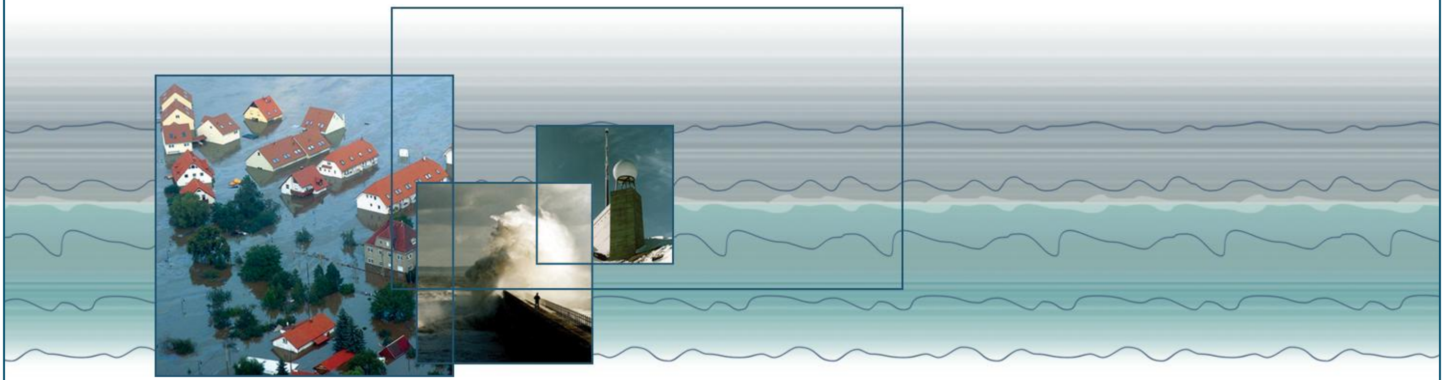
Integrated Flood Risk Analysis
and Management Methodologies

FLOODsite



Long-term strategies for flood risk management

SCENARIO DEFINITION AND STRATEGIC ALTERNATIVE DESIGN

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Summary

Flood risk management requires policy making for a relatively far and largely unknown future. Task 14 of Theme 2 in FLOODsite aims to provide methodological guidance on how to perform the design/ development of long term strategic alternatives for flood risk management and how to assess their performance in different future scenarios.

To begin with, this report reviews some mainstream existing methods of scenario development and use, as well as experiences with the design and assessment of strategic alternatives for flood risk management. Next, a procedure and methods are proposed and discussed. Thirdly, the procedure and methods are tried on the Schelde Estuary and the Thames Estuary and, finally, conclusions are drawn.

Review results

The review of scenario approaches results in the following recommendations for developing scenarios for flood risk management studies:

- follow a clear distinction between scenarios and strategic alternatives as defined in the FLOODsite *Language of Risk*;
- develop projective, exploratory scenarios;
- build on accepted and widely used scenario studies as much as possible and use either the two discriminate axes method or the perspectives method (in practice they work out very similar);
- distinguish no more than 4 different scenarios;
- examine the development of the main drivers, viz. climate change with its consequences for the flood hazard and economic growth, population growth and land use change with their consequences for exposure and vulnerability;
- qualitative narratives must be downscaled/concretised into quantitative scenarios for the geographical area of interest.

The review of how strategic alternatives are being designed results in the following recommendations:

- design strategic alternatives by content (guiding principle, measures and instruments) only; in contrast to strategies which also comprise process (institutions, responsibilities, timing, etc.).
- do, for practical reasons, not develop more than 4 strategic alternatives; a zero-alternative is quintessential for reference purposes.
- follow a top-down approach instead of a bottom-up one, defining clear guiding principles, such as resistance versus resilience, and/or by specifying different objectives (economy versus ecology, people versus material damage, etc.).
- in case scenarios are being developed related to ‘perspectives’ or world views, it is advised to name (and design) the strategic alternatives according to these perspectives as well: a controlist’s, an egalitarian and a market-optimist’s strategy;
- all strategic alternatives should consider both structural and non-structural measures/instruments; and all alternatives should aim at both hazard control and vulnerability reduction – although their respective shares may deviate substantially.

The review on the assessment of strategic alternatives results in the following recommendations:

- any assessment of flood risk strategies under various future scenarios should involve criteria related to the sustainability aspects people (social aspects), profit (economy) and planet (natural and cultural heritage) and the sensitivity to uncertainties (robustness and flexibility), and the criteria should be balanced over these aspects.
- The criteria can be translated into rough indicators. These indicators suffice when dealing with long-term scenarios with a time horizon of 50-100 years, for which detailed consequence analysis is practically impossible.
- A ranking of alternatives on the basis of both quantitative and qualitative indicators sholudl be possible.

Procedure

The review recommendations have been translated into a framework for the design and assessment of long-term strategic alternatives for flood risk management. The main elements of this framework are:

1. System exploration: specify the area of interest and relevant time-scales and define future scenarios (down-scale existing scenarios on European or national level to the region involved);
2. Analysis and assesssment of currrent flood risk management strategy: Analyse of the current flood risks and the future flood risks for the various future scenarios. Assess whether these risks are acceptable or call for the consideration of alternatives to the current strategy.
3. Development of strategic alternatives: Develop clear visionary alternatives which may be useful for a discussion on where flood risk management should be heading to in the long-term.
4. Assessment of strategic alternatives: Evaluate to what degree the alternatives contribute to the long-term sustainable functioning of society and environment in the region involved.

Methods to cover all these elements are provided in chapter 3. In chapter 4 and 5 the methodological framework of chapter 3 is tried in two real-world cases, viz. Schelde Estuary and Thames Estuary.

Cases

The procedure has been trialled in three cases. Two of these are reported in this volume, viz. the Schelde Estuary and the Thames Estuary. A third case, on the Elbe River, is reported seperately.

The flood-prone area surrounding the Schelde Estuary consists of low-lying polder areas with mainly agriculture, some cities and many small villages. The area is currently protected from flooding by high embankments which are designed to withstand 1/4000 year storm surge conditions. If this flood risk management policy is continued into the future, flood risks will increase with a factor 3 to 30 depending on future developments. Also the average number of expected numbers of affected persons and casualties will increase. Continuing the current policy is not cost-effective, unless the World Market scenario becomes reality. Because future risks increase and the strategy is not cost-effective other strategic alternatives were considered. The guiding principles resilience and resistance were used to develop three strategic alternatives: ‘A storm surge Barrier’, ‘A risk approach without spatial planning’, and ‘a risk approach with spatial planning.’ The flood risks and other effects of these strategic alternatives were determined and assessed. Next to these alternatives also the effects of doing nothing except continuing the maintenance of existing embankments were determined. The results indicated that the storm surge barrier alternative scores best on social-value-related indicators, while the spatial planning alternative scores best on nature-value-related indicators and reduces the system’s sensitivity to uncertain events and changes. The ‘risk approach with no spatial planning’ scores best on the profit-related indicators. The scores differ per scenario. If all scenarios and criteria are considered, the spatial planning alternative looks most promising. The case study showed that the long-term planning method of chapter 3 was applicable on the Scheldt Estuary and resulted in clear and meaningful results which help to develop a long-term vison on flood risk management in the Scheldt Estuary. During the assessment procedure it became clear that the meaning of the criteria ‘economic opportunities’ and robustness was still a little unclear, but still the assessment allowed a full assessment of the alternatives across all four scenarios. The case study resulted in recommendations for flood risk management of the Scheldt Estuary and for improvement of the general long-term planning method.

The procedure has also been applied to the Thames Estuary. The work was undertaken in close co-operation with a parallel UK project, viz. Thames Estuary 2100 (TE2100). The present flood risk management system provides a defence standard of 1/1000 per year in the year 2030 for most of the tidal Thames floodplain, which is protected by the Thames Barrier, except for parts of west London at risk from fluvial flooding, and parts of the relatively undeveloped lower Thames marshes. Four coherent storylines based on the Foresight World Views were developed and appropriately downscaled for the Thames region to simulate the details of the future socio-economic and climate scenarios on an estuary scale.

