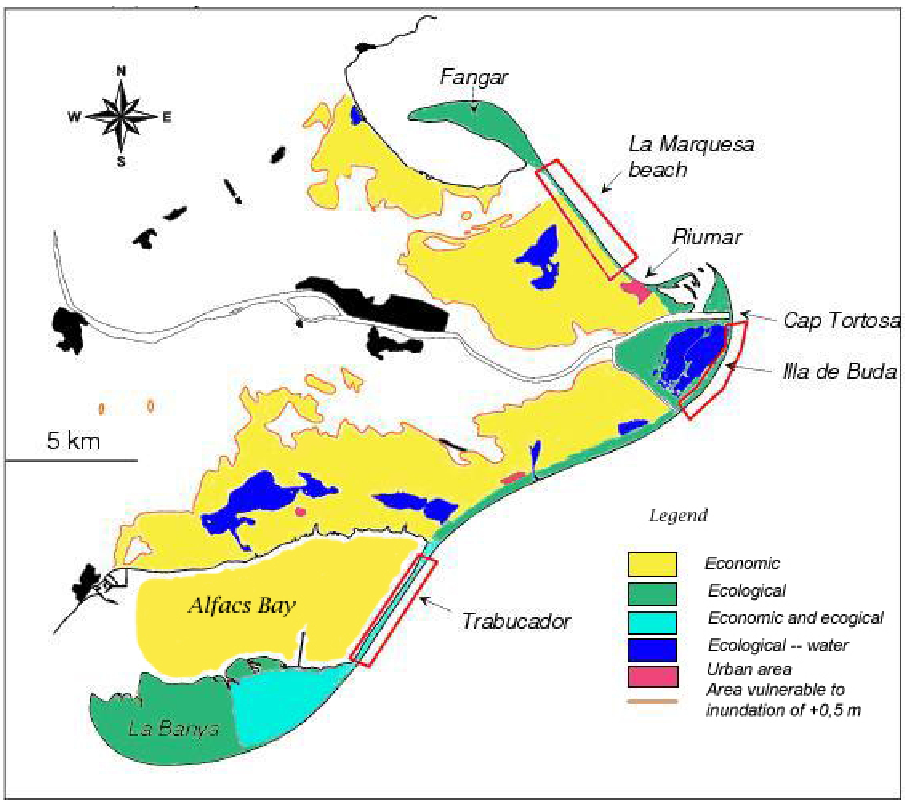


Figure 2.8: Main function of the vulnerable areas. *Adapted from:* [Sánchez-Arcilla et al., 1998]

consequences as for the Illa de Buda [Jiménez, 2005]

3. **Marquesa (*Economic*):** the overwashes over the hinterland at the Marquesa beach damages local rice production. Deposits of sands and salt negatively influence the productivity of the rice fields. Preliminary estimations determined that about 400 ha of rice fields are affected by storm impacts [GdC]. [Jiménez, 2005]

It can be concluded that there is a strong connection between the different socio-economic functions in the Ebro Delta coastal zone. When one function would disappear, this can have major consequences for the other. This dependency is shown in figure 2.9. This figure shows the relation between the functions/stakeholders in the delta, and how these functions influence each other positively (+) or negatively (-).

2.3.2 Authoroties involved

The organization of use of land and water involves public institutions from the supra-national level (European Union) to the local, community level. Figure 2.10 shows the hierarchical structure for water management in Spain on each level. The European Union influences the water and land use management on lower levels of governing through its directives and regulations on matters of environmental protection (for example the Natura 2000, birds and habitat directive), agriculture, water management (for example the water framework directive) and subsidies (for example the Common Agricultural Policy (CAP) subsidies). The main responsible for applying the policy from the supranational and national level for land and water use are the ministries of environment and agriculture. The watershed management bodies (the Confederciones Hidrográficas (CH)) report to the ministry of environment. The responsible body for the Ebro Delta is Confederacion Hidrográfica Ebre (CHE) [Alcácer-Santos, 2004]. The national water council is an advisory board made up of appointed representatives of the national and regional governments, the River Basin Authorities and private organizations with relation to water use. The Government in Catalunya is autonomous. Like national government it has a parliament and ministries. Natural resources, agricultural policies and land use planning are the primary responsibilities of the Autonomous Regional Governments. Autonomous governments are also responsible for setting environmental policies in accordance with national and European guidelines and for the management of natural and protected areas [Varela-Ortega et al., 2005a]. An example is the nomination of the PEIN habitats as areas subjected to Natura 2000.

The administrative division in Catalunya is made between regions and communities. These regions (in Spanish: comarcas) have no legislative powers. The Ebro Delta is divided into four communities; Deltebre, Sant Jaume d'Enveja, Amposta and Sant Charles de La Rápita. The first community is part of the region Baix Ebre and the last three are part of the region Montsià. The administrative devision of the Ebro Delta is shown in figure 2.11. These local

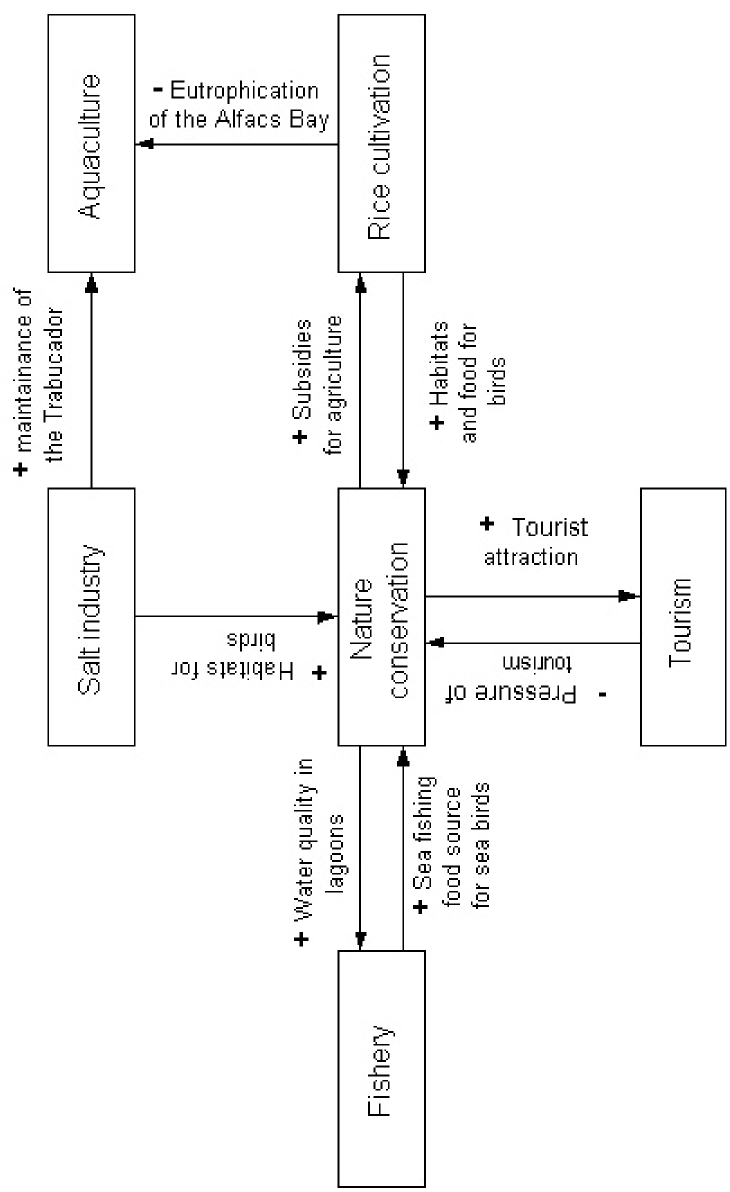


Figure 2.9: Relations between functions/stakeholders within the Ebro Delta

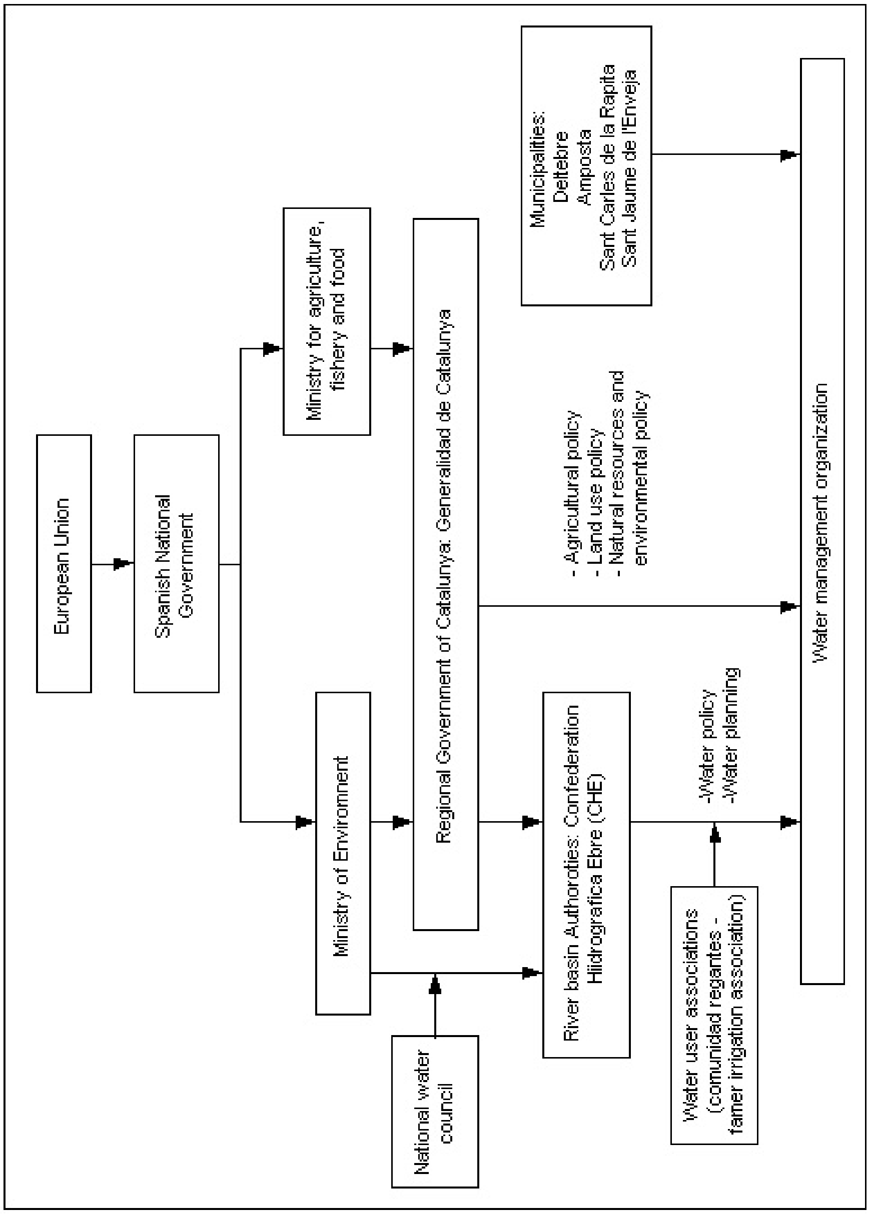


Figure 2.10: Water management hierarchical structure in Spain. Adapted from Varela-Ortega and Hernández-Mora [2005b]

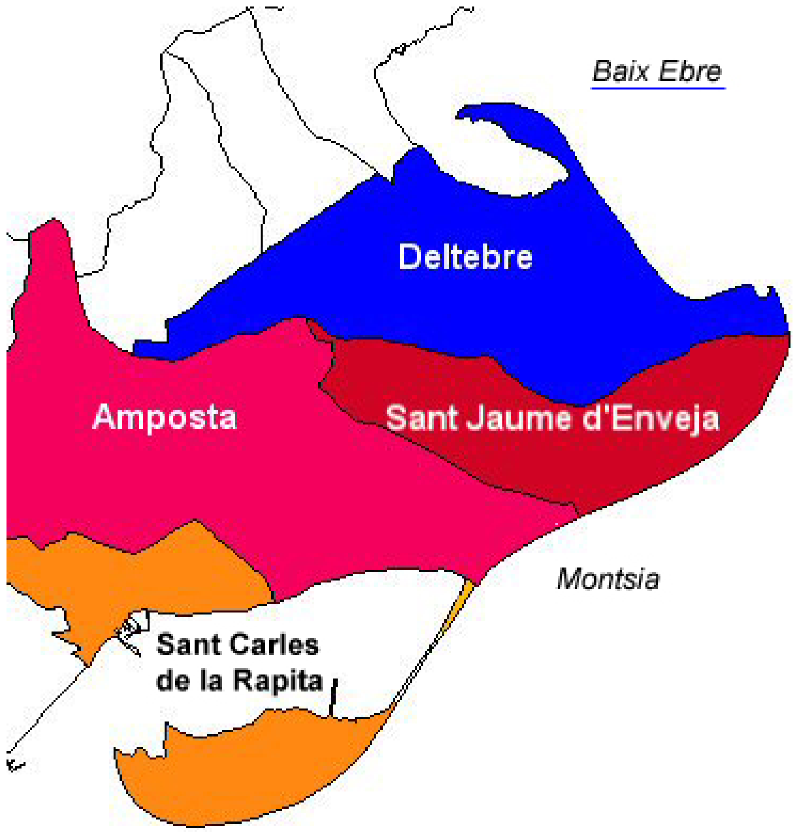


Figure 2.11: The administrative division within the Ebro Delta

municipalities are responsible for waste water treatment and management and for guaranteeing urban water supply. Furthermore they are responsible for urban land use planning [Varela-Ortega et al., 2005a]. The fair division of the water used for irrigation of the rice fields within the Ebro Delta is carried out by an irrigation organization, to which the farmers in the Delta make a financial contribution. The IRTA (Institut de Recerca i Tecnologia Agroalimentáries), is a state-owned firm, which works on food and agricultural research and technology and was created by the Generalitat de Catalunya. Concerning the Ebro Delta it is mainly involved in research on rice cultivation and agriculture and links the Catalinian ministry with its clients the agrarians [www.irta.es, 2006].

Chapter 3

Problem analysis

3.1 Problem definition

The task 26 research is a pilot study and is being undertaken to understand the value of integrated risk management for the Ebro Delta case, in order to increase the knowledge about practical usability of integrated flood risk management. Earlier work done by UPC (as described in section 1.5) can be characterized as flood risk analysis, and this research, of the University of Twente will contain many of the elements of Risk Assessment. The problem, as described in chapter 3, is that areas with different socio-economic functions in the Ebro Delta Coastal region are damaged due to storm induced flooding and coastal erosion. The coastal zone is defined as the area vulnerable to an inundation of +0,5 m, as shown in figure 2.8. Due to relative sea level rise the prospect is that the problem for the Delta further aggravates in the future. Before the end of this century more than 50% of the Ebro Delta could be below sea level. The different socio-economic functions within the Ebro Delta coastal zone; rice cultivation, nature conservation, salt industry, aquaculture and tourism, will experience more negative consequences of storm induced flooding and coastal erosion if present trends continue. To quantify the difference in consequences, the present and future socio-economic consequences of flooding and coastal erosion have to be compared. An altermative for the future is to change the land use of vulnerable areas in the coastal zone, which would aim at reducing the amout of damage for a specific type of land use. However land use changes may not be desirable as these changes affect the economic functioning of that specific area. Therefor these land use changes have aimed to be sustainable. For risk management problems like in the Ebro delta there is need of a methodology which guides towardes sustainable risk management.

3.2 Objective

Within task 26, the specific task has been assigned to the University of Twente to evaluate and quantify the integrated deltaic coastal response (physical, environmental and socio-economic) for flood effects in the Ebro Delta under different storm scenarios, through adaption of an integrated assessment framework [Jiménez, 2004]. Task 26 is a pilot study, so this means it should contain earlier work from the FLOOD*site* project, in order to *validate* its applicability in a real case. This research aims at combining physical aspects and socio-economic consequences of flooding. The intended result of this research is the formulation and application of a methodology which can be used to evaluate the effect of land use alternatives to the amount damage caused by present and future storm scenarios and sustainable spatial development of a coastal zone. This methodology combines elements of risk assessment with spatial multi criteria analysis and will be applied for different land use and storm scenarios for the Ebro Delta. The objective of this research is:
The formulation and application of a methodology which can be used to evaluate and compare land use alternatives on the amount of damage caused by a storm scenario and sustainable development
The amount of data which can be obtained for this research is limited. The goal of this research is to offer a methodology which could be used to assess the benefit of land use changes in a coastal zone have for the management of flood risk. The research will take six months to be completed.

3.3 Research questions

This section describes which knowledge is necessary in order to be able to reach the objective of the research. Therefor the questions have to be listed which have to be answered in this research to be able to gain the required knowledge. First a central question is posed, which will be split up in sub-questions.Each of the sub-questions is corresponding to a chapter in this report. The central question posed in this research is:
How can spatial multi criteria analysis and risk assessment be combined to a methodology that can be used to evaluate and compare land use alternatives on their suitability as a sustainable flood risk management alternative for the Ebro Delta coastal zone?
This central question is being split up into several sub-questions, which are listed below.

- **Chapter 4:** How can damage evaluation, risk perception and spatial multi criteria analysis be combined methodology?
- **Chapter 5:** For given scenario assumptions, what is the expected impact of storms and how will land use develop for the year 2051 in comparison to 2001 ?

- **Chapter 6:** What is the damage (risk) caused to the coastal zone by storm induced flooding and coastal erosion for each combined land-use and storm scenarios?
- **Chapter 6:** What is the perception of risk of the different stakeholders?
- **Chapter 7:** Which of these land scenario are judged as a sustainable flood risk management scenario according to this methodology?

In the final chapter, the conclusion and recommendations, the central question will be answered.

3.4 Definitions

In the previous sections (problem definition, objective and research questions), concepts used have remained unexplained. This section will give the theoretical background for the used concepts.

3.4.1 Risk

The concept of risk is closely related to the concept uncertainty. Risk is a concept that is invented in order to help people understand and cope with the dangers and uncertainty of life [Slovic, 2000]. There are two approaches for risk analysis: (1) the classical or objectivist view and (2) the Bayesian, constructivist or subjective view to risk [Singleton and Hovden, 1987, Rotmans, 1998, Aven and Kristensen, 2005]. In the classical view to risk analysis the uncertainty surrounding the risk is structured by producing an objective estimate of risk, which is done by analysing probabilities and consequences of events [Aven and Kristensen, 2005, Samuels and Gouldby, 2005]. The probability an event may occur is related to the analysis of the frequency this event has occurred, as reality was a laboratory experiment, where the experiment is repeated a large number of times [Covello and Merkhofer, 1993]. The classical definitions of risk always consists of a combination of the probability of risk and the negative consequence caused by the event. There are many different classical definitions for the concept of risk (see for example: Hanekamp and van Haren [1999] and Samuels and Gouldby [2005]), but within the FLOOD*site* project the most widely used definition is used (see the language of risk document: Samuels and Gouldby [2005]): Risk = (Probability) * (Consequence)

The Bayesian view holds risk as a product of perceptions [Covello and Merkhofer, 1993], which treats risk as a judgment rather than a fact [Aven and Kristensen, 2005]. In this approach probability is a number expressing the state of knowledge that depends on the information and experience of the individual who assigns it, so no true probability exists [Covello and Merkhofer, 1993, Aven and Kristensen, 2005]. Many attempts have been made to unify these two views on risk, for example Renn and Klinke [2002] and Aven and Kristensen [2006].

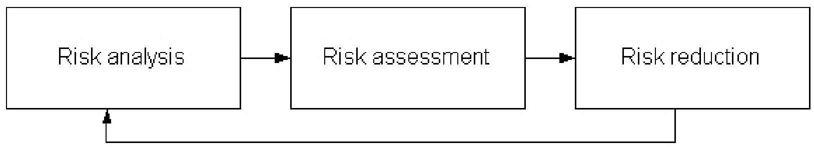


Figure 3.1: Basic framework for flood risk management

3.4.2 Risk management

Within the FLOOD*site* project flood risk management is defined as a continuous holistic and societal analysis, assessment and mitigation of flood risk. As stated, one of the main goals of the FLOOD*site* project is to manage these flood risks in an integrated way. How a flood risk is managed depends on the nature of the hazard, and this makes within the FLOOD*site* project, integrated flood risk management is spit up in three parts. *Risk Analysis* (1) is used to determine the nature and extend of the risk by analyzing potential sources of hazard and evaluating existing conditions of vulnerability. Secondly there is *Risk Assessment* (2) in order to evaluate the perceptions of risk and social tolerances in order to inform decisions and actions in the flood risk management process. This is then connected to the *risk management measures* (3), which compromises an action taken in order to reduce the flood risk. This FLOOD*site* flood risk management framework is presented in figure 3.1.

3.4.3 Scenarios

A scenario can be defined as an image of the future or of alternative futures. This is not a prediction or forecast, but an alternative image of how the future might unfold. Typical elements in a scenario are (1) the description of stepwise changes; the representation of the changes over time, (2) the driving forces; which describe the factors or determinants which are the drivers for the step wise change, (3) the base year; this is the starting year for the scenario (4) the time horizon and time steps and (5) the storyline; which is a narrative description about the scenario [EEA, 2001]. There are many different sorts of scenarios, of which in this report two sorts are used, (1) (storm induced) flooding and coastal erosion scenarios and (2) the land use change scenario:

1. **Flooding and coastal erosion scenarios:** the driver for these scenarios are the physical circumstances, as sea level and storm conditions at a certain moment, which are the cause flooding and coastal erosion. In this scenario the changes are represented by a story-line which explains how this possible future state might be reached. Important to note is that this sort of scenario is neither a prediction nor a forecast [EEA, 2001]

2. **Land use scenarios:** land use change is induced by an external driver, such as a bio-physical attributes or socio-economic drivers, as for ex-

ample land use policies [Veldkamp and Lambin, 2001]. This is an exploratory (or descriptive) scenario. An exploratory scenario is a scenario which starts in the present and explores trends in the future [EEA, 2001]. For the different land use change scenarios the performance can be calculated under input of the conditions prescribed by the storm scenarios. For each storm scenario the potential of a certain type of land use can be calculated in order to determine whether or not is advisable to change its current land cover.

The flood and coastal erosion scenarios are a boundary condition for the land use change scenarios; when flooding with certain characteristics occurs (for example a certain spatial scale), certain types of land use might be more appropriate (resilient) for such conditions.

3.4.4 Strategy

A strategy is a combination of long-term goals, aims, specific targets, technical measures, policy instruments and processes which are continuously aligned with the societal context. What is regarded as the best strategy today, may not be the best strategy tomorrow. Differences in perception between stakeholders, changing perception (for example because of a changing political context) may lead to changes in what is regarded as the 'best' strategy. [Samuels and Gouldby, 2005].

3.4.5 Sustainable Development

The concept of sustainable development originates from the Brundtland report. The classic definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to make their own needs" [UNCED, 1987]. A distinction can be made between weak sustainability and strong sustainability. Weak sustainable development accepts the loss of natural resources as long as they are replaced by man-made capital. Within strong sustainability natural resources and man-made capital are treated separately and cannot substitute each other [Opschoor, 1994]. Sustainable development comprises a certain balance among current and future socialcultural, economic and ecological developments [Martens and Rotmans, 2002]. Each of these pillars of sustainable development has indicators, which can be used to measure sustainable development [Barrera-Roldán and Saldivar-Valdés, 2002] These indicators are shown in figure 3.2.

When applied to flood risk management options/scenarios, these are sustainable when these strategies aim to be effective in the long term and these management options/scenarios can be integrated with economic, social and natural development. Effective in the long term means that on a long scale these scenarios are able to keep the flood risk to acceptable levels. Integration with development of socio-economic and natural functions implies that

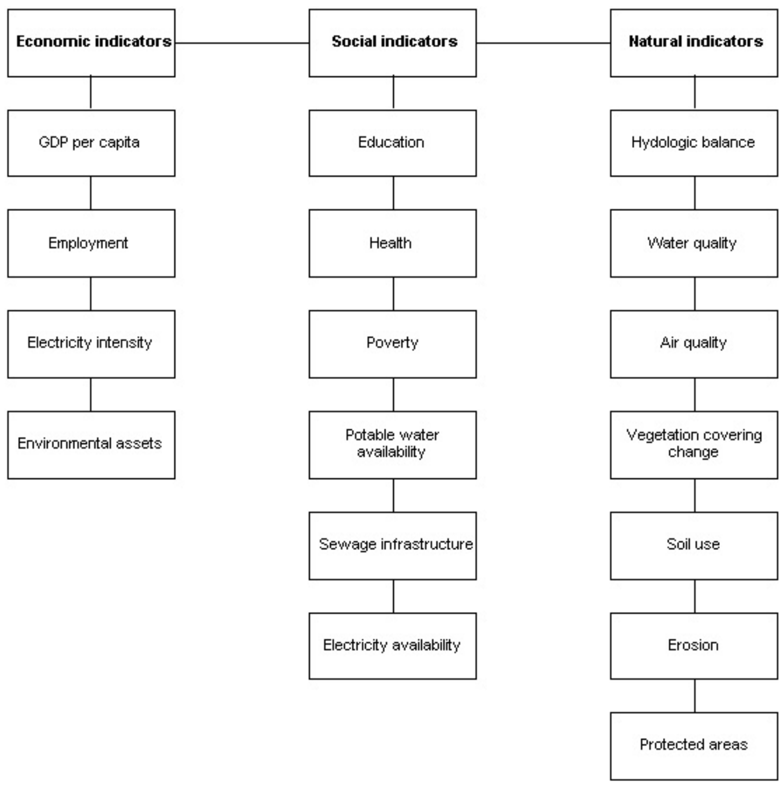


Figure 3.2: Sustainable development index [Barrera-Roldán and Saldivar-Valdés, 2002]

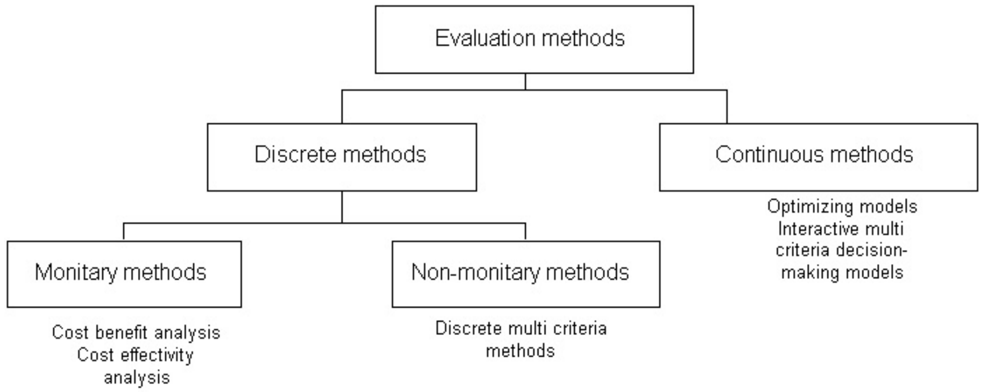


Figure 3.3: Different evaluation methods [Hellendoorn, 2001]

sustainable flood risk management options have to minimize effects on the development within the area at which the flood risk is imposed, the floodplain.

