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Toward Sustainable Decision Making

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6.1 Introduction

In this chapter, we analyze the issue of sustainable decision making for successful coastal flood management. In this framework, sustainable development is a key concept. This is defined as a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only today, but also for future generations (WCED, 1987). The concept implies the consideration of spatial and temporal dimensions, system components (i.e., economic, social and environmental aspects), and the interactions between these components. On the one hand, development is a dynamic process and a function of its dimensions and components. On the other hand, sustainability is complex and adaptive and can be achieved via innumerable paths, yielding contrasting results for system components. Decision making is also a dynamic process and is carried out at different levels of society, considering cultural, social, economic, institutional, political, and environmental differences. This process requires the design of a strategy, the definition of policies, and the implementation of actions. As a result, different types of information are required at different stages of the decision-making cycle (Winograd & Farrow, 2013). Thus, key to successful coastal flood management is the use of mitigation techniques that are appropriate for the local circumstances. This is best achieved if all alternatives are reviewed to identify the most efficient individual or suite of options for consideration by stakeholders and decision makers.

Different mitigation options change the consequences of flooding in different ways; engineering generally changes the amount or extent of flooding, whereas planning can change the nature of the flooded area and therefore the consequences.

Considering the long-term and large-scale aspects of coastal risks, the development of defense strategies should be based on a hierarchical planning approach, ranging from a top-down national (master) planning level to the analysis of individual flood-prone areas and the consideration of specific strategies and measures within these areas (Holman, Rounsevell, Berry, & Nicholls, et al., 2008, pp.1–187). The master plan should facilitate the necessary communication between coastal defense managers, contingency planners, and crisis managers and warrant the continuity of coastal risk management policies, the protection measures, and the related operational procedures (i.e., in terms of financing, institutional arrangements, legal rights/obligations, and operational responsibilities).

In general, the development of coastal protection strategies involves the following steps.

6.1.1 Specification of Detailed Regional Scenarios for the Time Period of the Decision (Often 50-100 years)

Regional scenarios should provide more specific and detailed information with respect to:

- the regional translation of the various aspects of climate change (to be included in the regional specification of hydraulic loads);
- spatial and infrastructural developments based on specific regional development potential, existing plans, and specified development priorities; and
- already planned developments in flood/erosion protection systems.

The regional scenarios should reflect the main scope of possible developments and capture the major uncertainties in developments driving future risks and the possible effects of measures and strategies to reduce these risks.

6.1.2 Problem Assessment and Identification of Promising Mitigation Measures

Problem assessment refers to establishing the extent of future coastal risks and carrying out a flood risk assessment for the relevant regional scenarios, as specified in step 1.

The feasibility of mitigation measures to be considered depends on many factors related to the natural and socioeconomic characteristics of the coastal area, the existing flood protection system, and the coastal management context (as affected by political, institutional, and cultural conditions). Within the directives provided by the master plan, a screening exercise should be performed to identify possible measures that are more plausible or promising than others, given the specific characteristics and conditions pertaining to the coastal area considered.

6.1.3 Analysis and Evaluation of Alternative Strategies

Alternative strategies regarding the protection and management of the coastal area should be based on various combinations of promising mitigation measures, each strategy representing a logical and coherent mix of measures. Assessment of the relevant impacts of the alternative protection and management strategies in terms of societal costs and benefits is required. To deal with the various (large) uncertainties, the impacts of possible strategies need to be considered for different regional scenarios. The evaluation should not so much aim at selecting the ‘‘best’’ strategy within a specific scenario, but rather to identify the most ‘‘robust’’ strategy, showing an acceptable performance (in terms of meeting required objectives or achieving anticipated benefits) across all relevant scenarios. Hence, the primary aim of the evaluation would be to minimize the risk of selecting a wrong strategy.

The development of decision-support methods is an important part of selecting and assessing mitigation options. Generally, they are unable to determine the best option or provide detailed option applicability or placement. They can, however, identify, examine and explore mitigation options by evaluating their relative efficiency, equity, and sustainability in determining risk levels and potential consequences. This is particularly important when selecting mitigation strategies under uncertain future conditions.

6.2 Efficiency, Equity, and Sustainability of Mitigation Options

6.2.1 Hydraulic Efficiency

The efficiency of engineering solutions consists of the degree of coastal protection they offer, and it can be evaluated specifically in terms of reduction of incident wave height, reduction (or stabilization) of sediment transport, reduction of wave run-up on the beach, and wave overtopping at the sea bank and of frequency and magnitude of inland flooding.

Results and methodologies to estimate both wave transmission and coastal erosion are reported already in Chapter 3 for some kind of defenses and interventions. The use of numerical and physical models may help to predict in extreme and ordinary meteo-marine climate conditions the hydromorphological consequences of each engineering mitigation option and their suitability to accomplish the overall design objectives (Burcharth, Hawkins, Zanuttigh, & Lamberti et al., 2007; Zanuttigh et al., 2005).

Estimated waves and currents allow, for instance, evaluation of the following:

- the near-shore wave transmission;
- the wave run-up on the beach and the overtopping at the sea bank;
- the water residence time inside the protected cells to assess water recirculation and quality;
- the current patterns and intensities, in particular at gaps and roundheads, to verify far field erosion and bathing safety; and
- the wave loads at structure, to verify structure stability and to assess possible detachment of colonizing organisms.

Estimated sediment transport allows, for instance, evaluation of the following:

- beach reshaping because of intense storms, and therefore the error that may be accounted for when modeling the flood process without modeling the beach retreat during the storm;
- the ‘‘global’’ sand volume balance for the protected cells the required frequency and quantity of periodic nourishments;
- the formation of local scour that may produce structure instability to redesign a proper toe protection or structure extension; and
- the erosive/depositional patterns and their rate to identify the level of disturbance to the assemblages.

Even in case detailed modeling results are available, there is the need to synthesize hydraulic maps, historical data, and modeling outputs through qualitative and/or quantitative indicators. This offers the chance to combine hydraulic effects with social, economic and ecological effects to be presented in Sections 6.2.2–6.2.4.

Different methods are available in the literature to qualitatively assess the hydraulic vulnerability of coastal stretches to erosion and flooding, including also the presence of structures and defenses. The approaches by EUROSION (2004, 44 pp.) and by Gornitz, Daniels, White, and Birdwell (1994, pp. 327–338) are selected because of their simplicity and adaptability to diverse coastal environments.

The method proposed by EUROSION (2004, 44 pp.) is based on a simplified Driving forcesdPressuredStatedImpactdResponses model (DPSIR) and aims at representing the current and future pressure factors as well as the potential impact of erosion and flooding to assets located in the coastal areas. To provide a proxy of the areas that may be affected, it introduces the concept of the Radius of Influence of Coastal Erosion (RICE). By accounting for sea-level rise, subsidence and other parameters such as tide, extreme sea storms, bottom, and shoreline morphology, the RICE is defined as all areas within 500 m from the shoreline extended to areas lying below —5 m. Once the RICE is defined, the approach considers 13 indicators, nine being related to pressure and four related to impact of coastal flooding and erosion in present and future conditions (Table 6.1). Indicators may have to be properly tuned considering the specific site under analysis (Martinelli, Zanuttigh, & Corbau, 2010).

The method by Gornitz et al. (1994, pp. 327–338) defines objective and univocal criteria for the classification of littoral vulnerability, providing also useful indications for integrated management plans (Simeoni, Tessari, Gabbianelli, & Schiavi, 2003)

A given coastal stretch is first described through a set of variables belonging to the following main groups:

- marine-weather conditions, that have a significant importance for characterizing the hazard to the extreme event;
- physical conditions (shoreface width, width and height of the emerged beach, mean grain size, and pressure of the use) that characterize the beach system in terms of accommodation and mitigation capacity against the inundation;
- coastline evolution (recent and historical shoreline trends, shoreface evolution) that indicates the beach system behavior within the short and long term;
- subsidence of the coastal territory that affects coastal submersion; and
- typologies of the defense structures along the coast and inland that identify the beach passive mitigation answer to flood.

The degree of submersion tendency or vulnerability is then synthesized by the use of indices, specifically:

- The potential vulnerability V_p. It expresses the degree of geomorphological, sedimentary, and anthropogenic tendency to submersion without accounting for the existing protection. The evaluation of V_p is done through a multiple regression such as:

$$V_p = v_1k_1 + v_2k_2 + v_3k_3 + \dots + v_nk_n \quad (6.1)$$

  where v is the codified value of the variable following a proper division into classes and k is the variable weight according to its contribution to the system vulnerability;
- The total efficiency of the structures IED is defined as:

$$\text{IED} = \text{IES} + \text{D}_i \quad (6.2)$$

  where IES is the Efficiency and Stability Index for natural dunes and D_i is the efficiency of each defense structure.
  The efficiency of each defense structure D_i is represented by:

$$\text{D}_i = d^* V_{\text{pmax}} \cdot e_{\text{max}} \quad (6.3)$$

TABLE 6.1 Indicators Used by the EUROSION (2004) Approach

Methodology for Rating European Regions in Terms of Coastal Erosion and Flooding			
Indicator	0 points	1 point	2 points
Pressure Scoring			
1. Relative sea level rise (best estimate for the next 100 years)	*<0 cm (per region)*	*Between 0 and 40 cm (per region)*	*>40 cm (per region)*
2. Shoreline evolution trend status	*Less than 20% of the shoreline is in erosion or in accretion (per region)*	*Between 20% and 60% of the shoreline is in erosion or in accretion (per region)*	*More than 60% of the shoreline is in erosion or in accretion (per region)*
3. Shoreline changes from stability to erosion or accretion between the 2 versions (CORINE Coastal Erosion (CCEr) and European Coastal Erosion Layer (CEL))	*Less than 10% of the shoreline changes between the 2 versions (CCEr and CEL)*	*Between 10% and 30% of the shoreline have changed between the 2 versions (CCEr and CEL)*	*More than 30% of the shoreline have changed between the 2 versions (CCEr and CEL)*
4. Highest water level	*Less than 1.5 m*	*Between 1.5 and 3 m*	*More than 3 m*
5. Coastal urbanization (in the 10-km land strip)	*Urban areas (in km^2) have increased of less than 5% between 1975 and present*	*Urban areas (in km^2) have increased of 5–10% between 1975 and present*	*Urban areas (in km^2) have increased of more than 10% between 1975 and present*
6. Reduction of river sediment supply (ratio)	*Ratio between effective volume of river sediment discharged and theoretical volume (i.e., without dams) is superior to 80%*	*Ratio between 50 and 80%*	*Ratio is less than 50%*
7. Geological coastal type	*>70% of "likely nonerodable" segments[1]*	*"likely nonerodable segments" between 40 and 70%*	*<40% of "likely nonerodable segments"*
8. Elevation	*<5% of the region area lies below 5 m*	*Between 5 and 10% of the region area lies below 5 m*	*>10% of the region area lies below 5 m*

TABLE 6.1 Indicators Used by the EUROSION (2004) Approachdcont'd

Methodology for Rating European Regions in Terms of Coastal Erosion and Flooding			
Indicator	0 points	1 point	2 points
9. Engineered frontage (including protection structure)	*<5% of engineered frontage along the regional coastline*	*Between 5 and 35% of engineered frontage along the regional coastline*	*>35% of engineered frontage along the regional coastline*
Impact Scoring			
10. Population living within the RICE	*<5000 inhabitants per Region*	*Between 5000 and 20,000 inhabitants per region*	*>20,000 inhabitants per region*
11. Coastal urbanization (in the 10-km land strip)	*Urban areas (in km^2) have increased of less than 5% between 1975 and present*	*Urban areas (in km^2) have increased of 5–10% between 1975 and present*	*Urban areas (in km^2) have increased of more than 10% between 1975 and present*
12. Urban and industrial living within the RICE	*<10% of the land cover within the RICE is occupied by urban and industrial areas (per region)*	*Between 10 and 40% of the land cover within the RICE is occupied by urban and industrial areas (per region)*	*>40% of the land cover within the RICE is occupied by urban and industrial areas (per region)*
13. Areas of high ecological value within the RICE	*<5% of areas of high ecological value within the RICE per region*	*Between 5 and 30% of areas of high ecological value within the RICE per region*	*>30% of areas of high ecological value within the RICE per region*

where d ¼ the original value of the class of the structure, V_{pmax} ¼ theoretical maximal V_p, and e_{max} ¼ maximal class of efficiency relative to the structure. The values of e_{max} are assigned based on structure position (in the sea, on the beach, etc.), typology (groins, breakwaters, barriers, etc.), and construction material (rocks, concrete, etc.). The value d is attributed based on the presence of the defense in the given coastal stretch;

- The IES for natural dunes is defined as

$$\mathrm{IES}\ ¼ \sum V_i=n \qquad (6.4)$$

where V_i represent the dune-related variables: dune crest height, dune seaward slope (¼height to seaward width ratio), dune system long-shore continuity (¼dune long-shore length to reach long-shore length ratio), conservation state (presence of breaches, blow outs), and vegetal cover (¼covered surface to whole surface ratio). The value of n is given by the sum of the maximum values attributed to the variables and is used to normalize IES in the range 0–1.