The emphasis of work on the Thames Estuary was, however, put on the development of various strategic alternatives and the assessment of the resulting flood risk under different future socio-economic and climatic scenarios. For the Thames pilot four strategic alternatives and/or references have been assessed, viz. 'Doing Nothing' (equivalent to the TE2100 P1 Policy), 'Resistant' (improving the existing system through defence raising and maintenance), 'Resilient' (small improvements to the existing system and introducing non-structural measures), and 'Highly Resilient' (similar to Resilient but with numerous non-structural measures). The management interventions for these alternatives are planned for 2040, 2070 and 2085 and hence the situation was evaluated before and after the planned interventions as well as in the present day and the year 2100. All in all 82 model runs were performed to establish the flood risk in each strategic alternative in the context of each future socio-economic and climatic scenario, for the present day, 2040, and before and after management interventions in 2070 and 2085, and in the final year of the appraisal period, 2100. Brief consideration of the non-intended side-effects of implementing the alternatives was given and an impression of robustness was gained by looking at the benefit/cost ratio of a given alternative across all scenarios considered. The flexibility of the strategic alternatives was not considered. In this sense, the Thames case differs from the Schelde case, as it put more emphasis on the role of probabilistic calculations of risk indicators whereas less effort was placed on assessing the side-effects of implementing the measures related to the alternatives; this can be regarded as a choice for more depth on risk at the expense of breadth of assessment. Robustness and flexibility of the Thames alternatives have, however, been given more attention in FLOODsite's task 18.

Conclusions on the use of scenarios

Since the future is inherently uncertain no long-term future predictions are possible. To cope with future uncertainty it is advocated to use contrasting future scenarios which together span the field of 'all' possible future developments. Scenarios describe autonomous developments in the world or region in which the case study area is situated. Autonomous developments are those developments which do not purposefully change flood risks. Consistency amongst the developments is guaranteed thorough a story-line which describes the full future picture. Based on the story-line those parameters are identified which need to be changed to visualize the effects of the scenario on the studied system. For long-term flood risk management studies these include flood hazard related parameters (probabilities of discharges/ water levels /rainfall), and vulnerability related parameters (land use / damage functions/ population figures).

The use of scenarios was found to be useful, because:

- It shows that the functioning of the strategic alternatives differs per future scenario;
- It thus shows that taking into account the uncertainty on the future is important, since strategic alternatives may function well in one scenario, while they are less preferable in others;
- There are strategic alternatives which function reasonably well in all future scenarios or which can easily be adapted to different scenarios.

The method in chapter 3 and the applications in the case studies show how scenarios can be used in long-term flood risk management planning. Since scenarios are rarely used in long-term flood risk management and since the assessment of the functioning of strategic alternatives across different scenarios is a new approach, the method developed here and its applications are useful for policy-makers.

Conclusions on the development of strategic alternatives

In order to show possible ways of coping with flood hazards and their effects different strategic alternatives need to be defined and assessed. These strategic alternatives must be visionary and clearly different. Therefore, it is advocated to define them according to a top-down approach by using guiding principles to select combinations of measures and instruments. As guiding principles, for example, various world views or the concepts of resilience and resistance may be used.

The case studies show that strategic alternatives are a good means to illustrate alternative possibilities for long-term flood risk management and their effects. The strategic alternatives are useful when developing a vision on where long-term flood risk management should be heading for. This vision facilitates making decisions for the middle and short-term flood risk management.

Conclusions on the full assessment of sustainability

To assess the functioning of the strategic alternatives in different possible future scenarios criteria have been defined. Together these show the contribution of strategic alternatives to sustainability by referring to the sustainability domains 'people', 'profit' and 'planet'. Also the 'sensitivity to uncertainties' is assessed. A Multi-Criteria Analysis (MCA) approach is followed which incorporates both quantitative and qualitative criteria. The qualitative criteria are assessed by a Delphi-approach. This allows one to show the effect of strategic alternatives on all relevant aspects of sustainability, also on those aspects which are very relevant, but difficult to quantify.

Robustness and flexibility are both very important criteria since they reveal the sensitivity of strategic alternatives to uncertain events and changes. Flexible strategic alternatives mostly function well across a range of future scenarios or they can be easily adapted if future developments differ from the ones anticipated. Future regret is thus less likely when such strategic alternatives are being adopted. Robust strategic alternatives are less sensitive to uncertain events such as very extreme water levels, mall-functioning of structures, malfunctioning communication systems, unforeseen behaviour amongst the inhabitants etc. Both robustness and flexibility were incorporated in the full assessment, scored for all strategic alternatives and evaluated. However, the precise elaboration differed per case. Although important progress has thus been made on the robustness and flexibility criteria, their definitions are not sufficiently clear and operational yet.

The qualitative criteria need a reference for scoring. If one is interested in the effects of the strategic alternative only and not in the effects of the scenario, as reference a future status in each of the used scenarios must be used and compared with the future status in the same scenario but after implementation of the strategic alternative. If the current status is used as reference the future combination of strategic alternative and scenario is scored. The reference for scoring must thus be consciously chosen.

Recommendations for further scientific research

1. Apply the proposed method en develop and assess long-term strategic alternatives for flood risk management in real cases.
2. Develop a method which allows making decisions on when to change to another strategy and the effects of choices on options for the future. Questions relevant for this topic are:
    a. How to incorporate 'decision-pipelines' in the analysis and assessment of long-term flood risk management?
    b. How to use this to improve our understanding of 'breakpoints' (when are developments such that a certain strategy does not function any more);
    c. Can this analysis in-time replace the assessment criterion 'flexibility' and how?
3. Develop the concept of robustness further.
4. Further develop methods to combine or weigh the scores of the different alternatives in the different scenarios to find which strategic alternative scores best in what scenario and which strategic alternative is best across all scenarios.

Recommendations for practitioners and policy makers

1. Develop a long-term flood risk management vision in order to better motivate short- and middle term decisions and to prevent future regret. Thus: think back from the future.
2. Study the effects of the continuing the current strategy and the effects of strategic alternatives in the long-term.
3. Aim for flexible tailor-made strategies, as these work better in an uncertain future. See for example the spatial planning strategy in the Schelde Case study area.

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1. Introduction

1.1 Background

Flood risk management requires policy making for the long term. This means policy making for a relatively far and largely unknown future. This implies dealing with many uncertainties and many possible futures. It also means that different policy alternatives must be examined.

In many research projects for policy planning *strategic alternatives for long-term policy making* are being developed and evaluated. Their assessment nowadays often involves assessing their performance in *different future scenarios*. Task 14 of Theme 2 in FLOODsite aims to provide methodological guidance on how to perform the design/ development of long term strategic alternatives for flood risk management and their assessment.

To begin with, this report reviews some mainstream existing methods of scenario development and use, as well as experiences with the design of strategic alternatives for flood risk management. Also criteria for evaluating the sustainability of such strategic alternatives are being reviewed. Next, the knowledge gained in these reviews is being summarized in a methodological framework which was tested in some real-world cases (Schelde Estuary, Thames River and Elbe River). Two of these cases are reported in this volume; the Elbe case is reported in a separate document.

1.2 Why consider long-term planning and why use scenarios?

Some arguments for long-term planning of flood risk management strategies are:

- Policy making in view of sustainability requires considering what ‘world’ we want to pass on to future generations.
- ‘Decisions taken today will have a profound impact on the size of flood risks that future generations will need to manage. They will also strongly influence the options available for managing those risks’ (Evans, 2004a,b).
- Some flood risk management measures and instruments, such as changing land use in floodplains and within cities, could take decades before they become effective.

> “One shouldn’t learn from history, but from the future” (Patrick van der Duin & Hans Stavleu, 2005)

In order to develop and evaluate the performance of long-term strategies scenarios are frequently used, especially when there are many complex and interacting variables, and where the future is very uncertain (Evans *et al*., 2004a). Motives for the use of scenarios in flood risk management are:

- Specifically for flood risk management the rate of climate change and its impact on floods is uncertain, the demographic and socio-economic developments of societies are uncertain, and the normative views of future generations are uncertain (cf. Hooijer *et al*., 2004).
- The future is inherently uncertain and cannot be predicted sufficiently accurate. It is therefore important to develop strategies that are adequate for a range of different futures or which can be adapted as the situation evolves.
- **“**Illustrating the future by means of scenarios is a way to overcome human beings innate resistance to change. Scenarios can thus open mental horizons that allow the individual to accept and understand change, and so be able to shape the world. This approach may therefore help in seizing

new opportunities ahead as well as avoiding undesirable effect or misconceived action" (Bertrand *et al.*, 1999).