3.4.6 Multi criteria analysis

There are several ways to discriminate between evaluation methods. Firstly there is the difference between discrete and continuous methods. A discrete method evaluates a limited number of alternatives which are independent of each other. Within continuous methodology the number of alternatives is unlimited and the alternatives are dependent [Hellendoorn, 2001]. Secondly the difference between monetary and and non monetary methods can be made. This is shown in figure 3.3.

Of the monetary methods Cost Benefit Analysis (CBA) is the most widely used. Cost benefit analysis is the most suitable for the evaluation of only one or very few alternatives, of which the most effects can be monetarized [Hellendoorn, 2001]. There is a growing concern CBA fails to take into account social and environmental factors [Risk and , RPA]. When dealing with a problem with a large number of social and environmental aspects that are difficult to be monitarized and there is a larger number of alternatives available it is better to choose for discrete multi-criteria analysis (MCA).

Inside the multi-criteria analysis mathematic algorithms are used to determine the most favorable risk-reducing activity in the context of different risk perceptions, risk attitudes and preferences of decision makers and stakeholders [Samuels and Gouldby, 2005].

3.4.7 Spatial multi criteria analysis

Within spatial multi criteria analysis one extra step is added to the multi criteria analysis. This methodology is extensively described in van Herwijnen [1999].

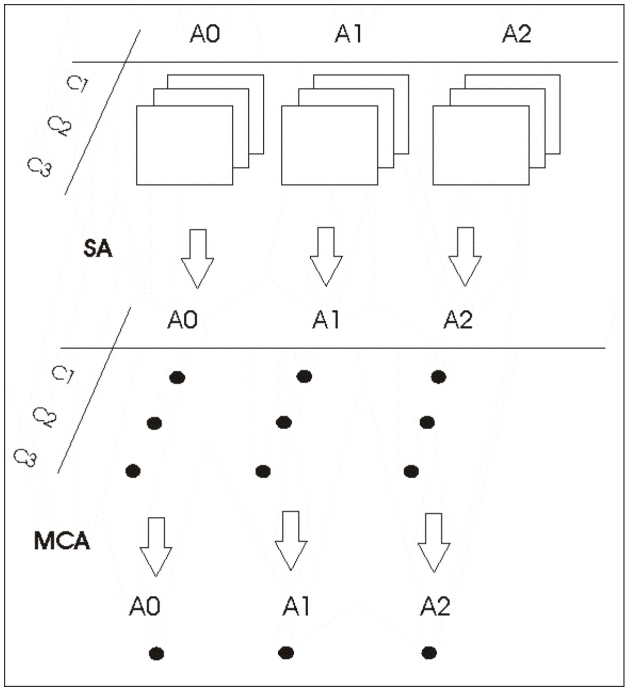


Figure 3.4: Spatial Multi Criteria Analysis. Adapted from van Herwijnen [1999]

The first step in the spatial multi criteria analysis is made by selecting different alternatives for the land use of the specific area. The alternatives are presented as maps in which the spatial arrangement of land use of each alternative is presented. The next step is to define the criteria on which the land use is measured. There are different objectives of the land use, for example ecological and economic development and by using the criterion the performance of each alternative can be quantified. After spatially arranging the scores on the criteria a *criterion map* is produced. This map shows the score of each alternative on the different criteria on a spatial scale. The criterion map is translated into a non spatial multi criteria analysis by spatial or non spatial aggregation. The most commonly used method is to take the average of the values in the map, but also a weighted average can be used for aggregation. After spatial aggregation the alternatives can be ranked according to the previously described multi criteria analysis. Figure 3.4 visualizes the spatial multi criteria analysis methodology.

3.4.8 Social multi criteria analyis

In recent literature there is a plea for the intensive involvement of stakeholders in the multi criteria analysis process. Banville et al. [1998] put forward that involving stakeholders makes the MCA procedures more democratic, as all interests can be incorporated, also those of the 'silent stakeholders'. These silent stakeholders are characterized by the fact that they personally have no direct control over the resources deemed relevant for solving the problem [Banville et al., 1998]. Different stakeholders have different cultural identities, goals and interests. A wrong image of the problem of most preferable solution may be created when multi-criteria is analysis based on the priorities and preferences of some decision-makers only [Munda, 2004]. In Social Multi Criteria Analysis stakeholders are involved in every step of the multi criteria analysis, especially within the determination of alternatives and criteria. The researcher takes the role as facilitator and for example defines the problem. Multi criteria analysis and stakeholder involvement are connected.

3.5 Software tools

The data needed for this research is partly available in literature. Land use data and statistics are available in English, Spanish and Catalan. Data not available in literature or not publicly available will be acquired by interviews with representatives of stakeholders. These interviews will be taken in writing and are inserted into the appendix of this report. Computer Programs are an important aid in order to process large amounts of data.

Miramon is the program that can read the maps produced by the Generalitat de Catalunya and other public organizations in Catalunya. Maps read this program have a *mmm or *mmz extention and can only be converted to a GIS format by one of the most recent versions of Miramon (5.2s). The procedure (in Catalan) is given in appendix B.

For the damage evaluation simulations of the effects of the two storm scenarios will be made with ARC-GIS, which is a Geographic Information System (GIS) used for processing and analyzing gegraphic data.

For the multi criteria analysis, which is part of the spatial multi criteria analysis the BOSDA program is used. The program supports the whole decision process: from the problem definition until to the sensitivity analysis. The user defines the different alternatives and criteria. The user scores these alternatives on the criteria. The program contains several methods to determine the weighing and ranking methods, which are both used to determine which alternative scores best on these criteria. The BOSDA program works on different scales; for example ordinal and binary scales. Next to the graphic presentation of the effects table, the correlation between criteria can be shown by the program. This to avoid double counting and to track possible conflicts between criteria.

Chapter 4

Methodology

4.1 Linking Integrated Assessment and Risk Assessment

Integrated Assessment (IA) can be described as a continuous iterative process, aimed at structuring complex issues, where insights from various scientific disciplines and stakeholder perceptions are communicated to the decision maker community. Learning effects gained in the policy process are taken as input in the iterative assessment process. [Rotmans, 1998, Pahl-Wostl, 2005] Communication between the decision and policy making community on one hand and the scientific and stakeholder community on the other hand guarantees the continuity of the process. Stakeholder involvement is not a necessary prerequisite within Integrated Assessment, however within the IA community the importance of stakeholder involvement recognized more and more [Rotmans, 1998, Hisschemoller et al., 2001].

Because of the uncertainty of the taking place and outcome of an event which poses a risk, Risk Analysis is complicated [Rotmans, 1998]. Integrated Assessment tries to structure and combine these various types and sources of uncertainty [Rotmans and van Asselt, 2001].

Risk Assessment is defined by Samuels and Gouldby [2005] as the understanding, evaluating and interpreting the perceptions of risk and societal tolerances of risk to inform decisions and actions in the flood risk management process. By risk assessment researchers try to understand and structure the negative consequences of a risk imposed in order to deal with this uncertainty. Risk Assessment is part of the Integrated Assessment methodology.

Clear similarities between Integrated and Risk Assessment are the link from scientist/stakeholder to the policy maker and the involvement of stakeholders. The FLOOD*site* project involves a large variety of scientific disciplines; for example Mathematics, Geography, Sociology, Chemistry and Civil Engineering. Like in Integrated Assessment, which attempts to describe the social dimension, economic dimension, institutional dimension and environmental dimension of the problem [Rotmans and van Asselt, 2001], Risk Assessment should make the same attempt to avoid disciplinary boundaries.

Recent research (see Aven and Kristensen [2005]) stresses the importance of unifying the traditional engineering approach and the social sciences perspective within Risk Assessment. This is the reason that Risk Assessment includes both damage evaluation (engineering) and research on risk perception (social sciences). Besides combining the work of disciplines, the opinion of stakeholders becomes important by taking into account risk perception.

4.2 Risk assessment

4.2.1 Risk perception

The methodology in this section can be related to the work of task 11 within the FLOOD*site* project. However the current status of this task shows not enough progress to include and fully test the methodology proposed in this task, however as much as possible elements from task 11 are being included.

Risk has a different meaning to different people. Risk perception is aimed at finding these differences and finding the causes for different perception of risk. Risk perception was first discussed by Starr [1969]. He made a distinction between voluntary and involuntary risks. In case of voluntary risk an individual uses his own value system whether or not to undergo the risk. Involuntary risks differ to voluntary risks in the way that the criteria and options are determined by a controlling body [Starr, 1969]. Later research of M. Douglas [1982] criticized the research of Starr, posing that the freedom of choice to undergo a risk, was not as large as Starr assumed. Also since 1969, society had changed. People required a higher safety and reliability, and stakeholders had intensified their action on rejecting involuntary risks [Sharlin, 1989, Aven and Kristensen, 2005]. From the 1980's a group of researchers around Slovic and Weber [2002] made a large contribution to the research on risk perception. They found that in risk perception there is a clear distinction between what experts perceive as risk and what the public (laypeople) perceives as a risk [Sharlin, 1989, McDaniels et al., 1996, Slovic and Weber, 2002]. Estimates of experts on risks are often based on the objective or classical determination of risk (risk is probability times consequence), while the judgment of risks by the general public are more related to the hazard characteristics. An example is the public perception on risks from the radiation of UMTS (Universal Mobile Telecommunications System) masts, which evokes large social concern, but according to experts is not more dangerous than drinking a cup of coffee. Until now research on risk perception has shown that when people undergo a risk they do not only take into account the risk itself, but also the benefit they gain from undertaking this risky activity. Their perception on the risk influences their trade-off between risk and benefit. Individuals and social groups judge risks intuitively and in a context of limited and uncertain information [Slovic, 1987], or as described in the FLOOD*site* Language of Risk document [Samuels and Gouldby, 2005]:

the view of risk held by a person or a group and reflects cultural and personal values, as well as experience.

This means that, translated to the flood risk arena, individuals and social groups mutually judge the risk of living in a flood plain differently, as well as they judge the risk differently from experts. Research in the perception of flood risk was mainly conducted in the UK; see Tapsell et al. [2002], Treby et al. [2005] and Messner and Meyer [2005]. Their research indicates that insight into perception, as well as managing these perceptions, is beneficial for the managing the flood risk in general. Within FLOOD*site* task 11 there are three concepts which are found to influence public perception on flood risk: *worry*, *prior awareness* and *preparedness* [Tapsell, 2006].

- **worry**: worry depends on the nature of the hazard, when the public has a large knowledge about the consequences and when the expected perceived damages/losses are small, the worry about the event is limited
- **prior awareness**: relates to the past experience with flooding and the information provided concerning the possible flooding to the public
- **preparedness**: preparedness of the people (pre-flood), their *capability to cope during a flood* and the *recovery capabilities and strategies* after a flood perception is linked to preparedness, and a well prepared society will experience less damage from a flood than an unprepared society, that maybe is not aware of the flood risk [Messner and Meyer, 2005].

4.2.2 Flood damage evaluation

Damage categories

The methods and guidelines in this part of the research originate from FLOOD*site* task 9, *'guidelines for socio-economic flood damage evaluation'*. The term flood damage refers to all sort of harm caused by a temporal covering of land by water outside its normal confines [Samuels and Gouldby, 2005, Pennning-Rowsell et al., 2006]. In some cases instead of the word damage, the word loss is being used. The words *damage* and *loss* refer to the same principle, but depending of the linguistic circumstances on of the two terms is preferred. For example the number of mortalities is referred to as loss of life, while to the loss of assets is mostly referred to as damage. Quoting Collin Green: 'everything we don't like about floods is either captured in the words damage or loss.'

Consequences of flood damages can be monetary as well as non-monetary. The flood damages/losses can be classified into four categories. Firstly the form of loss is *direct* or *indirect*. The direct loss refers the losses or damages caused by direct contact of the flood water. Indirect losses are caused by the disruption of *'physical and economic linkages'* and also include the costs of pre-flood measures, flood event measures and post flood measures. The second distinction can be made between tangible and losses. Tangible losses are losses that can easily be defined in monetary terms. Examples are losses of assets

	tangible	intangible
direct	Physical damage to assets	loss of life
indirect	loss of industrial production	inconvenience of post flood recovery

Table 4.1: Examples of direct, indirect, tangible and intangible damage

and production. Intangible losses are the casualties, health effects, damages to ecology and losses to all kind of goods or services, which are not traded in a market [Pennning-Rowsell et al., 2006]. The difference between intangible and tangible can also be characterized with the possibility to replace of a loss. Tangible losses can be replaced by financial compensation while intangible losses are not replaceable at all by financial compensation. This would characterize the losses of objects with a cultural or personal value (memorabilia) as intangible. Important in the work is to avoid double counting of damages/losses [Pennning-Rowsell et al., 2006]. Table 4.1 shows examples of direct, indirect, tangible and intangible losses.

The four basic steps of flood damage evaluation

Every flood damage evaluation has four basic steps.

1. Selection of an appropriate approach
2. Determination of damage categories and elements to be considered
3. Gathering necessary information and calculation
4. Calculation and presentation of the expected damages

The first step is conducted in order to find and appropriate approach for a damage evaluation study. This is primary scale dependent. The method depends on the spatial scale of the area under investigation [Pennning-Rowsell et al., 2006]. Equally important is the time scale for which the study is to be made. Next to this the scale of the study (objective, availability of time and money for the study and related to that, availability of pre-existing data for the study) is a selection criterion for the study [Pennning-Rowsell et al., 2006]. The methods for flood damage evaluation distinguish into three categories.

1. Micro-scale: object oriented approach, for example damages are calculated for single properties.
2. Meso-scale: aggregated land units, for example residential areas
3. Macro-scale: whole administrative units: for example municipalities

The macro, meso and micro scale have to be considered relative to the spatial scale whole study area considered. Damage databases have extended over the years and this enables researchers to do flood damage evaluations on regional or even national level. The smaller the scale for damage evaluation, the larger is the required precision of the study.

The second step is to make a first selection for damage categories, which are to be considered relevant for the study. Possibly, at first glance, a certain type of damage can be considered to be of negligible importance to the total amount of damages [Pennning-Rowsell et al., 2006]. For the direct, intangible effects a similar list of effects as for the tangible effects can be made. Important to remember is that these impacts are best expressed in non-monetary terms. For example storm induced impacts like salt intrusion or plant removal due to flooding and coastal erosion causes changes in the physical circumstances in the Ebro Delta coast region, which may lead to loss of habitats or changes in biodiversity. The loss of habitats is considered the most relevant intangible damage category for this research.

The third step is gathering the necessary information and calculation. Firstly the characteristics of the storm induced impacts have to be described. These impacts are flooding and coastal erosion. Simulations or previous recordings can be used to describe the impact after a storm with certain wave and water level conditions. The inundation characteristics is the first type of information required for the damage calculation. Important characteristics are (1) the area which is inundated by the flooding, (2) the water depth at a certain place during the flooding (which requires elevation maps), (3) the flow velocity (higher velocities will lead to higher damages), (4) the duration of the flooding (which is important how how much a specific building fabric in affected), (5) the time of the year the flooding occurs (which is relevant for damages to agriculture), (6) the rise rate (warnings can have a damage reducing effect) and (7) the contents and loads of the flooding water (salt of fresh water and possible contaminations of the water). Secondly the land use data has to be gathered. This land use data can be object oriented (micro approach) or aggregated (meso and macro approach. In the aggregated approach objects of a homogeneous sort of use are grouped. This can lead to some inaccuracies, as homogeneous distribution of the characteristics of the objects is assumed (for example mean value of buildings and an equal distribution) [Pennning-Rowsell et al., 2006]. An example of aggregated land use maps are the CORINE land use data used in this research. Thirdly, after documenting the location, number and type of elements at risk it is necessary to quantify their value in order to calculate damages in monetary terms [Pennning-Rowsell et al., 2006]. The value of tangible elements at risk is being calculated by determination of the current price for replacing the object for a similar one. This is called the *full replacement value*. The value of the loss of habitats, the intangible damage, is determined by relative valuation. A widely used method to estimate the value of habitats, which can be used in order to determine losses, is economic valuation (for economic evaluation of wetlands see for example Barbier et al. [1997]), wherein a monetary value is assigned to each habitat. However in this study a relative value approach is taken, in which the intangible values of each separate ecosystem compared in order to produce a relative value for each ecosystem which can be ranked. The advantage of this method is over economic valuation is that it requires less information and it is less time consuming [www.ecosystemvaluation.org, 2006]. Relative valuation can be conducted by expert judgment. Not each element at risk has the same resistance to flooding. On a spatial level, elements subjected to a flooding experience different inundation characteristics (as water depth) Therefore, fourthly, damage functions are formulated. Forms of damage functions are the depth-damage function in which the damage to a object is related to the inundation depth, and time-damage functions in which the amount of damage is related to the time in the year the flooding occurs. Some houses are more resistant to flooding (for example concrete more than wooden houses) and during a flooding the water in the house may only reach a certain level. For assets like housing and the interior the amount of damage is dependent on the inundation depth and the building material. A relative damage function, as used in this research shows the damaged share of the total value of the object as a function of the inundation depth [Pennning-Rowsell et al., 2006]. Then the fourth step, the calculation and presentation of flood damages can be carried out. Damages can be calculated with information of the previous steps. The damages can be presented as a single value per type of land use, but also the location is of these damages is important. The spatial distribution of damages is visualized in damage maps. The last step is to document the uncertainties within the damage estimation. Assumptions and inaccurate data lead to uncertain damage estimates These uncertainties which always occur, should be documented to inform policy makers and the public about possible inaccurate results. This makes it clear to them how much they can trust the data on which they may possible base their decision [Pennning-Rowsell et al., 2006].

4.3 Sustainable land use

Sustainable development has three major components (see figure 3.2); it is measured by economic, social and natural indicators. Sustainable development of land use in a particular area has to integrate aspects of environmental protection, social welfare and economic growth. Other landscape functions important for sustainable development are biodiversity and mitigation abilities to deal with extreme events [Wiggering et al., 2006]. Sustainable land use comprehends the development of human and environmental land use. The economic and ecological activities in the area have to be carefully balanced out in order to make the development sustainable [van Herwijnen, 1999].

A particular land use delivers products (outputs), as for example rice by agriculture. Two sorts of outputs can be distinguished; (1) *commodity outputs (COs)* and (2) *non-commodity outputs (NCOs)* [Wiggering et al., 2006]. Commodity outputs are the goods which we can sell on a market (tangible outputs), non-commodity outputs are the outputs which meet the social and environmental needs of society (intangible outputs). Non-commodity outputs of land use are the reduction of negative externalities (for example floods), as well as the production of positive external externalities (for example providing a habitat for birds and employment for local people). This is shown in figure 4.1.

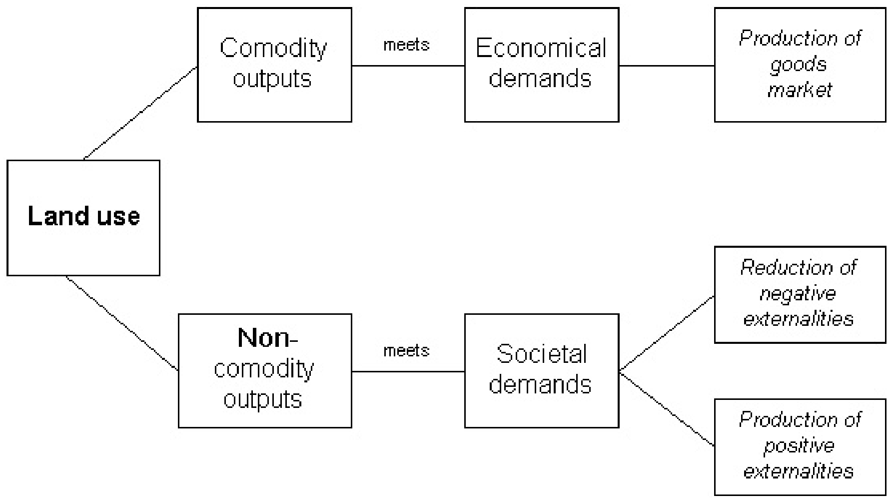


Figure 4.1: Commodity and Non-commodity outputs of land use. Adapted from Wiggering et al. [2006]

Sustainable land use requires the balancing of societal and economical demands on land use. This means the three indicators of sustainable land use; the output of goods, the production of positive externalities and the reduction of negative externalities have to be integrated in to a landscape, where the importance of each function depends on the weight a society gives to this function of land use. This requires the comparison of these three indicators. Within the FLOOD*site* project the comparison between tangible outputs and intangible outputs is already stressed (see Samuels and Gouldby [2005]). The comparison of these two indicators with the reduction of a negative externalities is less clear. The negative externality in the case of this research is the risk posed by storm induced flooding and coastal erosion.

Commodity and non-commodity outputs can be regarded as benefits of a particular land use. A benefit is a profit or gain made by a particular land use. Research over the years that these tangible and intangible benefits are related.Singleton and Hovden [1987] wrote:" when considering the risk of a certain activity it must always be weighted against the benefits of that action". From research over the years can be concluded that benefits play a significant role in the individual's choice to undergo a risk. Starr [1969] was one of the first to do research on the trade of between risk and benefit made by individuals and society. He concluded that a greater risk is accepted when there is a greater benefit of risk, or in other words there is large correspondence between the beneficially and acceptability [Vlek and Stallen, 1981]. This was later confirmed by Slovic [2000].

In the contrary to their agreement on the correlation between risk and benefit, researchers have different approaches on how to measure benefit. Starr measures benefit either as the average amount of money spent on this activity by a single participant or the average contribution this activity makes to the participants income [Starr, 1969]. Vlek and Stallen [1981] describe the judgments of beneficially in two dimensions; the first one can be described as personal necessity. The second one is described as the scale of production and/or distribution of benefits. The judgment of benefits of a hazardous activity are highly subjective, in which knowledge about the risk-benefit ratio is an important factor, and so considerable differences in the judgment of laypeople and experts may be expected [Fischhoff, 1979, Dreyfus, 1984].

When applied for land use, a stakeholder which receives large benefits from a particular land use under flood risk, may be willing to accept a higher risk. This may lead to the rejection of particular land use changes.

4.4 Alternatives and Criteria

4.4.1 Scenarios

A scenario is an alternative image of the future [EEA, 2001]. A scenario starts form the base year, the first year of the scenario. A scenario is hardly ever one description of one alternative future on its own, but is a set of alternative futures, with different assumptions for the stepwise development from the base year. Scenarios come in two forms, *qualitative scenarios* and *quantitative scenarios* [EEA, 2001]. Quantitative scenarios describe the future in word and visualisation rather than numbers. An example for a quantitative scenario is a land use scenario. A qualitative scenario use numerical information for calculation of future states of a system. An example of a qualitative scenario is a storm scenario. A second distinction can be made between *baseline scenarios* and *policy scenarios*. Baseline scenarios are known as the benchmark or non-intervention scenarios. They represent a future in which current trends are continued, without any intervention. An example is the Business As Usual scenario (BAU). These baseline scenarios have to be compared to future scenarios where intervention takes place, a policy scenario. Policy scenarios are sometimes also named mitigation or intervention scenarios. In these kinds scenarios a policy intervention is made to reduce the possible negative future impacts on a system observed in the baseline scenario. An example of a policy scenario is a land use change scenario. Land use change can be used as a mitigation measure for flood risk. Different assumptions about the future will lead to a different number of baseline scenarios and policy scenarios. However the use of a too large set of scenarios may be not wise as policy makers cannot absorb the information anymore. The downside of scenarios and especially qualitative scenarios is that they contain many implicit assumptions about the future. A larger set of scenarios may include more assumptions about alternative futures and may distinguish a larger uncertainty. A good scenario will describe a plausible future and systematicly gather information about certainty and uncertainty. Scenarios are not intended to be truthful, but rather provocative and helpful in strategy formulation and decision-making [Selin, 2005]. The use of scenarios may expose to a policy maker what is known about the future and what is not known and what are possible intervention alternatives. A policy maker can base his decision on better understanding of the future. Similarly as scenarios, multi criteria analysis is mostly used on the strategic level. This means it is not used as a tool for making the final decision itself, but rather as a tool to compare different kinds of impacts in the early phase of decision making [Janssen, 1999]. Scenarios deliver a large amount of data on future impacts and future consequences for different policies (strategies). Some of these policy alternatives will result in conflict among stakeholders. For example: what is the reduction in commodity output for farmland we allow in exchange for the reduction of risk? Multi criteria analysis is a tool to analyse these chosen strategies and compare them on conflicting viewpoints and criteria [Lootsma et al., 1990]. The goal of using the combination of scenarios and multi criteria analysis is to provide insight to a policy maker into future consequences of a land use alternative and to compare and provide insight into the conflicting interests for **a particular land use**.

4.4.2 Acceptability of risks

The Ebro Delta coast is subjected to risks from storm induced flooding and coastal erosion. When an individual examines risk, or determines his preference toward it, it is with the intent of determining whether or not to accept the level of risk, reduce the risk, or avoid it all together [Sharlin, 1989]. When the flood risk is regarded as unacceptable, two paths of action remain to the policy maker: reduce the risk or avoid it all together. However these management options the policy maker has will not only tend to reduce the risk, but as a possible side effect also influence the COs and NCOs. Reduction of risk typically entails reduction of benefit, thus posing serious dilemmas for society. When the policy maker takes the societal context into account, the policy maker will be confronted with the case that the reduction of risk often leads to a reduction of benefits (commodity outputs). In other words the policy maker must make a trade-off between risks and benefits [Fischhoff et al., 1978]. For example turning large parts of the Ebro Delta presently used for agricultural purposes into natural area may be a good measure to reduce the flood risk (probability or consequence), but may be regarded unacceptable from an economic standpoint, as it will reduce the agricultural output and employment in this sector in the area. So it can well be that a certain risk reducing management option is available, the policy maker under influence of part of the society subjected to the risk, may decide not to utilize this management option, because society prefers the benefit gained by an activity under risk over the reduction over the risk, but as well reduction of their benefit. The real risk posed is often not equal to the perceived risk. This means an individual unaware of the risk that he is subjected to may continue his activities, while after he has been subjected to the risk (for example experienced a flooding), may decide to abandon it. An individual or group will make a trade-off between the perceived risk and perceived (expected) benefits. Starr [1969] concluded that society has, by trail and error, found a sort of optimum balance between risk and benefits originating from a certain activity. He concluded that the acceptability of an activity is proportional to the third power of the benefits of that activity. According to Starr the public seemed roughly a thousand more willing to accept risks from voluntary activities than of involuntary activities. In later work [Fischhoff et al., 1978, Sharlin, 1989] is stated that the distinction between voluntary and involuntary risk is not as clear as Starr assumes. Fischhoff [Fischhoff et al., 1978] stresses the importance of risk perception characteristics other than voluntariness (like degree of control and acquaintance) on an individual's choice. More recently Sarin and M.Weber [1993] proposed the application of economic theory based risk-value models in risk benefit analysis. Later, Weber et al. [2002]. proposed to make the preference of risk function of the perceived (expected) benefit and perceived risk.

$$Preference(X) = a(expectedBenefit) + b(perceivedRisk) + c \tag{4.1}$$

The most important conclusion that can drawn from this formula representation and earlier work, that acceptability of risk is a sort of trade off between the factors risk and benefit in the context of the perception of risk.