Finally, the actual vulnerability V_r of each coastal stretch is obtained by considering that the potential vulnerability is mitigated by natural and artificial defenses.

$$V_r \text{ ¼ } V_p - \text{IED} \tag{6.5}$$

The degree of risk (R) depends both on actual vulnerability V_r and on socio-economic value E of the same area:

$$R \text{ ¼ } V_r\$E \tag{6.6}$$

where E represents the evaluation (through defined figures) of social, economic, and natural values of the exposed zones or the cost in monetary terms of direct and/or indirect impacts. According to the results and to the global characteristics of the coastal area under examination, the values of the risk may be finally divided into categories.

A quantitative analysis requires the definition of quantitative indicators, such as the flooded area to the examined area ratio, the beach retreat to the beach width ratio, the wave transmission coefficient, etc. These parameters can be obtained from simplified and detailed numerical models. Threshold values should be defined that of course are site-specific. An application of this type of is presented in Section 7.6, where hydraulic, social, economic, and ecological indicators are derived from simulations of different scenarios and defense strategies performed with THESEUS Decision Support System (see Section 6.6).

Besides the assessment of the effects induced by a coastal structure, the reliability of the structure itself should be considered and a scenario analysis of the probability of defense failures and related consequences should be considered (Naulin, Kortenhaus, & Oumeraci, 2011).

The event probability of failure, conditional on the applied load (the so-called fragility concept), is usually combined with flood system risk analysis models (Gouldby, Sayers, Mulet-Marti, Hassan, & Benwell, 2008) as the Source-Pathway-Receptor-Consequence (S-P-R-C) model outlined in Chapter 2. This type of failure can be determined by analyzing historical failure data and by probabilistic calculation of the limit states. In a real case, the loads in the limit state functions are nearly always functions of multiple variables and the problem has to be solved by means of Riemann integration or Monte Carlo simulations.

The reliability tools currently available (Kortenhaus & Kaiser, 2009; Morris et al., 2008, pp. 581–591) represent flood defense reliability as a snapshot in time. However, time-dependent processes in the hydraulic climate (e.g., water levels and wave conditions) as well as the behavior of flood defense properties (e.g., crest levels, vegetation, erosion) can lead to time-dependent defense reliability. The incorporation of such processes within a reliability analysis allows the explicit consideration of processes that may reduce (e.g., deterioration from history of loading) or increase (e.g., growth of vegetation) the structural stability of flood defenses in time (Gouldby et al., 2008). This can be extremely important when considering future flood defense reliability and may allow emergent failure processes to be revealed (e.g., the deterioration of a structure may trigger new failure mechanisms which need to be assessed).

6.2.2 Environmental Perspective

Environmental considerations relate to the ecological aspects of flooding. The selection of any mitigation option will affect local habitats, species, and ecological interactions. This can result in the loss of natural habitat, the modification of existing habitats, and/or the creation of new habitats. Habitats such as saltmarshes are naturally fairly insensitive to frequent saline intrusion, whereas others such as grazing marsh and pasture are highly sensitive prolonged seawater inundation, especially if such flooding has not previously been experienced.

To assess the vulnerability of ecosystems to changes in stresses and to disturbances, an index was adopted within the THESEUS project (THESEUS OD3.3, 2012). This provides a rapid and standardized method for characterizing vulnerability across coastal systems and identifies issues that may need to be addressed in order to reduce vulnerability. By looking at combinations of factors, ecosystem vulnerability can be assessed. Such factors are the inherent ecosystem characteristics, the natural drivers that act upon the ecosystems, human use of the ecosystem, and the effects of climate change.

Vulnerability of habitats is dependent on:

1. which part of a particular habitat area will be a subject to the unfavorable impact and which species will be affected and
2. the degree of sensitivity of habitats/key species to unfavorable impact/hazard.

Table 6.2 illustrates an Environment Vulnerability Index (EVI) based on determining to what degree the habitat is affected by flooding using a categorical method; short-term and seasonal processes are represented by categories 1 and 2; and for long-term processes it is assumed that habitats will have permanent physiological consequences (e.g., species composition or extent). To establish the thresholds, best scientific judgment is used based on published information relating to the habitats/

TABLE 6.2 Habitat Vulnerability Categories and Descriptions

	Effect of Driver on Habitat			
	Negligible	Transient Effect	Moderate Effect or Semipermanent Change	Permanent Effect/Change
Environmental vulnerability index	0	1	2	3
Habitat/key species	Negligible impact to habitats/ species	Changes within the range of receptor's natural seasonal variation and full recovery is likely within a season	Changes are beyond receptor's natural seasonal variation. Partial recovery is possible within several seasons, but full recovery is likely to require human intervention	Changes are so drastic that natural recovery of receptor is very unlikely without human intervention

species affected together with experiments, where appropriate. The advantage of using an index is that allows key step changes or tipping points (Scheffer et al., 2009; see also Rietkerk, Dekker, de Ruiter, & van de Koppel, 2004) in a habitat properties to be captured because it is these dynamic changes of an ecosystem that is of interest rather than the transition from one ecosystem to another.

The primary consideration should be the socioeconomic need to defend a coastline cross-referenced with the options that might effectively be used as part of an appropriate defense strategy. In other words, it is unlikely that the natural environment per-se will be a driver for coastal defense. Rather, it will be affected by defenses and management and the type and extent of such effects can be influenced by proper consideration of alternative options from an environmental viewpoint. In the broadest sense these options include do nothing (Hoggart et al., in press), the use of soft defense options such as saltmarshes (Bouma et al., 2013) or sand dunes (Hanley et al., in press), and incorporation of habitat into hard defenses (Firth et al., 2014).

Before reaching decisions, it is important from an environmental perspective to quantify on a case-by-case basis the ecological consequences of the various defense options. This needs to include an assessment of existing habitats and species in terms of local, national, or international rarity; potential ecosystem goods and services contributed (including any flood defense services); and the value of the natural habitat for tourism or for commercially important species. There needs to be an accompanying assessment of habitat and species under the modified scenarios resulting for each of the different defense options. Weighting the various options is to some extent a political decision which will inform the tradeoffs between the relative importance of the habitats and species lost versus those gained. From a purely ecological perspective, one might say that it is not possible to improve on nature so any change to the natural environment will be deleterious. However, the majority of our coastlines and inshore waters, and most of those in areas of interest for coastal protection, are already heavily modified by urbanization, fishing, tourism, and a range of other challenges, so due consideration of the defense options may allow opportunities to help mitigate for other problems. For example, to increase the spatial extent of a relatively rare habitat such as a saltmarsh while at the same time offering coastal protection or to provide habitat on a hard engineering structure for species that are locally rare or exploited.

It is essential to recognize there is no universal best option and a case-by-case ecological assessment needs to be made. Alongside this, it is also important to be aware of the limitations to any predicted outcomes. The natural environment is inherently very variable, influenced by natural variations in environmental factors including seasonality and long-term weather patterns, and often leading to stochastic consequences for biota such as interannual variability in recruitment of juveniles. In addition, there are a wide range of other anthropogenic factors, such as climate change, eutrophication, and species invasions, acting in isolation and in combination to influence the natural environment. Hence, although our ability to anticipate generic outcomes is good, it can be very difficult to make precise predictions on species composition and abundance or the timescales associated with some of the anticipated ecological changes.

6.2.3 Economic Perspective

Coastal areas provide a diverse array of goods and services that directly or indirectly translate to economic services and values to the human population. Any interventions in terms of flood risk reduction measures will interfere with the delivery of these goods and services. Some may be enhanced and others adversely affected. In economic terms, what we seek are efficient solutions to these risk problems at the coast, namely those measures where the outputs in terms of risk reduction are maximized in relation to the costs of those intervention measures (i.e., the ‘‘inputs’’ necessary for that intervention).

Taking a broad view of impacts, these include both tangible flood damages, indirect flood losses (i.e., the disruption of communication and other links in the economy), and so-called ‘‘intangible’’ effects in terms of the trauma and health impacts of flooding and the disruption of people’s lives during the recovery period. However, many of the values associated with beneficial functions are difficult to assign a monetary value and are therefore consequently often ignored in planning and decision making. This can often lead to decisions that turn out to be unwise. But research has developed approaches to circumvent this situation, and as a result stated preference approaches (i.e., the construction of the market for the goods through the use of questionnaires) can be used to establish some appropriate valuations. These approaches include the Contingent Valuation Method (CVM) and Choice Experiments (CE) that provide economic valuations of preferences so that the costs and benefits of different policy designs can be compared.

In terms of cost, we need to think about the capital costs of the intervention measures and the maintenance costs for continuing to see the measures maintain their effectiveness. Each of these costs has a different time profile, with capital costs typically front-ended to pay for an intervention measure, and maintenance costs following behind. But that is a traditional engineering approach to flood risk management at the coast, whereas the costs of nonstructural flood risk reduction measures such as warning systems or spatial planning have a more even profile during their lifetime. Notwithstanding this point, some of the costs of nonstructural flood risk management measures are difficult to disentangle from their attribution to other parts of society. For example, spatial planning at the coast is not just about flood risk reduction, but also about environmental protection, landscape conservation, heritage protection, and economic regeneration efforts. The whole cost of the spatial planning system cannot be attributed to flood risk management, but rather should be apportioned between the different objectives of that spatial planning system.

Similarly, many of the benefits of flood risk reduction measures are not just the flood risk reduction achieved. The building of promenades that incorporate sea walls to defend against flooding at coastal locations brings recreation and leisure opportunities as benefits that need to be counted. Coastal defense structures may also enhance navigation at the coast, or in estuarine situations, and bring improved port facilities. The artificial nourishment of beaches, to provide protection to the sea walls behind them and therefore protection to urban areas behind those walls, brings opportunities and benefits to those seeking seaside recreation. Indeed, one of the principal benefits or coastal protection is the construction of such recreational resources. Quantification may be difficult, but that does not deny the importance of the benefit obtained.