"If history taught us one thing, it is that it teaches us less and less. Indeed, a paradox." (Patrick van der Duin & Hans Stavleu, 2005)

1.3 Definitions

In the context of FLOODsite, and more general in relation to flood risk management, we make a *distinction* between scenario and strategic alternative, as can be deduced from the following definitions (free after FLOODsite, 2005):

- A (future) **scenario** is defined as all future ***autonomous*** developments, i.e. all future developments which are not ***purposefully influenced*** by flood risk management measures and related policy instruments.
- A (flood risk management) **strategic alternative** is defined as a coherent set (or 'portfolio') of flood risk management measures and related policy instruments.

The term 'scenario' is also frequently used by others for the combination of autonomous development and policy response (e.g. Van Asselt *et al*., 2001; or: Office of Science & Technology, 2004). Again others call these 'futures'. ***In this report we try to keep scenario and strategic alternative apart.***

Flood risk management is here defined in a way which may go beyond the present sphere of influence of flood risk managers. Future land use changes, for example, which *aim* to reduce flood risks are considered part of flood risk management even if current flood risk managers have no possibility to implement such measures. Measures which are currently outside the scope of flood risk managers must be included in the long-term planning process of flood risk management, since on the long-term even this scope may be discussed and changed.

The term 'flood risk manager' is also frequently used in the report. Flood risk managers are defined here as persons who purposefully influence flood risks. They may, for example, be individuals who put temporary defences to their homes or carry their valuable possessions upstairs, or they may be national authorities implementing some large-scale measures.

1.4 Aim of this report

This report aims to provide guidance on designing comprehensive flood risk management strategies and assessing their effects on sustainability. The latter requires assessing their performance in different future situations, of which the autonomous developments are represented as scenarios.

As FLOODsite as a whole focuses on methods rather than on their application, so does task 14, but the methods are tried (and exemplified) in three FLOODsite case studies. This report first reviews approaches to the design of strategies and their assessment against future scenarios, then provides a methodological framework and finally discusses the application of the framework in two of the three case-studies. The third is reported on seperately. The case studies primarily serve:

- to try the method and to provide improvements to it;
- as illustration of how the method can be used;

Besides, the analyses of the case studies are of interest for the flood risk managers in the case study areas themselves.

The target audience for the methodological part are persons and institutions who support the development of long-term strategies for flood risk management by performing policy analyses.

2. Review of existing methods for scenario definition and strategic alternative design and assessment

2.1 Approach

In order to select the most adequate methods for defining scenarios and for designing and assessing strategic alternatives, we first provide a rough review of existing and successfully applied methods. Only a rough review is provided as there is no need for a full review of methods, as the approach has evolved over decades already. Therefore, we focus on those projects which can be considered good examples of the approach by not remaining academic exercises but by being really applied for policy making.

For ***scenario*** definition we particularly refer to experiences of the European Commission Forward Studies Unit (Bertrand *at al*., 1999) as well as to environmental outlooks and 'sustainability outlooks' (a.o. RIVM, 2005; Evans *et al*., 2004), but also include experiences with applying scenarios for long-term policy development in water management at large (Alcamo *et al*., 2000; Van Asselt *et al*., 2001 for IRMA-SPONGE; ICIS, 2002 for the Netherlands' 'Drought Study').

For the flood risk management ***strategic alternatives*** we particularly refer to experiences within IRMA-SPONGE (Vis *et al*., 2001, Klijn *et al*., 2004; cf. also De Bruijn, 2005), the Netherlands' River Management Policy (PKB) and the UK Foresight project (Office of Science & Technology, 2004).

For the assessment or full assessment of strategic alternatives we refer mainly to experiences in which strategic alternatives were assessed on their contribution to sustainability, such as in IRMA SPONGE project (Vis *et al*., 2001), in the Foresight project (Office of Science & Technology, 2004; Evans *et al.*, 2004a, b) and in the work of De Bruijn (2005) and of Bana E Costa (2004).

2.2 Scenario definition

Much of what will happen in the next decades has already been set in motion by policy decisions and actions taken in the past. Also decisions that are taken at present will have a crucial role in the process of shaping the future. By exploring different future scenarios, policy makers can get a clearer picture of what the future may look like and what the impact of their decisions may be. They can thus determine more precisely what they might or ought to do to create a more desirable future. Scenario analysis is thus an important tool to gain insight and for exploring the unknown (UNEP & RIVM, 2003).

2.2.1 Types of scenarios

Prospective scenarios or projective scenarios?

In the 1980's and 1990's, Van Doorn & Van Vught (1981) and Schooneboom (1995) distinguished between prospective and projective scenarios. Both aim to explore alternative courses of future development, but the lines of reasoning differ substantially between the two. In *prospective* scenarios, the line of reasoning starts from a designed – and often desired – future image and then back to the present situation. This is also called *backcasting*, in contrast to forecasting: given desired future situations, how to realize these? In *projective* scenarios, in contrast, the line of reasoning runs from the past, through the present, into the future; i.e. in forward direction: how may things change in future?

Studies involving backcasting have been applied to river systems by, among others, Harms (1995) and Harms & Wolfert (1998) on nature rehabilitation for the River Rhine, the Netherlands, and by Baker *et al.* (2004) on alternative futures for the Willamette River Basin, Oregon.

Backcasting relies on alternative designs by landscape architects, with or without having taken into account stakeholder views. In the last decade, the approach has been applied in many countries, but *the term scenario is gradually abandoned* and replaced by, for example, target image.

In FLOODsite, we ***use the term scenario for projective scenarios only***, and plea not to use the term scenario in the context of backcasting, as designed futures are not the result of autonomous development.

Forecasting or exploration?

The term scenario may be used for the extrapolation of trends – also called forecasts –, or for explorations of possible futures. In FLOODsite we prefer to use the term ***forecast for straightforward trend extrapolation*** and/or for predictions of future situations involving more sophisticated modelling of – in essence – predictable developments[1] (cf: *weather forecast*). ***Exploratory scenarios***, in contrast, are *not* predictions, but stylized constructions of ***possible future developments***, sometimes quite deliberately in the form of stereotypes, archetypes, optimum or doomsday situations, or other extremes. They refer to 'what might happen if…', not to 'what will happen' (Veeneklaas & Van den Berg, 1995).

Extrapolation of a trend can safely be done for developments of phenomena which are governed by a strong momentum or which are characterized by an inherent inertness, such as CO_2 levels or temperature at a global scale (Schooneboom, 1995). But exploratory scenarios (WHAT, IF ...) are definitely required for developments which are inherently unpredictable or which are triggered by unpredictable events, e.g. precipitation in Western Europe in dependence of a halt of the Gulf Stream, a loss of confidence in the dollar, an economic crisis, an pandemic, a terrorist attack, another Bush war, etc. The development of flood risk in future of course depends on developments of the hazard and vulnerability which can partly be regarded as trends – e.g. sea level rise –, but for a large part are quite unpredictable –e.g. precipitation in different parts of Europe, economic growth in different parts of Europe, etc.

Also, trend extrapolation can only safely be applied when exploring the relatively short-term future (Schooneboom, 1995). Then many developments can safely be considered as remaining constant or of a known dynamic. But for long-term future developments one must reckon with the possibility of important changes in trends, even when they seem very rigorous now, as well as with changes in relationships which now seem stable. This explains why studies for the long term increasingly apply an exploratory scenario approach.

In FLOODsite, we are concerned with planning for the ***long-term future***, which implies that we have to take into account ***both trends and unpredictable developments***; together they form ***exploratory scenarios*** (as the weakest chain determines the strength of the whole).

Qualitative versus quantitative scenarios

Sometimes, a distinction is made between qualitative scenarios and quantitative scenarios (UNEP & RIVM, 2003), but in practice the boundary is quite gradual.

Qualitative scenarios are descriptive narratives that explore relationships and trends for which few or no numerical data are available. They present a number of plausible, internally coherent, illustrations of the future. They often incorporate human motivations, values and behaviour and create images that

[1] Usually physical and biological processes (including demography) can be predicted within certain time limits and boundaries of constraints; socio-economy and human behaviour are, in contrast, regarded as less predictable.

capture the imagination of those for whom they are intended. This type of scenarios should not be too complex in the sense that each scenario should be clearly recognizable and have a character of its own. Qualitative scenarios are usually intended to contribute to a *debate* on future strategies by forming the background for a meaningful discussion and by offering the participants the possibility to acquire a common language.