4.4.3 Risk perception and decision making

Roughly a distinction between two approaches to risk assessment can be made. The first one is a technical one, which tries to capture the concept of risk in the framework of probabilities and consequences. It is a useful instrument, as this is the way how risks can be compared relatively to each other [Renn, 2004]. Policy based on this approach will find solutions that minimize the product of probability times consequence. However, technical risk assessment gives only part of the information for a meaningful risk assessment. In the second approach, the Bayesian, holds risk as a judgment based on the background information the assessor has, thus risk perception plays an important role [Aven and Kristensen, 2005]. The policy maker has to take into account that the societal context plays an important role in the decision making process. The reduction of risk has to be weighted against the reduction of benefits [Fischhoff et al., 1978]. Slovic [1998] argues that whoever controls the definition of risk controls the rational solution to the problem at hand. As the policy maker will choose the safest or most cost-effective solution, while laypeople may choose a solution that will least affect their benefits, but may not the most cost-effective or lead to the highest levels of safety [Fisschhoff et al., 1984]. Pidgeon [1998] describes both five arguments both for and against including risk perception into decision making. Not each of these arguments is equally important for this research, the most important arguments will be described. The main argument against the inclusion of risk perception is that the public perception is biased. This is illustrated earlier the example on UMTS in section 4.2.1. This may lead to the diversion of resources and attention to problems that scare the most instead of harm the most. A counterargument is that the judgment of the policy maker may be biased as well, for example due to overconfidence in their own analysis. Not much an argument against, but more an important note is that risk perceptions are not homogeneous, while for decisions on acceptability often a single view is required. However, it is questionable if in decision making process a single view ever exists, as even when a decision is taken all stakeholders have the same opinion on a solution or all interests of stakeholders have been met. An important argument for including risk perception is the that it makes the decision process more democratic by including opinions of stakeholders. Engagement of stakeholders is an important part of Integrated Assessment as it is argued that including values, preferences and knowledge of stakeholders will enrich and improve the quality of research as it gives access to practical knowledge, experience and a wider range of perspectives and options [van Asselt and Rijkens-Klomp, 2002]. Including risk perception in risk management may eventually contribute to social learning. Social learning involves the building of a shared problem perception of stakeholders (not reaching consensus, but recognizing and using differences in perception to deal with problems constructively), enhancing mutual trust and relations between stakeholders and the provision for better insights into the system to be managed [Pahl-Wostl, 2005]. Risk perception can give insights into the extend risk can be accepted by voluntary agreement [Renn, 2004]. For flood risk, risk perception can be measured in terms of three indicators: (1) worry (2) awareness and (3) preparedness. The more people worry about or even fear the risk, the larger the demand from society is to reduce the risk [Slovic and Weber, 2002]. The same is valid for awareness; the more stakeholders have been confronted with the negative consequences of a risk, the more the demand for reduction of the risk will be. For preparedness an inverse relation is valid; the more prepared a society or system is for a risk event the less the demand will be to reduce the risk. Accordingly there is a larger willingness-to-pay for risks with a high demand for reduction, risks which is worried about and the possible pathways to solutions are known [Savage, 1993]. The acceptability of risk is a sort of trade-off between risk and benefit in the context of risk perception. This is shown in figure 4.2.

4.5 Spatial Multi criteria analysis

4.5.1 Introduction

The major advantage of multi criteria analysis over cost-benefit analysis is its ability to take into account non monetary criteria (for example intangibles) [Nijkamp and van Delft, 1977]. The downside of this approach is that the weights given to each of the criteria are *uncertain* as the evaluation methods include different assumptions of the researcher. Multi criteria analysis is an instrument that is often mistrusted at the start of a decision process by the decision

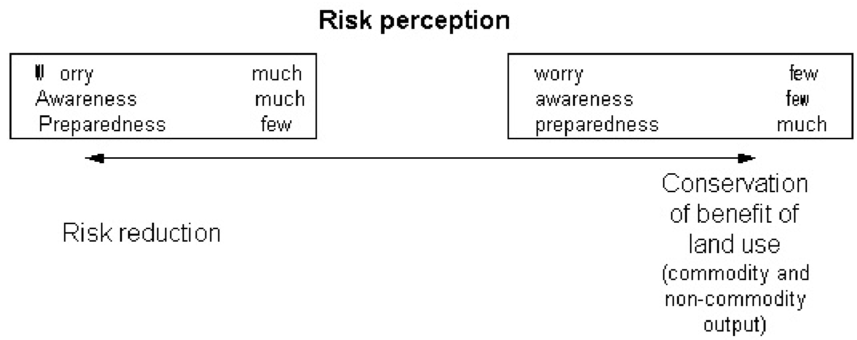


Figure 4.2: The influence of risk perception on the trade-off between risk and benefit

or policy maker. They fear a technocratic instrument that can be manipulated easily [Janssen, 1999]. In section 4.5.6 is described how this problem is treated. In order to select the spatial performance of alternatives spatial multi criteria analysis is an effective tool. Spatial data can be described by two components; (1) attribute and (2) position. The attribute is the non-spatial component, for example the amount of damage, and the position is the spatial component, for example the location which is subjected to damage. A third component is time, because spatial data is mostly valid for a certain point in time. There are four dimensions for spatial data. A point, which has the spatial dimension of zero, a line, plane and cube, with a spatial dimension of respectively one, two and three. Basically, there are two ways to deal structure spatial data; in a vector or raster data [van Herwijnen, 1999]. Vector data are used for the storage of line information and/or for the storage of homogeneous areas at closed lines (polygons). One line connects two end points (nodes) each, which also have coordinates. Each vector object can be assigned with none, one or several attributes. Raster data are data continuously spread in space, which are structured in a measured matrix of usually quadratic cells and cells with the same size. This is illustrated with figure 4.3 [GDF-Hannover]. For overlay and spatial analysis the raster structure is the more easy method, but vector analysis is the more precise.

4.5.2 Selecting spatial alternatives and criteria

The alternatives are represented by two kind of scenarios (1) baseline scenarios (the business as usual scenario (BAU)) and (2) policy scenarios (land use change scenarios). These scenarios are described in chapter 5. The Business as usual scenario is the zero alternative, this is to compare the scenario that propose changes to the scenario no policy interventions are made to current policies. The land use change are meant to reduce the vulnerability of the coastal zone.

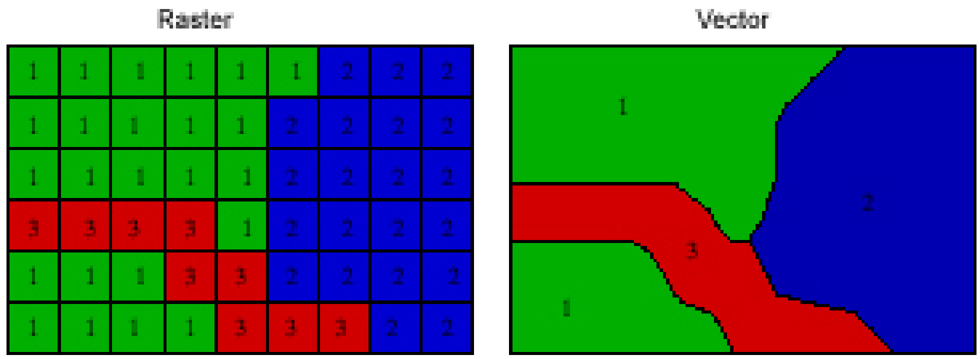


Figure 4.3: Raster and vector visualization for identical spatial objects [GDF-Hannover]

Criteria are used to evaluate the effects or impact of alternatives. They measure how effective the alternatives are at reaching the objective. A criterion can be either (1) explicitly spatial (2) implicitly spatial or (3) non-spatial. The values of explicitly spatial criteria differ per location, while an implicitly spatial criterion does not differ per location within the research area, but to find its value spatial data is needed. [van Herwijnen, 1999]. The objective of the report is to find sustainable risk management measures. A risk management measure is an action taken to reduce either the probability of flooding or the consequences of flooding or some combination of the two [Samuels and Gouldby, 2005]. Land use changes reduce the consequence of flooding, but will in general also effect the COs and NCOs of the landscape.

The first group of criteria will be the amount of risk which is posed to the coastal zone, which consists of a combination of probability and damage due to flooding or coastal erosion. The possible damage can be tangible as well as intangible. The due to their different nature (monetary and non monetary) damages can not be added and have to be treated separately. These criteria are explicitly spatial.

The second group of criteria will be the change in outputs of a particular land use. This is divided into the commodity output (tangible), measured as the *market* value of outputs per habitat type per year and the non-commodity output, measured as the relative value V_e of the habitat. The criteria are listed here:

- Risk:
  - risk due to tangible damage [Euro]
  - risk due to intangible damage [relative value]
- Sustainability:

- commodity outputs: commodities produced per land use type per year [Euro/year]
- non-commodity outputs: relative value of habitat types

Spatial models, as damage evaluation result in maps that show the impacts for every location. This means the effect for a land use scenario on a criterion (for example: tangible damage) is not just one value, but a matrix of values. These values can be visualized as a map, which is named a criterion map [van Herwijnen, 1999].

4.5.3 Aggregation

Aggregations methods are methods that transform of a map into one value. There are two different methodologies of aggregation; non-spatial aggregation and spatial aggregation. The most simple methods are the non-spatial aggregation methods. In this method the aggregation of a value map is most simply done by taking the average of the values in the map. By taking the average it is assumed that the performance at all locations is equally important. If this is not the case, the weighted average can be calculated. For this method a weight is assigned to every location in the grid. A spatial aggregation method is spatial auto correlation. This method compares the degree to which the values in a map are equal to the ones surrounding it. This method can be used to calculate the degree to which advantages or disadvantages are grouped. The scale of this index ranges from -1 to +1. With low values (approaching -1), the advantages or disadvantages are equally spread over the grid, while when (approaching +1) the advantages or disadvantage are grouped.

4.5.4 Multi Criteria Analysis

After spatial aggregation the problem evaluation is reduced to a (non-spatial) multi criteria analysis. The score for the different alternatives on the criteria is known. This can be represented by the effects table. After the effects table was filled in, the next step is to evaluate the problem. The evaluation of the problem has four steps: (1) standardization, (2) determination of weights (3) ranking (4) sensitivity analysis [Janssen et al., 2000].

4.5.5 Standardization

The first step in evaluation is standardisation of the effect scores. Data for different criteria are expressed in different units. These data can only be compared when these units are made dimensionless. This is done in a standardization procedure. In BOSDA two different linear standardisation methods available for this purpose. The most important methods are: (1) Maximum standardisation and (2) Interval standardisation. The standardized value is named (v_j) [Janssen et al., 2000].

1. **Maximum standardization:** The effect score (P_ji) is divided by the maximal score of the alternative on that criterion (the maximal value in that row: $\max_j$). The maximum standardization is expressed by equation 4.2:

$$v_j(p_{ji}) = P_{ji}/max(p_j) \tag{4.2}$$

2. **Interval standardization:** this method determines the distance of the score to the minimal effect score $\min_j$, divided by the maximal difference between the effect scores. This is expressed by equation 4.3:

$$v_j(p_{ij}) = (p_{ij} - min(p_j))/(max(p_j) - min(p_j)) \tag{4.3}$$

4.5.6 Determination of weights

weights for multi criteria analysis

Criteria reflect the performance of the sub-goals, which have to be achieved to reach the objective of the study. The criteria are not always equally important. The weights in a multi criteria analysis are assigned to prioritize the relative importance of the criteria [van Herwijnen, 1999]. A major problem in multi criteria analysis is that the weights are subjected to the judgment of the policy maker. For a policy maker it is difficult to assess the relative importance of each sub-goal for reaching the objective. This can lead to the production of inconsistent weights, which may lead to unreliable outcomes of the multi criteria analysis [Yeh et al., 1999]. There is a large number of methods available to determine the weights. The process of gathering weights for input to MCA is arguably the most time consuming and controversial part of the MCA-based process. The fundamental problems affecting the process are in determining whose weights are to be used and ensuring that the weights are credible and justifiable [Risk and , RPA]. Examples are (1) own judgment (2) pairwise comparison (3) expected value method and (4) extreme weight method [Janssen et al., 2000]. When applying weighted summation it is important to choose a good standardization method. The total of the assigned weights has to sum up to the value of one. Firstly a method including risk perception for the calculation of weights will be described, this weighting is based on the own judgment methodology, in which a policy maker determines the weights based on own knowledge and judgment. This method will be compared with the pairwise comparison methodology which is a more mathematical approach.

public consultation in determining weights

The method of public consultation for determining the weights faces some problems and controversies. Weights are strongest indicator for the preference of stakeholders for a category of impacts (reflected in the criteria). Since different stakeholders with different backgrounds are consulted weights reflect the opinion of stakeholders. The weight for different criteria reflects the weight given to different groups in society [Munda, 2004]. When stakeholders would be asked to directly assign a weight to criteria, which are used to determine the most preferable alternative, they would value the weight in this way that their interests are best met and would aim at an outcome which results in preference for the alternative with the least negative consequences for their interests. This means when all stakeholders would assign a weight to a specific criterion, obtaining one aggregated weight would create problems as the researcher would have to assign a relative importance to these opinions. The researcher would have to develop a method to aggregate these weights. For example taking the average of all by stakeholders assigned weights, would be a method subjective to discussion, as taking the average would not reflect the possible importance of one stakeholder over another in context of the problem. For example a land owner at the Marquesa would directly experience (negative) consequences of a land use change there, while a change would have no direct consequences for the salt industry. Another disadvantage is that stakeholder consultation does not always provide enough information and is difficult to interpret, so in practice this method would be useful for high level or preliminary assessments [Risk and , RPA].

Risk perception in multi criteria analysis

Why can risk perception be a useful instrument in determining weights for multi criteria analysis? The first downside of using stakeholder opinions for determining weights is that groups in society would be given a relative importance. However risk perception is not an opinion as such but an intuitive judgment. The most obvious demographic predictors (age, political affiliations etc.) either show no measurable effect on risk perception or account for only a small percentage of the variance in judgments [Pidgeon, 1998]. This means risk perceptions can be aggregated to one indicative value which is the general influence of risk perception has on the trade-off between reduction of the risk or reduction of the benefits. In most cases reduction of risk is not possible without reduction commodity outputs and/or non-commodity outputs. A large worry among the public will legitimize action to reduce the risk, which has as a consequence that commodity or non-commodity output will decline.

Both the risk perceptions of experts and the laypeople can be biased. This may mean the public attaches more importance for reduction a particular risk than authorities do. The initiative for putting a risk on the political agenda lies with the decision maker, for which he compares his perception to that of the stakeholders. It may be that stakeholders prioritize a certain risk less or more than the policy maker. So comparing risk perceptions of lay-people may help prioritizing the political agenda.

Worry, preparedness and awareness correlate. People which have never directly experienced a flood (not aware of its consequences) will worry less than other people. People which are not (possibly) directly affected by will not have the need to prepare themselves. In most cases these indicators will amplify or weaken each other. The weighting by risk perception for the trade-off between risk and benefit for mca is shown in figure 4.4. For quantitative expressions for worry, preparedness and awareness stakeholders have to be asked to score this characteristic on a scale of 0 to 1 (or another relative scoring which can be translated into a scaling from zero to one). Using equations 4.4 and 4.5 a weighting based on risk perception determined for each stakeholder can be calculated. The individual weights each stakeholder assigned can be aggregated by taking the average.

Every risk posed has a certain ubiquity, the dispersion in space of potential consequences of an event [Renn and Klinke, 2002]. This means the risk will affect certain stakeholders while others not. The same applies for risk management measures. Measures reducing risk but also benefits will directly affect some stakeholders, while others might not be affected. For an effective Multi Criteria Analysis it is wise to only select those stakeholders which may possibly affected by the event in the future, for a research on risk perception. There is a large probability the negative consequences of measures will also affect those persons. Some stakeholders may not be affected currently, but from scenario analysis may result that they will be affected in the future (for example because of sea level rise). Therefore it will be useful to include their perception/opinion in a Multi Criteria Analysis. A negative consequence of including the 'currently not affected stakeholders' is that the currently affected stakeholder, which will probably experience the largest negative consequences of a measure, feels like bearing the negative consequences of risk management measures for provision of safety to others. Representing the weighting like in equations 4.4 and 4.5 is that stakeholders which are currently not, or not directly affected by the flooding will have a low average score on awareness and preparedness and therefor will make the conservation of benefit weight stronger. This means the influence of people on decisions that don't directly negatively affect them (reduction of risk) may be limited. The same applies for a large preparedness and small worry, which may lead to acceptance of higher levels for risk. As in every research it is important for the policy maker to address the representative stakeholders, within a spatially defined area for which the risk is considerable enough.

- Weight for reduction of risk

$$\frac{worry + awareness + (1 - preparedness)}{3} \tag{4.4}$$

- Weight for conservation of commodity and non-commodity output

$$1 - \frac{(worry + awareness + (1 - preparedness))}{3} \tag{4.5}$$

Social learning processes, like informing or educating stakeholders , and better preparing people for a risk by technical (increasing susceptibility) or non-technical measures (evacuation plans), will change the scores for the indicators for flood risk perception (awareness, preparedness and worry) of the

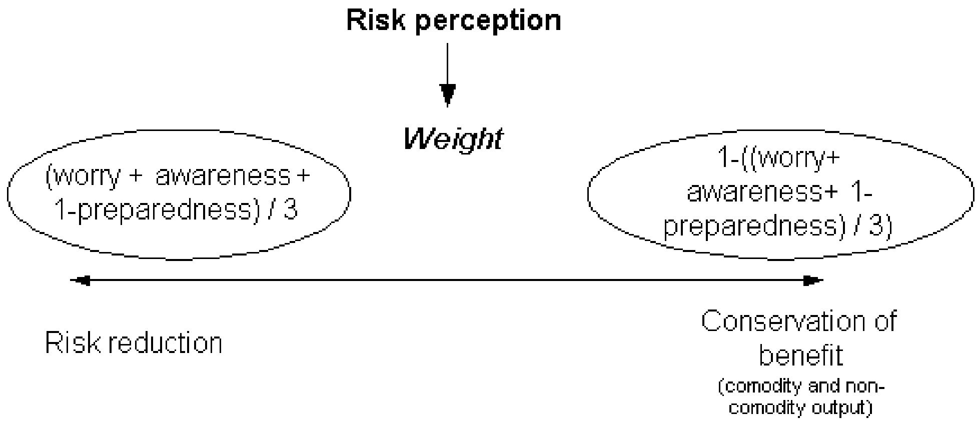


Figure 4.4: Weighting by risk perception in multi criteria analysis

public. Measures itself may change the outcome of the multi criteria analysis. Thus, for example better preparedness may lead to a higher acceptance of risks, where less costly investments for technical solutions have to be made. For natural disasters, there is sometimes a lack of awareness; knowledge of the perception patterns of stakeholders can be used to structure and implement educational measures in order to increase awareness [Renn, 2004].

Pairwise comparison

Weights resulting from the pairwise comparison methodology will be compared with the methodology where risk perception is used for obtaining weights. Pairwise comparison was developed by Saaty. It is based on the observation that it is more easy to compare pairs of criteria than more than two criteria. The pairwise comparison method requires to compare all categories of impact with one another, indicating which of the pair is believed to be more important, and by how much [Risk and , RPA]. The policy maker is asked to estimate the ratio r_{ij} between two subjectively determined weights (w_i and w_j) for two criteria; $r_{ij} = (w_i/w_j)$ [Kok and Lootsma, 1985]. Pairwise comparison can be used to fine the the weights obtained in risk perception After pairwise comparison of the all the alternatives an inconsistency index can be calculated. This index ranges between 0 and 1. When the index indicates a value larger than 0.1, this could indicate an inconsistent judgment [Janssen et al., 2000]. Pairwise comparison is only effective for a small number of criteria, because otherwise a too large number of comparisons would have to be made [Risk and , RPA]

4.5.7 Ranking

For the ranking of alternatives four multi-criteria methods are available within BOSDA: (1) weighted summation (2) concordance method (3) the regime method (4) the evamix method [Hellendoorn, 2001]. There is a wide range of mathematical algorithms available for the ranking of different alternatives. The table developed by FHRC/RPA gives an overview four methods and their characteristics (see table 4.2)

1. **Weighted summation:** for weighted summation the preferences of the policy makers are translated into a weight w_j. The standardized value is expressed by v_j The total value for a measure $V(P_i)$ is obtained from equation 4.6:

$$V(P_i) = \sum_{j=1}^{J} w_j * v_j \tag{4.6}$$

   In order to deal with quantitative information, the weighted summation methodology seems to be the most appropriate; it retains a high level of transparency, it is simple to apply and has low costs.

2. **Outranking methods:** This method is based on the pairwise comparison of alternatives. The method makes a comparison on the basis of the effect scores and the weights. Firstly a concordance set is determined on the basis of the scores higher for one alternative compared to another on a criterion compared to the other. Simultaneously the disconcurdance set can be determined on the basis of the scores of lower for one alternative compared to the other. On the basis of these results a nett concurdance index can be determined, which is represented by the added values of the criteria on which measure i scores better that measure i' minus the added values of the criteria on which measure i scores worse that measure i'. This is represented by equations 4.7, 4.8, and 4.9:

$$C_i = \sum_{i}^{'} (c_{ii'} - C_{i'i}) \tag{4.7}$$

   in which

$$c_{ii'} = \sum_{j} \in C_{ii'} w_j \tag{4.8}$$

   and

$$c_{i'i} = \sum_{j} \in D_{ii'} w_j \tag{4.9}$$

   Next to this the nett discordance dominance matrix can be determined which is made out of the added values of the standardized effect scores for which measure i scores lower than measure i'. This is represented by equations 4.10, 4.11 and 4.12.

$$D_i = \sum_i^{'} (d_{ii'} - d_{i'i}) \tag{4.10}$$

in which

$$d_{ii'} = \sum_j \in D_{ii'} v(p_{ji'}) - v(p_{ji}) \tag{4.11}$$

and

$$d_{i'i} = \sum_j \in C_{ii'} v(p_{ji}) - v(p_{ji'}) \tag{4.12}$$

The measure that has the highest value for $C_i - D_i$ is ranked as being the best. A downside of this method is complex and not very transparent.

3. **The regime method:** This method is also based on pairwise comparison of alternatives. For every criterion two alternatives are compared. The best alternative receives +1, the worst -1 and if both alternatives score equal they receive 0. The scores are combined with the weights of the criteria to determine which of the two alternatives is preferred relatively to each other.

4. **The evamix method:** for the evamix method the set of criteria and the effects table is divided into a set of ordinal criteria (quantitative) and a set of qualitative criteria. The method calculates a dominance score. The total dominance score is determined by calculating the weighted sum of the qualitative and quantitative dominance scores

4.5.8 Sensitivity analysis

The evaluation will result in a ranking in order of preference of the alternatives. Differences in the evaluation methods will cause differences in the outcome of the evaluations. Also scores and weights subjected to the judgment of the person that makes the evaluation and this can result in a difference in ranking [Hellendoorn, 2001]. In a sensitivity analysis a confidence interval is calculated. Within this interval the ranking is not sensitive to changes in the scores. There are two sorts of uncertainty which influence the ranking which can be researched within BOSDA. The uncertainty within scores and the uncertainty within weights. The third uncertainty is a combination of those two.

1. **Uncertainty within scores:** a percentage of uncertainty is attributed to every attributed score. This is extent to which the weights are expected to differ from the originally determined weight in a positive or negative way.

2. **Uncertainty within weights:** a percentage of uncertainty is attributed to every weight. This is extent to which the weights are expected to differ from the originally determined weight in a positive or negative way.

Method	Information	Result	Transparency	Computation
Weighted summation	Quantitative	Performance scores/ ranking	High	Simple
Outranking methods	Quantitative	Ranking/ incomplete ranking	Low	Very Complex
Analytical hierarchy Process	Qualitative	Performance scores/ ranking	Low	Complex
Regime method	Quantitative/ qualitative and Mixed	Ranking/ probability	Low	very Complex
Permutation method	Qualitative	Ranking	Low	very Complex
Evamix method	Mixed	Ranking	Low	Simple

Table 4.2: Overwiew of multi criteria methods

3. **Uncertainty within scores and weights:** this is the combination of the uncertainty in both weights and scores

4.6 Research model

In this section is shown how the different elements of the methodology connects to the other elements. This is illustrated in figure 4.5. For developing sustainable land use both societal and economic demands have to be met. Economical demands, the market demand, can be expressed as the output of goods (with a certain tangible value) for a particular land use per year.For this research the societal demands, are expressed by the production of positive externalities and the reduction of negative externalities. To serve as input for a spatial multi criteria analysis these indicators for sustainability have to be translated into measurable criteria. The economical criterion is expressed as the value of the commodity outputs per type of land use per year. The most important negative externality for the Ebro Delta coast is the flood risk. Reduction of negative externalities is expressed by the criterion flood damage, for which data can be acquired by damage evaluation. Production of positive externalities will be expressed by the relative values of habitats [V_e]. Risk and stakeholder perception, part of risk assessment, serves as input for the research in order to estimate the relative importance (weight) of each indicator of sustainability and gives an idea about stakeholder perception on risk management alternatives. These alternatives are a formed by a combination of both storm induced flooding and coastal erosion scenarios and land use scenarios. The criteria and alternatives serve as input for the spatial multi criteria analysis, in which different MCA methodologies are compared. The result of the MCA analysis should be the answer to the question whether or not this land use scenario is a sustainable one or not.