What these examples show, of course, is that flood risk reduction measures at the coast should not be considered in isolation from other economic and social functions active at the relevant locations (ICE and RIBA, 2010). In simple terms, making coasts safer brings other advantages as well as safety. A comprehensive economic evaluation of the sustainability of flood risk mitigation options need to take all these considerations seriously.

But the choice of intervention measures is not just about economics. Economists, in this respect, tend not to consider the distributional consequences of investment decisions. Rather they concentrate on the efficiency of those intervention measures. But the relevant stakeholders will be interested in distributional effects, in terms of who pays for intervention measures and who benefits from them. This raises the question of equity and ‘‘fairness.’’ In this regard, there are ‘‘procedural fairness’’ considerations, as to whether stakeholders’ concerns are all considered within the process of making decisions about intervention measures, and ‘‘outcome fairness’’ considerations, for example in terms of whether an equitable degree of risk reduction is provided to all the stakeholders at risk. Such social justice considerations are relatively new in flood risk management (Johnson, Penning-Rowsell, & Parker, 2007), but reflect a growing realization of the substantial cross-subsidies between those who pay for these measures and those who benefit from them.

Flooding is a natural event that occurs in variable social, economic, and governance settings and it is the setting that determines planning response strategies. This includes situations where, despite the potential consequences, a flood is either not perceived as a significant risk or is a risk worth taking (Aven & Renn, 2010). This has been largely ignored in technical risk estimates (Burns, 2007; Renn, 2008), yet it determines what are appropriate, acceptable, and realistic management decisions over both the short and long term. It is therefore essential to involve the full range of stakeholders and the public when making decisions on flood management (de Boer, Wardekker, & van der Sluijs, 2010; Dilling & Lemos, 2011).

This has the advantage of (1) understanding what is important to those ‘‘on the ground,’’ (2) building an appreciation and/or understanding of the flood system and the steps required to manage itdthose affected will participate most effectively and accept decisions if they understand the purpose of the process, and (3) encouraging the scientific community to communicate in an effective manner, particularly as public perception of risk is often not driven by facts, or by what is understood as facts by risk analysts and scientists (Renn, 2008).

6.2.4 Society’s Perspective

Social vulnerability is a complex phenomenon and no single measure comprehensively covers the whole spectrum of how vulnerability is manifested (Adger, Brooks, Bentham, & Agnew, 2004; Adger, Hughes, Folke, Carpenter, & Rockström, 2005).

The Social Vulnerability Index provides a comparative spatial assessment of human-induced vulnerability to environmental hazards (Cutter, Boruff, & Shirley, 2003; Wisner, Blaikie, Cannon, & Davis, 2004). The Social Vulnerability Index is based on a large set of measurable variables that can be grouped into major common factors such as: population structure, gender, income, socioeconomic status, and renters (www.csc.noaa.gov/slr). Analysis and mapping of social vulnerability should also consider critical facilities or resources (such as schools, hospitals, and transportation) to help prioritize potential hazard mitigation.

More recently, social vulnerability is modeled in Decision Support Systems (see Section 6.6) considering two main aspects: (1) the damages to critical facilities (CFs) and (2) the expected number of fatalities. Flood damages to society also include psychological consequences that are mainly qualitative in nature and are hard to be translated in linear functions with quantitative outputs for practical and ethical reasons (Tapsell, 2011). Continued development of social vulnerability methods is to be expected.

CFs are defined as ‘‘the primary physical structures, technical facilities and systems which are socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency’’ (UNISDR, 2009). On the one hand, the notion has been adopted recently in disaster management, and is related to the creation of geographic information systems (GIS) maps on community vulnerability (e.g., DEFRA, 2005; FEMA, 2007); on the other hand, CFs have been applied in the development of priority lists for the effective reactivation of buildings after disasters and applied emergency management (e.g., Hillsborough County–Florida, 2009).

The impact of the flooding process on CFs is estimated following three steps.

1. Ranking of critical facilities
   In the THESEUS project (Zanuttigh et al., 2014), a rank was derived based on the function of buildings in relation to social vulnerability (Hillsborough County–Florida, 2009). Considerations were made both in terms of use in emergency management, function in ordinary activities and community aggregation, and symbolic function. The corresponding approximated social value (ASV) was derived and is reported in Table 6.3, with values from 1 (low) to 5 (high). The final output is an overall view of possible intangible damages in the range 0–100. Even if it maintains high levels of uncertainty, it is one of the first attemptsto provide to end users the possible effects of floods on the community and individuals.
   The ASV also provides a reactivation list in reverse order because the highest values are supposed to receive priority in emergency interventions for reducing social damages. From the perspective of land use planning, the adoption of such an approach should lead to the identification of possible relocation of high scoring buildings to safer areas or encourage measures to increase building’s resilience. Similarly, higher scores indicate where efforts for higher education and training of personnel should be concentrated and where emergency measures such as mobile barriers could be deployed with maximum effectiveness.
2. Estimation of physical damage for structures
   The damage scale is estimated based on flood depth and duration.
   Following the method by Schwarz and Maiwald (2008), the damage grade is related to the flood depth (De) through a nonlinear function.
   Intuitively, the effects on society and structures are inversely proportional to flood duration (D), if one excludes flash flood phenomena. Long-duration floods, even

TABLE 6.3 Ranking Values and Factors Required to Estimate the CSD

ASV	Associated Social Vulnerability Factors: Definition
5	Critical structures that if involved could compromise the emergency action, the coordination chain, public safety and public health in the long term. For example, hospital and emergency facilities. Depending on local features, main military facilities, power plants, and institutions can be included in this category
4	Facilities that provide significant public services and should be activated within 24 h. For example, nurseries, major water and sewer facilities, fire and police stations, schools, and park facilities used to support critical purposes can be included
3	Facilities that provide important public services but should be sequent to critical facilities are ranked 4 and 5 points. Main centers of aggregation, education, or prayer that are important for symbolic belonging to the community. Some particular place that links those features to economics can be included, too
2	Facilities that provide public services but that are less critical for the community. Common storage areas and sport centers can be included depending on the context. Literature on social capital can be used also as reference
1	Places which value are mainly symbolical, but can influence anyway the overall amount of social damages. For example, particular community areas of meditation and prayer
	Depth-Induced Damage
Factor De	Depth range from Schwarz and Maiwald (2008): has to be adapted to the site
1	0.1-0.5 m
2	0.6-1.5 m
3	1.6-2.5 m
4	2.6-5 m
5	>5m
	Duration-Induced Damage
Factor D	Flood duration
1	Hours
2	Days
3	Weeks
	Seasonality
Factor S	Definition
1	Low seasonality
2	High seasonality

(Continued)

Table 6.3 Ranking Values and Factors Required to Estimate the CSDdcont'd

	Collateral Social Damage Scale
Score	Definition
0	No collateral social damage
1-10	Possible malfunctions in citizen's ordinary life are possible but can be prevented. The damage is limited and could be managed with experimented procedures and stakeholders activation. The situation could require more details about which critical facilities involved and planning of alternative solutions
11-20	Malfunctions in citizens' life are expected. The damage is still limited but diffused (or high and very concentrated), and requires higher mobilization for the rehabilitation process
21-30	Social damages are concrete and visible. A major involvement of local relief and reprise resources is expected. The presence of external help is suitable and should be activated in advance to avoid higher losses
31-50	Massive social damages in ordinary period or medium involvement of critical infrastructure in high touristic period. Massive damages could be managed with timing alert and planning, but the presence of external help is absolutely needed. Long times for reactivation of services and community reprise should be prevented
51-100	Exceptional damages, calamity. The situation could have terrible social damages and should be mediated with external help and cooperation at the highest level possible. Very long times for reactivation of services and community reprise should be prevented

if relatively limited in space, produce greater impacts on social functions: a bridge blocked might be a nuisance for an hour, whereas it could compromise trade routes or tourism activity if blocked for a week. Therefore the following scenarios (corresponding to different scores, see Table 6.3) should be considered: (1) short D (hours), (2) medium D (days), and (3) long D (weeks).

3. Definition of touristic impact

The geographic features that determine the social vulnerability are related both to the physical structures and to the situation where the action is settled (Cutter, 1996). In many coastal areas, one of the most relevant variables affecting the ordinary social pattern should be considered the presence of tourism. It can be presumed that not all the tourists have previous experiences in flooding, and that if a flood happens with a large number of tourists in place, critical infrastructures may suffer higher pressure and warning messages may face more problems in their dissemination. The tourist presence can be represented through a value reflecting seasonality S; this factor will act as a final scale multiplier, where low season (S ¼ 1) denotes ordinary conditions and high season (S ¼ 2) implies that the effects will be exacerbated. Timing is also key and, for example, the seasonality of tourism and flooding should be considered, which may not coincide.

The collateral social damages (CSD) are finally estimated as:

$$\mathrm{CSD} = \Sigma_I \mathrm{ASV}_i \cdot \mathrm{De} \cdot \mathrm{D} \cdot \mathrm{S} \lim_{x \to \infty} \tag{6.7}$$

The value of CSD is related to a common scale to allow exportability to other case studies and comparison of the results. The scale is also reported in Table 6.3.

For tangible social damages, we derived a function of life losses and injuries (NI) from Penning-Rowsell, Floyd, Ramsbottom, and Surendran (2005)

$$\mathrm{NI} = (H^{*}\mathrm{AV})/(\mathrm{Pa} + \mathrm{ID}) \tag{6.8}$$

where H is the hazard rate, AV is the area vulnerability, Pa is the sensitive population (age <14 years and >65 years), and ID is the number infirm/disabled/long-term sick people.

The value of H is computed in each cell of the domain as

$$H = \mathrm{NI} \cdot y \cdot v \cdot \mathrm{DF} \tag{6.9}$$

where N is the number of people involved in the flood, y is the flood depth, v is the flood velocity, and DF is the debris factor equal to 1 for the Mediterranean and 2 for the ocean.

The area vulnerability (AV) is derived as:

$$\mathrm{AV} = \mathrm{W} + \mathrm{Fo} + \mathrm{Na} \tag{6.10}$$

where W denotes the warning, Fo is the speed of onset of flooding and Na is the nature of the flooded area; see Table 6.4.

The value of Na can be derived from statistical demographic data or can be schematized based on Penning-Rowsell et al. (2005). If statistical data are available, their main use should be identified and impact levels from 1 (low) to 3 (high) are attributed as shown in Table 6.5. Because social patterns determine the impact levels of special attributes, three main scenarios were identified: day, night, and touristic periods. Higher impact was attributed to residential areas when people are generally at home sleeping (night), whereas zones identified for schools and education are vulnerable when children are in classes (day). Finally, tourist resorts are most susceptible during holidays (touristic period).

The percentage of the population aged (Pa) can be derived from demographic data (ISTAT, 2009 for the case of Cesenatico, presented in Section 7.6) or referred to national middle average. The final value of Pa should be conformed to a common value of 50 as: $N\mathrm{Pa}: \times 50 = \mathrm{Pa}:50, \times 100 = n\mathrm{Pa} * (100/\mathrm{Pa})$.

The percentage of ID can be set based on perception or on the national average.

TABLE 6.4 Ranking Values and Factors Required to Estimate Life Losses and Injuries

W	Not Present	Present But Not Implemented	Present and Working Well
	3	2	1
So	Slow flooding (many hours)	Gradual flooding (an hour or so)	Rapid flooding
	1	2	3
ID	Low presence	Medium presence	High presence
	10%	25%	50%
Na	Touristic season	Day	Night
Residential area	2	1	3
Tourist area	3	2	1
Manufacturing	2	3	2
Common or religious area	2	3	1
Education area	1	3	1
City center	3	3	3
Parking and green	1	1	1

TABLE 6.5 An Eight-Step Process to Inform the Compliance of New Modification with the Water Framework Directive

Step	Action
1	Collect up-to-date water body baseline data
2	Collect proposed scheme baseline data
3	Preliminary assessment
4	Design and options appraisal
5	Detailed impact assessment
6	Apply Article 4.7 tests
7	Reporting
8	Follow-up post-project appraisal work

(Source: EA, 2011.)