In contrast, ***quantitative*** scenarios imply the use of figures which indicate the estimated change in certain relevant parameters. Examples are population growth, economic growth and climate change. These scenarios may be assigned a probability and the most likely scenario or an 'average' scenario may be composed.

Many quantitative scenarios are based on the qualitative scenarios described above, or they go along with them. In such a case, quantitative estimates for all different autonomous developments described in the qualitative storylines are presented. These scenarios consist therefore of a consistent set of mono-disciplinary assumptions. The consistency is obtained by the storyline which describes roughly the development in the world. In a scenario in which the world is turning more market-oriented, climate change and economic growth will differ from those in a scenario in which nature values, ecosystems and sustainability will receive more attention.

In practice, many assumptions on future developments can only be defined in qualitative terms, but for subsequent predictive modelling it is required to translate the assumptions into quantitative terms as much as possible. Generally, after roughly sketching consistent scenarios, they are translated to quantitative assumptions. These can be used as the input for models which translate, for example, emission scenarios to increases in rainfall, discharge and flood patterns (cf. UNEP 2001; and http:///www.globio.info). These effects on rainfall, discharges and flood patterns can then be used to estimate a scenario's effects on flood risks.

2.2.2 Requirements for scenarios

General requirements for scenarios

In order to be able to explore the unknown a set of scenarios is needed which fulfils the following criteria:

- scenarios must be consistent,
- the different scenarios must be clearly distinguishable,
- and using the set must be feasible.

These criteria are discussed below.

A main requirement for scenarios is that they must be internally ***consistent***. Not each combination of demographic development can be combined with economic development and/or environmental degradation, because there are feedback mechanisms within the man-environment system which cause co-evolution of this system. Consistent scenarios are scenarios of which the underlying assumptions, preferences and choices are transparent and consistent among different sectors, problems and scales (Van Asselt *et al.*, 2001). Generally some sort of framework is applied in order to develop consistent multi-disciplinary qualitative scenarios or story-lines, which are then used to make a consistent set of mono-disciplinary quantitative assumptions.

A second requirement is that the scenarios are ***clearly different***. Contrasting scenarios may seem somewhat unrealistic. However, they are clear, understandable, and they form an envelope around the whole range of uncertainties. Most likely, the future will in reality prove to lie somewhere between the different scenarios. Strategies which score well across the whole range of exploratory scenarios will probably also function well in a real future somewhere between the different scenarios.

A third and mainly ***practical*** requirement is that the ***number*** of scenarios is limited, so that the results can be understood, interpreted and communicated. After all, the whole research process must be feasible.

Specific requirements for scenarios for long-term planning of flood risk management strategies

In order to develop flood risk management strategies the effect of autonomous developments on flood risks need to be clear. Flood risks change when flood probabilities change, when flood patterns change or when flood impacts are affected. We can make this even more specific by starting with the notion of what flood risk is (cf. FLOODsite, 2005, p. 5): Flood risk is a function of flood hazard, exposure and vulnerability. Because in practice exposure is often incorporated in the hazard or in the vulnerability risk can be considered as having two components- the hazard, or the probability that an event will occur and the consequences associated with that event (vulnerability).

Flood risk = f (Hazard * (Exposure) *Vulnerability)

The most important autonomous developments which may cause changes in hazard (+ exposure) or vulnerability are:

- Hazard (+ exposure):
  - climate change (precipitation, evaporation, storm frequency and force)
  - changes in the upper catchment which increase runoff,
  - land subsidence.
- Vulnerability:
  - economic growth,
  - population growth, and
  - land use change.

This means that future scenarios which are to be relevant for flood risk management planning must specify the development in these key variables. And the use of scenarios allows taking into account uncertainties about their future development.

The different scenarios must be made consistent by drafting story-lines in which the changes in the most important autonomous developments are described and quantified as interrelated phenomena.

2.2.3 Overview and comparison of commonly used scenarios

Three main groups of scenarios can be distinguished in recent projects:
- Firstly, there are scenarios resulting from the method ‘shaping actors and factors’ of the European Commission Forward Studies Unit (Bertrand *et al*., 1999).
- Secondly, there are a number of environmental outlooks, which apply a very similar set of scenarios, including the Netherlands’ ‘Sustainability Outlook’ (RIVM, 2005), “Spatial visualisations of the Netherlands in 2030” (Borsboom, *et al*., 2005), the “Future of Europe” of the Netherlands’ Central Planning Bureau (De Mooij & Tang, 2003) and the UK Foresight project (Office of Science & Technology, 2004).
- Thirdly, there are examples where scenarios and strategies are being based on ‘Cultural Theory’ (Thompson *et al.*, 1990). Examples are the IRMA-SPONGE project (Van Asselt *et al*., 2001; Middelkoop *et al*., 2004) and the Netherlands’ outlook on water resources management (the ‘Drought study’; ICIS, 2002).

Shaping actors and factors

The EU used a method called 'shaping actors and factors' to produce scenarios for Europe (Bertrand *et al.*, 1999). In this method, first partial scenarios describing developments in the five most important themes in Europe were developed. These themes were institutions and governance, social cohesion, economic adaptability, enlargement of the EU and Europe's external environment. Secondly, variables within these scenarios were distinguished and each variable was classified as an actor or factor. For the most relevant variables mini-scenarios were developed. The mini-scenarios were then logically combined into partial scenarios for each theme. In the second phase the partial scenarios were combined and checked for consistency. Global scenarios were derived from consistent combinations of partial scenarios.

This procedure resulted in five scenarios for Europe:

- *Triumphant Markets* ("a triumph of trade over war"): increased economic growth due to forces of competition. Important values are self-reliance and economic achievement. Further characteristics are technological innovation, increased productivity, free trade, strongly reduced social expenditure and public intervention. In this scenario inequality and exclusion increase.
- *The hundred flowers:* slowdown of economic growth. An important value is belief in solidarity, but only locally. Further characteristics are devolution of large organisations, belief in neighbourhood solidarity, 'green values', regions and localities versus central government, apathy at national and European level, mistrust of government, big business and media boycotts;
- *Shared responsibilities*: increased economic growth. An important value is belief in solidarity, which results in the regeneration of the public sector. Further characteristics are the renaissance of social/ecological awareness, responsibility and civic solidarity, tolerance of diversity, political correctness, increasing public participation in social and political life;
- *Creative societies:* slowdown of economic growth. A leading value is the belief in solidarity. Further characteristics are an increasing public participation in social and political life, revolution against former attention for economic values and against old political elites.
- *Turbulent neighbourhoods* (armed conflicts, raising protectionism): slowdown of economic growth. Important values are security and the need for protection against violence.

The scenarios are especially useful for the exploration of the political and economic role of the EU in a global context. They are primarily qualitative and they pay little attention to geographical differences. Natural hazards are not incorporated.

Two- discriminate axes method

In various environmental outlooks, scenarios are being distinguished in relation to two main axes in a multi-dimensional space. ***The main axes are usually the 'international dimension' of economy and a gradual transition between maximum efficiency and maximum solidarity***.

The 'international dimension' is indicated by the terms 'globalisation' versus 'regionalisation' in the *Sustainability Outlook* (RIVM, 2005), and as 'autonomy' versus 'interdependence' in the *Foresight* project (Office of Science & Technology, 2004; Evans *et al.*, 2004a, b). The balance between efficiency and solidarity is indicated with these very words by RIVM (2005), whereas *Foresight* (Office of Science & Technology, 2004) uses the terms 'consumerism' (or also: 'individualistic values') against 'community' (or also: 'community-oriented values').

By naming each of the four corners in the two-dimensional space, four scenarios (or possible futures) can be distinguished. In the *Sustainability Outlook* (RIVM, 2005) these are called 'Global Solidarity, Caring Region, Safe Region and Global Markets', which largely correspond (cf. figure 2.1) with the four *Foresight* Futures 'Global Sustainability, Local Stewardship, National Enterprise and World Markets', as well as with the scenarios used in the project '*Spatial visualisations of the Netherlands in 2030'*.