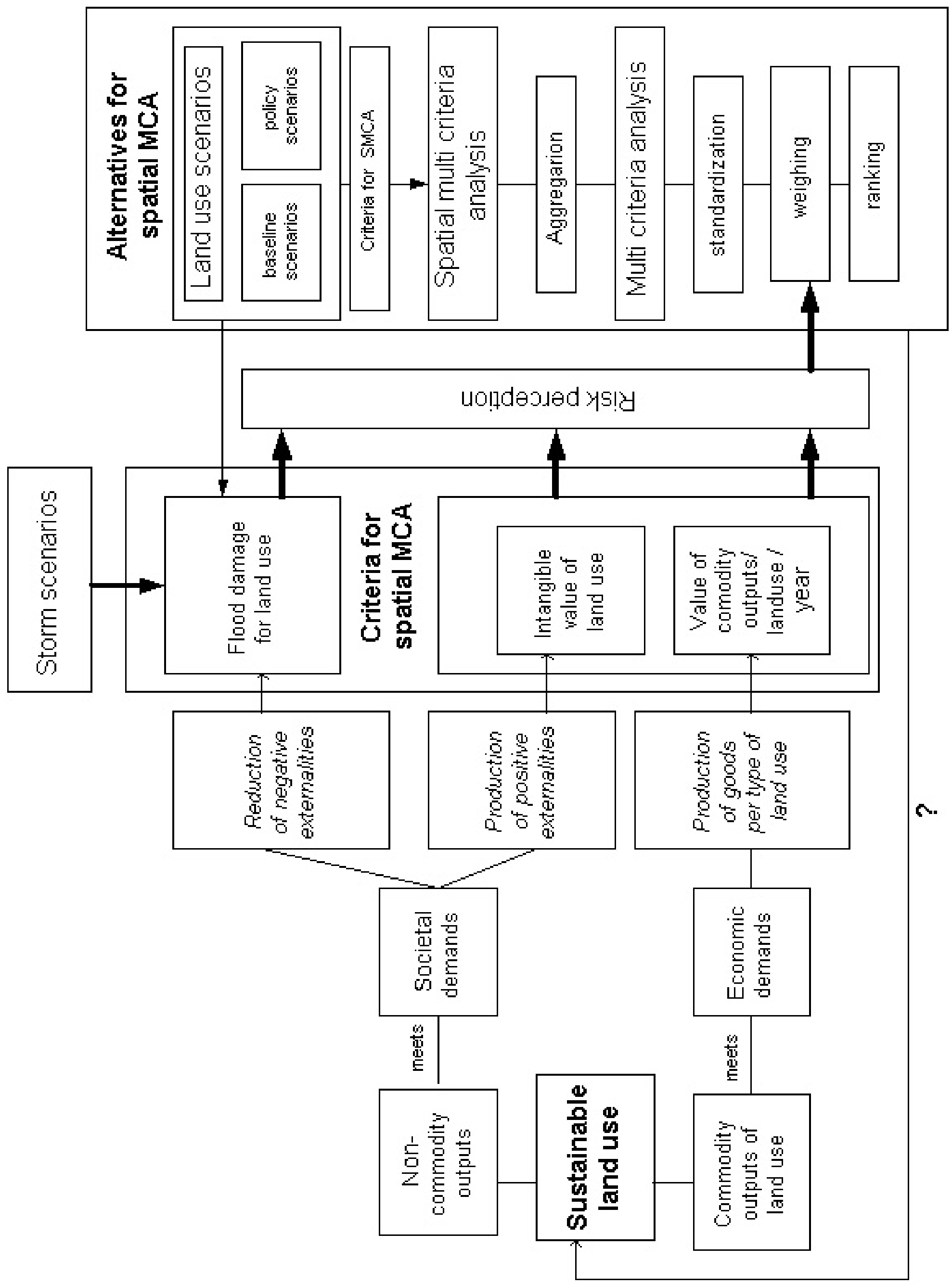


Figure 4.5: The research model

Chapter 5

Scenarios for the Ebro Delta

5.1 Introduction

This chapter describes all scenarios for the Ebro Delta used in this report. Initially a distinction is made between (1) storm scenarios and (2) land use scenarios, which are later combined into one scenario and compared with data from the base year. The base year of these scenarios is 2001 and the time horizon is 2050. The scenarios and their main drivers are:

1. **storm induced flooding and coastal erosion scenarios:**
   (a) *The 2001 storm scenario:* The storm which occurred in November 2001 was the storm that until today had the largest socio-economic impact for the Ebro Delta. The Trabucador was breached, the Marquesa beach was inundated and the natural barrier which separates the lagoon at the Illa de Buda and the open sea was breached.
   (b) *The 2051 storm scenario:* This scenario is based on the 2001 scenario. A storm with the same characteristics would occur in 2051 as in 2001. This means the probability of occurrence (related to the return period) is the same as the flooding in 2001. The time of occurrence is the same and the beaches are overwashed on the same places as in 2001. The main driver for change is the relative sea level rise (sea level rise + subsidence of the Delta). As described before the RSLR for the Ebro Delta is in the order of 3mm -7mm year, which would mean in a period of fifty years the delta would 15 - 35 cm. For the 2051 scenario the mean relative sea level rise for 2051, +25cm, is taken as a starting-point. This means the same storm as in 2001 has a larger impact as the land is lower in comparison to the sea level.
2. **land use scenarios:**
   (a) *The Business As Usual scenario (BAU):* the Business As Usual scenario takes the continuation of current trends for land use as a starting

point. The main drivers for changes in this scenario are the socio-economic. The scenario is based on current trends and current policy of different authorities.

(b) *The nature development scenario:* the main driver for changes in this scenario is the wish of local stakeholders and authorities to reduce the risk posed by flooding and coastal erosion for the Ebro Delta coast.

The land use scenarios will be compared with the current land use, described in figure 2.1 and table 2.1.

5.2 Storm induced flooding and coastal erosion scenarios

5.2.1 Description of storm impacts for the 2001 scenario

Storm impacts on the Ebro delta coast usually occur under the coexistence of surged water levels due to the passage of low pressure systems off the Ebro delta coast and eastern wave storms [Jiménez, 2005]. During storms the water level surges. In most cases for the Ebro Delta there was a surge of about 0.3 - 0.4 meters. On average the coastal defenses are not higher than about one meter for the Marquesa beach. As a matter of fact, this is also true for the other stretches of beach in the Ebro Delta. The difference is that the beach for the Marquesa is more narrow in comparison to other stretches. When water levels are surged this means that the coastal defenses are easily overwashed by waves.

La Marquesa

A very vulnerable area is the Marquesa beach, as shown in figure 5.2 (1997) and 2.3 (2006). Due to lack of data similar photographs as the areal photographs in shown figure 5.2, from Jiménez [2005] have been used to make an estimation of the effects of flooding in 2001. These photos show the sedimentation as a result of flooding, which marks the area which has been flooded. Three locations at the Marquesa beach were inundated after the storm of 2001; (1) the beach north-east of Riumar (2) the area north west of the restaurant and (3) the area south east of the Fangar spit. The data has been georeferenced in order to produce a flood map for the flooding in 2001. The result is shown in figure 5.3. The first vulnerable area is the area north-west of Riumar. Here the coastal road has been overwashed several times and it was broken down after it was damaged at several occasions. The road in present status (April 2006) is shown in figure 5.1. The second vulnerable area to erosion and breaching is the area north-west of the restaurant at the Marquesa beach. The restaurant functions as a breakwater. Due to wave driven sediment transport, the beach south-east of the restaurant accretates under eastern wave conditions

Figure 5.1: The coastal road north west of Riumar

and erodes north-west of the restaurant. This means is plausible that future erosion of the coastal defenses and breaching/ overwash will occur at this location. The third area are the rice fields south-east of the Fangar spit. This area is the most low lying piece of land near to the coast and is occupied by rice fields. The total area flooded in 2001 according to the model is 5,08 hectare.

Illa de Buda

The Illa de Buda is protected by a beach, which separates the Els Calaixos lagoon from the sea. During the 2001 storm the beach was overwashed and this berm was breached, which resulted in inflow of salt water into the lagoon. The Els Calaixos lagoon is a brackish water lagoon, which is both dependent on overwash of salt water and the inflow of fresh water from the rice fields. This area is not subjected to tangible damage, as it contains no monetary replaceable objects.

Trabucador, La Banya and Alfacs bay

After almost every large storm the Trabucador is overwashed. During the breaching large amounts of sediments from the bar are transported into the Alfacs bay [Jiménez, 2005]. For example in 1990 a volume of 70.000 m^3 was eroded after a storm, which is equivalent to about 85% of the bar [Sánchez-Arcilla et al., 1997]. The profile of the Trabucador is low, the maximum height is 1,5 meters [Santalla, 2002]. The breaching after the storm of 2001 is shown in

Figure 5.2: Breaching after the storm of November 1997

figure 5.4. The breaching of the bar also affects the Alfacs bay, as the pysico-chemical circumstances for the bay change, as a result of the inflow through the breached bar.

5.2.2 Description of storm impacts for the 2051 scenario

The 2051 storm scenario has the same characteristics as the scenario of 2001. This means the return period T_r for the storm in 2051 is the same as for the storm in 2001, which means the probability of occurrence is the same. For 2051 the average predicted relative sea level rise is 0,25 m. This means the same flooding will have a larger consequence for the delta. There is no sufficient model for this research to model any given possible flooding.

La Marquesa

Due to the Relative Sea Level Rise the Marquesa will be more vulnerable for flooding. The effect of the same flooding in combination with the predicted RSLR of 2051 is modeled in Arc-GIS. The scenario is introduced into Arc-GIS by a trick. The elevation of the land at the edge of the inundation of 2001 is taken and the land +0,25 meters of that will also flood due to a similar flooding as in 2001. Due to lack of time to model the coastal erosion and flooding for the Ebro Delta a very simple model has been used to predict the area which will possibly be flooded in the 2051 scenario. There are two main assumptions made for the modeling of the 2051 scenario and flooding in case of the different land use scenarios. Important for the different land use scenarios is the assumption on soil roughness. For the 2051 scenario the assumption on infiltration is important.

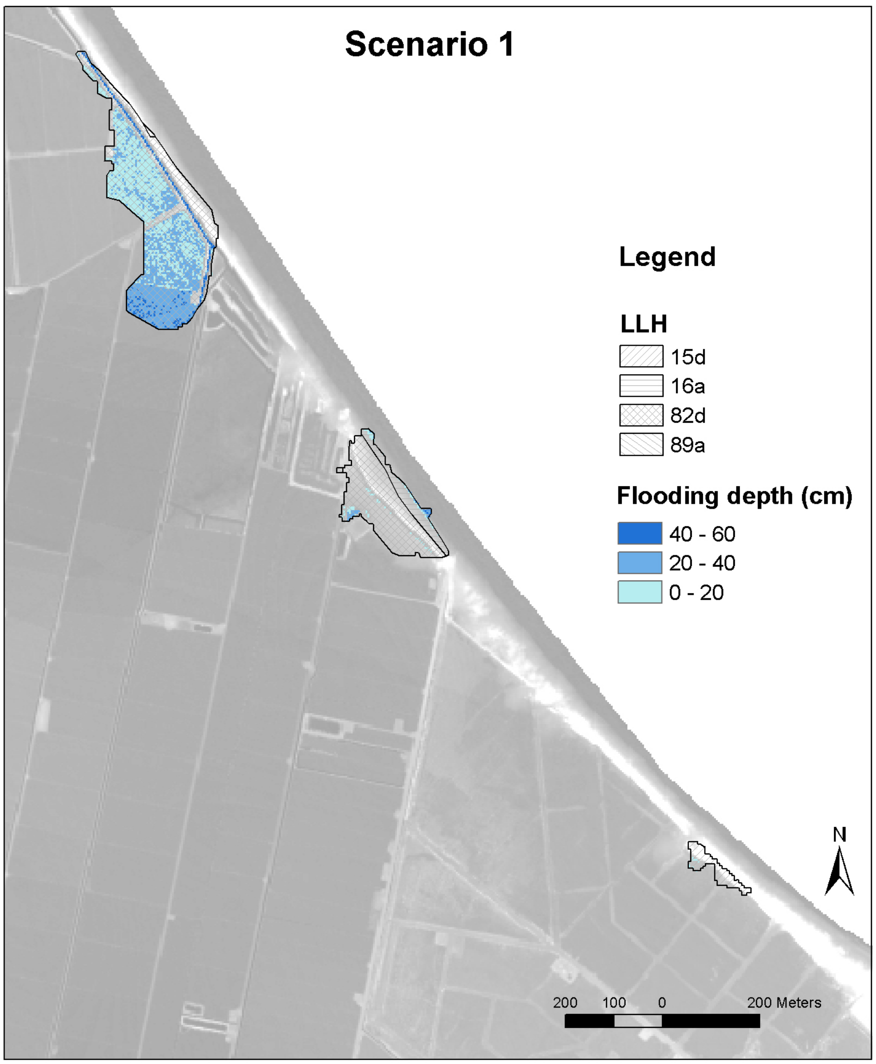


Figure 5.3: Schematization of the flooding in November 2001

Figure 5.4: Breaching of the Trabucador after the storm of November 2001

1. **soil roughness:** for different kinds of land use the soil roughness has a different value. This can be expressed in the value for the roughness height (k_s [m]), a value which is larger for terrain with vegetation or obstacles. This implies that due to a land use change, for example when the roughness height rises at a certain place, the water level will also rise. For the different land use scenarios the same water level each storm scenario is taken, which means that is assumed that land use change has no effect on the water level during a flood

2. **infiltration:** part of the water which floods the land during a storm will infiltrate into the ground. The amount of infiltration depends on the saturation of the ground, the soil type, land use and cultivational practice. For urban areas infiltration usually is low. Large infiltration means part of the flooded water is drained into the soil which will lower the water level due to a flood.

The modeled flooding for 2051 is shown in figure 5.5. The total area which is flooded in the 2051 storm scenario for the Marquesa coastal zone is 24,97 hectare, which is almost five times as much as in 2001. The Marquesa beach will be the only site for which storm scenarios will be made available in this research, and will serve as an example to apply the methodology for other sites (like the Illa de Buda and The Trabucador). For that case much data is enlisted in tis report to make it easy to extend this research.

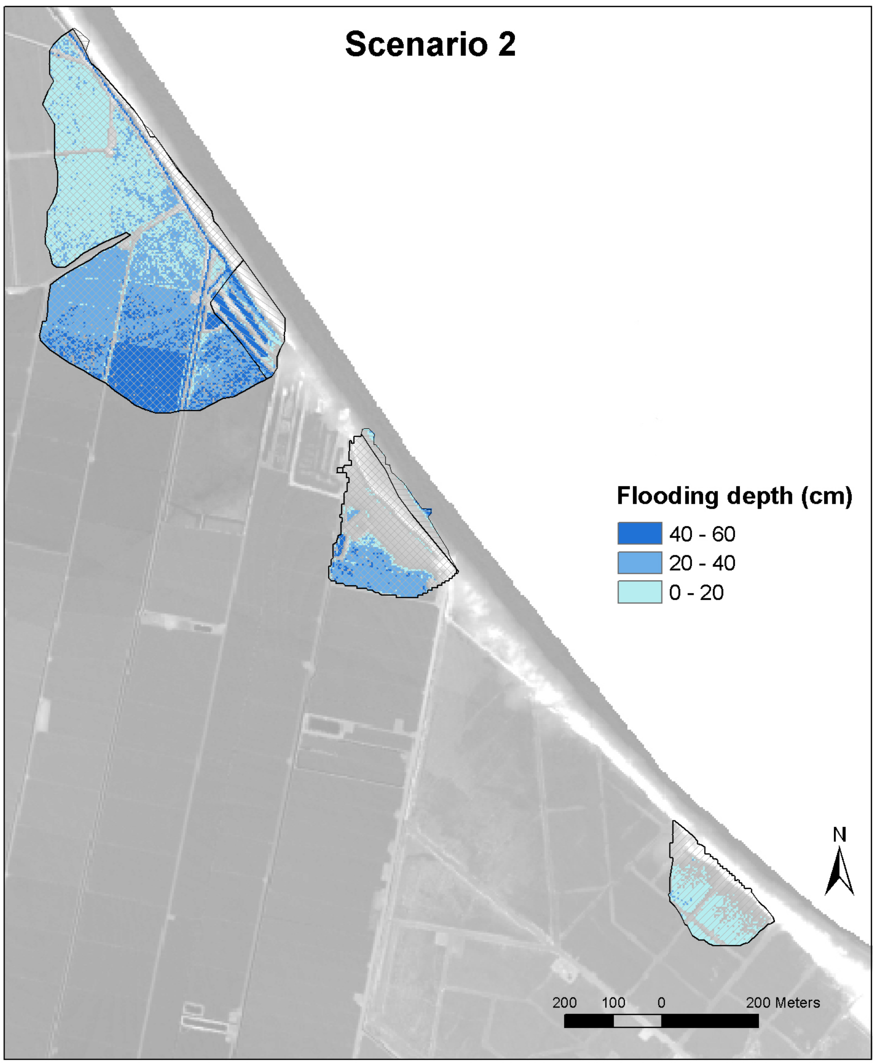


Figure 5.5: Schematization of the flooding in November 2051

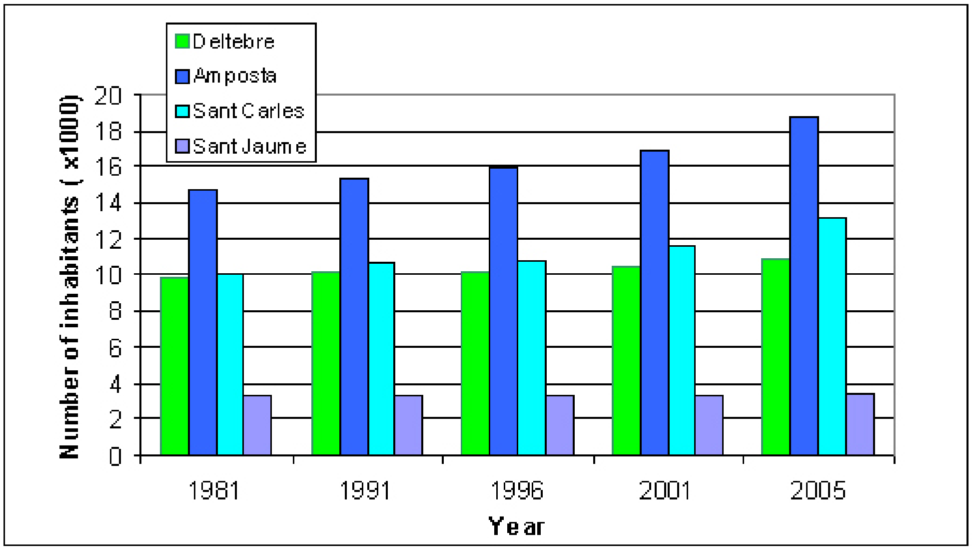


Figure 5.6: Past population growth in the Ebro Delta [www.idescat.net, 2006]

5.3 Land Use Scenarios for the Ebro Delta

Next to the base year 2001, two land use scenarios for the Ebro Delta are formulated in this report; (1) The business as usual scenario and (2) the nature development scenario. The first one is a baseline scenario for land use in the Ebro delta, the second one is a policy scenario. An important note here is that not only the land used as a natural area has an ecological function, but also the land used for rice cultivation and the salt industry.

5.3.1 The Business As Usual Scenario

In a business as usual scenario the future projections are made for the continuation of current trends. This section describes the socio-economic trends for the Ebro Delta. The population in the Delta is rapidly growing in the last years. In 2005 the total number in the Delta added up to 46145 inhabitants [www.idescat.net, 2006]. The past population growth is shown in figure 5.6.

The development of the economic environment for the different sectors in the Delta is based on available data of expected future marked development and changes in legislation. The following developments are expected for each sector:

- **Agriculture:** the rice production in the Ebro Delta is currently subsidized by the European Union. There is low profitability from the rice and without the subsidies it is difficult to compete with the cheap rice from Asia.

Because of the growing Asiatic community in Europe there is a growing demand for scented rice, for example the Basmati type. There are farmers in the Ebro Delta, which change to cultivating this sort of rice, in order to utilize this new market to their advantage. For the rice cultivation in Europe there are two important reforms the coming years that are aimed at liberalizing the market and will make it more difficult to maintain the present competitiveness of the rice originating from the Ebro Delta with the Asiatic rice. Currently the rice imported from third countries (outside the EU) is still taxed by the EU. The tariff cut of the taxes for third country rice in 2006 was 20%, in 2007 it will be 50% and in 2008 these cuts wil be 80%. In 2009 the rice marked in Europe is fully liberalized with no tarriffs and quatas for rice from third countries. On top of this the EU ministers agreed to reform the CAP (Common Agricultural Policy) subsidies. The intervention price is decreased by 50% and the amount is limited to 75.000 tons per year [Ferrero, 2005].

The cutback in the competitiveness of the farmers makes it very difficult to sustain rice production in the Ebro Delta. However the EU recognizes the importance of the rice cultivation for the ecology. The rice fields provide an important habitat for many important birds. The rice field can be considered to be an artificial wetland, providing feeding and reproduction grounds for birds, amphibians and fishes [Ibànez, 1998]. Therefor it will provide compensation subsidies for the agriculture in the Ebro Delta, in order to maintain its ecological function.

The other treat for sustaining rice cultivation in the Ebro Delta which is the decreasing and aging of the labor force working in agricultural activity. Due to the aging, low profitability and abandonment of agricultural activity the land is principally rented out [ACA, 2002].

- **Aquaculture:** The aquacultural production in Alfacs and Fangar bays in tonnes per year is shown in figure 5.7. It shows that the total production has declined in 2005, compared to 1994. The figure shows fluctuations in the production over the years. The production through the years is most dependent on the water temperature in the bays. A too high temperature in combination with nutrient loads from agriculture causes algae bloom which causes mortalities among the mollucs population in the bays. An example of this is the year 2003, when the mollucs production was harmed due to the high temperatures in the summer of that year [www.gencat.net/darp, 2006]. Water quality deterioration is threatening the maintenance of this activity [Ibànez et al., 1997].

- **Fisheries:** the fish landings in the coastal lagoons have decreased from 171 kg/(ha year) from 1966-1976 to 74 kg/(ha year) from 1977-1987, and these low values have remained from then on [Day et al., 2004].

- **Nature conservation:** the protected area has grown over the years.

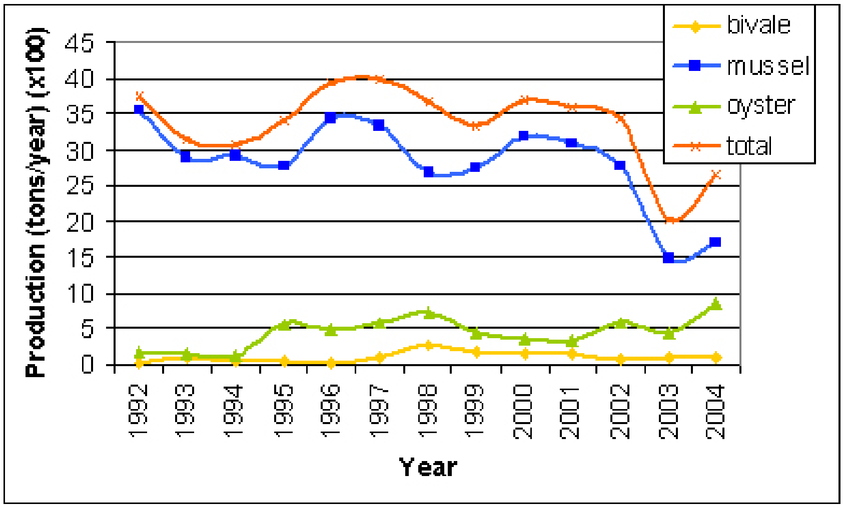


Figure 5.7: The aquacultural production in the Ebro Delta [www.gencat.net/darp, 2006]

- **Tourism and recreation:** tourism is a growing activity in the delta. From 1992 until 2001 the touristic sector steadily grew [Santalla, 2002]. Especially the Eco and Rural tourism are expected to experience growth [Saurì and Llurdés, 2005]. The most tourists are attracted to the Natural Park and the beaches. The number of visitors to the visitor and information centers for the Natural park in the Delta has been counted. This is shown in figure 5.8. Parallel studies have shown that 40% of the people visiting the Ebro delta visit these centers. This can be used to estimate the total number of visitors to the Ebro Delta (see figure 5.8) The tourist information office in Deltebre has also made estimates of visitors to its facilities, which is also shown in figure 5.8. It can be concluded that the number of tourists visiting the Delta has increased between 2000 and 2005. besides plans exist to expand the number of facilities for tourists. The growth of tourism will put additional stress on the Ebro Delta.

  The Ebro Delta Coast is attractive to tourists. Current tourist pressure is comparatively low and has not yet created major damaging impacts [www.ramsar.org, 2006]. The eco and rural tourism in the Ebro Delta is expected to grow. To attract more tourists to the Ebro Delta it is foreseen that the number of accommodations for tourists will expand (especially the number of hotels), as well as the network of bicycle lanes and footpaths. There will be an intensification of navigation of tourist ships on the Ebro Delta, which will increase the need for river harbor facilities. Tourism in the coastal zone is mainly facilitated by secondary housing

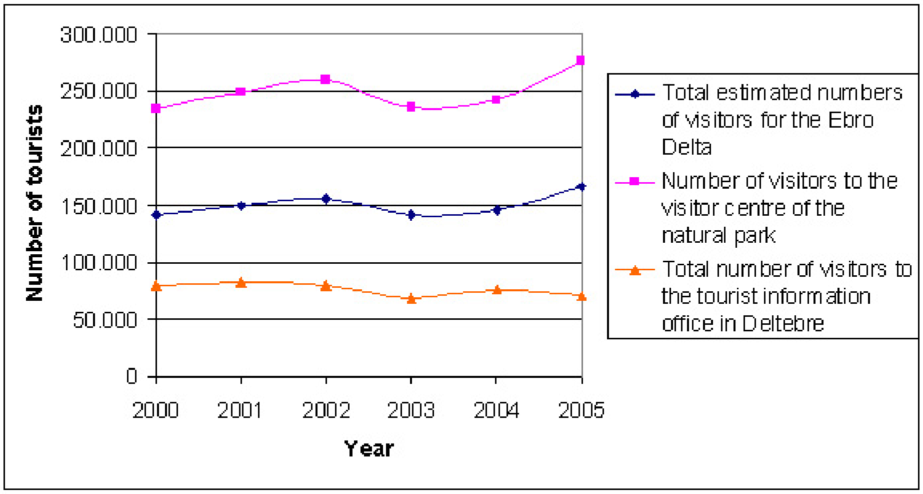


Figure 5.8: The number of tourists per year visiting the visitors center of the natural park and the estimated total number of tourists visiting the Ebro Delta per year

in the towns Riumar and Els Eucalitus. In the urban development plans for the coastal zone is advised to restrict building in the areas with high agricultural, environmental or landscape value. Keeping the agricultural function (for rice growth), is also important for environmental reasons, as the flooding of the land suppresses the salt water intrusion. This means the whole coastal zone is restricted from building activity, except for the area surrounding Riumar [de Catalunya, 2005]. The area around Riumar is shown in figure 5.9. In the sixties and seventies of the last century Riumar was promoted to a 'tourism center of national interest', protected by sectoral legislations, specified in the fringe of the urbanistization legislation. The urban development in the area is strongly limited to the areas left white in figure 5.9. The building in these development areas is limited to a gross density of 0,125 m^2/m^2 and 9 houses per hectare [de Catalunya, 2005]. Future expansion of Riumar is planed to take place in the areas named Riumar I and Riumar IV. The total area to be developed has a surface of 55.5 ha and will contain a total of 544 houses. The building will expand the tourism sector for the coastal zone in the Ebro Delta, however building in a coastal zone under flood risk will increase its vulnerability.