The values for the ID factors are synthesized in Table 6.4. In general, this function provides an overall count of people that could be subject to death or injuries. These two aspects were not distinguished because too many external variables such as local lifestyle, wealth, or public health services influence the final output of life losses, and the uncertainties are high.

For economic vulnerability analysis, major sectors of economy and the primary centers of activity in those sectors need to be identified. These economic centers are areas where flooding can have major impacts on the local economy.

An EVI was proposed (Guillamont, 2009), based on the composition of the following seven indicators: (1) population size; (2) remoteness; (3) merchandise export concentration; (4) share of agriculture, forestry, and fisheries in gross domestic product; (5) homelessness resulting from natural disasters; (6) instability of agricultural production; and (7) instability of exports of goods and services.

However, within a multicriteria analysis (MCA; see Section 6.3.2), where social and economic impacts must be distinguished and separately weighted, this index turned out to be inadequate because it combines social and economic indicators. Instead, where detailed data on economic activities in gross domestic product terms are available, a consistent approach based on incomes for each economic land use can be adopted (e.g., hotels are evaluated in terms of annual gross domestic product, houses are evaluated in terms of annual rents, and beaches are evaluated in terms of annual willingness to pay to preserve them).

The overall economic consequences (EC) of flood in terms of flood depth and flood duration can be estimated by applying the following expression (Zanuttigh et al., 2014):

$$EC = vij \cdot bj \cdot Fd + vij \cdot aj \sqrt{Fy} \qquad (6.11)$$

where vij are the values of land uses in euro/m^2/year from census statistical data; Fd is flood duration and Fy is flood depth; aj are proportionality constants as functions of Fy that are normalized for each land use j at the maximum value of Fy in a given year for a storm with a fixed return period Tr, assuming different reference percentage of damage depending on the use; and bj are proportionality constants as functions of Fd that express the expected period to restore economic activities as a factor of duration, depending on the land use and are normalized to annual incomes with the days/year. Note that flood velocity is not considered and hence is assumed to be irrelevant.

Beach losses can be derived by combining the beach value function with the beach loss because of erosion. The value function can be derived from specific surveys, see for instance the surveys carried out within the DELOS (Zanuttigh et al., 2005) and THESEUS projects (Diaz et al., in press, Zanuttigh et al., 2014).

Alternatively, a consistent approach based on market values of infrastructures may be used. Note that it is theoretically possible to move from an income approach to an infrastructure approach under a standard set of assumptions about market competition.

6.3 Evaluation of Mitigation Options

To evaluate costs and benefits from a pool of different mitigation options, valuation methods are required (both marketed and nonmarketed). There is a range of methods and techniques that can help decision-making concerning investment appraisal, and cost-benefit analysis (CBA) is one of them (DEFRA, 2009). Similarly, there is a range of techniques that can be used to quantify the environmental impacts of a number of policy options. This is an important component of the data that the decision maker requires.

An important theoretical approach for capturing and describing costs and benefits is the total economic value (TEV) framework. This tool considers the full range of impacts a mitigation option has on human welfare. The way to derive TEV is from preferences of individuals. Such preferences are elicited using stated preference methods and revealed preference methods (see Figure 6.1). Revealed preference methods use data regarding individuals' preferences for a marketable good based on market-based and surrogate market-based methods. Surrogate market-related methods include travel cost methods and hedonic pricing. Stated preference methods use structured questionnaires to elicit individuals' preferences for a given change in a natural resource or environmental attribute. The CVM and CE are included in this category. The CVM is based on the development of a hypothetical market or scenario in which the respondents to a survey are given the opportunity to state their willingness to pay (WTP) or willingness to accept. Because WTP and willingness to accept values are contingent on the hypothetical market, this method is called CVM (Koundouri, Dá;vila, Stithou, & Stuitver, 2013).

In a CE framework, the good in question is broken down into its component attributes. Then, a set of combinations of such attributes and levels is presented to respondents and they must state their preferred combination. (Bennett & Adamowicz, 2001; Birol & Koundouri, 2008) Flooding, land loss, and their impact on water resources are important sources of concern.

An example of how to use this approach is found in D´ıaz-Simal, Koundouri, Rulleau, and Remoundou (2013). They used a choice experiment to elicit the WTP for avoiding climate change challenges (i.e., environmental and health risks in marine environments) via the payment for mitigation measures. The experiment was implemented in Santander, Spain (Section 7.9), a coastal region with vulnerability to marine dynamics and the effects on its beaches (and their role as crucial locations for social and touristic activities), loss of marine biodiversity, and a surge in exposure to medusas and other dangerous species present on the beaches that have motivated restrictions of bathing activities due to health risks. They followed a split-sample approach to elicit the value people place on improvements in biodiversity and recreational opportunities and reductions in the health risks associated with the presence of jellyfish species in the short, medium, and long run.

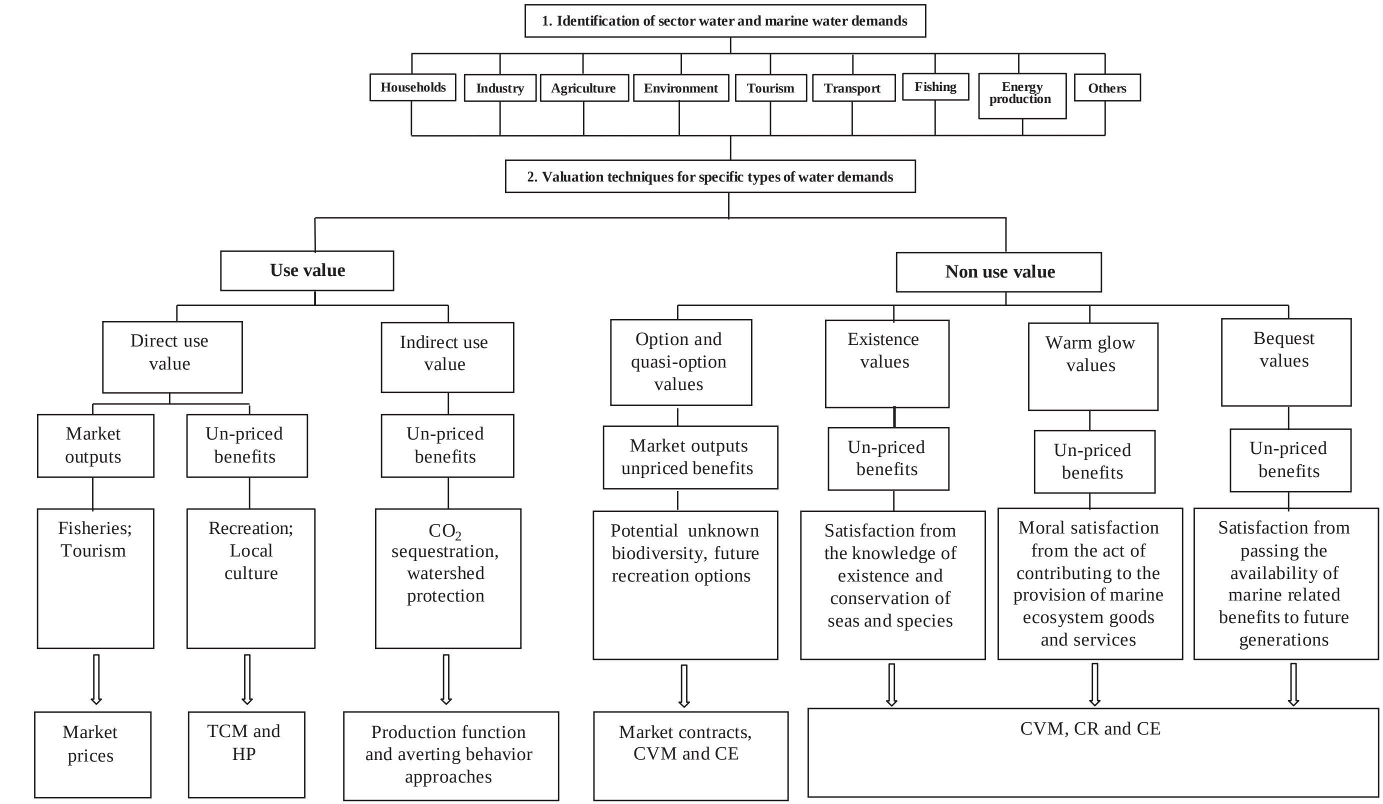

Figure 6.1 Economic valuation methods.
Source: Adapted from Pearce and Moran (1994) and Remoundou et al. (2009).

In a CE, the good under valuation is described in terms of its characteristics, attributes, and the levels these attributes take (Bennett & Blamey, 2001, p. 269). Price is usually included as an attribute because this allows the evaluation in monetary terms of the marginal value of the other attributes. Then, the respondents are requested to choose their most preferred option among different combinations of levels of attributes that are shown to them. The results show that people place a positive value on increased biodiversity and recreation opportunities in all the considered time frames and imply that the present value of future biodiversity and recreation related benefits increases with the time frame.

Another important finding is that people are willing to accept health risks from the presence of jellyfish. The monetary estimations under their exercise could inform the assessment of a long-run CBA to investigate whether different planned mitigation measures are economically efficient.

CBA assesses the monetary social costs and benefits of an investment project over a time period in comparison to a well-defined baseline alternative. In this way, the costs and benefits of a project are evaluated and compared and the long-run economic efficiency of implementing such project is assessed. In this framework, the estimated economic values are aggregated over their relevant populations and added to capture the TEV generated by the investment project. If the total benefits exceed the total costs of the project, then it is considered to be profitable (Koundouri et al., 2013). CBA is part of a more general procedure named environmental assessment. This is because CBA is concerned with a particular ‘‘product’’ (the cost-benefit ratio or net present value as the measure of the economic return from that investment). Environmental assessment is first and foremost more concerned with a process of incorporating information on all environmental attributes, values, and changes into the decision-making sequences.

On the other hand, MCA attempts to quantify in some way all aspects of environmental and economic significance related to a particular decision, and weight them so that a simple range of indices can be developed that capture all adverse and beneficial resultsdor potential adverse and beneficial resultsdfrom an investment decision (DEFRA, 2009). Therefore:

- CBA can provide a sophisticated means of comparing very different investments and outcomes by reducing them all to a common monetary form. It is limited to consideration of those impacts to which a monetary value can be attached but it leads to a simple set of parameters on which choices can be made (e.g., the benefit-cost ratio);
- MCA can be used to broaden the scope of analysis, but brings significant difficulties in terms of determining the appropriate weights to use or the different criteria involved;

- Environmental assessment is broader still, but lacks the precision (or apparent precision) of CBA, and can avoid the kind of discipline involved in quantification that both CBA and MCA bring to the decision-making process;
- Decision makers should not reject any vehicle which clarifies the decision that they are to make, but excessive simplification brings dangers as well as advantages.