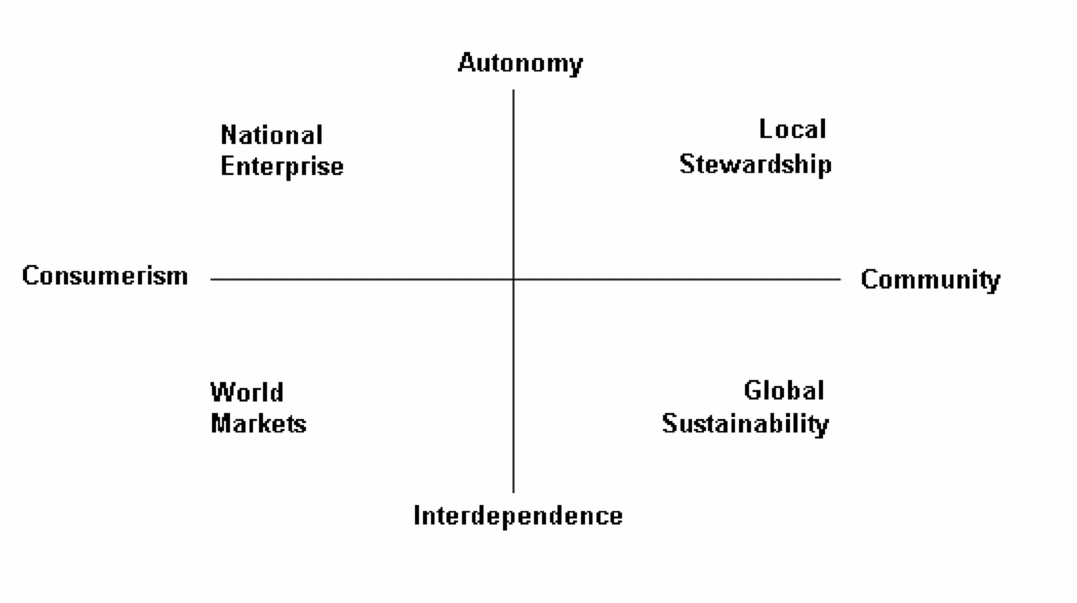


Figure 2.1The Foresight futures in relation to the governance axis (vertical) and the values axis (horizontal) (from Office of Science & Technology, 2004).

Also in *EURURALIS* (Wageningen UR & RIVM, 2004) and '*The future of Europe'* (De Mooij & Tang, 2003) a similar approach with two main differentiating axes has been used. In *EURURALIS* four scenarios were used which again correspond to th eothers mentioned to a large extent, namely Global Economy (A1), Continental Market (A2), Global Co-operation (B1), and Regional Communities (B2). In '*The future of Europe'*, however, the main axis differs, as it concerns the role of the public sector (the other axis being international co-operation). The resulting scenarios 'Strong Europe, Regional Communities, Transatlantic Market and Global Economy' show parallels with the ones mentioned in Table 2.1, but because of the different axis, they cannot directly be compared. Finally, also in a project on the future of the Netherlands' Rhine-Meuse delta (Projectgroep Delta in de toekomst, 2005) two scenarios were used out of four very similar ones again. Obviously, in each project the focus is slightly different, and therefore the level of detail differs as well.

Table 2.1 Overview of scenarios used by different authors, grouped according to their – more or less similar – focus and scale

Values and scale	Market & international	Market & local	Social & international	Social & local
RIVM 2005	Global Markets	Safe Region	Global Solidarity	Caring Region
Foresight 2004 (Office of Science & Technology, 2004)	World Markets	National Enterprise	Global Sustainability	Local Stewardship
EURURALIS 2005	Global Economy	Continental Market	Global co-operation	Regional communities

TEXT BOX A: The Foresight Project (Office of Science & Technology, 2004)

The Foresight project has been performed for the UK Environment Agency by a large group of research institutions (Office of Science & Technology, 2004; Evans *et al*., 2004a, b). Foresight studied, among other things, flood problems, for which it defined the flooding system as "all physical and human systems that cause, influence, or are influenced by flooding" (Evans *et al.*, 2004a). Foresight aimed at developing a challenging vision for flood and coastal defence in the UK between 2030 and 2100. The vision had to include rivers, sea, flooding in towns and cities and coastal erosion and it involved "sustainability analysis at the heart" which means that economic, social and environmental consequences of strategies were considered (Office of Science & Technology, 2004; Evans *et al*., 2004a, b).

The Foresight framework
In order to develop such a vision scenarios for the future were used. The scenarios used are based on a framework that describes how flood risk management issues evolve or in broader sense, how the world functions from a systems perspective. This 'Foresight Framework' is based on the so-called PSIR and SPR-models, well-known in environmental science. The *pressure- state- impact- response* (PSIR) involves a representation of flood risk management issues by distinguishing *pressures* which are caused by socio-economic drivers and which result in changes in the environmental *state* of a system. These changes in the state are reflected in environmental and socio-economic *impacts* which lead to policy *responses*. The other framework, the *Source-Pathway-Receptor (SPR) model* is well established as a tool for environmental risk assessment (Evans *et al*., 2004a). In the context of flooding the *sources* are weather events, *pathways* are the mechanisms that convey water originating from weather events to places where they may impact on *receptors* and receptors are the people, industries and built and natural environments that flooding affects (Evans *et al*., 2004a)[2].

The framework used in the Foresight Method combines the PSIR and SPR models as follows: The flooding system is characterised in terms of sources, pathways and receptors or a combination of these as in the SPR model. Drivers may have impact on these sources, pathways and receptors and on the relationships between them. When the impacts are known, feasible responses can be considered. In Foresight Method a *driver* is defined as 'any phenomenon that may change the state of the flooding system'. Even responses (measures) may themselves become drivers for other areas, e.g. when flood risks are transferred downstream. Some drivers can be controlled by flood risk managers, others, such as global gashouse emissions cannot.

Because the interactions within the flooding system can be very complex and may involve timescales of decades, they are considered not to be open to conventional quantified risk analysis (IPCC, 2000; referred to in Evans *et al*. (2004a, p. 16). Therefore, Foresight adopted an approach based on scenarios.

Scenarios in Foresight
Two types of future scenarios were formulated: emission scenarios and socio-economic scenarios. These two types were combined into *four* "Foresight Futures".

The **four** *emission scenarios* used are: low emissions, medium low emissions, medium high emissions and high emissions. The emission scenarios are translated into climate-change projections by using knowledge available at the IPCC. The climate change projections were translated into the following predictions relevant to flooding in the UK for the 2080's:

- Annual average precipitation across the UK may decrease between 0% en 15% depending on the scenario;
- Seasonal distribution of precipitation will change: winters will become wetter and summers drier;
- The daily precipitation intensities with a frequency of once every two years on average may become up to 20% heavier;
- Relative sea level may be between 2 cm and 58 cm above the current level in western Scotland and between 26 and 86 cm above the current level in south-east England;
- The water level near some coastal areas which has currently a 2% annual probability of occurrence may have a 33% annual probability in the 2080's for Medium High emissions.

The *socio-economic scenarios* explore the direction of social, economic and technological changes in coming decades. Figure 2.1 shows the scenarios. The vertical axis in this figure shows the type of governance which ranges from autonomy - where power remains at the regional or national level - to interdependence - where

[2] This SPR(C) model is also adopted in FLOODsite, although its applicability is questionable in the case of natural hazards.

power moves to international institutions such as the European Union. The horizontal axis reflects different social values, ranging from individualistic values to community-oriented values. Table A-1 provides a summary of the scenarios.

Table A-1. Summary of the Foresight Futures (source: Evans *et al.*, 2004a)

	World Markets	National Enterprise	Local Stewardship	Global sustainability
Social values	Internationalist, libertarian	Nationalist, individualist	Localist, co-operative	Internationalist, communitarian
Governance structures	Weak dispersed, consultative	Weak, national, closed	Strong, local, participative	Strong, co-coordinated, consultative
Role of Policy	Minimal, enabling markets	State-centered, market regulation to protect key sectors	Interventionist, social and environmental	Corporatist, political, social and environmental goals
Economic development	High growth, high innovation, capital productivity	Medium-low growth, low maintenance innovation, economy	Low growth, low innovation, modular and sustainable	Medium-high growth, high innovation, resource productivity
Structural change	Rapid, towards services	More stable economic structure	Moderate, towards regional systems	Fast, towards services
Fast-growing sectors	Health & leisure, media & information, financial services, biotechnology, nanotechnology	Private health and education, domestic and personal services, tourism, retailing, defence	Small –scale manufacturing, food and organic farming, local services	Education and training, large systems engineering, new and renewable energy, information services
Declining sectors	Manufacturing, agriculture	Public services, civil engineering	Retailing, tourism, financial services	Fossil-fuel energy, traditional manufacturing
Unemployment	Medium-low	Medium-high	Medium-low (large voluntary sector)	Low
income	High	Medium-low	Low	Medium-high
Equity	Strong decline	Decline	Strong improvement	improvement

Each socio-economic scenario from table A-1 has been combined with the most likely corresponding emission scenario, thus resulting in 4 overall future scenarios. To test the effect of climate change for the future "World Markets" additionally to a high emission scenario also a low emission scenario has been considered (see table A-2).