- **Salt extraction and transport:** Data of salt removal on the La Banya spit exists from 1947. the average production is 60.000 tons, but in warm years production increases. This means that due to climate change, where more warm summers are expected, the future production of salt is likely to

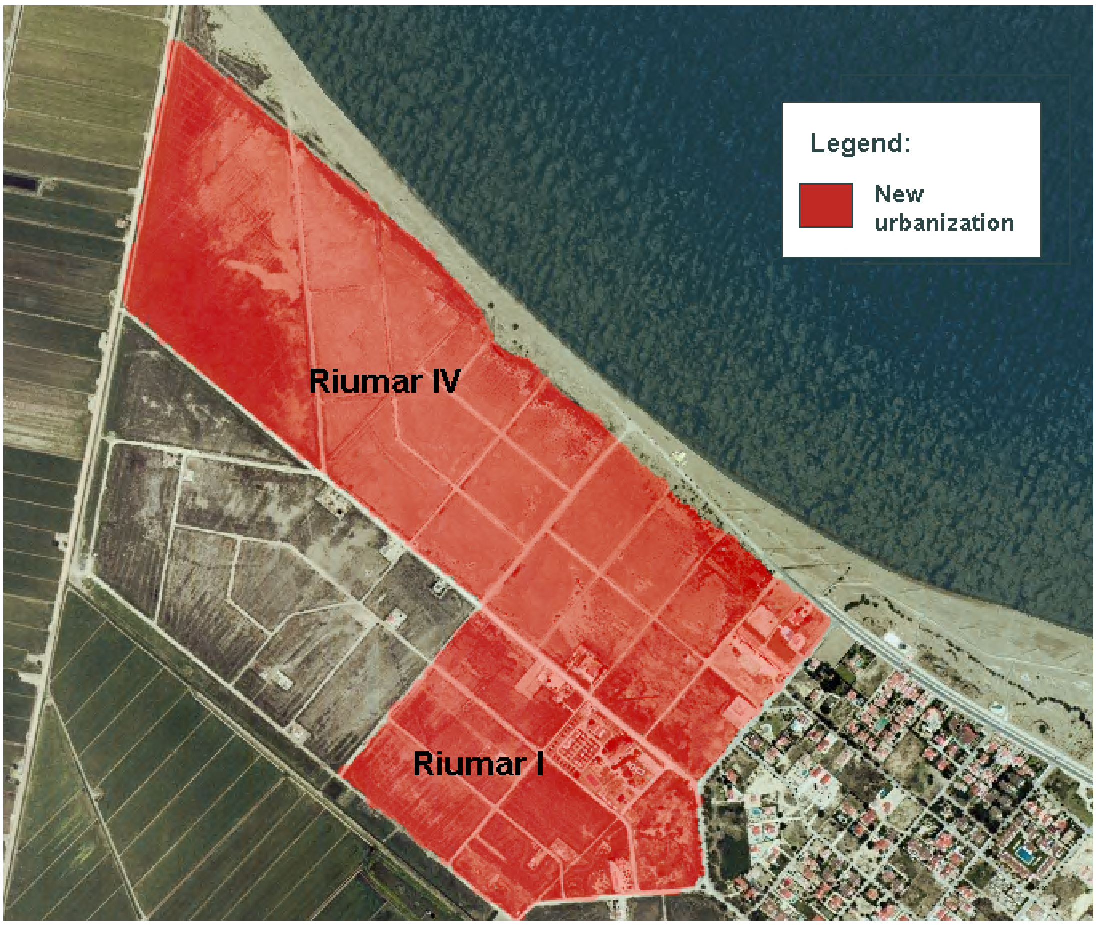


Figure 5.9: Development of Riumar (BAU scenario)

increase. There are plans to remove the Trabucador bar and change the transport mode of the salt.

Concluded can be that rice cultivation will continue its presence in the Ebro Delta, due to subsidies from the EU for its importance as habitat for birds. A scale-up of rice cultivation is expected, with fewer farmers cultivating same surface. Aquaculture and salt industry will continue, however aquacultural production may decline due to deterioration of the water quality in the bays, but will remain present. Tourism is a growing activity and this will result in the growth of the coastal town Riumar, where 544 houses will be build on a surface of 55.5 ha. This change is shown in figure 5.9. Concluding the land use change can be listed as:
15. Salt marshes, salt steppes and gypsum scrubs ⟶ 86. Urban and industrial areas [55,5 ha]

5.3.2 The natural development scenario

Policy scenarios for the Ebro Delta

There are some policy alternatives for long term management of the flood risk and coastal erosion for the Ebro Delta.

1. **Build defense structures similar to those protecting the Dutch polders:** the construction of dikes to protect the hinterland for flooding is an unsustainable (not valuable in the long term) solution. With sea level rise and possibility of breaching, the effects of a flooding would be much larger consequences for the Delta. This solution is difficult and costly to maintain, as a lot of pumping is needed. This solution may cause the loss of wetlands [Ibànez et al., 1997]

2. **Supply sediments:** Another technical solution would be to dredge sediments which have accumulated in front of the dams and supply them to the Ebro River downstream in order to allow the river to transport them to the delta [Ibànez et al., 1997].

3. **land use changes:** Due to land use changes where economic functions are replaced by ecological functions the economic consequences of a flooding would decrease. When the sea is allowed to deposit sediments, the land will naturally accretate.

This report will describe a land use change scenario for the Marquesa beach. This is one of the few possible land use change scenarios which are a possible alternative.

Natural development at the Marquesa beach

The driver for this land use change scenario is the wish to manage the risk of coastal erosion and flooding to which the Ebro Delta coastal zone is exposed.

An area of 4.500 ha of the Ebro Delta of the coastal zone is protected by the Plan for Natural Sites of Specific Interest (PEIN, decree 328/1992 Generalitat de Catalunya). This area not only covers natural area but also rice fields. Figure 2.6 shows the boundary of the area under PEIN regulation. In this area no building is allowed. The land behind the Marquesa beach currently used for rice cultivation. The land has been flooded several times during a storm (for example in 2001, 2003 and 2004), this caused damage to the crops. Agricultural land is more vulnerable for flooding than natural area. In economic sense it has a smaller susceptibility (ability to recover after a flood) and a higher tangible value than natural area. In order to reduce the vulnerability of the areas under flood risk a land use change is proposed. In this case it means that land currently used for agricultural purposes is changed to use as natural areas. The downscaling of agriculture in the Ebro Delta offers the main possibility for these changes. Due to an aging labor force the agricultural land may become available without pressure from authorities. The main possibility for a land use change is within the area already PEIN protection. A stretch of coast of 400 meters wide and 3000 meters long directly behind the Marquesa beach will be converted from rice cultivation (82.) to Salt marshes, salt steppes and gypsum scrubs (15.). The land use changes and the affected surfaces for this scenario are listed below. The latter land-use change is shown in figure 5.10.

1. *15. Salt marshes, salt steppes and gypsum scrubs ⟶ 86. Urban and industrial areas [55,5 ha]*

2. *82.Rice cultivation ⟶ 15. Salt marshes, salt steppes and gypsum scrubs [120 ha]*

5.4 Combination of storm and land use scenarios

In figure 5.3 and 5.5 show the total area flooded for each storm scenario. The inundation depth is divided into three classes; 0-0.2m, 0.2-0.4m and 0.4-0.6m. When the flooded surface of 2051 is overlaid over the land use scenarios of 2051 the flooded surface for each land use type can be determined. The flooded area per scenario and for the base year is listed in table 5.1.

5.5 Uncertainty

An important statement earlier in this chapter is that scenarios are neither predictions nor forecasts. Of course the designer of the scenario will search for a plausible possible future, with a logical and credible storyline. Thereby the designer has some certainties (like the liberalization of the rice market in 2009), but mostly the designer gathers a lot of uncertainty. A way to express this uncertainty is the description of many possible futures for a development. Different assumptions for future uncertainties will lead to different outcomes of

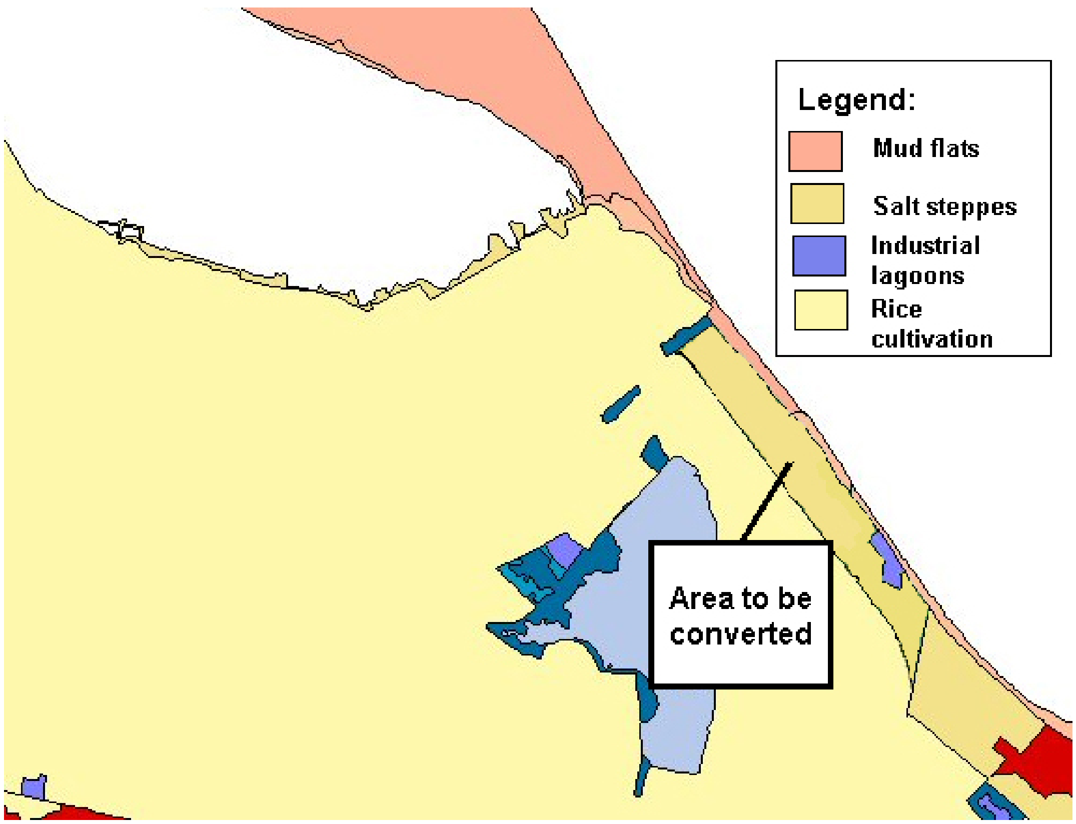


Figure 5.10: The natural development scenario

		affected area [m^2]		
storm scenario	*damage category*	*h (0-0.2m)*	*h (0.2-0.4m)*	*h (0.4-0.6m)*
	Base year			
2001	15. Salt marshes, salt steppes and gypsum scrubs	121	1	0
	16. Coastal sand dunes and sand beaches	633	234	151
	82. Rice cultivation	23057	22624	3991
	89. Industrial lagoons and reservoirs, canals	0	1	0
	BAU			
2051	15. Salt marshes, salt steppes and gypsum scrubs	0	0	0
	16. Coastal sand dunes and sand beaches	1849	1028	555
	82. Rice cultivation	11515	40921	159160
	86. Urban and industrial areas	5944	14850	1434
	89. Industrial lagoons and reservoirs, canals	1362	1979	7982
	Natural development			
2051	15. Salt marshes, salt steppes and gypsum scrubs	11515	40921	159160
	16. Coastal sand dunes and sand beaches	1849	1028	555
	82. Rice cultivation	0	0	0
	86. Urban and industrial areas	5944	14850	1434
	89. Industrial lagoons and reservoirs, canals	1362	1979	7982

Table 5.1: The area affected by flooding for the land use scenarios

a scenario. Uncertainty and scenarios go hand in hand; scenarios are not intended to be truthful, but rather provocative and helpful in strategy formulation and decision-making [Selin, 2005]. Due to a large time horizon [2051] and short trend line there is uncertainty in the plausibility of the scenarios. Main uncertainties for the Business as Usual scenario are:

- **market development for rice cultivation:** factors of uncertainty are the development of the rice market. Rice cultivation is a activity which thanks its existence largely to subsidies from European Union. An aging population and loss of subsidies rice cultivation as an economic activity would be threatened. However, rice cultivation serves an essential ecological function; not only is it important for birds, it is also important for denitrification. Therefore possibly rice cultivation would presumably continue to exists, however it is threatened by activities as nature conservation (that could replace and serve the same function as denitrification), or tourism which may be a more profitable activity.

- **Ebro river basin management:** In 2001 the Spanish National Hydrological plan was approved. This plan envisaged to build more dams in the river Ebro and regulate the river stronger. It concerned the diversion of large amounts of water from the river Ebro to basins in the north and the south. This plan would have had important consequences for the delta, as subsidence would further increase and economic functions as rice cultivation would have been further endangered by deterioration of water quality conditions . Due to the lower discharge of the river, more salt sea water would intrude up from the river mouth. The new Spanish government changed the political course and the plan was moderated in 2004, establishing new alternative solutions for supplying water to the Mediterranean coasts [Day et al., 2004]. However, the change of political courses, the adaption of another National Hydrological Plan of some kind would have large impact for the physical circumstances and the socio-economic functions of the Ebro Delta.

- **eutrofication and closure of the Fangar and Alfacs bays:** As stated earlier, aquaculture in both bays could disappear as a result of eutrofication and closure of the bays.

- **dependency of functions:** The socio-economic functions in the delta are dependent as described in section 2.3, this means the disappearance of one function could threaten the existence of another.

The nature development scenario is a risk management alternative, which might be a possible future strategy to manage the flood risk, however this research does not present the solution to the problem, but does give insight in the consequences of a certain way of flood risk management. This should serve the provocative function scenarios have.

Chapter 6

Flood risk assessment for the Ebro Delta coast

6.1 Selection of an appropriate approach

The data available for damage evaluation in this study, is available for aggregated land units, as for example the residential area of Riumar. The consequence is that this study has to be done on a meso-scale. A study at micro-scale (single properties) would be an option as the total flooded surface in both scenarios is relatively small (in 2001). However, a micro scale approach would be too time consuming for this study and would require data unavailable for this study. The results of a study on micro scale would be more accurate than one on macro scale. The aggregated land units which are considered here are the habitats ordered according to the CORINE biotope classification as shown in figure 2.1 and listed in table 2.1.

6.2 Selection of relevant damage categories

Next the relevant damage categories for this study have to be selected. The first damage category to be considered in this research is *direct, tangible flood damage*. A first screening can help to select the tangible damage categories to be considered using the S-AST method [Risk and , RPA] lists all tangible damage categories, which can be used as a checklist for determining the relevant damage categories. Table 6.1 shows these tangible damage categories and the areas or sectors that are probably impacted by storm induced flooding and coastal erosion.

The second damage category to be considered are the *direct, intangible effects*. The intangible effects of flooding and coastal erosion considered in this study are the effects of coastal erosion and flooding on the different habitats in the Ebro Delta, important for birds and plants. Urban and industrial areas (82.)

categories	is impact likely?	qualitative description of impacts
assets	yes	Riumar, Els Ecaliptus, Trinidad salt pans, Camp sites in the coastal zone
land use	yes	Agriculture in coastal zone, aquaculture in Fangar and Alfacs bays
transport	yes	Trabucador, roads near coasts, irrigation channels

Table 6.1: The S-AST method for direct tangible effects

and parks and gardens (85.) are considered to have no intangible value at all, as these habitats can be rebuilt just as they were. Indirect losses for the Ebro Delta could be the disruption of business linkages. Rice cultivation, Aquaculture and Salt industry and associated sectors (purveyors, companies processing the good and buyers) flooding of the Ebro Delta could have indirect consequences. These industries need few resources (only seeds and fertilizer for agriculture) and are mostly directly delivered to the costumer. For the processing of the harvested rice farmers pay a contribution to the rice cooperation, so this cost is already incorporated in the production costs. So, except for the direct loss of goods the indirect disruption of business is assumed to be small. Because it seems, after a first screening that the indirect effects of a flooding are small in comparison to the tangible effects, indirect (tangible and intangible) losses will not be taken into account in this research.

6.3 Gathering necessary information and calculation

6.3.1 Inundation and land use characteristics

For each storm scenario specific *inundation characteristics* are available. The area which is flooded and the inundation depth within this area is shown in figures 5.3 and 5.5 and listed in table 5.1. The time of occurrence of this inundation is the month November (for both scenarios) and it concerns flooding from the sea, so salt water. Flow velocity is not taken into account. The influence of the flow velocity is assumed to be low, as it concerns overwash by waves on an inland profile which has a very small range of elevation (in orders of centimeters for the coastal zone).

6.3.2 Direct, tangible damage

Assets

The losses to private and public property such as residential industrial or commercial property, which concerns the houses in Riumar and Eucalyptus in this case. The first category for damage to assets is the damage to housing. in Euros The (tangible) damage (L_t) to housing (in Euros) will be calculated using equation 6.1:

$$L_t(assets) = \overline{C}[Euro] * \%P * N[ha^-1] * A[ha] \qquad (6.1)$$

Wherein $\overline{C}$ are the average construction costs for a building in the area, N is the number of houses per m^2, A is the surface affected by flooding in m^2 and %P is the percentage of damage dependent on the depth of flooding. Therefor a depth-damage function has to be derived. For the given storm scenarios Ruimar IV the only area to be possibly affected by flooding. The data needed for calculation of damages to assets in Ruimar possibly affected by flooding is obtained from comparison to current characteristics of assets. The current average construction costs are obtained from an inventarisation of the prices for houses currently being constructed in Eucalitus, which gives an impression about the replacement values for these houses. These houses have a ground surface area of 55 m^2 and a total build up area of 63 m^2. The distance from the sea of these houses is about 100m. The average value of a house in the area ($\overline{C}$ [Euro]) is 450.000 Euro and the number of houses per ha (N [ha^-1]) is 9.8. For residential areas in the Ebro Delta depth-damage function can be formulated. Unfortunately no depth-damage function is available for the Ebro Delta itself. Apriximatory damage fucctions can be derived from the HOWAS damage database, a German database on flood damages, for full documentation see [Meyer and Messner, 2005]. For a two story building without a basement the percentage of damage %P depends on the depth according to the relation shown in equation 6.2

$$\%P = 5 * D \qquad (6.2)$$

In which D is the depth of inundation. The results for different depths of inundation are shown in figure 6.1.

Primary sector: agriculture and aquaculture

The primary sector in the Ebro Delta Coast region consists of Agriculture and Aquaculture. There is also some fishing activity in the coastal region, but the main fishing ports are based in l'Ampolla and Sant Carles de la Ràpita, which is outside the research area. Both Agriculture and Aquaculture experience damages as a result of flooding and coastal erosion.

Agriculture: within the coastal zone rice is the main cultivated crop. The reason for this is that only when the intrusion from salt water (for example through groundwater intrusion) is suppressed by a layer of fresh water, the

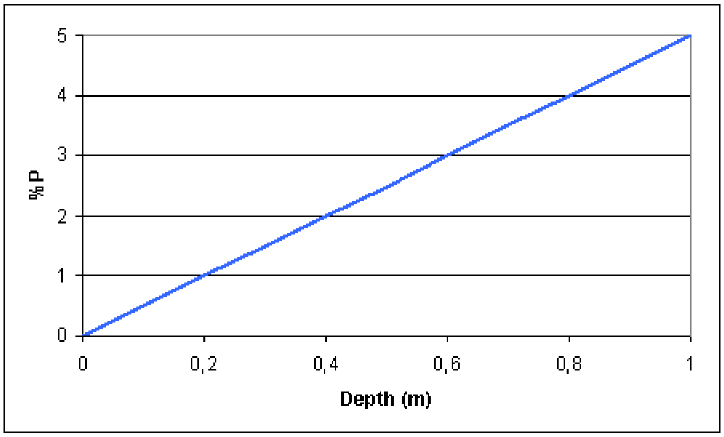


Figure 6.1: Depth damage function for two story house without basement

right conditions are provided for the cultivation of any crops. For the calculation of damage for rice cultivation, apart from the land use withing the flooded area, there is the need of the production costs of rice and an understanding of the seasonal progress of the rice cultivation cycle, in order to calculate the percentage of damage for each month.

In case of a flooding from the sea the rice production is disrupted in two ways: (1) due to the inundation by salt water (2) due to the deposition of sediments taken by the flood. Due to the salinity of the water the whole rice production can be considered to be lost. A time damage-curve is drawn in order to consider the effects of a single flooding within the different seasons of the year. The damage in each season depends on the investments made for the production of rice for that season [Pennning-Rowsell et al., 2006]. After the rice is harvested, no damage will occur to the rice itself, so the costs of harvest and transporting the harvest are not taken into account.

Rice is a fresh water plant, which grows well on saline soils. The fresh water is supplied by the river Ebro and is taken upstream and distributed among the fields using gravitational force. This requires an efficient management of the elevation in the Delta, in order to prevent that additional investments have to be made for pumping stations. The rice fields in the Ebro Delta are leveled by laser-directed equipment, not only in order to obtain better water management, but also to reach a higher crop stand and a more effective weed control. The main fertilization of the soil takes place during the land preparation period. The irrigation is carried from October till January if the land lies fallow for a short time, the main purpose is to flush out the salts as far as possible. After the winter rains, when the soil loses it wetness, the rice fields are prepared using a plow to allow the soil to dry. Later on smoothing and leveling is necessary in order to remove high and low surfaces created by machinery.

Environmental costs	**Costs [Euro/ha]**
Loss of seeds	85,64
Planting costs due to birds eating the seeds	138,63
Production losses	72,96
American Crab Plague	150,25
Production costs	**Costs [Euro/ha]**
Machinery	
Previous works (leveling, flooding and fertilization)	189,32
Sowing	140,64
Collecting	189,32
Transport	45,80
Replanting by hand	76,33
other costs	
Seeds	184,88
Fertilizer	100,07
Treatment of weeds	198,33
Drying	76,33
Work by hand	210,35
Agricultural tax	67,61
Contribution to fresh water association	81,14
Contribution	36,06
Total Costs	**2023,66**

Table 6.2: Costs for production of rice in the Ebro Delta [Euro/ha] [CPIDE, 2002]

The rice fields are flooded in the start of April, for about fifteen days. The rice requires preferably a water depth of about 5-7 cm in the first stages of crop growth and later a water level of about 10-15 cm [Ferrero, 2005]. The fresh water has a lower density that the salt water and suppresses the salt water table. The sowing takes place from 15th of April till the 15th of May [Casanova, 1998]. One month after the sowing, the farmer replants rice by hand on the patches where the rice production is disrupted, for example due to the birds eating the rice seeds. Weeding is applied from the sowing till the harvest. Full Heading (when 80% of the panicles emerge), occurs from the end of july till the middle of august. Harvesting from the 10th of September till the 10th of Oktober [Ferrero, 2005, www.arrossaires.com, 2006], then the grain is delivered to the cooperatives where it is carefully dried, and made ready for sale. Table 6.2 shows the cost of each activity and a timetable in which month this activity occurs. The tangible damage to agriculture is calculated by equation 6.3:

$$L_t[Euro] = A_i * C_i * \%P_i \tag{6.3}$$

in which A is the area of flooded farmland [ha], C are the costs of crops per 1 ha (Euro/ha), %P is the percentage of damage for each crop and month of

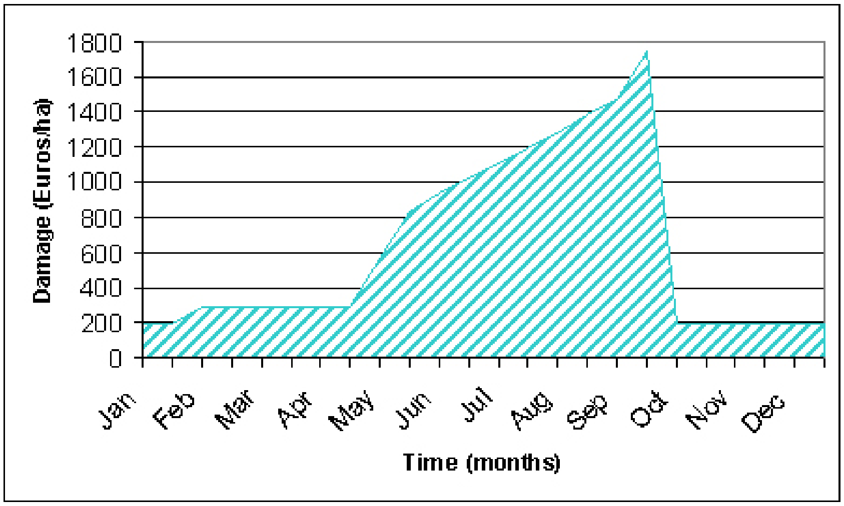


Figure 6.2: The time-damage curve for the rice cultivation in the Ebro Delta

flooding [Satrapa et al., 2006] For calculation of losses to farm production by a flood it is necesary to remove the subsidy element from the agricultural prices to obtain an estimate of the economic loss, this includes subsidies on inputs as well as outputs [Pennning-Rowsell et al., 2006].

The total costs of production for one ha of rice in the Ebro Delta is 2043,66 Euro. Recorded yields in the area varied from a minimum of 4.000 kg/ha to a maximum of 11.000 kg/ha and a minimum number of 160-180 plants was necessary to maximize the yield. Total area in the Delta cultivated is 32.000 ha.

Because the cultivation has not reached the same stage each month, not the same damage can be expected the same month of flooding. Therefor for agriculture a time-damage curve can be drawn, where for each month a flood would occur the damage is dependent on the investments made by the farmer. What is lost is the real economic value of the crop minus the variable costs (for example: harvesting and drying) avoided because the crop is destroyed. For each month a storm would occur, a percentage of the production could be considered to be lost. Separate costs for each activity in rice cultivation are shown in table 6.2. The basic costs for removal, used in the months the land lies fallow, are approximated by the costs for preparation of the land; 190 Euro/ha. The percentage of loss of rice production for each month is shown in figure 6.2. The taxes and the costs for treatment of weeds are divided equally over the months, for which the agricultural land is used for the growing of the crop. These taxes are an investment for services provided by others, for example for fresh water deliverance and can be seen as a necessary investment into production. In reality these investments will be divided over the whole year, however they cannot be considered to be a loss when the production is

not lost.
Aquaculture: with the breaching Trabucador, the aquacultural production in the Alfacs bay can be harmed. The Trabucador ensures that small wave action reaches the bay, so that the velocity of the water remains low. These conditions are changed when the Trabcador is breached as a result of a storm. The effect of the storms of 2004 are believed to have caused a decrease in production of 15% mussels [Generalitat de Catalunya, 2004]. The damage to aquaculture is calculated by equation 6.4

$$L_t[Euro] = \sum_{1}^{N} A_i * C_i * \%P_i \tag{6.4}$$

in which A is the mollucs production within the affected bay area [metric ton], C are the costs of crops per metric ton of production (Euro/ metric ton), %P is the percentage of damage for each mollucs and month of flooding and N=the number of mollucs (%)

Secondary sector: salt industry

The production of salt of the firm Infosa on the la Banya spit is dependent on the weather conditions, in warm and dry years the salt production can extend to 90.000 tons. The salt crystals are obtained after flooding of the salt flats after which the water is evaporated. The pools, in which the salt is produced, are protected from flooding by sea water, by small dikes. The damage to salt industry is caused by sea water overwashing or breaking these barriers and mixing with the concentrated salt dissolvent. The previously affected area of the salt works has a surface of 52 ha. The total surface of the salt industry is 725 ha, of which 4.5 ha is used for office buildings. this means 7.2% of the surface used for salt production was previously affected by flooding. An other effect for the salt works is the breaking of the Trabucador by the overwash affecting it. This makes it impossible to reach the salt pans over land, which makes it impossible to carry of the produced salt over land. After breaking of the Trabucador the salt pans have a storage capacity of one month. On average about 30.000 tons of salt are stored on the la Banya spit. The damage function for the salt pans of the salt industry is expressed by equation 6.5:

$$LOSS = A_i * C_i * P_i \tag{6.5}$$

Herein A is the surface of salt basins which is flooded [ha], C are the costs for production of one ton of salt [Euro/ton] and P is the production in of salt [ton/ha]. Due to breaching of the Trabucador no more salt can be transported over land. The average storage capacity is 30.000 tons for a maximal production 90.000 tons of salt a year. This means that due to long breaching (more than one month) of the Trabucador the maximal storage capacity would be exceeded, which would lead to additional damage for the salt industry. However, the salt industry has restored the Trabucador themselves after previous storms before damages could occur.

tertiary sector: tourism

The campings in the coastal zone are not affected by flooding. The secondary housing in Riumar could be affected, as is described for assets. it is unclear how much the total number of tourist coming to the Delta would be affected due to flooding or erosion of stretches of the coast. As the most of the tourist facilities lay inland and are not directly affected, and the direct effects of a flooding and erosion are only influential for a short time for access to the beach, it is assumed that the effect on tourism is negligible.