6.3.1 Cost-Benefit Analysis

As mentioned in the previous introduction to Section 6.3, CBA is a systematic process for calculating and comparing benefits and costs of a project, decision, or government policy (hereafter, ‘‘project’’). CBA has two purposes:

1. To determine if the project is a sound investment/decision (justification/feasibility).
2. To provide a basis for comparing projects. It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

CBA is related to, but distinct from cost-effectiveness analysis. In CBA, benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value (NPV). If the project is expected to have long-run impacts on the local economy and ecology, its sustainability is to be tested using a long-run cost CBA, and the NPV of the project is estimated using different discount rate schemes (Birol, Koundouri, & Kountouris, 2010). The NPV results reveal whether the net benefit generated by the investment project is positive and significant well into the future. CBA helps to predict whether the benefits of a policy or a set of measures outweigh their costs, and by how much relative to other alternatives (i.e., one can rank alternate policies in terms of the cost-benefit ratio). Generally, accurate CBA identifies choices that increase welfare from a utilitarian perspective. Assuming an accurate CBA, changing the status quo by implementing the alternative with the lowest cost-benefit ratio can improve Pareto efficiency. An analyst using CBA should recognize that perfect evaluation of all present and future costs and benefits is difficult, and although CBA can offer a well-educated estimate of the best alternative, perfection in terms of economic efficiency and social welfare are not guaranteed.

The following is a list of steps that comprise a generic CBA.

1. List the alternative risk management measures at the coastal site.
2. List stakeholders that need to be involved.
3. Select value measurement(s) and measure all cost/benefit elements.
4. Predict outcome of cost and benefits over relevant time period.

5. Convert all costs and benefits into a common currency.
6. Apply a discount rate.
7. Calculate net present value of project options.
8. Perform sensitivity analysis.
9. Adopt the recommended choice of measures.

Uncertainty in CBA parameters (as opposed to risk of project failure, etc.) can be evaluated using a sensitivity analysis, which shows how the resultsdand hence the recommended choice of measuresdrespond to parameter changes.

The two economic criteria to be used in comparing different options are:

1. Cost-benefit ratio: the ratio of the present value of all of the streams of benefits over the present value of all of the streams of costs; and,
2. NPV: the difference between the present value of all of the streams of benefits and the present value of all of the streams of costs.

Brent (1990) provides the following rules for the use of the cost-benefit ratio and NPVs:

1. When the options are mutually exclusive: e.g., in a flood risk management project with options with, say, different standards, select the project with the highest NPV; and
2. When there is a budget constraint: e.g., when the issue is which projects to include in a national program, select the projects that maximize the benefit-cost ratio of the program as a whole.

6.3.2 Multicriteria Analysis

Multiple-criteria decision-making or MCA explicitly considers multiple criteria in decision-making environments rather than the single criterion of NPV. The reason for this approach is that there are typically multiple conflicting criteria that need to be evaluated in making decisions. Cost or price is usually one of the main criteria; some measure of quality is typically another criterion that is often in conflict with cost.

A key aspect of this approach is the need for greater consideration of social and environmental impacts within appraisal. MCA is used to factor in societal and the environmental considerations in flood risk management appraisal, in addition to the traditional focus on protecting against property damage from flooding. As with CBA, the approach also seeks to place value on the environmental and social impacts and benefits of flood risk management options. It remains an economic approach, however, to the extent that these wider impacts are evaluated in terms of the ‘‘worth to society’’ as expressed often in monetary terms. Factoring in social and environmental outcomes can change the view of which options have the biggest benefits compared with the more traditional CBA. The difficulty of the problem originates therefore from the presence of more than one criterion. There is no longer a unique optimal solution to an MCA problem that can be obtained without incorporating preference information and normally one has to ''tradeoff'' certain criteria for others.

There are many different approaches to MCA, and no one is necessarily superior to another. Some approaches seek to convert environmental values into monetary values, whereas others avoid this approach and simply score and weight particular aspects of the resource problem being investigated. Some have a mixture of methods, with some criteria being evaluated in monetary terms, whereas the others are left unquantified. This diversity of methodologies should not be seen as a weakness, but as a strength of this approach to decision making.

A scoring and weighting methodology can be used to estimate monetary values for those impacts that are difficult to measure in monetary values (EA, 2010). It has been developed for use in UK flood and coastal erosion risk appraisals. The method is based on three main steps:

- Step 1: scoring of project impacts;
- Step 2: weighting of these impacts; and
- Step 3: calculating implied monetary values for the intangible impacts.

This includes a step 4 of verifying the implied values.

After identifying the decision alternatives and the relevant criteria to be assessed a full MCA includes, scoring, weighting, and finally the combination of these factors into an overall value for each alternative (Communities and Local Government, 2009).

The methodology forms part of an approach to project appraisal, relying on options that have been identified elsewhere and impacts (benefits and damages) that have been described using an Appraisal Summary Table, see EA (2010). The approach requires scores to be assigned to each option and weights to be assigned to each category of benefit. Once all the scores and weights have been assigned, implied monetary values can be calculated as a method for estimating the value of the intangible benefits (where intangible benefits are defined as those that are difficult to value in monetary terms, such as environmental and social benefits) relative to the tangible benefits (where tangible benefits are defined as those that can be readily valued in monetary terms, such as property damages avoided).

Scoring and weighting can, therefore, provide a less costly alternative to stated preference and other willingness-to-pay techniques as a method for directly eliciting monetary values for those project impacts that are otherwise difficult to estimate in monetary terms. It is therefore most useful when the intangible impacts are likely to be significant and hence influence the choice of preferred option.

Implied values could also be used alongside benefits transfer values as a method of validation/verification that the estimated benefits are reasonable. Overall, the use of implied values could help to keep the costs of appraisal down while allowing all of the benefits to be valued. The outputs from step 3, described previously, can be designed to be compatible with the current method for identifying the preferred option since they enable the NPV, cost-benefit ratio and incremental cost-benefit ratio to be calculated.

6.4 Legislative Constraints

In addition, there are a number of legislative constraints to option choice. Every country in the world has a different approach to this, designed to fit local circumstances and/or reflecting the current national legislative position regarding environmental protection. Particularly prescriptive is the situation in the European countries that are members of the European Union. Here a decade of legislative process has accorded particular status to many environmental sites, and attached to this designation fairly stringent conditions about their modification. Preeminent in this situation is the Water Framework Directive (WFD) and other European legislation, translated into national legislation by each national government, which virtually prohibits interference with particular resources such as water bodies, habitats, and related designated areas.

These examples of legislative constraints usually override consideration of economics, so that conventional economic appraisal of investment decisions becomes redundant. This is not to say that risk assessments and economics are unimportant, but the traditional approach is one that seeks a cost-effective solution, minimizing costs, which complies with the relevant legislative imperatives.

These legislative constraints are discussed before examining the economic and the deliberative methods. The involvement of stakeholders is essential within this process as opinions will vary according to the site and personal experiences. This emphasizes the point that we are making value judgments, rather than this being an exact science. However, it is possible to provide general methods to assist this judgmental process.

6.4.1 An Example of a Legislative OverrideꟷThe European Directives

6.4.1.1 Water Framework Directive

The WFD is a European Directive (European Commission, 2000) that introduces a new strategic planning process designed to manage, protect, and improve the water environment (EA, 2011). The Directive means that interventions in the water environment are strictly controlled, including at the coast, and this will affect all selection criteria.

The purpose of the WFD is to establish a framework for the protection of water bodies (including terrestrial ecosystems and wetlands directly dependent on them) which aims to:

- prevent further deterioration;
- enhance their status;
- promote sustainable water use;
- reduce pollution; and
- mitigate the effects of floods and droughts.

In this context river basin management plans are statutory plans for protecting and improving the water environment. They describe the main issues for the water environment within each river basin district. They tell us, at a local level, which measures the competent authority (the Environment Agency in England and Wales) and others need to implement to achieve the objectives of the WFD.

The WFD requires organizations such as the Environment Agency in England to aim to achieve good status or potential in all water bodies. For surface waters, this means:

- good ecological status in water bodies; or
- good ecological potential (GEP) in water bodies designated as artificial or heavily modified water bodies (AWB/HMWB); and
- good chemical status.

GES is the WFD default objective for all water bodies and is defined as a slight variation from undisturbed natural conditions. This term includes both the hydrological and geomorphological characteristics that can support a healthy functioning aquatic ecosystem. GEP is the WFD objective for AWB/HMWBs and are designated for a specific uses, such as recreation, flood risk management, or urbanization. Water bodies are designated as AWB/HMWBs when the level of modification in these water bodies means the biological status is not able to achieve good ecological status or the uses for which the water body has been modified are still needed and cannot be achieved through ‘‘other means.’’

The AWB/HMWB designation accepts that the biological status of the water body has been impacted by its modification and so the alternative objective of GEP is set: GEP is the best ecological status an AWB/HMWB can achieve without compromising the use for which it was designated. No WFD action can be taken on these water bodies that will have a significant adverse impact on its use. So a water body that has been designated as having a flood risk management use should maintain that use. Only when all the relevant mitigation measures have been put in place can an AWB/HMWB be said to have reached GEP.

The WFD includes an obligation to prevent deterioration in the overall status of water bodies, referred to as ‘‘no deterioration.’’ New activities such as flood alleviation schemes could lead to deterioration. This may lead to a water body failing to meet its ecological objectives.

For new Defra and Environment Agency flood and coastal erosion risk management schemes any hydromorphological impacts need to be fully assessed to establish if they will cause deterioration or prevent the achievement of ecological objectives. To do this, a WFD assessment needs to be made, for which an eight-step process has been developed by the Environment Agency in England to help assess the compliance of new modifications with the WFD (Table 6.5). Exceptionally, there may be situations in which it is not possible for a scheme to be designed to prevent deterioration in ecological status/potential. Under these circumstances, the project needs to satisfy the exemptions criteria set out in Article 4.7 of the Directive. These criteria are summarized below:

- All practicable steps or measures are taken to minimize the impact;
- The reasons for the modification are explained in the river basin management plans;
- The reasons for the modification are of overriding public interest and/or the benefits to human health, safety, or sustainable development outweigh the benefits of achieving WFD objectives;
- The benefits of the modifications cannot be achieved by another means (i.e., they are not technically feasible or are disproportionately costly).

6.4.1.2 The European Habitats Directive and the Birds Directive

The Habitats Directive, together with the Birds Directive, forms the cornerstone of Europe's nature conservation policy. It is built around two pillars: the Natura 2000 network of protected sites and the strict system of species protection. The Directive protects more than 1000 animal and plant species and 220 so-called ‘‘habitat types’’ (e.g., special types of forests, meadows, wetlands), which are of European importance. The protection of these sites is a legislative requirement, overriding consideration of the costs and benefits of any coastal protection measures.

The Habitats Directive (more formally known as Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) is a European Union directive adopted in 1992 as an EU response to the Berne Convention (EC 1992). The Directive led to the setting up of a network of Special Areas of Conservation, which together with the existing Special Protection Areas form the Natura 2000 network across the European Union. Article 17 of the directive requires EU Member States to report on the state of their protected areas every six years. The first complete set of country data was reported in 2007.

The Birds Directive bans activities that directly threaten birds, such as the deliberate killing or capture of birds, the destruction of their nests and taking of their eggs, and associated activities such as trading in live or dead birds, with a few exceptions (listed in Annex III; III/1 allows taking in all Member States; III/2 allows taking in Member States in agreement with European Commission).

The directive also recognizes that habitat loss and degradation are the most serious threats to the conservation of wild birds. Therefore, it places great emphasis on the protection of habitats for endangered as well as migratory species (listed in Annex I), especially through the establishment of a coherent network of special protection areas comprising all the most suitable territories for these species. Since 1994, all special protection areas form an integral part of the NATURA 2000 ecological network and the protection of these sites overrides any consideration of the costs and benefits of any relevant coastal protection measures.