Table A-2. The Foresight 'Futures', scenarios consisting of combinations of related socio-economic and emission scenarios (when reference is made to "World Markets" the high emission scenario is meant unless mentioned otherwise).

Future	Socioeconomic scenario	Emission scenario
1	World Markets	High emissions
2	National enterprise	Medium high emissions
3	Local Stewardships	Medium low emissions
4	Global sustainability	Low emissions
	World markets*	Low emissions

Strategy development and analysis

In the Foresight project strategy development and strategy analysis was carried out in some iterations. First a literature review and consultation of a wide range of experts and stakeholders was carried out. This resulted in about 120 possible response measures, policies and interventions. These measures, policies and interventions were clustered into 26 '***response groups***' consistent with the SPR model. The 26 groups were further classified into 5 broad themes. For each theme a group of experts elaborated the response groups in more detail by making narrative accounts which define the response group, by commenting on costs and funding, by analysing the ways in which the response group interacts with other response groups, by giving examples, and by describing the degree of uncertainty and factors that limit the implementation. Next, the flood risk reduction effect of each response group was assessed by assigning a multiplier to each combination of this response group and Foresight future. Next, the uncertainty in the different response groups' scores was considered. Finally, the sustainability aspects of the response groups were addressed.

Then, realistic combinations of response groups ("portfolios of responses") were analysed. These can be regarded as alternative ***strategies***, because the portfolios were selected in such a way that they correspond to the different government types and social values in the Foresight futures (Evans *et al*., 2004). The different futures were also assigned different target levels for protection from flooding. The project showed that an integrated portfolio of responses could reduce the risks from the worst scenario of 20 billion pound per year down to around 2 billion in the 2080's (which is still twice as high as present-day risk).

TEXT BOX B: EURURALIS project after Klijn & Vulings, 2005; slightly edited)

EURURALIS is developed for policy makers dealing with the future of agricultural and other land use in the enlarged Europe of 25 member states. As it was expected that major developments will affect the rural areas in Europe, it was felt that rural policy must be informed timely and in a targeted and crispy way. A scenario study was performed which built upon: (1) recognizable and internationally authorized scenarios encompassing drivers such as world trade, climate change, demography, (2) predicted transformations in land use (area, regions, intensity), (3) impacts on the various domains of sustainability (People, Planet, Profit), and (4) possibilities of policy instruments. The study builds upon IPCC and related scenarios, though adapted for the EURURALIS goals, a global economy model (GTAP/LEITAP) linked to an environmental model (IMAGE), and thirdly a land use allocation model (CLUE). Modelling outcomes were generated for 30 years in 10 year time steps; indicators were selected from economical, socio-cultural and environmental/ ecological domains respectively.

EURURALIS followed an exploratory scenario-approach with a focus on conceivable futures (plural), i.e. the development of story lines, assumptions and ideologies that form a consistent line of reasoning. EURURALIS built on 'state-of-the-art' scenarios that suited the desired application: for Europe, for the long term, including large scale (global) processes of various kinds, and affecting all aspects of sustainability. The IPCC scenarios and various close relatives were used as the foundation. This yielded four alternative scenarios, titled Global Economy, Continental Market, Global Co-operation, and Regional Communities. Their respective positions are determined by two perpendicular axes defining four quadrants: the assumed role of the government (high versus low regulation, the latter fitting the ideas on the benevolence of a free market) and the scale level of processes and interventions (global versus regional).

The EURURALIS study could build on GEO-3 studies, the study of the four futures of Europe by the Dutch CPB Economic Assessment Bureau (De Mooij & Tang, 2003) and the Sustainability Outlook (RIVM, 2005).

First, narrative storylines (qualitative scenarios) were specified in tables under headings such as:
- Conditions: general development philosophy, political situation EU, market protection, pollution, nature, and
- Consequences: economic growth and technology development

This was done by the members of the research team, without involvement of stakeholders.

Next, the qualitative storylines were translated into concrete and quantitative assumptions in extended tables in order to serve as input for predictive models, for instance concerning:
- trade arrangements, export subsidies and consumer preferences for GTAP;
- protected nature area, crops for bio-fuels, countries in EU for (for IMAGE)
- or policy measures to control fragmentation, effects of erosion and type of growth (for CLUE)

Perspectives method

The method used in the IRMA-SPONGE project '*Development of flood management strategies for the Rhine and Meuse basins in the context of integrated river management*' (Van Asselt *et al*., 2001; Middelkoop *et al*., 2004) relies on the recognition of different 'water management perspectives', following the idea on 'perspectives' as defined in the so-called '*Cultural Theory*' in social sciences (Thompson, 1990). Therefore, it will be referred to as 'Perspectives Method' in the remainder of this text. The perspectives method is also applied in the Netherlands' outlook on water resources management (the 'Drought study'; ICIS, 2002), and was earlier applied by Hoekstra (1998) on water resources management.

In the Perspectives Method scenarios of socio-economic and environmental changes are derived from 'perspectives', where perspective stands for a certain 'world view' (ideas about how the world functions) and 'management style' (ideas about how policy should be carried out). The world views can be translated into scenarios and the management styles into policy strategies.

In the cultural theory, at least four different perspectives are recognized, of which three[3] were considered relevant for water management policy (Van Asselt *et al*., 2001, p. 8-9):

- *The Hierarchist* or *Controlist* (focusing on control; strong group boundaries and adherence to standards and rules);
- *The Individualist* or *Market-optimist* (strong adherence to economic development/growth; weak group boundaries and few prescribed roles);
- The *Egalitarian or Environmental-pessimist* (high valuation of the environment; strong group involvement and minimal regulation).

Usually, the perspectives are plotted against two axes which stress the contrasting views between individualists and egalitarians with regard to the benevolence of a free market, and which also opposes hierarchists and fatalists in their belief in the controllability of the world (or rather: its environment and its socio-economy) (Van Asselt *et al.*, 2001; also cf. Thompson, 2002, p. 6).

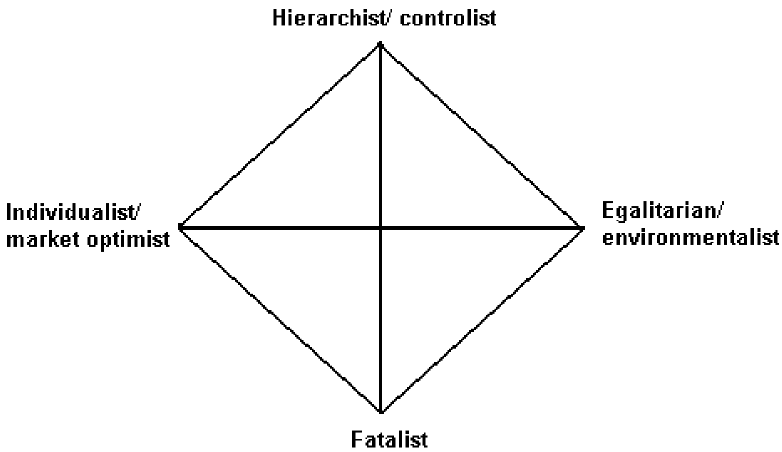


Figure 2.2 The perspectives as used in IRMA-SPONGE (after: Van Asselt et al., 2001), with emphasis on belief in governance (vertical) and values (horizontal) (cf. also Thompson, 2002, p. 6).