Infrastructure

Includes damage to roads, bridges, energy transport, pipelines and navigation. The damage to infrastructure is calculated by formula 6.6.

$$L_t(Euro) = \sum_{1}^{N} Le_i * C_i * \%P_i \tag{6.6}$$

in which Le_i= the length of the affected infrastructure [m], C_i is the costs of construction / stretch of infrastructure (Euro/m), $\%P_i$ is the percentage of infrastructure damaged and N is the number of units of infrastructure affected. Infrastructure most affected by storms is the Trabucador. The total length of this barrier is about 6 kilometers [Santalla, 2002]. The replacement costs/meter for the Trabucador are unknown.

6.3.3 Direct, intangible damage

The intangible damage from storm induced flooding and coastal erosion is the damage to the natural values to the Ebro Delta. Whether or not storms and coastal erosion cause intangible damage leads to an interesting discussion. From the point of view of the ecologists at the natural park the species and habitats are perfectly adapted to the impact of sea storms and flooding. As a matter of fact, in many cases without these storms they would be replaced by other species and habitats. In the case of the Illa de Buda, as well as in other areas of the Nature Reserve, not the storms, but the coastal erosion produce the main impact. However, the loss of habitats is counterbalanced by the accretion of in other zones (the tips of the Fangar spit and La Banya spit), creating similar habitats in quality and extension. Concluding, this means that storms and erosive processes are not a hazard for the natural park, as long as the natural balance is not disturbed, but these processes are regarded as a necessary perquisite for conservation of the natural areas. In table 6.3 the relative value of the habitats is shown, as determined by the ecologists of the natural park. Firstly the ratio value is determined on a scale from 0 to 4. Zero is no value, one is small value, two is an intermediate value, three is a large value and four is a very large value. Secondly an ordinal value is assigned to the habitats. This is to classify on which geographical scale the habitats are important. The scale is

No.	Habitat type	Ratio value	Ordinal value	Combined value	Resilience [%]
11	Coasts and seas	4	N	4,6	100
14	Mud flats and sand flats	4	N	4,6	100
15	Salt marshes, salt steppes and gypsum scrubs	4	I	4,8	75
16	Coastal sand dunes and sand beaches	4	I	4,8	75
21	Saline or hypersaline lagoons	4	I	4,8	75
22	Standing fresh water	4	N	4,6	0
23	Standing brackish or saline water	4	I	4,8	50
24	Running waters	3	R	3,6	100
34	Dry calcareous grass-lands and steppes	1	NI	1	0
37	Humid grassland and tall herb communities	4	R	4,4	25
44	Alluvial and very wet forests and brush	4	R	4,4	25
53	Water-fringe vegeta-tion	4	N	4,6	50
82	Rice cultivation	2	R	2,4	0
83	Orchards, groves and tree plantations	1	NI	1,0	0
84	Tree lines, hedges, small woods, bocage, parkland, dehesa	1	NI	1,0	0
85	Parcs and gardens	0	NI	0	0
86	Urban and industrial areas	0	NI	0	0
87	Abandonned fields, uncultivated lands and ruderal vegeta-tion	1	NI	1,0	0
89	Industrial lagoons and reservoirs, canals	2	L	2,2	50

Table 6.3: Habitats and their determined value

from no importance (NI); this habitat can be found everywhere and are of none importance for sustaining the eco-system, local importance (L); can be found everywhere but are of importance for sustaining the local ecosystem, regional importance (R); The Delta is one of the few places in the region where the habitat can be found (radius of 100-200 km), national importance (N); the Delta is one of the few places in Spain where the habitat can be found, to international importance (I); the Delta is one of the few places in Europe where the habitat can be found. The ratio and ordinal value can be combined to one value. The calculation is made translating the ordinal value into a ratio value, where NI=0, L=0.2, R=0.4, N=0.6 and I=0.8. The total relative value for a certain type of habitat (V_e) is calculated by adding the ratio value and the converted ordinal value.

When affected by flooding a system will have the ability to recover. This is called resilience, which is defined as the ability of a system to persist if exposed to a perturbation by recovering after the response [Vis et al., 2003]. The ability to recover, will reduce the intangible damage to a system. The ecologist from the natural parc has been asked to value this resilience for each of the habitat types, a percentual value ($\%R_h$), shown in table 6.3. The values have the following meaning: 0% no resilience to situation with minimum storm impact; 25% resilient to the minimum situation storm impact; 50% resilient to an intermediate situation of storm impact; 75% resilient to a scenario that is almost worst case; 100% resilient to worst case scenario of storm impact. In other words for a resilience value of 100% the habitat type is resistant; it shows no reaction at all to the perturbation. The percentual represents the part of the system that is recovered after a flood by natural processes, and thus cannot considered to be a loss. The intangible damage to a eco-system thus can be seen as the value of this system multiplied by the resilience percentage, this is expressed by equation 6.7:

$$L_i[-] = V_e[m^{-2}] * A_i[m^2] * (100 - (\%R_e)) \tag{6.7}$$

In this equation V_e is the relative value per hectare for a certain habitat, $\%R_e$ is the percentage of system recovered (resilience) for a certian habitat and A_i is the affected area in hectares. This results in a dimensionless value L_i for intangible damage.

6.4 Calculation and presentation of the expected damages

6.4.1 Expected damages

The data from tables 6.3 and 5.1 serves as input for the equations 6.3 and 6.7 to calculate the tangible and intangible damage for each storm scenario combined with a land use change scenario. The calculation is given in appendix C. The results of this calculation are shown in table 6.4.

storm scenario	**damage category**	**damage**
	Base year	
2001	*tangible damage [Euro]*	
	82. Rice cultivation	944
	intangible damage [relative]	
	15. Salt marshes, salt steppes and gypsum scrubs	146
	16. Coastal sand dunes and sand beaches	1222
	82. Rice cultivation	596332
	89. Industrial lagoons and reservoirs, canals	1
	BAU	
2051	*tangible damage [Euro]*	
	82. Rice cultivation	4020
	86. Urban and industrial areas	143361
	intangible damage [relative]	
	15. Salt marshes, salt steppes and gypsum scrubs	0
	16. Coastal sand dunes and sand beaches	4118
	82. Rice cultivation	253915
	89. Industrial lagoons and reservoirs, canals	12455
	natural development	
2051	*tangible damage [Euro]*	
	82. Rice cultivation	0
	86. Urban and industrial areas	143361
	intangible damage [relative]	
	15. Salt marshes, salt steppes and gypsum scrubs	253915
	16. Coastal sand dunes and sand beaches	4118
	82. Rice cultivation	0
	89. Industrial lagoons and reservoirs, canals	12455

Table 6.4: Damage for the land use scenarios

6.4.2 Uncertainty

The uncertainty in the calculation of damage is caused by the assumptions made in the hydraulic modeling of the flooding and the assumptions made in the damage functions. The assumptions for the model of the flooding have been described in subsection 5.2, but it has to be stressed that assumptions in this model have implications for the calculation of damages. For the damage functions the following assumptions are important:

- **Scale:** the current study takes place on meso scale, but a study on micro scale would deliver a more detailed result and a more exact and reliable result for the expected damages. The use of aggregated land use data leads to inaccuracies as it assumes equal distribution of damaged tangibles and intangibles over the aggregated area, which is (mostly) not in accordance with reality.

- **characteristics of inundation:** the damage functions in this research are only depth dependent and not dependent on other inundation characteristics as flow velocity, rise rate and flood duration have not been considered in this research.

- **depth-damage function:** at present, no depth-damage function is available for housing in the Ebro Delta. The depth damage function used is an estimation.

- **Damage for rice cultivation for each month of flooding:** The flooding of rice fields at the Marquesa in 2001 took place in November, when the lands laid fallow, but in addition figure 6.2 shows that the losses due to a storm for rice cultivation are much higher in the months August until October.

- **Aquaculture:** few data is available for this research concerning the tangible damages to aquaculture due to breaching of the Trabucador. Next to flooding like eutrofication and temperature play an important role in the amount of loss for aquaculture.

- **Subjectivity of the relative value of a habitat (V_e):** For each stakeholder the relative value of a specific habitat is different. The relative value of each habitat has been assigned by an ecologist, which is assumed to be the expert. However, other stakeholders, may assign other values to habitats (for example: rice farmers may value the intangible value of rice fields higher). It could be discussed that it is better to aggregate relative values assigned to habitats by different stakeholders.

The conclusion is that with more data the study on damages could be extended to produce a more reliable result on damages for the Ebro Delta coast due to flooding. Next to this a study on micro scale would deliver a more exact and reliable result

6.5 Perceptions on flooding and coastal erosion in the Ebro Delta

The research on risk perception and stakeholder perception is conducted by means of questionnaires. In order to obtain an impression of these indicators of risk perception, stakeholders in the Ebro Delta have been interviewed. These questionnaires have been send by means of e-mail. The participants are representatives of:

1. the town council (ajuntament) of Sant Jaume d'Enveja
2. department of coastal engineering for the region Tarragona
3. the salt pans (salines)
4. the community of irrigators (comunitat de regants)
5. Arrosaries (rice producers agrupation)
6. The owner of the restaurant and rice fields at the Marquesa beach

More stakeholders have been asked for their opinion, but they did not respond to the request to fill the questionnaire.

6.5.1 Risk perception

Three important subjects in risk perception for flooding are awareness, preparedness and worry, as explained in section 4.2.1. The worry about flooding in the coastal zone is very large among the stakeholders. The degree to which they were worried is scaled on a scale from zero to five. Zero means the participants are not worried at all about flooding and four means the are very worried about flooding. A distinction is made between authorities etc. and local stakeholders, who have no administrative function. The results are shown in figure 6.3. Translated into the scaling of 0 to 1 the average worry is 0,88.

The farmland at the Marquesa beach is regarded to be very vulnerable to flooding by the local stakeholders. They feel unprepared for a flooding. The preparedness for flooding of the Marquesa beach is estimated to be 0,1. This is based on the answers that most people regard the Marquesa beach as very vulnerable to flooding (mean score 0,9) and they feel there is a need large for a plan that describes them what to do in case of a flooding. An interesting result was that none of the local stakeholders was aware of a plan which describes them what to do in case of a flooding, but they all felt the need for such a plan. The representative of the town council of Saint Jaume de L'Enveja pointed out that the town council plans the elaboration of a plan of civil protection that includes flood risk.

The awareness relates to past experience with flooding. All local stakeholders have been directly or indirectly exposed to the consequences of flooding

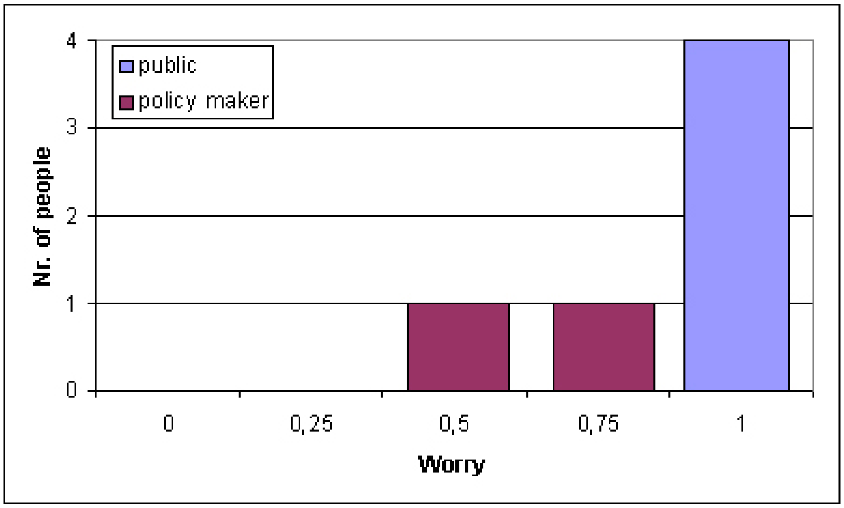


Figure 6.3: Worry

and coastal erosion. One of the stakeholders was directly involved in flooding (assignes score 1) at the Marquesa beach, four of them indirectly (assigned score 0,5). Therefor the average score on awareness is 0,6.

Using equations 4.4 and 4.5 the weight of conservation of commodity and non-commodity output versus the reduction of tangible and intangible damage is 0,21 versus 0,79.

6.5.2 Stakeholder perception

Often measures which are proposed by authorities are rejected by local stakeholders which defend their own interests. Public participation, the involvement of stakeholders, is an important mean to reduce the resistance of stakeholders against certain changes. For this research three measures have been proposed to the stakeholders and to one of those they had to assign their preferences. The first option is the 'do nothing' option, or the business as usual scenario. The second option is reinforcement of the beach by rock works and the third option are land use changes in general comparable to the ones proposed in this report. A clear distinction can be made between the management options the general public and the authorities prefer. As shown in figure 6.4 local stakeholders prefer technical measures, like reinforcement of the beach by rock works, while authorities prefer land use changes. Both stakeholders and authorities want action to reduce the risk, only the envisaged measures to do so are different. A conflict between stakeholders and authorities could arise, not in risk assessment but in risk management. The main reason local stakeholders (rice farmers) give is that for them the options 'do nothing' and 'change the land use' have no result on the deltaic continuum, when the land use is changed the subsidence would continue its trend. One farmer called these two options an insult to the local farming community, as their property would be threatened in both cases. A multi criteria analysis could compare alternative measures and show advantages and disadvantages, this information can be used in a negotiation process with the stakeholders. So, the multi criteria analysis does not select the solution as such, but makes the trade-off between criteria easier and better to present to stakeholders.

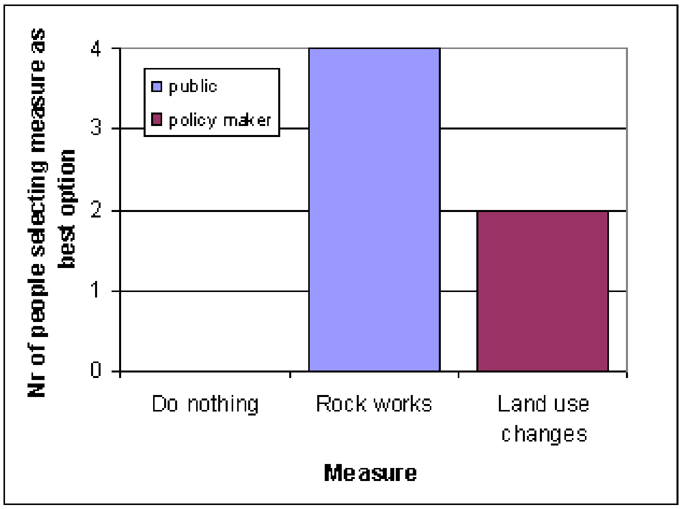


Figure 6.4: Preference for flood defense measures

As shown in figure 6.5 local stakeholders feel their participation in flood risk policy is low. This means current public consultation and participation processes may be expanded, which may lead to better risk management practice. The advantage of participatory decision making may be the increase of the commitment of stakeholders to the course of action selected, especially when the participation process was regarded as being fair [Rayner and Cantor, 1987]. The second advantage is the possible increase in trust in the organizations which manage the risk, which may lead to a greater acceptance of hazards [Slovic, 1993]. Thus there lie opportunities ahead for participation in flood risk management in the Ebro Delta.

6.5.3 Uncertainty

Not all stakeholders could be directly approached for this research. The response to the questionnaire on risk perception was 6 from a total of 12 polled stakeholders. This small number of responding stakeholders means that deviating answers have a larger impact to the aggregated result of the question-

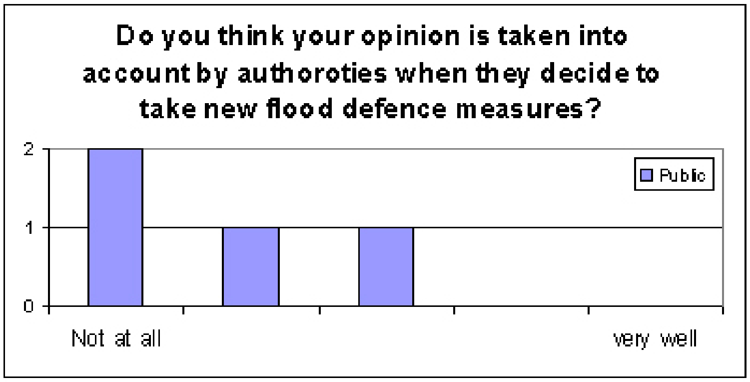


Figure 6.5: Participation by stakeholders

naires. For a future research more stakeholders have to approached to produce more reliable results.

For a questionnaire it is necessary to test the phrasing of the questions on the forehand. Different cultures have different phraseology and concepts could be understood differently [Swanborn, 1981] and previous testing will help to make sensible phrasings. The questionnaire is written in English and was translated into Catalan. There has been no testing of the questionnaire and in both processes information could be lost or interpreted in a wrong way. An useful technique to test the questionnaire is to pose the question:' why did you give the previous answer?'. This question has been added for tracking different interpretations (for example for the concept of worry).

Preparedness is such a concept, which has not been posed right in the questionnaire. Instead of asking, are you prepared for flooding (and continuing questions), the questions 'are you aware of any plans for what to do in case of a flooding' and do you think the 'following location (Marquesa, Salt Pans, irrigation canals) is vulnerable to flooding?'. The wrong questioning makes the reliability of the given score (0.9) low. However it is unquestionable that the preparedness for flooding is very low at the Marquesa beach, only a more reliable score has to be based on more extensive research.

Chapter 7

Spatial multi criteria analysis

Because in the Ebro Delta Coast case is dealt with several alternatives and the criteria are monetary as well as non-monetary. Thus multi-criteria analysis is the most suitable method for evaluation.

7.1 Spatial MCA: scores on criteria

7.1.1 Damage

The damages for each type of scenario are presented as maps. Because tangible and intangible damage serve as an criterion, these presentations can be seen as criterion maps. The tangible damage for the three scenarios is shown in figure 7.1 and the intangible damage for the three scenarios in figure 7.2.

7.1.2 COs and NCOs

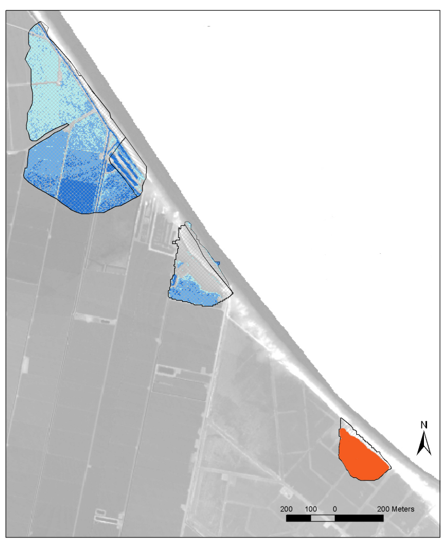
Changes in land use have effects for the commodity output as well as the non-commodity output of a certain land-use. The commodity output is the change in the change in production of goods, as is the case for the rice cultivation at La Marquesa. The change in non-commodity output is the change in ecological value. Some types of habitats are more valuable to certain species (plants, birds etc.) and have been a higher intangible value. The scores for each habitat change are shown in table 7.1.

7.2 Aggregation

The spatial scores will be translated into non-spatial scores by (non-spatial) aggregation. Therefor the mean tangible damage $\overline{L_t}$ and intangible damage $\overline{L_t}$ per hectare will be calculated. The average tangible damage will be calculated

(a) Damage 2001

(b) Damage BAU



(c) Damage Nat.

Figure 7.1: Criterion maps for tangible damage

(a) Damage 2001

(b) Damage BAU

(c) Damage Nat.

Figure 7.2: Criterion maps for intangible damage

Current habitat type	tangible value [$Euro * ha^{-1} * year^{-1}$]	changed to	new habitat type	tangible value [$Euro * ha^-1 * year^{-1}$]	changed surface	changed tangible value [Euro/year]
15. Salt marshes, salt steppes and gypsum scrubs	*0*	$\longrightarrow$	86. Urban and industrial areas	*88200*	55,5	+4895100
82.Rice cultivation	*2043*	$\longrightarrow$	15. Salt marshes, salt steppes and gypsum scrubs	*0*	120	-254160
Current habitat type	**relative intangible value [V_e/ha]**	**changed to**	**new habitat type**	**relative intangible value [V_e/ha]**	**changed surface**	**changed intangible value [V_e]**
15. Salt marshes, salt steppes and gypsum scrubs	4.4	$\longrightarrow$	86. Urban and industrial areas	0	55,5	-244.2
82.Rice cultivation	2.4	$\longrightarrow$	15. Salt marshes, salt steppes and gypsum scrubs	4.4	120	+240

Table 7.1: The tangible and intangible value difference per habitat change

using equation 7.1.

$$\overline{L_t} = A_{ij} * L_t / \sum A_{ij} \tag{7.1}$$

The average intangible damage will be calculated using equation 7.2.

$$\overline{L_i} = A_i j * L_i / \sum A_{ij} \tag{7.2}$$

In these formulas $\sum A_{ij}$ is the total area affected by the flooding. The whole calculation is shown in appendix D.1. Because the change in commodity and non-commodity output is already non-spatial these values do not have to be aggregated. The results of the aggregation are shown in table 7.2

	Base year	**BAU**	**natural development**
Tangible damage	923	16241	12819
Intangible damage	58,3	21,7	21,7
Change in commodity output	0	+4895100	+4640940
Change in non-commodity output	0	-244,2	-4,2

Table 7.2: Aggregated values for MCA

7.3 Multi-criteria analysis for the Ebro Delta

After aggregation a multi criteria analysis is carried out using the methods described in subsection 4.5.4. For calculation the BOSDA computer program is used. BOSDA uses cost and gain criteria. For a gain criterion the higher the score the better the alternative scores on the criterion. For a cost criterion the opposite applies; the lower the score, the better the alternative is [Janssen et al., 2000].

7.3.1 Standardization

The two methods to choose from are interval and maximum standardization. However maximum standardization is not suitable for this multi criteria analysis, because the maximum score for the change in non-commodity output is zero. This means maximum standardization cannot be directly applied for this study, as a division by zero would have to take place (see formula 4.2). A trick to be able to apply maximum standardization is to change the criterion ”change in NCO” from a gain-criterion into a cost criterion. This means the minus signs can be turned into plus signs, since a higher score means more negative counting. The results of interval standardization are shown in table 7.3, results of the maximum standardization are shown in table 7.4.

7.3.2 Weighing

Firstly the weights will be determined with the methodology to base the weighting on risk perception. This methodology is described elaborately in subsection 4.5.6. Firstly let's assume that tangible and intangible damage are equally important in comparison to each other and that the same applies for conservation of CO and NCO output. This can be deducted from the questionnaire on risk perception where all stakeholders have valued the conservation of economic activities as conservation of the natural areas. However, policy makers or stakeholders would not have to agree with this weighting, and therefor it is good to use pairwise comparison in addition. In pairwise comparison the criteria can be compared relatively to each other, which means the weighting can be fine-tuned. Suppose the policy maker thinks tangible damage is two times as important intangible damage is. A motivation could be that intangible damage is a natural process to which the ecosystems will adapt. The relative weighting of tangible and intangible damage will change in favour of tangible damage.

There are numerous possibilities for varying the weighting according to own insight of the policy maker and stakeholders. It is not the meaning of this report to present the weighting which must be used to base a decision on, but to present the possibilities within the given methodology. The weights are shown in table 7.3 and 7.4.

	Base year	**BAU**	**natural development**	*weight risk perception*	*weight pairwise comparison*
tangible damage	1	0	0,22	*0,395*	*0,467*
intangible damage	0	1	1	*0,395*	*0,328*
Change in CO	0	1	0,95	*0,105*	*0,103*
Change in NCO	1	0	0,98	*0,105*	*0,103*

Table 7.3: Multi criteria analysis with interval standardization

7.3.3 Ranking

Ranking is done by weighted summation. The results of the ranking are shown in table 7.5. The table shows the prioritization of the alternatives resulting from different methodologies, with the best scoring alternative emphasized bold. A look at the table shows that the prioritization differs significantly for different methods. Especially the standardization seems to have a significant influence on the ranking. The contribution of each score to the total score for an alterna-

	Base year	**BAU**	**natural development**	*weight risk perception*	*weight pairwise comparison*
tangible damage	0,94	0	0,22	*0,395*	*0,467*
intangible damage	0	0,63	1	*0,395*	*0,328*
Change in CO	0	1	0,95	*0,105*	*0,103*
Change in NCO	1	0	0,98	*0,105*	*0,103*

Table 7.4: Multi criteria analyis with maximum standardization

tive is shown in appendix D.2. The business as usual scenario overall scores the least well, representing a decline, representing the worst sustainable flood risk management strategy. Overall the natural development scenario scores the best, representing the best flood risk management strategy according to this analysis with these methods.