6.4.2 Further Examples of Legislative Override: the USA and Japan

In the United States, there are several federal statutes passed by Congress and signed into law by the President that are central to the Office of Water's mission. In addition, Presidential Executive Orders play a central role in a number of Office of Water activities. These executive orders are legally binding orders that direct the Environmental Protection Agency and other federal agencies in their execution of established laws and policies. Thus, for example, the Clean Water Act is the cornerstone of surface water quality protection in the United States, designed to achieve the broad goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support the protection of fish, shellfish, wildlife, and recreation.

Specific to the US coast, the Beaches Environmental Assessment and Coastal Health Act of 2000 authorizes the Environmental Protection Agency to award grants to eligible states, territories, and tribes to develop and implement beach water quality monitoring and notification programs for coastal and Great Lakes recreational beach waters. The grants also help these governments to inform the public about the risk of exposure to disease-causing microorganisms in the water at the nation's beaches. The Coastal Zone Act Reauthorization Amendments Section 6217 addresses nonpoint pollution problems in coastal waters, requiring states and territories with approved Coastal Zone Management Programs to develop Coastal Nonpoint Pollution Control Programs. The Endangered Species Act provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The lead federal agencies for implementing the Endangered Species Act are the U.S. Fish and Wildlife Service and the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. Federal agencies are directed to carry out programs for the conservation of threatened and endangered species. Thus, federal agencies must consult with

NOAA Fisheries Service and/or Fish and Wildlife Service on activities that may affect a listed species. The Marine Protection, Research, and Sanctuaries Act (also known as the Ocean Dumping Act) prohibits the dumping of material into the ocean that would unreasonably degrade or endanger human health or the marine environment.

In Japan, the Basic Environment Law sets out basic principles and directions for formulating environmental policies, enacted in 1993. In the same year, the National Action Plan for Agenda 21 was submitted to the United Nations. In December 1994, an action plan called the Basic Environment Plan was adopted as the most important measure introduced under the Basic Environment Law. The plan systematically clarifies the measures to be taken by the national and local governments as well as actions to be carried out by citizens, businesses, and private bodies. It also defines the roles of parties involved and the ways and means for effectively pursuing environmental policies. The Japanese Nature Conservation Law, which provides the basic frames for nature conservation, gives powers to protect and manage natural resources and natural ecosystems in cooperation with other related laws. In accordance with this law, locations are designated and established as nature conservation areas including areas that preserve and maintains their valuable natural ecosystems in rivers, lakes, marshes, sea coasts, and marine areas with valuable wildlife.

6.5 Decision Making

6.5.1 Deliberative’ Decision-Making

Consensus or ‘‘deliberative’’ decision making is a group decision-making process that seeks the consent of all participants. Consensus may be defined professionally as an acceptable resolution, one that can be supported, even if not the ‘‘favorite’’ of each individual.

Consensus is defined as (1) general agreement and (2) group solidarity of belief or sentiment. It has its origin in the Latin word cōnsēnsus (agreement), which is from cōnsentiō, meaning literally feel together. It is used to describe both the decision and the process of reaching a decision. Consensus decision making is thus concerned with the process of deliberating and finalizing a decision, and the social and political effects of using this process.

As a decision-making process, consensus decision making aims to be:

- agreement seeking: A consensus decision-making process attempts to help everyone get what they need;
- collaborative: Participants contribute to a shared proposal and shape it into a decision that meets the concerns of all group members as much as possible;

- cooperative: Participants in an effective consensus process should strive to reach the best possible decision for the group and all of its members, rather than competing for personal preferences;
- egalitarian: All members of a consensus decision-making body should be afforded, as much as possible, equal input into the process. All members have the opportunity to present, and amend proposals;
- inclusive: As many stakeholders as possible should be involved in the consensus decision-making process;
- participatory: The consensus process should actively solicit the input and participation of all decision makers.

Consensus decision making is an alternative to commonly practiced adversarial decision making processes or one based mainly on economic considerations. Proponents claim that outcomes of the consensus process include:

- better decisions: Through including the input of all stakeholders, the resulting proposals may better address all potential concerns;
- better implementation: A process that includes and respects all parties and generates as much agreement as possible sets the stage for greater cooperation in implementing the resulting decisions;
- better group relationships: A cooperative, collaborative group atmosphere can foster greater group cohesion and interpersonal connection.

6.5.2 Decision Making and Local Perception of Risk

Risk is both real and socially constructed. Residents who choose to live in area exposed to coastal erosion and floods are often assumed to take this risk knowingly and willingly. However, the views and opinions of those potentially affected by any flood event should be considered throughout the risk assessment process in addition to those involved in flood risk management to answer relevant issues such as: how can consequences be dealt with and how are consequences ranked? For such a participatory approach, selection of the stakeholders for interview should be as representative as possible within the confines of time and availability.

Stakeholders have a wide concept of risk which is often ‘‘grounded’’ within their knowledge and experience of flooding and erosion events. By systematically collecting this information through group and individual interviews, the insight derived is more to resemble ‘‘reality’’ providing an improved understanding of flood risk in the local community, and is therefore a meaningful guide for decision makers (Strauss & Corbin, 1998). Issues and values raised in these discussions can also be addressed throughout the science-based appraisal process, allowing important cross-fertilization to occur.

Key to this process is the analysis of statements made by individuals. Coding transcripts of recorded interviews provides the opportunity to compare responses to

TABLE 6.6 Common Coding for Risk Perception Studies

	Category	Description
Perception of flooding	Relevance claim	Quotes where the interviewee states what is important
	Evidence claim	Quotes where the interviewee establishes a cause-effect link related to coastal flooding
	Normative claim	Quotes where the interviewee states what is good, acceptable, and tolerable regarding coastal flooding risk management options
Emerging themes	Uncertainty	Quotes where the interviewee states the role of uncertainty
	Future	Quotes where the interviewee states his or her beliefs about future states of the coastal flooding risk related issues
	Options	Quotes where the interviewee states his or her beliefs about coastal flooding risk mitigation options

identify emergent themes as well as how risk perception is articulated. Statements or claims frequently belong to three categories: (1) relevance, (2) evidence, and (3) normative (see Table 6.6) (Renn, 2008). Relevance claims are expressing what matters to society, what are the important phenomena that should receive our attention. Evidence claims express causal linkages and are influenced by knowledge and are potentially associated with a need for science-based information. Finally, normative claims express what is good, tolerable, and/or acceptable. These three claim categories can be intertwined to produce specific attitudes toward risk.

The undertaking of this process helps to:

1. clearly define national and regional coastal risk management goals in a broad and long-term perspective;
2. reduce and better manage uncertainty identify methods to explicitly include uncertainty in all decisions relating to coastal management;
3. further develop the integrated planning approach to manage coastal risks, including scenario development, coastal risk assessment methodology, linking short- and long-term time horizons, and different geographical scales; and
4. continue the cooperation and learning process, similarities in coastal problems and possible solutions, and the commonality in methodological approaches.

6.6 Decision Support Systems

A spatial decision support system (DSS) is a computer-based software tool that can assist decision makers in their decision process. Such a DSS is an exploratory tool that allows assessing the conditions of a system under a variety of scenarios and the consequences of different adaptation and mitigation measures. A DSS will generally integrate the relevant environmental models, database and assessment tools, coupled within a graphic user interface. Spatial problems such as flood and erosion risk require a GIS approach. GIS is a set of computer tools that can capture, manipulate, process, and display spatial or georeferenced data facilitating spatial data integration, analysis, and visualization (Burrough & McDonnell, 1998). These functionalities make GIS tools useful for efficient development and effective implementation of DSS within the management process. For this purpose, GIS tools are used either as data managers (i.e., as a spatial geo-database tool) or as an end in itself (i.e., media to communicate information to decision makers). The use of GIS for coastal zone management has expanded rapidly during the past decade. (Bartlett & Smith, 2004, 300 pp.; Sheppard, 2012, 514 pp.; Wright & Bartlett, 2000; Wright, Dwyer, & Cummins, 2011, 350 pp.)

Based on a review of a range of existing DSSs that deal with coastal areas (Table 6.7), the main objectives of these tools are the analysis of vulnerability, impacts and risks, and the identification and evaluation of related management options to support robust decisions for sustainable management. Specifically, the objectives of the examined DSS tools are concerned with three major issues (with examples in brackets from Table 6.7):

- the assessment of vulnerability to natural hazards and climate change (DIVA, RegIS, CVAT, DESYCO, KRIM, Coastal Simulator);
- the evaluation of present and potential climate change impacts and risks on coastal zones and linked ecosystems to predict how coastal regions will respond to climate change (RegIS, CVAT, Coastal Simulator); and
- the evaluation or analysis of management options for the optimal use of coastal resources and ecosystems through the identification of feasible measures and adequate coordination of all relevant users/stakeholders (COSMO, WADBOS, SIMCLIM, RAMCO).

The THESEUS project (www.theseusproject.eu) built on this experience by developing a comprehensive GIS-based intended as a vehicle for communication, training, forecasting, and experimentation (Zanuttigh et al., 2014).

The tool is based on the SPRC model described in Chapter 2 and supports an assessment of the change in risk from a range of scenarios and selection of the most appropriate intervention measures from an available portfolio of engineering, ecological and social measures.

It filled in the gap among the existing tools, based on the following pillars.

- It provides seamless integration across disciplines: physics, engineering, ecology, social sciences, and economy;
- It considers intermediate spatial scales (10–100 km) and short-, medium-, and long-term time spans (1–10–100 years);

TABLE 6.7 Review of Existing Exploratory Tools That can be Used for Supporting Decisions Applied to Coastal Areas. These GIS-Based Tools Perform Scenario Construction and Analysis.

Name	Year	Reference	Processes	Functionalities
COSMO	1992	Feenstra, Programme, and Milieuvraagst (1998)	Sea-level rise	Problem characterization (e.g., water quality, coastal erosion) Impact evaluation of different development and protection Plans Multicriteria decision analysis Ecosystem-based
Coastal simulator	2000-	Mokrech et al. (2009) Dawson et al. (2009)	Storm surge Flooding Coastal erosion Sea-level rise Socioeconomic scenarios	Environmental status evaluation Risk analysis Management strategies identification and evaluation Uncertainty analysis Integrated risk assessment
CVAT	1999-	Flax, Jackson, and Stein (2002)	Multihazard Extreme events Storm surge	Hazard analysis Social, economic, and environmental vulnerability indicators Mitigation options analysis Risk analysis at regional scale
DESYCO	2005-2010	Torresan et al. (2010)	Sea-level rise Storm surge Flooding Coastal erosion Water quality	Impacts and vulnerability analysis Adaptation options definition Multicriteria decision analysis Regional risk assessment
DIVA	1999-	Vafeidis et al. (2008) Hinkel and Klein (2009)	Sea-level rise Coastal erosion Storm surge Flooding Wetland loss and change Salinization	Environmental status evaluation Impact analysis Adaptation options evaluation Cost-benefit analysis
KRIM	2001-2004	Schirmer, Schuchardt, Hahn, Bakkenist, and Kraft (2003, pp. 269-273)	Sea-level rise Extreme events Coastal erosion	Environmental status evaluation Adaptation measures evaluation Information for nontechnical users Risk analysis

RegIS	2003-2010	Holman et al. (2008), pp. 1-187	Coastal and river flooding Wetland loss and change Sea-level rise Emission scenarios Socioeconomic scenarios	Implementation of DPSIR conceptual model Management measures evaluation Impact analysis Integrated risk assessment Information for nontechnical users
RAMCO	1996-1999	De Kok, Engelen, White, and Wind (2001) http://www.riks.nl/resources/papers/RamCo2.pdf	Socioeconomic scenarios Coastal and river flooding Policy options Impact of human activities Integrated management	Environmental status evaluation Management measures evaluation
SimCLIM	2005-	Warrick et al. (2009)	Sea-level rise Coastal flooding Coastal erosion	Environmental status evaluation Impact and vulnerability evaluation Adaptation strategies evaluation Cost/benefit analysis
WADBOS	1996-2002	van Buuren, Engelen, and van de Ven (2002)	Socioeconomic scenarios Policy options Impact of human activities Integrated management	Socioeconomic, hydrological, environmental, ecological data Socioeconomic, ecological, landscape models Management measures identification and evaluation
CLIMSAVE	2010-2013	Harrison et al. (2013)	Emission scenarios Agriculture Forests Water resources Coastal and river flooding Urban development	Implementation of DPSIR conceptual model Impact analysis Adaptation strategies
THESEUS	2010-2014	Zanuttigh et al. (2014)	Sea-level rise Coastal flooding Coastal erosion Socioeconomic scenarios	Hydraulic, social, economic, ecological vulnerability Combination of engineering, social, economic, and ecologically based mitigation options Multicriteria analysis High-resolution risk assessment

From Zanuttigh et al. (2014).