When other axes would be chosen to plot the perspectives against – which we may, as we are dealing with a fundamentally multi-dimensional hyperspace –, we might also stress dimensions which resemble the axes of the two discriminate axes method. This has already been done by Thompson

[3] The fourth perspective being that of the *Fatalist*, who does not (want to) act, as he/she regards future developments as not being manageable in whatever manner.

himself (cf. Thompson, 2002, p. 1; figure 2.2). Then, the four different perspectives are no more, nor less, than – again – the four corners in a continuum of gradually mixing perspectives in a hyperspace with two dimensions made explicit as axes. ***As such, the approach very much resembles that of the two discriminate axes method; the only difference being that of the choice of axes from a fundamentally multi-dimensional hyperspace.***

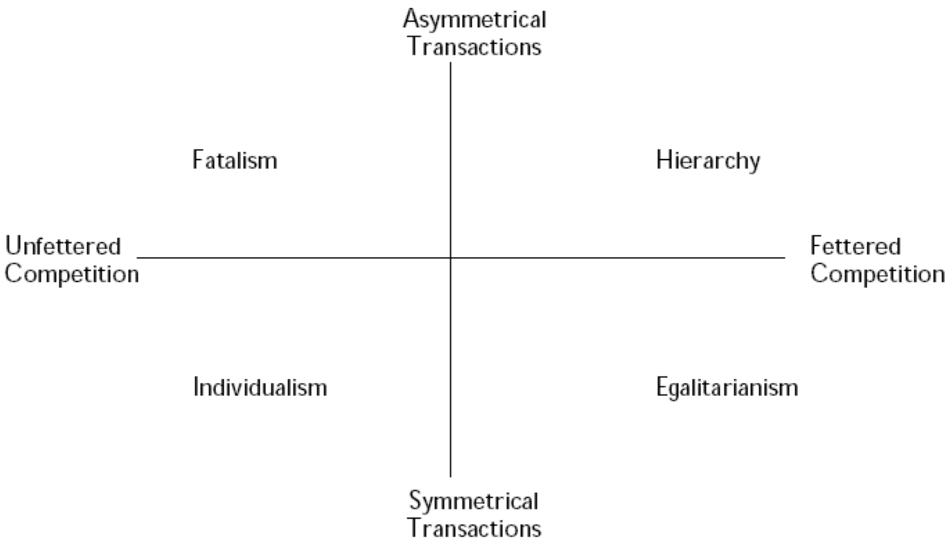


Figure 2.3 The four perspectives that are distinguished in the Cultural Theory (Thompson, 1990) can also be regarded as corners in a two-dimensional space (from: Thompson, 2002, p. 1)

In the perspectives approach, the world view of *individuals* is stressed, which explains the choice of the axes and the terms used to characterise the extremes; but in IRMA-SPONGE it was found that the same perspectives apply to *institutions* (Van Asselt *et al.*, 2001). In the two-discriminate axes approaches treated in the previous section, the international orientation of economy (of a country) and the degree of solidarity (within a country) form the main axes, or in other words: political or societal preferences.

TEXT BOX C: 'Perspectives and flood management strategies in IRMA-SPONGE

The second example of the use of scenarios is the IRMA-SPONGE project "Development of flood management strategies for the Rhine and Meuse basins in the context of integrated river management" (Van Asselt *et al*., 2001; Middelkoop *et al*., 2004). The project aimed at *developing a methodology to find integrated, robust water management strategies for the Rhine and Meuse Rivers.* The method used in this project will be referred to as "Perspectives Method'.

Perspectives as basis for both scenarios and strategies
In this project consistent scenarios of socio-economic and environmental changes in the Rhine and Meuse basins were identified, as well as associated water management policy changes. These combinations of future scenarios and future policies were addressed as 'water management perspectives', following the idea on 'perspectives' as recognized in social sciences; the so-called 'Cultural Theory' (Thompson *et al.,* 1990, 1999).

Thompson (2002) gave the following characterisations of what the four perspectives imply (and as these texts are difficult to improve, we prefer to give a literal citation):

- "For **individualists**, nature is benign and resilient—able to recover from any exploitation—and man is inherently self-seeking and atomistic. Trial-and-error in self-organizing, ego-focused networks (markets) is the way to go, with Adam Smith's invisible hand ensuring that people only do well when others also benefit.

Individualists trust others until they give them reason not to and then retaliate in kind (the winning, "tit for tat" strategy in the iterated Prisoner's Dilemma game), and see it as only fair that those who put the most in get the most out (as in the joint stock company). Managing institutions that work "with the grain of the market" (getting rid of environmentally harmful subsidies, for instance) are what are needed.

- Nature, for **egalitarians**, is almost the exact opposite—fragile, intricately interconnected and ephemeral—and man is essentially caring and sharing (until corrupted by coercive and inegalitarian institutions such as markets and hierarchies). We must all tread lightly on the earth, and it is not enough that people start off equal; they must end up equal as well. Trust and levelling go hand in hand, and institutions that distribute unequally are distrusted. Voluntary simplicity is the only solution to our environmental problems, with the "precautionary principle" being strictly enforced on those who are tempted not to share the simple life.

- The **hierarchist's** world is controllable. Nature is stable until pushed beyond discoverable limits, and man is malleable: deeply flawed, but redeemable by firm, long lasting, and trustworthy institutions. Fair distribution is by rank and station or, in the modern context, by need (with the level of need being determined by expert and dispassionate authority). Environmental management requires certified experts to determine the precise locations of nature's limits and statutory regulation to ensure that all economic activity is then kept within those limits.

- **Fatalists** find neither rhyme nor reason in nature and know that man is fickle and untrustworthy. Fairness, in consequence, is not to be found in this life, and there is no possibility of effecting change for the better. "Defect first"—the winning strategy in the one-off Prisoner's Dilemma—makes sense here, given the unreliability of communication and the permanent absence of prior acts of good faith. With no way of ever becoming in sync with nature or of building trust with others, the fatalist's world (unlike those of the other three solidarities) is one in which learning is impossible."

Three of the four perspectives distinguished in the cultural theory, were used by Van Asselt *et al.* (2001) to develop consistent and coherent 'world views' (descriptions of how the world is supposed to function) and 'management styles' (how policy should be carried out). ***The world views can be translated into scenarios and the management styles into policy strategies***, as the perspectives determine the primarily subjective perceptions on the world's functioning and development, as well as the preferred approach to policy and management throughout the whole cause-effect chain of socio-economic and physical changes in a river basin.

All uncertainties in future developments were identified and the qualitative interpretation of these uncertainties according to different perspectives were studied. This resulted in 'perspective-based' quantitative assumptions. Future developments which were considered are: climate change, soil subsidence, economic development and population growth, urbanization, agricultural development and the increase in drinking water supply. Next, hydrological changes which result from the different scenarios were analysed and the consequences of these changes for the utilization of the water were established. Thirdly, the robustness of different water management strategies under different possible futures was assessed.

A combination of a strategy based on assumptions which match with the assumptions in the scenario is called a ***utopia***, while a mismatch is called a dystopia. By analyzing not only the utopias but also considering the dystopias for different management styles, the robustness of each management style can be assessed. The assessment criteria used included safety, costs, economic benefits, agriculture, transport, nature, flexibility and quality of life.

Comparison and conclusions

The scenarios in the first method were not developed for flood risk management. They focus on political changes and changes in administrative structures. They may therefore be less useful for flood risk management. They are not structured according to axes, and consequently no opposites – such as self-reliance versus solidarity in Foresight – are defined. Since the scenarios are less contrasting, less explainable and not specifically useful for flood risk management, it is advised ***not to use these any further***.

Both the two-discriminate-axes (Foresight) method and the 'Perspectives Method' result in consistent scenarios. Both methods use coherent – but broad – qualitative sketches of different futures and use these to make their more specific quantitative assumptions consistent. The most important difference between the two methods is that the perspectives method is based on the well-known – though frequently disputed – 'cultural theory' which focuses on the view of individuals, whereas the motivation for the choice of the axes in the two-discriminate-axes method is less clear and may not be the most suitable for flood risk management. It depends on the geographical scale of analysis: the scenarios for the UK (Foresight) differ substantially from those at EC level (UNEP & RIVM, 2003). However, within the realm of application, the scenarios proved also sufficiently clear, contrasting, explainable and consistent to allow for interesting analyses. The perspectives method is explicitly based on how people perceive the world, while in the two-discriminate-axes method this remains more implicit: in a 'World Market' the market-optimists will dominate, but so they do in a 'National Enterprise'. Obviously, 'Global Sustainability' can only be attained when egalitarians have a large say, but also in 'Local Stewardship' sustainability is a key issue. The hierarchist cannot be linked so easily, but contains elements of both 'Local Stewardship' (strong governance, interventionist) and 'regional markets' (market regulation, protection). All in all, the scenarios in the two-discriminate-axes method (at least in Foresight) are more difficult to understand and less distinct.

Experience shows that both methods yield clear, contrasting, explainable and consistent scenarios. An advantage of the perspectives method is found in its clear contrasts, recognisability, and general applicability (independent of scale), and also that only 3 scenarios suffice.