7.3.4 Sensitivity analysis

After conducting a multi criteria analysis it is necessary to carry out a sensitivity analysis to determine how sensitive the outcome of the multi criteria analysis is for the uncertainty in weights or scores for criteria. To give an example of a sensitivity analysis, the sensitivity of the ranking to changes in the weight for tangible damage following method 1 (interval standardization, risk perception and weighted summation) is shown in figure 7.3. This procedure could be repeated for every method and every weight or score. Due to time limitations and lack of data, a sensitivity analyis for all weights and all scores is not carried out within this report.

method	**Base year**	**BAU**	**natural development**
1. Interval standardization ⟶ risk perception ⟶ weighted summation	0,5	0,5	**0,69**
2. Maximum standardization ⟶ risk perception ⟶ weighted summation	0,48	0,35	**0,53**
3. Interval standardization ⟶ pairwise comparison ⟶ weighted summation	0,57	0,43	**0,63**
4. Maximum standardization ⟶ pairwise comparison ⟶ weighted summation	**0,54**	0,31	0,5
Average ranking	*0,52*	*0,40*	***0,59***

Table 7.5: Ranking according to combunation of different multi criteria methods

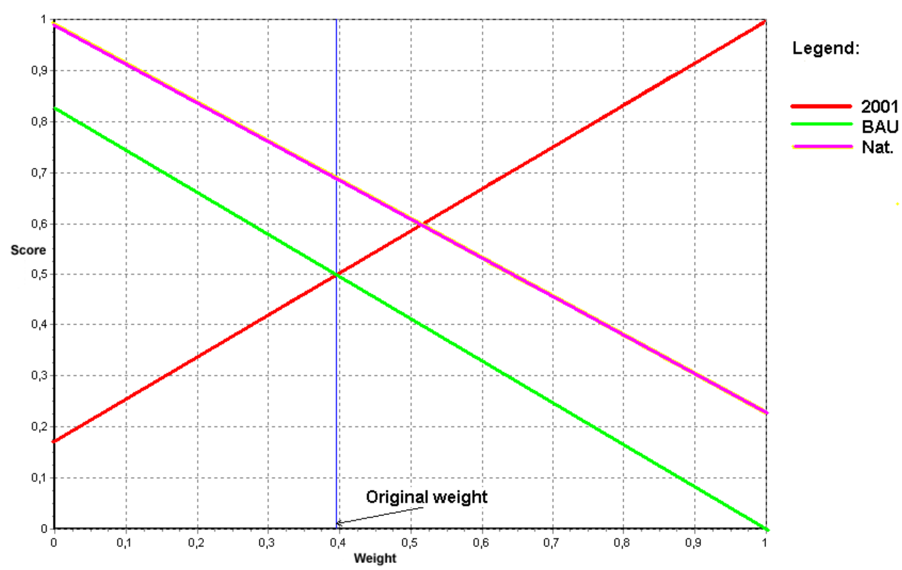


Figure 7.3: Sensitivity analysis for the weight of tangible damage for method 1

Chapter 8

Conclusion and recommendations

8.1 Conclusion

The future for many of the socio-economic functions in the Ebro Delta in Spain is unsure. Sea level rise and subsidence cause a relative sea level rise (RSLR). Large storms, which regularly cause coastal erosion and flooding of the Ebro Delta coast will have larger impacts in the future than these storms have now, under the plausible assumptions that present trends continue. Land use changes may be a possible alternative solution to reduce the impacts of storms for the Ebro Delta coast. In order to compare the different advantages and disadvantages of these land use alternatives, there is the need for a methodology which assesses consequences of a specific scenario. The following central question has been posed.

How can spatial multi criteria analysis and risk assessment be combined to a methodology that can be used to evaluate and compare land use alternatives on their suitability as a sustainable flood risk management alternative for the Ebro Delta coastal zone?

The main concepts within this methodology are spatial multi-criteria analysis, risk assessment (damage evaluation and risk perception), land use scenarios, storm scenarios. These existing methods and concepts had to be ordered into a consistent combination to form a useful methodology. To start a (spatial) multi criteria analysis requires both *alternatives* and *criteria* to judge these alternatives on are needed. This methodology aims at judging different land use scenarios which can be divided into baseline and policy scenarios. A baseline scenario implies continuation of the present trends, while in a policy scenario these (negative) trends are attempted to be influenced by policy. The suitability as sustainable flood risk management is judged on the basis of criteria. Flood risk management implies a reduction of the flood risk; a reduction of the probability of flooding and/or the (negative) consequences, which both imply that less tangible or intangible losses occur on a certain spatial and time scale. Within this methodology land use scenarios and the physical flooding (obtained from a storm scenario) for the same time of occurrence are combined in an overlay operation. Hereby for each location and specific land use a tangible and intangible damage can be assigned. As the policy maker wants to know the effectiveness land use change as a flood risk management alternative, the spatial distribution of direct, tangible and intangible damages both serve as criteria.

Sustainable land use demands the balancing of societal demands of land use and economic demands of land use. A policy which aims a reducing a risk will often also reduce the benefit of activities in the area. Hence, for policy making risk has to be weighted against benefit, which can be translated into the conservation of commodity output (CO) and non-commodity output (NCO).

Each land use alternative (scenario) is combined with the criteria in order to create criterion maps, in which the scores on each criterion are shown. Aggregation, standardization, weighting by risk perception and/or pairwise comparison and ranking in multi criteria analysis leads to a comparison of the scenarios in their effectiveness for sustainable flood risk management.

The trade-off between risk and benefit takes place in the context of risk perception. Worry, preparedness an awareness add weight to one side of the balance that weights the conservation of CO and NCO on the one side against reduction of tangible and intangible damage on the other side. Thus, the aggregated score for risk perception can be implemented as a method to determine the weights for multi criteria analysis, to determine which relative importance risk reduction gets in comparison to conservation of NCOs and COs of land use. Risk perception of stakeholders can be changed, for example by preparing them better for flooding. Using the notion of risk perception in multi criteria analysis can make the policy maker aware that measures itself can change the tipping of this balance, which can lead to favorable result as for example an acceptance of higher levels of risk by stakeholders. An other method for weighting, pairwise comparison, is an effective method for determining weights to fine tune the weighting by risk perception.

To show how this methodology works in practice it has been applied to the Ebro Delta coast. In this report two land use scenarios for the Ebro Delta coast have been formulated and compared with the base year, 2001. The two alternatives are the Business As Usual scenario and the Natural Development scenario. The combination of different methods of standardizing (maximum and interval) and weighting (risk perception and pairwise comparison) with ranking by weighted summation leads to the conclusion that the natural development scenario is the most favorable as sustainable flood risk management alternative. The Business As Usual scenario is the least favorable future, and building secondary housing in the coastal zone clearly has negative influence for the flood risk management in the Ebro Delta coastal zone. Without measures to reduce this risk, damages will grow to even more unacceptable levels. However the outcome of multi criteria analysis is very sensitive to changes in the chosen combination of methods, which is one of the uncertainties in this research. This means the multi criteria analysis should not be used to make the solution as such. The combination of Risk Assessment (damage evaluation and risk perception) and Spatial Multi Criteria Analysis can give the policy maker insight into the consequences of land use changes for sustainable flood risk management and compare these consequences. This methodology can be of valuable guidance in the policy making process and negotiating process which should in the end really lead to sustainable flood risk management.

8.2 Uncertainty

Uncertainties occur due to explicit and implicit assumptions made in this report . Uncertainties influence the reliability of the outcome of the report. For the application of the methodology for the Ebro Delta the main assumptions are listed here.

- **Storm scenarios:**
  - The difference between the minimal and maximal predicted relative sea level rise (RSLR) for the Ebro Delta is 4mm/year. Because the Ebro Delta has no coastal defenses small differences in the RSLR could have large consequences for the magnitude of the surface which is exposed to a certain flood risk.
  - The flood model, which is used to calculate the area and depth of flooding for 2051 assumes no infiltration and soil roughness.
- **Land use scenarios:**
  - The future market development and physical conditions for production (as eutrofication) for the primary sector in the Ebro Delta are unsure, therefor it is difficult to make a reliable scenario.
  - The river basin management policy for the river Ebro could change drastically with a change of policy of authorities, which could endanger the supply of water for both agriculture and nature and could aggravate the subsidence of the Delta.
  - The socio-economic functions of the Ebro Delta are dependent, the loss of one function could threaten the existence of the other, or in some cases could provide better conditions.
- **Damage evaluation:**
  - Some inundation characteristics as flow velocity and flood duration are not considered in the damage functions. Additionally the damage for agriculture is dependent on the time of occurrence of flooding (time of the year).

  - A meso-approach is used. This methods uses aggregated land use data which leads to inaccuracies for damage calculation as it assumes equal spread of the damaged, of the averagely valued objects over the area.
  - Indirect damage is assumed to be negligible in comparison to direct damages
  - The value of a specific habitat is subjective and not objective as assumed in this research. Averaging a lot of subjective values could give a more accurate estimate.

- **Spatial multi criteria analysis:**
  - Multi criteria analysis is a tool very sensitive to changes in the mathematical algorithms (for standardization, ranking, etc.) which are combined. It is wise to use more than one combination of algorithms and to do a sensitivity analysis afterward.

Uncertainties in a research can never be avoided, but by recognizing their existence they can be dealt with of reduced in successive research.

8.3 Recommendations for further research

The methodology is suitable to be applied for deltas and floodplains in general. Sustainable land use contains many economic, societal and environmental aspects. Successful consideration of all these aspects, will lead to an integrated assessment approach for flood risk management. This methodology will be able to support decisions of policy makers where knowledge about and the understanding of the interaction between socio-economic processes and flood risk can be used to reach to more effective flood risk management. It is wise to use this methodology as a tool to support decision making and not for making the decision itself.

With access to more data many of the uncertainties can be reduced. A better hydromorphologic model should give insight into the quantitative influence of storms on coastal erosion and flooding. The number of land use scenarios used in this report for multi criteria analysis was limited to two. When applying this methodology for the Marquesa beach, many more land use alternatives have to be considered, as for example a natural development scenario (land use change from rice culture to salt steppes) with a land use change of less magnitude or of a different nature (land use change between other habitat types). With data provided in this report the analysis could be easily extended to the whole Ebro Delta, to risk prone areas as the Illa de Buda and the Trabucador. The use of multi criteria analysis in decision making is subject of many discussions. Multi criteria analysis cannot be used to make the decision itself, but can used as guidance for sustainable risk management policy.

An increase in commodity outputs for the coastal zone, increases the flood risks. Policy makers and local stakeholders are aware that flood risk will increase due to relative sea level rise. The awareness that the flood risk for the Ebro Delta coast increases with the building of Riumar I and IV has to grow. Under the right storm conditions (with a return period of about 1/25 years) the housing in this urbanized area will be damaged. Both local stakeholders and policy makers have to be prepared for a flooding. Part of this need for preparedness can be met by making and communicating a plan which tells residents of the coastal zone what to do in case of a flooding. The land use change proposed in this report is just one out of many possibilities and serves as an example for the evaluation of other (similar) land use changes.

Appendix A

Questionnaires

A.1 Introduction

This section shows the questionnaires which have been answered by the stakeholders within the Ebro Delta. These are the questionnaires for the topics:

1. risk perception
2. natural park
3. tourism
4. salt industry
5. aquaculture

Some of these questionnaires have been translated into Catalan, in order to retrieve answers more efficiently. To each of the questionnaires one section is devoted.

A.2 Questionnaire on risk perception in the Ebro Delta

There is strong evidence the risk of flooding will increase in the future because of climate change. Therefore the European Union investigates how we can cope with these increased flood risk in the FLOODsite project. The University of Twente (The Netherlands) and the Universitat Politchnica de Catalunya undertook a joint research about flood risk in the Ebro Delta. This questionnaire, about risk perception, is part of this research. The questionnaire includes 14 questions and will not take more than 10 minutes to fill. Thank you very much for your cooperation.

Part I: general information (Informació general)

1. What year were you born? A quin any vas nixer?
[19 ..]

2. Gender (Gènere)
[Male (Masculí) / Female (Femení)]

3. Where do you live and work?

4. What is your profession?

Part II: the flooding of the marine region (La inundació de regions martimes)
5. Have you ever experienced a flood in the Ebro Delta (directly of indirectly)
Yes
No

6a. In general, how worried are you about the flooding and its effects in the area? (En general, quant et preocupa la inundaciÓ de zones costaneres i els seus efectes?)

Not worried (No em preocupa) - Very worried (Em preocupa molt)
0 - 1 - 2 - 3 - 4

6b. When you are worried can you give any particular reasons for that? (Si et preocupa, pots donar alguna raó?)

7. In 2001 a storm occured after which parts of the Ebro Delta were flooded. The Trabucador was breached, the Marquessa beach was flooded and there were breachings near the Illa de Buda. In how many years do you expect a similar flood event as in 2001 would occur? (En quants anys esperes una inundació semblant a l'any 2001?)

I expect within the next ... years (L'Espero en ... anys)
I don't know, there are too many uncertain factors to make a good estimate (No ho sé, hi ha masses factors incerts per fer una bona estimació)

8. At present there are some engineering or land use management options to prevent the impact of flooding. Could you say which option you would like the most?

1. Do nothing
2. Protect the hinterland reinforcing the beach by rock works
3. Change the land use of the vulnerable areas from agricultural to natural

9. When you not prefer certain measures, why would you not want author-

Function	Hazard (score)
The natural park (Illa de Buda, Fangar and La Banya spits)	
The housing in Riumar	
Infrastructure (like roads close to the beach)	
The irrigation canals	
Rice production in the coastal zone (for example la Marquesa)	
Salt industry	
Aquaculture in the Alfacs bay	

ities taking these measures?

10a. Are you aware of any plan that describes you what to do in case of a flooding?

Yes
No

10b. Do you have the need of more information for what to do in case of a flooding?

Yes
No

11. How large you think the hazard of that storm impacts (flooding and coastal erosion) is for the following functions of the Ebro Delta Coastal zone?

Score on a scale from 0 - 4
0 = No hazard
1 = Small hazard
2 = Intermediate hazard
3 = Large hazard
4 = Very large hazard

12. How important is maintaining the natural areas in the Ebro Delta in comparison to the maintenance of existing economic activities [rice production, salt industry, tourism, fishery and aquaculture] within the Ebro Delta?

1. Maintaining the economic activity in the area is more important than maintaining the natural areas in the Ebro Delta.
2. Maintaining the economic activity in the area is equally important as maintaining the natural areas in the Ebro Delta.
3. Maintaining the economic activity in the area is less important than maintaining the natural areas in the Ebro Delta

13. Do you think your opinion is taken into account by authoroties when they decide to take new flood defence measures?
Not at all - Very well taken into account
0 - 1 - 2 - 3 - 4

A.3 Questionnaire for the Natural Park

General introduction

This research is part of the FLOODsite project. The FLOODsite project is part of the first round of the Sixth Framework Programme of the European Commission. This is an 'Integrated Project' on flood risk management. The goal of the FLOODsite project is to create an integrated flood risk management framework and network. Within this research there are several tasks of which one is task 26, a pilot study on the Ebro delta, merely aimed at testing the previous research wherein a framework for flood risk management was designed. The task is carried out by three institutions: UPC (Universitat Politechnica de Catalunya), the University of Twente (Enschede, the Netherlands) and UniLund (Lunds Universitet). The task of UPC is to deliver storm scenarios for the Ebro Delta coast. The University of Twente will do a risk assessment, which concerns the socio-economic consequences of a storm scenario. This questionnaire is part of the research of the university of Twente. It is divided into two parts: the first one about intangible damage and the second one about risk perception.

Valuing intangible damage in the natural park

When evaluating damages, there can be made a distinction between tangible and intangible damages. Tangible damages are the damages that can directly be expressed in monetary terms, as for example damages to assets. Intangible damaged cannot directly be expressed into monetary terms, but has to be expressed in other values. The goal of this questionnaire is to find a method to measure the intangible damage to the natural park caused under different storm scenarios. Thank you very much for your cooperation.

0. Map and list of all the habitats in the Ebro Delta Coast

1a. Have you ever made an estimate of the value of each habitat type in the Ebro Delta?
Yes ⟶ go to question 1b.
No ⟶ go to question 2.

1b. What type of estimate have you made and what was it based on?

2. Can you make an estimate of the relative value of each habitat type in the Ebro Delta on a scale from 0 (no value) to 4 (very large value)?

0 No value
1 Small value
2 Intermediately value
3 Large value
4 Very large value

Nr. Habitat Type Relative value
1.
2.
..

3. The ranking of the different habitat types. In the table below there is made a classification. Can you classify each of the habitat types into one of the scales of importance?
On which geographical scale are the habitats important? :
Meaning - Number of habitats - Habitat type (numbering as below will do)

Not important: Can be found everywhere and are of none importance for sustaining the eco- system
Local: Can be found everywhere but are of importance for sustaining the local ecosystem
Regional: The Delta is one of the few places in the region where the habitat can be found. (radius of 100-200 km)
National: The Delta is one of the few places in Spain where the habitat can be found.
International: The Delta is one of the few places in Europe or the world where the habitat can be found.

4a. Biodiversity: have you measured biodiversity for the Ebro Delta?

Yes ⟶ Go to question 4b
No ⟶ Go to question 4c

4b. how is it scored and which is the value scored?
4c. are you planning to make a measurement for it?

5a. Storm impacts: do you think that storm impacts (flooding from the sea) are a hazard for the natural park?
Yes ⟶ Go to question 5b
No ⟶ What do you think of the storm impacts of the last years to Illa de Buda or any other sensitive area in the Ebro Delta coast?

5b. Location and processes for the impacts: at which locations could a storm have an impact to the natural park and which are the physical processes that cause those impacts?

Examples of processes responsible for impacts are:

1. coastal erosion
2. flooding
3. salt intrusion
4. plant removal
5. breaching (linking fresh water to salt water areas)
6. other

Location of storm impact Processes responsible for impacts.
5. Storm impact scenarios:
5a. which will be the minimum conditions to consider a problem should appear, associated to storm-induced flooding or coastal erosion, and what will be the consequences for the conservation of the natural values?
5b. which will be the worst case storm-induced flooding coastal erosion scenario for conservation of the natural values of the Ebro Delta and what will be the expected consequences for these natural values?

6. Resilience: can you give a relative ranking to the resilience of each habitat type to a induced flooding or coastal erosion impact scenario on a scale from 1 to 5. In which 0 = no resilience to the situation there is a minimum problem caused by flooding and 5 = resilience the worst case flooding scenario

0.No resilience to situation with minimum storm impact
1.Resilient to the minimum situation of storm impact
2.Resilient to an intermediate situation of storm impact
3.Resilient to an scenario that is almost worst case
4.Resilient to worst case scenario of storm impact

Nr. Habitat Type Relative value of resilience
1
2
..

7a. Relative importance of the natural park in comparison to existing economic activities: how important is maintaining the Delta ecosystem in comparison to the maintenance of existing economic activities [rice production, salt industry, tourism, fishery and aquaculture] of the Ebro Delta?

7b. Relative importance of economic functions for natural park: how important are the economic activities [rice production, salt industry, aquaculture,

fishery and tourism] for the natural park?
1. Rice production
2. Salt industry
3. Aquaculture
4. Fishery
5. Tourism

7c. Threats of economic activity: What are the main threats for the park associated to these economic activities?

8. Tourism:
8a. What is the number of tourists that visits the Natural Park over the last years?
8b. Which are the main visited areas?
8c. Which are the areas valued the most by tourists?

A.4 Questionnaire tourism

1. Growth of the number of visitors
The tourist sector in the Ebro Delta Coast region is mainly aimed at eco-tourists and tourists attracted to the beaches. Tourism is a growing activity in the delta. From 1992 until 2001 the tourist sector steadily grew. Especially the Eco and Rural tourism are expected to experience growth.

1a. Do you have any estimate of the current number and distribution of visitors in the Ebro Delta?

1b. Do you have any estimates visitors you expect to come to the Ebro Delta in the coming years?

2. Expansion of the current tourist facilities in the Ebro Delta.

2a. Are you involved into any plans to expand the number of facilities in the Ebro Delta?
Yes ⟶ go to question 2b
No ⟶ go to question 2c

2b. Which are these plans (location, sort and number of facilities) for expansion of tourist activity.

2c. Is there a lack of a certain type of tourist activities which are currently not efficiently covered or that can be expanded (like for example secondary houses or bikeways)?

year	Description and/or quantification (financial damage) of the effects of storm induced flood and coastal erosion events onto the salt pans
1997	
2001	
2002	
2003	

3. Expenditure of tourists.

3a. On which activities within the Ebro Delta do tourists currently spent their money?

A.5 Questionnaire for the salt industry

1. Production and assets

1a. Can you make an estimate of the value of the assets of the salt pans?

1b. Can you make an estimate of the current and past production at the salt pans (tons/year) (the figures of 1996-2005)

1c. How many tons of the salt production on average you regularly store at the La Banya split itself?

2. Previous damages

2a. There were previous storm induced flood and coastal erosion events which directly affected the salt pans or affected the Trabucador. Examples are the storms of 1997, 2001, 2002 and 2003.

- Can you describe or quantify (the financial damage) the effect of these storms on the salt industry?
- Can you describe or quantify the effort you had to put in the restoration of the Trabucador for each particular storm induced coastal erosion and flood event?

2b. why did you decide to let part of the land you previously used for salt industry to lie fallow?

2c. Which would be the worst case flooding or coastal erosion scenario for

year	Loss of production due to breaching in the Trabucador (percentage)
2001	
2002	
2003	
2004	

the salt pans (for example inundation of the salt pans or breaching of the Trabucador)?

2d. Do you feel the government is giving you the right protection for a flood event?

A.6 Questionnaire for Aquaculture

1. The relation between the breaching of the Trabucador and the aquacultural production in the bays.

The Trabucador ensures that small wave action reaches the bay, so that the velocity of the water remains low. The storms of 2004 are believed to have caused a decrease in production of 15%

1a. Can you explain which are the circumstances for which there is believed to be a loss of production for aquaculture (the changed physical circumstances)

1b. Have you ever researched the relation between the breaching of the Trabucador and the loss in production?

1c. Can you quantify the relation between the breaching of the Trabucador (in the years 2001, 2002 2003, 2004) and the loss of aquacultural production in the Alfacs Bay?

1d. Can you imagine what consequences the scenario of permanent breaching of the Trabucador would have for the aquacultural production in the Alfacs Bay ?

2. The relation between accreditation of the Bayna and Fangar splits to the aquacultural production.

From 1957 till 1998 the tip of the Fangar Spit has advanced in the order of 1400 meters. If the present trend is extrapolated to the future and if there is no human intervention the Fangar bay will possibly close.

2a. Do you believe there currently is a relation between the closure of the Fangar bay and the amount of aquacultural production within the bay?

Yes ⟶ go to question 2b.
No ⟶ go to question 2c.

2b. Can you explain what this relation is and can you quantify the difference in aquaculture production in the bays?

2c. What will you do when the Fangar bay is near to closure?

3. Relative effects of breaching of the Trabucador

3a. How much does the loss in aquacultural production due to breaching in the Trabucador compare itself to loss in aquacultural production due to a very warm year?

- The loss is very small compared to the losses of production in a very warm year
- The loss is small compared to the losses of production in a very warm year
- The loss is the same compared to the losses of production in a very warm year
- The loss is large compared to the losses of production in a very warm year
- The loss is very large compared to the losses of production in a very warm year

4. Species used for aquacultural production

4a. Which are the species (bivalves, muscles or oysters) that are most capable of surviving the changed circumstances due to temporal breaching of the Trabucador and which are the species least capable of surviving these changes?

Appendix B

Software

The first step is converting Miramon land use files to *E00 vector format. These are the steps in the 5.2s version in Catalan. The first step is to press the layer icon which will take you into a menu titled ”canviar ordre i proprietats de les capes” in this menu switch the ”nom del fixter” on, and make sure all the other boxes are also switched on. Pres D’accord. Then click on the map with the right mouse button. The selecció d’objectes screen will appear. Press ”seleccionar tot” and press ”desar com..”. Here keep ”desar com fixer estructurat” swithced on and save as a *pol file. Then go to the Fixter > Exportar menu. Here select the option Pol > E00 and switch on miramon -> arcinfo, and load the just created *pol file into the fixter a convertir space. Select a filename you want to convert the file to in fixter de sortida. Press d’accord.

There are numerous surveying points that are indicated as Datum and that can be calibrated by their heights data.

UTM zone 31
Datum = eur50

B.1 Procedure

1) Georeference the two flood events (polygons)
2) Set Spatial Reference for
- LU1stDIS.shp
- LU2ndDIS.shp
- delta_ebre

B.1.1 Scenario 2001

- Clip the LandUse map with the polygons on the Flood layer (1st scenario)

- Dissolve so that adjacent polygons with the same value of land use are merged into one polygon
- Explode the features so that we have not multipolygon features anymore (otherwise we cannot make the statistics per single flooding)
- Group polygons per single flooding (numbers in the tables are given as follows: NumberZone = 1 is the northern area; NumberZone = 2 is the middle area; NumberZone = 3 is the southern area)
- Select the elevations:

  h2 > con([delta_ebre] >= 0.2 & [delta_ebre] <= 0.4, 1)

  [This will assign a 1 to those pixels where the diference between the 0.4 and elevation at that location is within the range of 0 - 20 cms]

  h4 > con([delta_ebre] >= 0 & ([delta_ebre]) < 0.2, 1)

  h6 > con([delta_ebre] < 0, 1)

  - Use Zonal Statistics per table, to compute the AREA of the cells within each Land Use class (each class is determined by the LLH attribute)

B.1.2 Scenario 2051

- Clip the LandUse map with the polygons on the Flood layer (2nd scenario)
- Dissolve so that adjacent polygons with the same value of land use are merged into one polygon
- Explode the features so that we have not multipolygon features anymore (otherwise we cannot make the statistics per single flooding)
- Create a delta_025 (raster that has the original elevation map - 0.25 m)
- Select the elevations:
  h2 > con([delta_025] >= 0.2 & [delta_025] <= 0.4, 1)

  [This will assign a 1 to those pixels where the diference between the 0.4 and elevation at that location is within the range of 0 - 20 cms]

  h4 > con([delta_025] >= 0 & ([delta_025]) < 0.2, 1)

  h6 > con([delta_025] < 0,1)

Appendix C

Damage

C.1 Calculation of damages

The damage calculation for tangible and intangible damage is shown in tables C.1 and C.1. Noted has to be that 190 in the table C.1 is the value for $C_i * \%P_i$.

Scenario	habitat nr.	damage function	calculation	tangible damage (L_t) [Euro]
2001	82.	$A_i * C_i * \%P_i$	$4,9672 * 190$	=944
BAU	82.	$A_i * C_i * \%P_i$	$21,1596 * 190$	=4020
	86.	$\overline{C}[Euro] * \%P * N[ha^-1] * A[ha]$	450.000 $* 0,005 * 9,8 * 0,5944$	=13107
			450.000 $* 0,015 * 9,8 * 1,4850$	=98232
			450.000$*0,03*9,8*0,2434$	=32202
			total	143361
Nat. dev.	82.	$A_i * C_i * \%P_i$	0*190	=0
	86.	$\overline{C}[Euro] * \%P * N[ha^-1] * A[ha]$	450.000 $* 0,005 * 9,8 * 0,5944$	=13107
			450.000 $* 0,015 * 9,8 * 1,4850$	=98232
			450.000$*0,03*9,8*0,2434$	=32202
			total	143361

Table C.1: Calculation of intangible damage

scenario	habitat nr.	$A_i * (100 - (\%R_i/100)) * V_e$	intangible damage $= L_i$
2001	15.	$122 * 0,25 * 4,8$	=146
	16.	$1018 * 0,25 * 4,8$	=1222
	82.	$49694 * 0,5 * 2,4$	=596332
	89.	$1 * 0,5 * 2,2$	=1
BAU	15.	$0 * 0,25 * 4,8$	=0
	16.	$3432 * 0,25 * 4,8$	=4118
	82.	$211596 * 0,5 * 2,4$	=253915
	89.	$11323 * 0,5 * 2,2$	=12455
Nature development	15.	$211596 * 0,25 * 4,8$	=253915
	16.	$3432 * 0,25 * 4,8$	=4118
	82.	$0 * 0,5 * 2,4$	=0
	89.	$11323 * 0,5 * 2,2$	=12455

Table C.2: Calculation of intangible damage

Appendix D

Spatial multi criteria analysis

D.1 Aggregation

The aggregation of the tangible and intangible damages can be found in table D.1.