- It allows diverse portfolios of mitigation options such as engineering defenses (i.e., barriers, wave farms, etc.), ecologically based solutions (i.e., biogenic reefs, sea-grasses, etc.) and socioeconomic mitigations (i.e., insurance, change of land use, etc.);
- It supports decision making based on a balance between deterministic models and expert, discussion-based assumptions;
- It uses an open source approachdbased on a specific request from the European Commissiondto maximize the availability and uptake of the tool. The technological framework selected for the development is Microsoft. NET 4.0, a solid software platform which includes a wide class library for common tasks such as data access, user interface, or network communications. DotSpatial, a free, open source set of libraries for .NET, is the GIS component of the DSS to easily incorporate spatial data, analysis and mapping into an application. A relational database management system has been implemented with SQLite engine to store the site-specific data and information.

THESEUS DSS is developed on top of an integrated simulation model suitable for performing ''What if'' analyses based on scenarios. By means of this kind of analysis, the user tries to find out how management strategies and scenario sensitive variables and parameters influence risk at the selected coastal site. The policy analysis mainly focuses on the consequences of changing coastal management options.

Figure 6.2 gives an overview of the structure of the integrated model at the most synthetic level. The integrated model is the actual calculation kernel of THESEUS DSS. It contains relations in the form of mathematical equations, formal rules, or transfer functions representing the real-world processes.

The primary end-users are intermediate-level coastal managers who need to make sound evidence-based decisions regarding spatial planning and coastal protection.

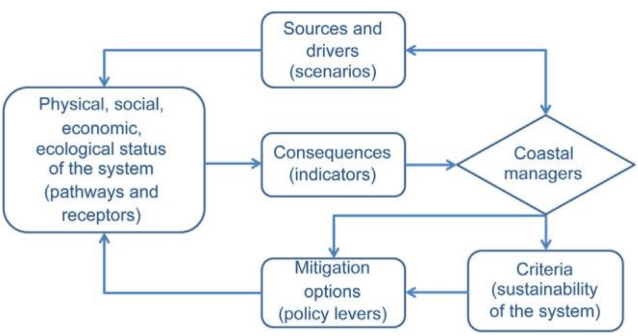

Figure 6.2 System diagram view of THESEUS DSS. *From Zanuttigh et al. (2014).*

The main foundation of this DSS is that it has to be ‘‘open and parametric,’’ not only in terms of source code and technology but also in terms of usability. This software is designed to be easily modified and distributed across many sites with many diverse characteristics: this requires adequate flexibility in terms of configuration parameters and input materials.

The DSS should also be ‘‘interactive’’ so that users can explore a combination of scenarios, whereas being trained in interdisciplinary risk assessment, including the best (i.e., sustainable) solution or combination of solutions for risk mitigation. Here sustainable means protecting the coast while preserving its socioeconomic development and the integrity of the ecosystem services.

The inclusion and participation of relevant stakeholders (coastal managers) is essential to test the outcomes of the modeling, to identify the most relevant parameters and related scenarios to be included in the analysis and to evaluate adaptation options (Dessai & Hulme, 2004). To maximize the utility of THESEUS DSS, the stakeholders gave their input on:

- definition of the site boundaries;
- identification of critical pathways of the existing management that may lead to failure and are worthy of further investigation;
- usefulness of output indicators for each of the meta-models;
- appropriateness of the mitigation measures to be included in future coastal management strategies for a given site;
- site-specific relevance of the social, economic, and environmental components of risk; and
- functionality and user-friendliness of the interface.

Following Holman et al. (2008, pp. 1–187), the setup of the tool considered two key points.

1. Intuitive and interactive design of the GUI and possibility as follows.
   a. The physical layout of the tool should closely mirror the conceptual model (i.e., the SPRC components).
   b. The user should be able to vary the input parameters through sliders to analyze the potential changes induced by different scenarios or mitigation strategies.
   c. ‘‘Realistic’’ and plausible ranges of values for a given parameter should be used to give guidance on the uncertainty associated with a scenario.
   d. The users should be allowed to save and compare the graphical outputs from more than one model or scenario.
2. Balance of simplified modeling assumptions and speed to promote the use of the tool for testing different combinations of mitigation options by:
   a. avoiding extensive or prolonged model setup has been avoided and
   b. providing rapid outputs.

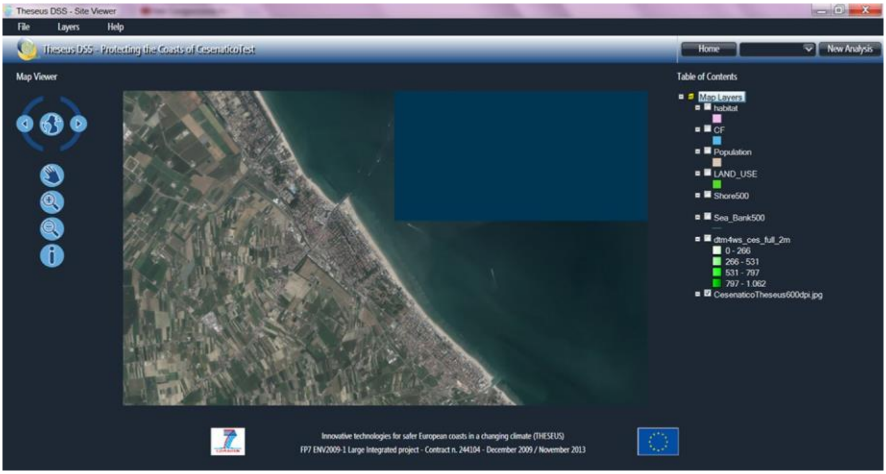

Figure 6.3 The viewer at the startup for the Cesenatico site, Italy; see details in Section 7.6.

THESEUS DSS operates at high resolution to provide geographic specific outputs. Although users should be encouraged to study the detailed maps, this output is not suitable for direct application, nor should it be confused with the policies that would accomplish those outcomes and judged based on the avoided monetary damage only. Therefore although the intermediate maps of specific results (e.g., flood depth, land value loss, life losses) are shown with their own scale, the results of (hydraulic, social, economic, and ecological) vulnerability and the overall risk assessment map are given as normalized quantitative indicators.

Based on these guiding concepts, on the experience gained from other tool development (and specifically RAMCO and RegIS) and on the feedback from stakeholders, the interface for each site consists of a viewer at start up (Figure 6.3), where the user can visualize the input data (bottom elevation, habitats map, land use map, etc.) and evolves to the following four screens, each with a different purpose.

1. Definition screen: this allows the user to define the name of the test and write a short description; he or she can also load the settings of a previously performed analysis.
2. Scenarios screen (Figure 6.4): this allows the user to select among climate, social, environmental, and economic scenarios. The user can adopt preset scenarios defined by scientists; in this case, the default set of input parameter values for each preset scenario allows a rapid model setup. The user can also create their own scenarios by directly changing the input parameter values used in the models. This enables the user to become familiar with the most significant parameters related to the site-specific scenarios and to explore the effects of uncertainty in any scenario, which cannot be defined by a single set of unique values.

Figure 6.4 Scenarios screen. *From Zanuttigh et al. (2014).*

3. Mitigations screen (Figure 6.5): this allows the user to include:
   a. engineering mitigations, such as wave farms, barriers, floating breakwaters, sea walls, and nourishments;
   b. ecologically based mitigations, such as management or construction of dunes, reinforcement of saltmarshes, and creation of biogenic reefs; and
   c. economic and social mitigations such as evacuation plans, land use change and zoning (for instance, managed realignment), insurance scheme.

   When selecting a mitigation option for which size and location has to be defined (for instance, a biogenic reef, a breakwater, a managed realignment), the user can: (1) include the shapefile prepared by the scientists with the suggested configuration of the mitigation (position, extension, design parameters); (2) upload a shapefile and enter the design parameters; or (3) draw the mitigation directly from the graphic user interface. For other mitigations, such as insurance schemes or evacuation plans, the user can interact by modifying the insurance premium value, the percentage of evacuated people or the destination of a given area.
4. Execution screen (Figure 6.6): this guides the user through the analyses to be performed based on the selections made in the previous windows; these analyses include the following steps: (1) modeling of the physical processes (erosion, flooding); (2) modeling the impacts on the environment, the society and the economy; (3) assessing the global hydraulic, social, and environmental vulnerability; and finally (4) assessing the risk. It also imposes constraints on the analysis.

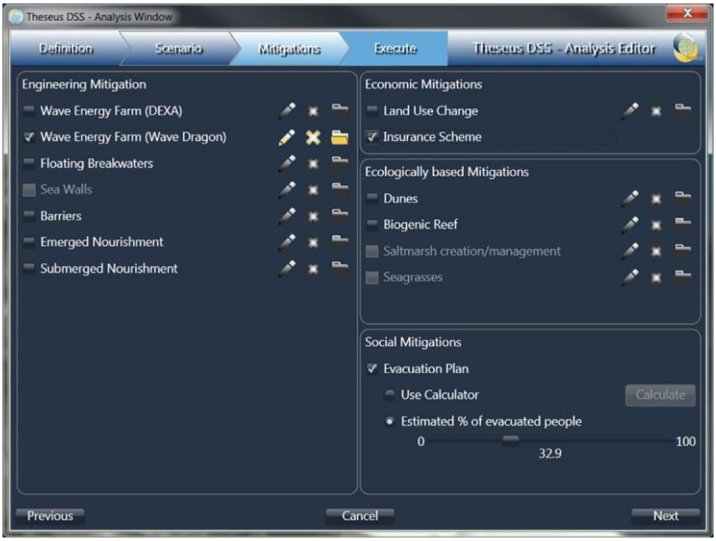

Figure 6.5 Mitigation screen. *From Zanuttigh et al. (2014).*

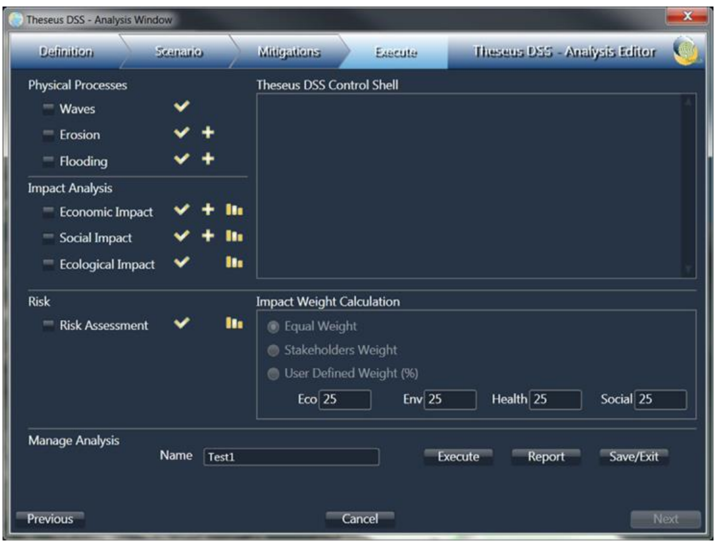

Figure 6.6 Analysis screen. *From Zanuttigh et al. (2014).*

For instance, if the user does not include the erosion process in the Scenarios screen, he or she cannot flag the corresponding analysis to be run in the Execution screen. Let us suppose that the user changes the settings of the analysis just performed by including for instance a new mitigation in the Mitigation screen. When he or she is back at the Execution screen, he or she will be forced to rerun the flooding model if the mitigation is such that it affects the physical processes (for instance, a seawall or a dune), whereas the flooding model will be hidden if the mitigation does not interfere with the physical processes (for instance, an evacuation plan or a change of land use).

Hydraulic, social, and economic vulnerability maps are generated, being vulnerability assessed as:

vulnerability ¼ exposure ¼ —resilience

where exposure is the value at risk (De Vries, 2011) and resilience is the damage that will not alter the main functions of human and physical systems in equilibrium in discrete times and at local scale (De Bruijn, 2004).

Appropriate impact functions were developed to link economic (see Section 6.2.3), social (see Section 6.2.4) and ecological (see Section 6.2.2) data to hydraulic parameters, such as: beach retreat, flood depth, flood duration, and flood velocity. These functions allow obtaining the maps of social, economic, and ecological consequences, each one expressed with the typical unit. The economic losses are divided into the losses in the urban area, expressed as euro/m^2, and into the beach losses, expressed as euro/m. The social losses are derived in terms of life losses, expressed as a percentage of the number of expected deaths of the local population in the area, and of CF losses, expressed as a percentage of the functionality loss of each CF (see the example in Figure 6.6).

A normalization procedure of each map of consequences is then carried out to obtain a 1–4 scale, in which 1 ¼ low, 2 ¼ medium, 3 ¼ high, and 4 ¼ very high impact. The normalization is performed by dividing the local values of the consequences by the corresponding site-specific thresholds that are obtained by comparing the consequences of different scenarios with the historical experience and/or data available in the sites (i.e., through a process that involves both stakeholders and experts). Site-specific threshold values for low, medium, high, and very high impact are defined for each relevant parameter: flood depth, velocity and duration; beach retreatment; beach and land use value losses; and life and CF losses. The normalized ecological vulnerability map is directly derived from the calculated values of the EVI, by associating the EVI 0–3 scale to the 1–4 vulnerability scale.

The hydraulic vulnerability map is derived from a weighted average with equal weights of the normalized maps of flood depths, velocities, and durations. The economic vulnerability map is obtained by a spatial combination of the normalized beach losses and of the normalized inland value lost, with the two areas being complementary. The social vulnerability map is derived as an equally weighted combination of the normalized maps of life losses and CF losses.

Social, economic, and ecological vulnerability maps are then combined through a weighted procedure to obtain the overall risk map (Figures 6.7 and 6.8). Within this additive combination, the hydraulic vulnerability is not explicitly considered to avoid duplication, because it is already indirectly included through the social,

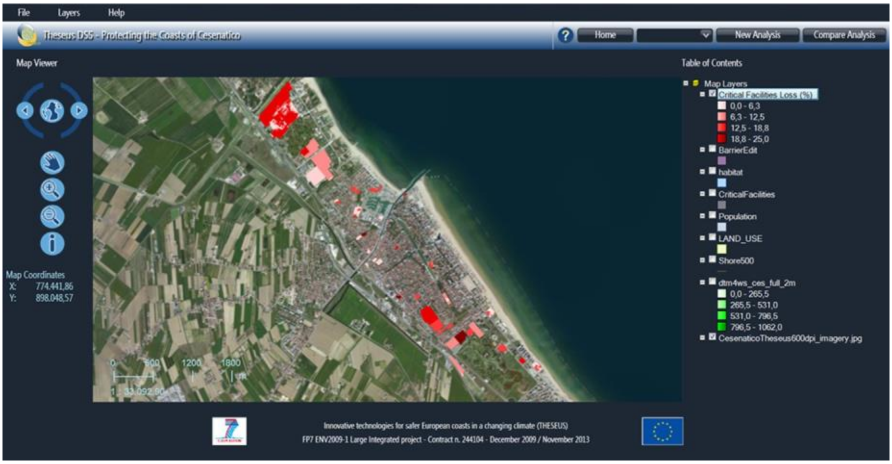

Figure 6.7 Example of impact on critical facilities (%). Long-term (2080) scenario with return period (combined wave and storm surge statistics) Tr ¼ 100 years. *From Zanuttigh et al. (2014).*

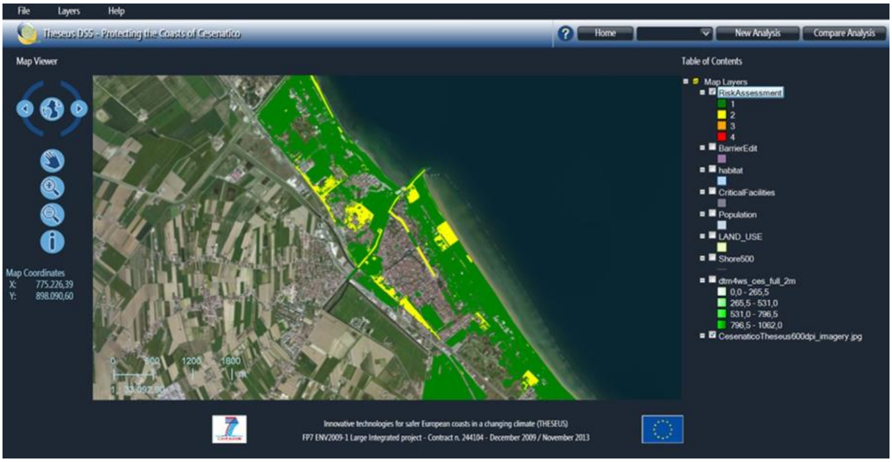

Figure 6.8 Example of integrated risk map, scale from 1 to 4 (from low to very high impact). Long-term (2080) scenario with return period (combined wave and storm surge statistics) Tr ¼ 100 years. *From Zanuttigh et al. (2014).*

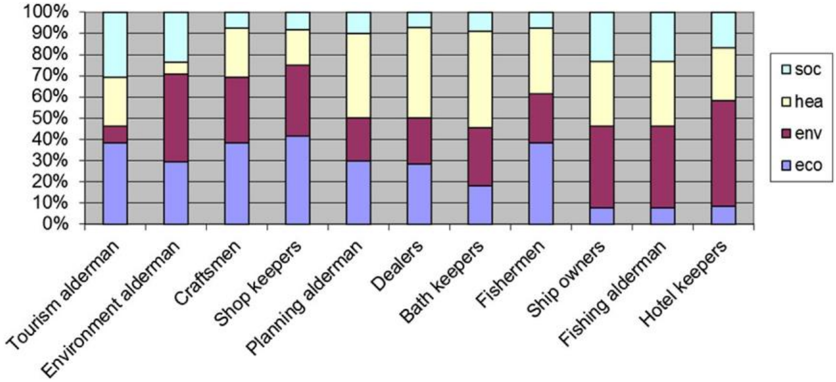

Figure 6.9 Weights assigned by stakeholders in Cesenatico, Italy (see Section 7.6) to impact on human health (hea), infrastructures and activities (soc), environment (env), and economics (eco). *From Zanuttigh et al. (2014).*

economic, and ecological vulnerabilities that are all estimated on the basis of selected hydraulic parameters (flood depth, velocity, and duration).

In the generation of the risk map, the users have the chance to select equal weights, their own weights, or to use the results of the surveys carried out in THESEUS study sites (see Figure 6.9 for the synthesis of the results in the Italian case study, Section 7.6). Within these surveys, the stakeholders were asked to rank three cards where the three titles referred to the represented main issues (economic, environmental, and social). Some items were clarified with some examples, for instance: the ''economic'' card shows "houses, tourism, fishery, …"; the environmental card presents "pine forest, biodiversity, animal species, habitats, …"; and the social card shows "social cohesion, meeting facilities, sports, psychological distress, fatalities, injuries, …". Stakeholders were then asked to insert one or more blank cards between the ordered cards to stress relative differences in importance attached to each issue or group of issues.

The normalization procedure suggested by Kodikara et al. (2010) led to obtain the relative weights for each stakeholder and consequently the weights of each criterion were estimated as the average values.

An example application of the tool for decision making purposes is given in Section 7.6 for the study site of Cesenatico, Northern Adriatic Sea, Italy.

6.7 Conclusions

The key to successful coastal flood management is the use of mitigation techniques that are appropriate for the local context. Thus, the development of coastal protection strategies should involve the specification of detailed regional scenarios, an appropriate problem assessment, and identification of promising measures and the analysis and evaluation of alternative strategies.

During the decision-making process, the range of possible flood mitigation alternatives should be reviewed to identify the most efficient individual or suite of options.

The efficiency of engineering solutions consists of the degree of coastal protection they offer, and it can be evaluated specifically in terms of reduction of incident wave height, reduction (or stabilization) of sediment transport, reduction of wave run-up on the beach and wave overtopping at the sea bank, and of frequency and magnitude of inland flooding.

From an environmental perspective, it should be noted that the selection of any mitigation option will affect local habitats, species, and ecological interactions. To assess the vulnerability of ecosystems to changes in stresses and to disturbances, an index was adopted within the THESEUS project (see THESEUS OD3.3, 2012). This provides a rapid and standardized method for characterizing vulnerability across coastal systems and identifies issues that may need to be addressed to reduce vulnerability.

From an economic perspective, marketed and nonmarketed valuation methods are required to value costs and benefits from a pool of different mitigation options.

Nonmarket valuation methods are useful to assign monetary values for environmental goods and services that are not traded in actual markets. Such market price data are missing and purchasing behavior is observed within the context of a hypothetical market using the methods described in Figure 6.1. On the other hand, there is a range of methods and techniques that can help decision-making concerning investment appraisal. For example the CBA (it assesses the monetary social costs and benefits of an investment project over a period in comparison to a well-defined baseline alternative) and the MCA (it considers multiple criteria in decision-making environments rather than the single criterion of net present value).

From society's perspective, social vulnerability can be modeled in DSSs considering damages to CFs and the expected number of fatalities (see Section 6.6). It should be noted that flood damages to society also include psychological consequences that are mainly qualitative in nature and are hard to be translated into linear functions with quantitative outputs.

In any case, the decision maker should recall that there are several legislative constraints on option choice, and every country has a different approach to this, designed to fit local circumstances and/or reflecting the current legislative position regarding environmental protection (examples in the European Union are the WFD and the European Habitats and Birds Directive).

Finally, an important part of selecting and assessing mitigation options is the development of decision-support methods because they can examine different mitigation options by evaluating their relative efficiency, equity, and sustainability in determining risk levels and potential consequences. This is important when selecting mitigation strategies under uncertain future conditions.

Spatial DSSs can assist decision makers in their decision process. Among these, the THESEUS project (www.theseusproject.eu) developed a comprehensive GIS-based DSS intended as a vehicle for communication, training, forecasting, and experimentation. It supports an assessment of the change in risk because of a range of scenarios and selection of the most appropriate intervention measures from an available portfolio of engineering, ecological and social measures.

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