Tangible damage		
Scenario	calculation	result
Base year	$(944 * 49672)/50812$	=923
BAU	$(22228 * 143361 + 211596 * 4020)/248579$	=16241
Nat.dev	$(22228 * 143361)/248579$	=12819
Intangible damage		
Scenario	calculation	result
Base year	$(0,0122 * 146 + 0,1018 * 1222 + 4,9694 * 596332 + 0,0001 * 1)/50812$	=58,3
BAU	$(0,3432*4118+21,1596*253915+1,1323*12455)/248579$	=21,7
Nat.dev	$(0,3432*4118+21,1596*253915+1,1323*12455)/248579$	=21,7

Table D.1: Aggregation of damages

D.2 Ranking

The result of the ranking is per category for weighted summation is shown in figures D.1 to D.4. Inportant to not is that if a alternatie scores high on the criterion tangible damage the damage itself is not high, but low in comparison to the other alternatives.

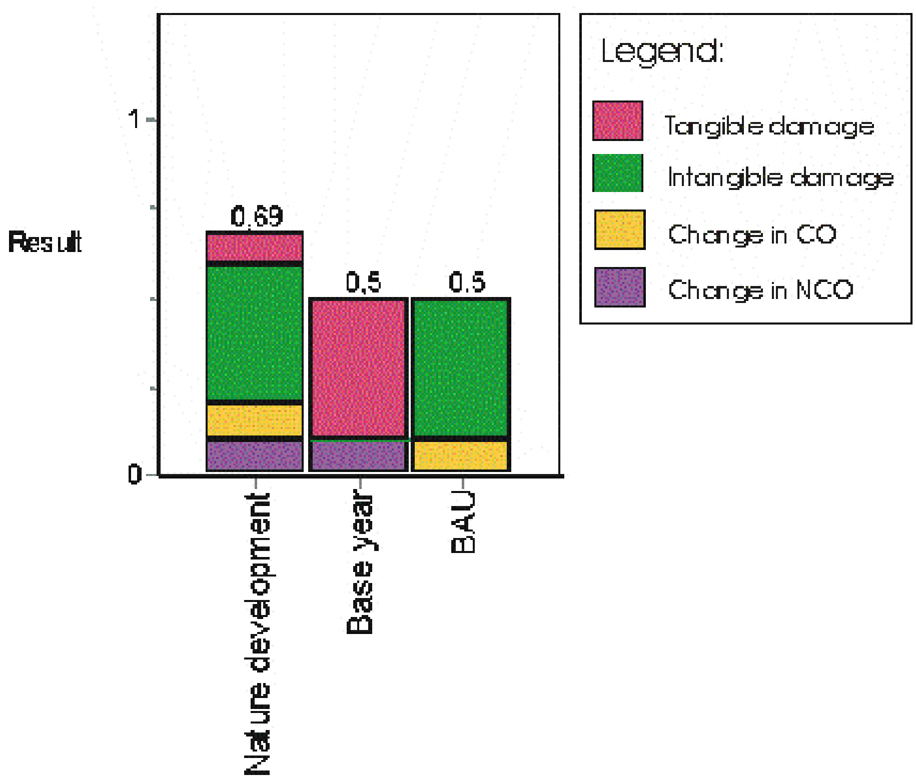


Figure D.1: Interval standardization ⟶ risk perception ⟶ weighted summation

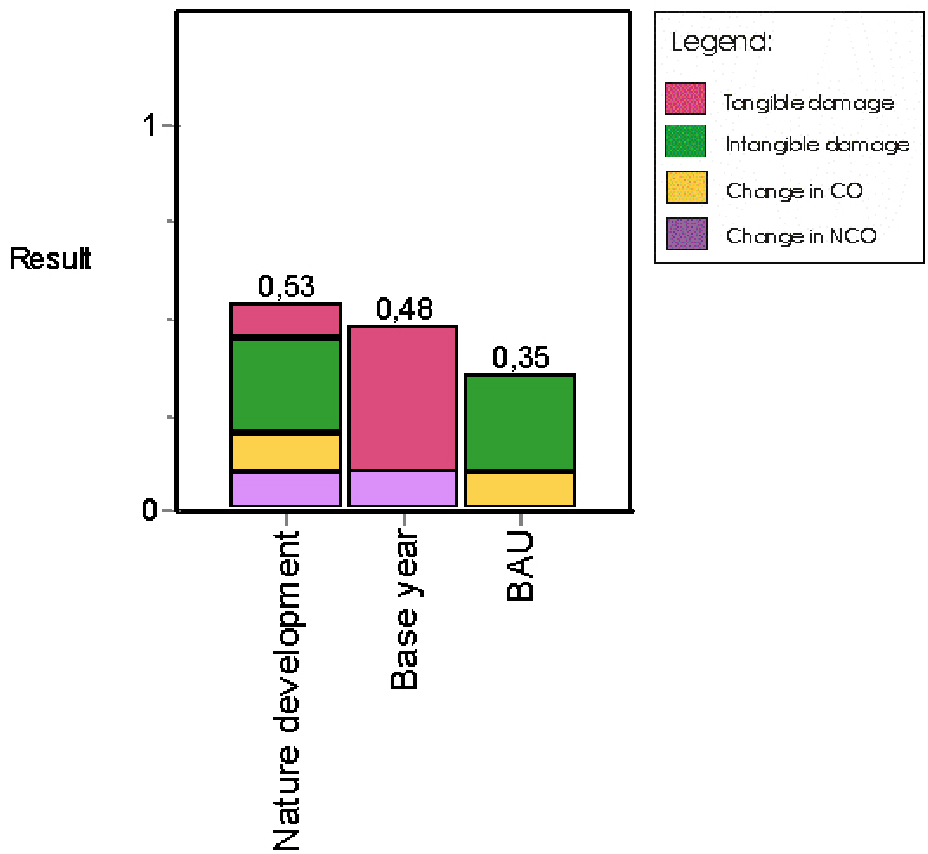


Figure D.2: Maximum standardization ⟶ risk perception ⟶ weighted summation

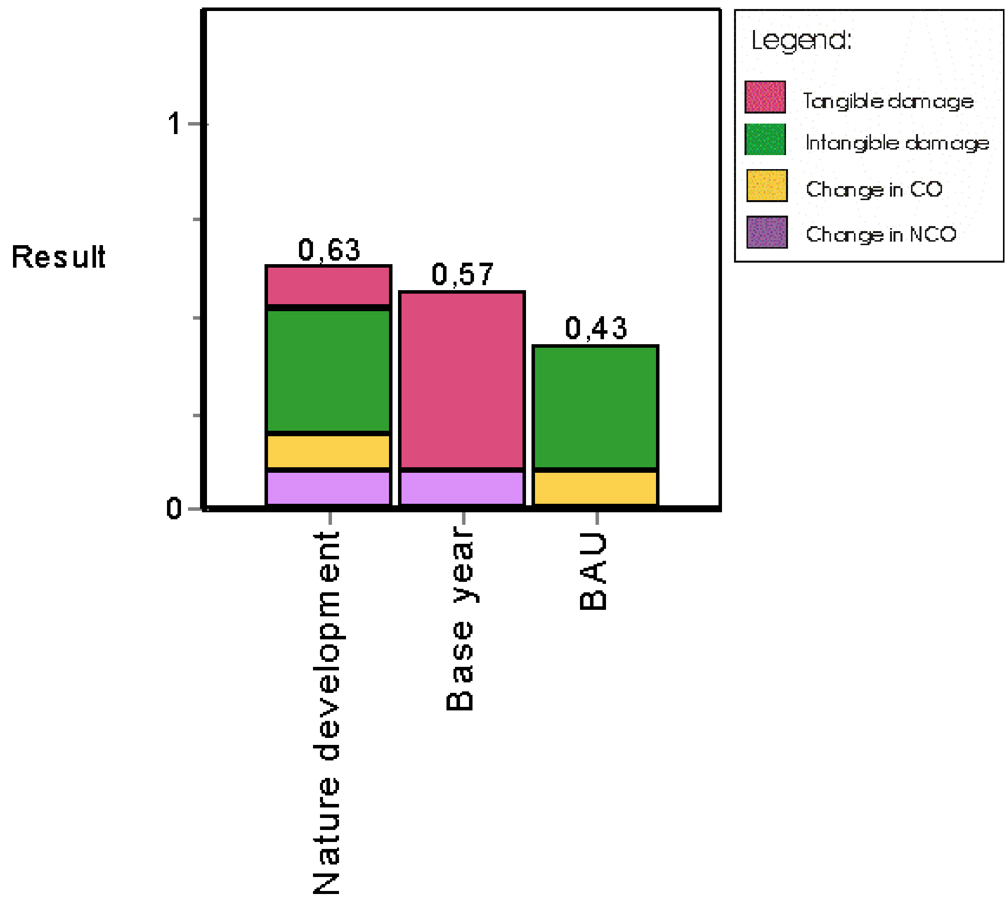


Figure D.3: Interval standardization ⟶ pairwise comparison ⟶ weighted summation

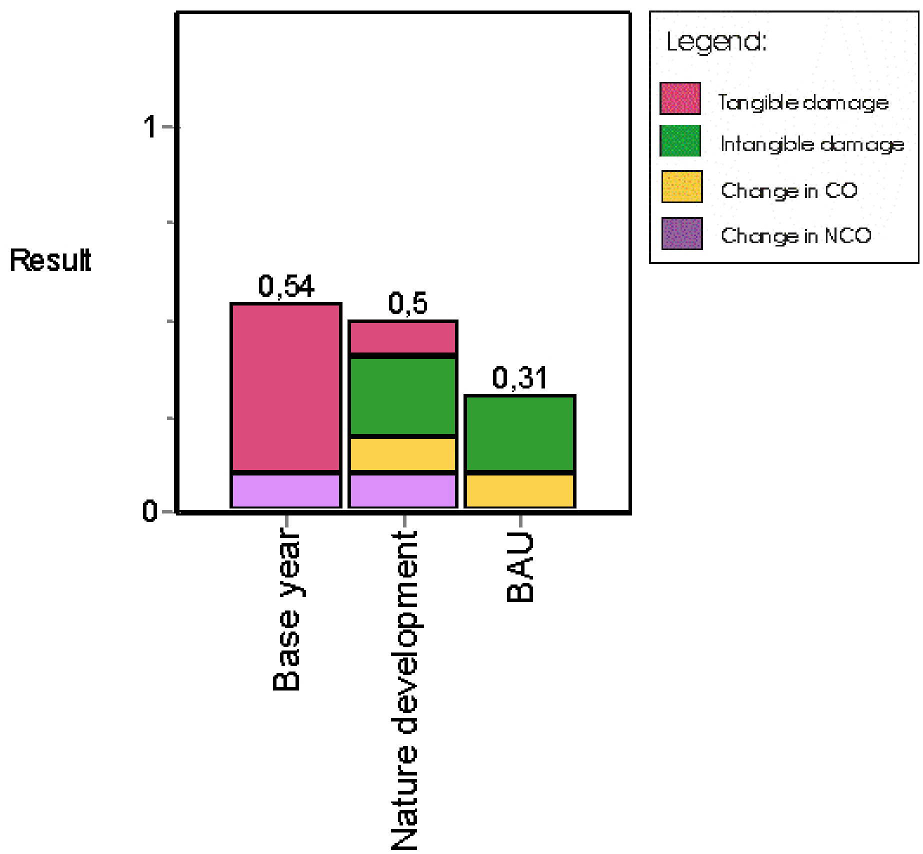


Figure D.4: Maximum standardization ⟶ pairwise comparison ⟶ weighted summation

Bibliography

ACA. An agronomic study of the area of the ebro delta. Technical report, Agècia Catalana de l'aigua, 2002.

C. Alcácer-Santos. Environment flow assessment for the ebro delta in spain - improving links between wetland and catchment management. Technical report, IUCN, 2004.

T. Aven and V. Kristensen. Perspectives on risk: review and discussion on the basis for establishing a unified and holistic approach. *Relibility Engineering and System Safety*, 90:1–14, 2005.

T. Aven and V. Kristensen. A new perspective on renn and klinke's approach to risk evaluation and management. *Relibility Engineering and System Safety*, 91:421–432, 2006.

C. Banville, M. Landry, J. Martel, and C. Boulaire. A stakeholder approach to mcda. *systems research*, 15:15–32, 1998.

E. Barbier, M. Acreman, and D. Knowler. Economic valuation of wetlands. Technical report, IUCN-the world conservation union, 1997.

A. Barrera-Roldán and A Saldivar-Valdés. Proposal and application of a sustainable development index. *Ecological indicators*, 2:251256, 2002.

D. Casanova. *Quantifying the effects of land conditions on rice growth*. University of Wageningen, Wageningen, 1st edition, 1998. PHD thesis.

A. Cazenave, P. Bonnefond, F. Mercier, K. Dominh, and V. Toumazou. Sea level variations in the mediterranean sea and black sea from satellite altimetry and tide gauges. *Global and Planetary Change*, 34:5986, 2002.

V. Covello and M. Merkhofer. *Risk assessment methods approaches for assessing health and environmental risks*. Plenum Press, New York, 1st edition, 1993.

CPIDE. Tomo iii capítulos 2-6 dagnóstico, incidencias y actiaciones. Technical report, Concorci par la protecció Integral del delta de l'Ebre, 2002. unpublished.

J. Day, E. Maltby, and C. Ibá nez. River basin management and delta sustainability: a commentary on the ebro delta and the spanish national hydrological plan. *Ecological Engeneering*, 15:1–15, 2004.

Generalitat de Catalunya. Pla director urbanístic dels àmbits del sistema costaner integrats per sectors de sòl urbanizable delimtitat sense pla parcial aprovat. Technical report, Generalitat de Catalunya, 2005.

S. Dreyfus. Risks! and benefits? of risk benefit analysis. *International journal of management science*, 22:335–340, 1984.

EEA. *Scenarios as tools for international environmental assessments*. European Environmental Agency, 1st edition, 2001.

A. Ferrero. Economic and ecologic sustainability of rice production in europe and the mediterrean region. In *First Asia-Europe workshop on sustainable resource management and policy options for rice ecosystems*. ALTERRA, 2005.

B. Fischhoff. Informed consent in societal risk-benefit decisions. *Technological forecasting and societal change*, 13:347–357, 1979.

B. Fischhoff, P. Slovic, and S.Lichtenstein. How safe is safe enough? a psychometric study of attitudes towards technological risks and benefits. *Policy sciences*, 9:127–152, 1978.

B. Fisschhoff, S. Wattson, and C.Hope. The risk game. *Policy sciences*, 17:139–139, 1984.

J. Galofré, A. Sánchez-Arcilla, J. Jiménez, and M. Garcia. A note on fans conclusions: from research analyses to management implications. *Continental Shelf Research*, 22:379–385, 2002.

GdC. Technical report.

GDF-Hannover. Technical report.

Generalitat de Catalunya. Programa de actuaciones urgentes en las zonas costeras del delta del ebro afectadas por los temporales. Technical report, Generalitat de Catalunya, 2004. unpublished report.

V. Gràcia. The ebro delta coast pilot site - inventory of available data. Technical report, Universitat Politèchnica de Catalunya, 2006.

J. Hanekamp and W. van Haren. *Normering en risico in wetenschappelijk perspectief*. Stichting Heidelberg Appeal Nederland, Amsterdam, 1st edition, 1999.

J. Hellendoorn. *Evaluatiemethoden ex ante - een introductie*. Sdu uitgevers, Den Haag, 5th edition, 2001.

M. Hisschemoller, R. Tol, and P.Vellinga. The relevance of participatory approaches in integrated environmental assessment. *The Integrated Assessment Journal*, 2:57–72, 2001.

http://biodiver.bio.ub.es/biocat/homepage.html, 2006. Databank of biodiversity in Catalunya.

http://mediambient.gencat.net/cat/el_departament/cartografia/fitxes/inici.jsp, 2006. The website of the ministry of environment containing Miramon maps.

C. Ibànez. Integrated management in the spa of the ebro delta: implications of rice cultivation for birds. Technical report, SEO/Birdlife, 1998.

C. Ibànez, A. Canicio, J. Day, and A. Curcó. Morphologic development, relative sea level rise and sustainable management of the ebro delta, spain. *Journal of Coastal Conservation*, 3:191–202, 1997.

R. Janssen. On the use of multi-criteria analysis in environmental impact assessment in the netherlands. *Journal of multi-criteria decision analysis*, 10:101–109, 1999.

R. Janssen, M. van Herwijnen, and E. Beinat. Help-file for the bosda dicision support program, 2000.

J. Jiménez. Effects of storm impacts in the ebro delta coast. Technical report, Universitat Politèchnica de Catalunya, 2005.

J. Jiménez. *Research implementation plan-Task 26-pilot study"river Ebro Delta Coast*, 2004.

J. Jiménez and A. Sánchez-Arcilla. Medium term coastal response at the ebro delta, spain. *Marine Geology*, 114:105–118, 1993.

J. Jiménez, A. Sánchez-Arcilla, H. Valdemoro, V. Garcia, and F. Nieto. Processes reshaping the ebro delta. *Marine Geology*, 144:59–79, 1997.

J. Jiménez, J. Guillén, V. Garcia, A. Palanques, M. García, A. Sánchez-Arcilla, P. Puig, J. Puigdefábregas, and G. Rodríguez. Water and sediment fluxes on the ebro shoreface: on the role of low frequency currents. *Marine Geology*, 157:219–239, 1999.

M. Kok and F. Lootsma. Pairwise-comparison methods in multiple objective programming, with applications in a long-term energy-planning model. *European Journal of Operational Research*, 22:44–55, 1985.

F. Lootsma, P. Boonekamp, R. Cooke, and F van Oostvoorn. Choice of a long-term strategy for the national electricity supply via scenario analysis and multi-criteria analysis. *Journal of Operational Research*, 48:189–203, 1990.

A. Wildavsky M. Douglas. *Risk and culture. An Essay on the Selection of Technological and Environmental Dangers*. Berkely University of California Press., Berkely, 1st edition, 1982.

P. Martens and J. Rotmans. Transitions in a globalizing world. *Futures*, 37: 1133–1144, 2002.

T. McDaniels, L. Axelrod, and P. Slovic. Perceived ecological risks of global change. *Global environmental change*, 6:159–171, 1996.

M. Meier and M. Dyurgerov. How alaska affects the world. *Science*, 279:350–351, 2002.

F. Messner and V. Meyer. Flood damage, vulnerability and risk perception - chalenges for flood damage research, 2005. unpublished.

V. Meyer and F. Messner. National flood damage evaluation methods a review of applied methods in england, the netherlands, the czech republic and germany. Technical report, UFZUmweltforschungszentrum LeipzigHalle, 2005.

P. Milly, H. Wetherhald, K. Dunne, and T. Delworth. Increasing risk of great floods in a changing climate. *Nature*, 415:414–417, 2002.

G. Munda. Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research 158*, 158: 662–667, 2004.

P. Nijkamp and A. van Delft. *Multi-criteria analysis and regional decision making*. Stenfort Kroese B.V, Leiden, 1 edition, 1977.

H. Opschoor. Sustainable development and paradigms in economics. Technical report, Vrije Universiteit Amsterdam, 1994. Research Memorandum 1994-30.

A. Orellana. Estudi de lafluència turistica al delta de l'ebre. *Soldó - informatiu del parc natural del delta de l'Ebre*, 25:38, 2005.

H. Otter, A. van der Veen, and H. de Vriend. Analysis of the effects of sea level rise on the socio-economy of the ebro delta. *Marine Geology*, 1996.

J. Overpeck, B. Otto-Bliesner, G. Miller, D. Muhs, R. Alley, and J. Kiehl. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science*, 311:1747–1750, 2006.

C. Pahl-Wostl. Actor based analysis and modeling approaches. *The Integrated Assessment Journal*, 5:97–118, 2005.

D. Pastor, C. Sanpera, J. González-Solís, X. Ruiz, and J. Albaigés. Factors afecting the organochlorine pollutant load in biota of a rice field ecosystem (ebro delta,ne spain). *Chemosphere*, 55:567–576, 2003.

E. Pennning-Rowsell, A. van der Veen, C. Green, S. Turnstall, V. Meyer, and F. Messner. Guidelines for socio-economic flood damage evaluation. Technical report, 2006. FLOOD*site* document reference unknown - DRAFT.

N. Pidgeon. Risk assessment, risk values and the social science programme: why we do need risk perception research. *Relibility Engineering and System Safety*, 59:5–15, 1998.

S. Rayner and P. Cantor. How fair is safe enough? the cultural approach to social technology choice. *Risk Analysis*, 7:3–9, 1987.

O. Renn. Perception of risks. *Toxicology Letters*, 149:405–413, 2004.

O. Renn and A. Klinke. A new approach to risk evaluation and management: risk-based, precaution based, and discourse based strategies. *Risk Analysis*, 22:1071–1094, 2002.

Risk and Policy Analysts Ltd (RPA). Evaluating a multi-criteria analysis(mca) methodology for application to flood management and coastal defence appraisals. Technical report, Defra, London, 2005.

J. Rotmans. Methods for ia: the chalenges and opportunities ahead. *Environmental Modeling and Assessment*, 3:155–179, 1998.

J. Rotmans and M. van Asselt. Uncertainty in integrated assessment modelling: A labyrintic path. *Integrated Assessment*, 2:43–55, 2001.

P. Samuels and B. Gouldby. *Language of risk-project definitions*, 2005.

A. Sánchez-Arcilla. Impacts of sea level rise on the ebro delta: a first approach. *Ocean and Coastal management*, 30:197–216, 1996.

A. Sánchez-Arcilla, J. Jim'enez, G. Gelonch, and J. Nieto. El problema erosivo en el delta del ebro. *Revista de Obras p(u)blicas*, 3368:23–32, 1997.

A. Sánchez-Arcilla, J. Jiménez, and H. Valdemoro. The ebro delta: morphodynamics and vulnerability. *Journal of Coastal Research*, 14:135–149, 1998.

R. Santalla. Eurosion case study: Ebro delta (spain). Technical report, Escuela Superior de Ciencias Experimentales y Tecnologìa, 2002.

R. Sarin and M.Weber. Risk value models. *European Journal of Operational Research*, 70:135–149, 1993.

L. Satrapa, P. Fošumpaur, and M. Horský. methods for the evaluation of potential flood losses in methodology-application in the procedure for the evaluation of the economic effectiveness of flood defense measures, 2006. Powerpoint Presentation.

D. Saurì and J. Llurdés. El turisme. Technical report, Generalitat de Catalunya, 2005. In: Informe sobre el canvi climàtic a Catalunya.

I. Savage. An empirical investigation into the effect of psychological perceptions on the willingness-to-pay to reduce risk. *Journal of Risk and Uncertainty*, 6:75–90, 1993.

C. Selin. Trust and the illusive force of scenarios. *futures*, 38:1–14, 2005.

H. Sharlin. Risk perception: changing the therms of debate. *Journal of Hazardous Materials*, 21:261–272, 1989.

W. Singleton and J. Hovden. *Risk and Decisions*. John Wiley & Sons Ltd., Chisester, 1st edition, 1987.

P. Slovic. *The perception of risk*. Earthscan publications Ltd., London, 1st edition, 2000.

P. Slovic. The perception of risk. *Science*, 236:280–285, 1987.

P. Slovic. Perceived risk, trust and democracy. *Risk Analysis*, 13:675–682, 1993.

P. Slovic. The risk game. *Relibility Engineering and System Safety*, 59:73–77, 1998.

P. Slovic and E. Weber. Perception of risk posed by extreme events. In *Risk Management strategies in an uncertain world*, 2002.

C. Starr. Social benefit versus technological risk. *Science*, 165:1232–1238, 1969.

P. Swanborn. *Methoden van sociaal wetenschappelijk onderzoek*. Boom, Meppel, 1981.

S. Tapsell. *Analysis of the UK report (task 11) -Reanalysis of FHRC data*, 2006.

S. Tapsell, C. Penning-Rowsell, S. Turnstall, and T. Wilson. Vulnerability to flooding: health and social dimensions. *Phil. Trans.*, 860:1511–1525, 2002.

R. Thomas, E. Rignot, G. Casassa, and P. Kanagaratnam. Accelerated sea-level rise from west antarctica. *Science*, 306:256–258, 2004.

E. Treby, M. Clark, and S. Priest. Confronting flood risk: implications for insurance and risk tranfer. *Journal of Environmental Management*, 79:x–x, 2005.

J. Turner. *Editorial:*the role of pilot studies in reducing risk on projects and programmes. *International Journal of Project Management*, 23:1–6, 2005.

UNCED. *Our common future*. Oxford University Press., Oxford/New York, 1987.

H. Valdemoro, A. Sánchez-Arcilla, and J. Jiménez. Coastal dynamica and wetlands stability, the ebro delta case. *Hydrobiologia*, 2005. in review.

M. van Asselt and N. Rijkens-Klomp. A look in the mirror: reflection on participation in integrated assessment from a methodological perspective. *Global Environmental change*, 12:167–184, 2002.

M. van Herwijnen. *Spatial decision support for environmental management*. Van Herwijnen Design, Amsterdam, 1st edition, 1999.

C. Varela-Ortega and N. Hernández-Mora. *Water policy in Spain. Issues in Water Resource Policy.*, chapter Institutions and Institutional Reform in the Spanish Water Sector: A Historical Perspective. RFF Press, 2005b.

C. Varela-Ortega, A. Iglesias, and I. Blanco. Research action plan for the guadiana basin case study. Technical report, Universidad Politcnica de Madrid (UPM), 2005a. NEWWATER report.

A. Veldkamp and E. Lambin. Predicting land-use change. *Agriciculture, Ecosystems and environment*, 85:1–6, 2001.

M. Vis, A. Klijn, K. de Bruin, and M. van Buuren. Resilience strategies for flood risk management in the netherlands. *International Journal of River Basin Management*, 1:33–40, 2003.

C. Vlek and P. Stallen. Judging risks and benefits in the small and the large. *Organizational behaviour and human performance*, 28:235–271, 1981.

E. Weber, A. Blais, and N. Betz. A domain-specific risk-attitude scale: Measuring risk perceptions and risk behaviors. *Journal of Behavioral Decision Making*, 15:263–290, 2002.

H. Wiggering, C. Dalchow, M. Glemnitz, K. Helming, K. Muller, A. Schultz, U. Stachow, and P. Zander. Indicators for multifunctional land use linking socio-economic requirements with landscape potentials. *Ecological indicators*, 6:238–249, 2006.

www.arrossaires.com, 2006. The website of rice producers in the Ebro Delta.

www.ecosystemvaluation.org, 2006. Website on economic evaluation of ecosystems.

www.floodsite.net, 2006. FLOOD*site* project website.

www.gencat.net/ctc, 2006. Website of the ministry of Trade, Tourism and Consumer Affairs.

www.gencat.net/darp, 2006. Website of the ministry of agriculture, livestock and fishing.

www.iberianature.com, 2006. Website for the Spanish natural parks.

www.idescat.net, 2006. Statistics website for Catalunya.

www.irta.es, 2006. Website of the the Institute for Food and Agricultural Research and Technology.

www.nbn.org.uk/habitats/habitatInClass.asp, 2006. Website listing the CORINE habitats classification.

www.ramsar.org, 2006. European committee Ramsar project website.

www.villaweb.cat, 2006. Website of the local newspaper.

C. Yeh, R. Willis, H. Deng, and H. Pan. Task oriented weighting in multi-criteria analysis. *European journal of operational research*, 119:130–146, 1999.