2.2.4 Specification (downscaling and quantification) of narratives

In order to allow the use of the scenarios in models, the storylines (or: narratives) – which are usually of a qualitative nature – must be ***downscaled*** to the area of interest (e.g. a river basin, a river stretch, a delta, a coastal area or an Estuary with its surroundings), and transformed into ***quantitative*** assumptions (or: input parameters) as much as possible. Only then can they be used in further modelling activities to yield forecasts. In general, this is an important step in a scenario study, but it is seldomly adequately described.

In general, downscaling of global (e.g. climate) or (super-)national (e.g. population or economic growth) assumptions is required down to national or regional assumptions. But as scenarios are defined as autonomous developments, the downscaling should go ***no further than required*** and should ***not interfere with the strategic alternatives*** (to be designed later). This means that, for example, population growth or economic growth (investment level) should be defined at the level of the region, but not at the level of dike-ring, a town or a quarter, as they may be affected by regulation (zoning) or town-planning in view of risk management; after all, zoning and town planning are elements of a flood risk management strategy!

In practice, many studies mix up scenarios and strategies and call these composites either scenarios, or futures or storylines. ***For reasons of conceptual clarity we consider it essential to keep scenarios and strategic alternatives separate as much as possible and as long as possible by defining scenarios one spatial scale level higher than the strategic alternatives.***

2.3 Developing strategic alternatives

2.3.1 Introduction

Different societies apply different flood risk management strategies. The currently applied strategies are a product of historical developments, in which flood risk management has evolved together with the society in the flood-prone areas (De Bruijn, 2005). They have not been designed within a short time-span but have instead evolved over a long time. The strategies are usually tuned to the societal and physical characteristics of the region involved, but they also differ with cultural preferences[4].

Flood risk management is a means to enable the society and ecosystems in the region involved to function well although it is threatened by high water levels or high precipitation quantities. The optimal flood risk management strategy thus strongly depends on the socio-economic and ecological characteristics of the area. Since the current strategy and society in a given region have co-evolved, they usually match well. However, due to changes in society or in the physical characteristics of the system, the flood risk management strategy may need to be adapted. Other strategic alternatives may better suit the changed society and changed physical characteristics.

Knowledge of the advantages and disadvantages of strategic alternatives can be gained by evaluating how they will perform in different future scenarios and what their side-effects will be. For such an ***exploratory*** policy analysis it is essential to define strategic alternatives from which we may learn in which direction flood risk management policy might best move. ***This requires that strategic alternatives are designed which differ sufficiently, or even: as much as possible.*** After all, we want to explore the consequences of alternative ***long-term management policies***, – i.e. for a far-away future, say >30 -100 years.

Some definitions

FLOODsite (2005) defined a ***strategy*** as:

> '*a combination of long-term goals, aims, specific targets, technical measures, policy instruments, and process which are continuously aligned with the societal context'*.

Thus we can distinguish between:

(1) the overall goal of flood risk management in view of sustainability,
(2) the measures and instruments to achieve this, and
(3) the process of their gradual and continuous implementation.

(cf. also Task 13).

This being true, *in the present context* of policy analysis we confine the research work to the contents of a strategy without its implementation process – 2 in the above definition –, which in FLOODsite is called a strategic alternative, viz.:

> *A (flood risk management)* ***strategic alternative*** *is a coherent set (or 'portfolio') of flood risk management measures and related policy instruments*[5].

The question addressed here is then: how to design coherent sets of flood risk management measures and related policy instruments? Where ***designing*** means '*the selection and combination of options into a plan'* (after Stevers & De Groot, 1991; see also FLOODsite task 13: Hutter *et al.*, 2005).

Strategic plans versus operational plans

Designing can be aimed at applicable, concrete plans – or ***operational plans*** – or alternatively at ***strategic plans*** in the context of future exploration. It is in this latter type that we are interested here.

When exploring the ***far future***, there is no need to achieve a plan which is feasible, practicable and societally supported. Instead, one may explore the implications of very diverse, sometimes radical, visionary plans. The main aim is to hold a mirror to the authorities which decide on management

[4] e.g. the UK giving lots of responsibility to individuals and insurance companies, France relying on centralistic (state) arrangements and collectivism, Germany arranging things by decentralized co-operation (regional plans), etc., but also with different emphasis on technical flood defence versus non-structural instruments.

[5] Compare the 'strategic alternative' in Hutter et al. (2005).

policy at strategic level. This requires that more than one strategic plan is being explored, and that various ***alternatives*** are designed which are far apart.

After an exploratory policy analysis for the far-future, a decision on a certain management policy can be made on a strategic level. Next, more concrete plans for immediate implementation may be designed and subjected to EIA. This, again, involves the design of alternatives, which must be more realistic however, and which will generally differ much less. The design of such feasible alternatives for immediate implementation is ***not*** the subject of this study.

2.3.2 How to define strategic alternatives?

A sound problem analysis – in our case of flood risk in the context of sustainable development of a region (De Bruijn, 2005) – is likely to reveal that the problem is very complex and that no simple solutions are available (compare Galloway, cited in Samuels *et al*., 2005). It will also reveal that there are many options – or plan elements – to tackle parts of the problem. These can be incorporated in a strategic plan design, but how? And, moreover, it should be kept in mind that a comprehensive plan is always characterised by overall system characteristics, which do not follow directly from its constituents; or, in other words: the whole is more than the sum of its parts[6], and has 'emergent' characteristics.

Bottom-up versus top-down

A basic distinction in the development of alternative strategies is between:

- bottom-up, combining individual measures and instruments (also: inductive), versus
- top-down, by reasoning from guiding principles (also: deductive).

Usually, a bottom-up approach to designing does not yield a coherent whole: the result is rather the sum of the constituents, or even less. A top-down approach will sooner take into account the emergent characteristics of the whole system at stake: the flood risk system of cause (hazard), pathway (defence works) and receptor (land and society) (cf. De Bruijn, 2005).

As FLOODsite intends to make a difference in comparison with the majority of earlier work on flood risk management, a whole systems – or comprehensive – approach to flood risk management is required. And consequently, ***a top-down approach to strategy design is preferred, as this requires due acknowledgement of the key issues in flood risk management*** (cf.. also De Bruijn, 2005; Samuels *et al.*, 2005; Hooijer *et al.*, 2004), viz.:

- that flood risk management is relevant only in view of its contribution to the sustainable development of societies;
- that flood risk management is part of integrated water *and* land (use) management
- that risk exists only when people or property are at stake;
- that a risk approach includes both hazard control and vulnerability management;
- that not only technical, but also non-structural measures may be applied;
- that non-structural measures include regulatory, financial and communicative instruments.

A top-down approach requires that aims or objectives are made explicit at different related levels (cf. Van der Voet *et al.,* 1989), from the highest level of the foundation of western societies (e.g. democracy, 'free' market), via basic principles (e.g. efficiency, equity, sustainability, security (cf. Hoekstra, 2005)), down to the guiding principles – or: *Leitmotive* (D) – for flood risk management (e.g. resilience, resistance, Room-for-Rivers; cf. Vis *et al.,* 2001; De Bruijn, 2005) (see figure 2.4).

[6] this goes not only for any existing and tangible system, such as an ecosystem or a man-environment system, but it also applies to a strategic or operational plan, such as that of flood risk system.

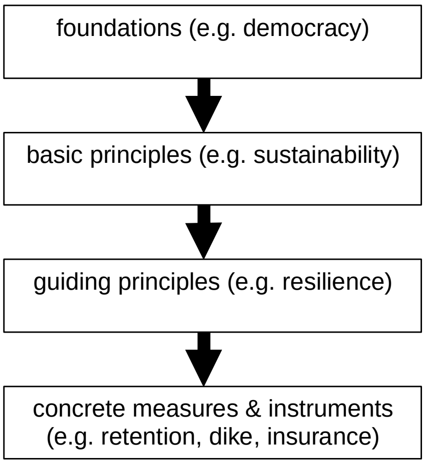


Figure 2.4 Hierarchy of principles for top-down strategy design; the foundations and basic principles are usually fixed constraints, at the level of guiding principles and below more options are available (free after Van der Voet et al., 1989).

Involving stakeholders?

Both in a top-down and in a bottom-up approach it is possible to use stakeholders' ideas and to apply some sort of *participatory planning method* which may result in a wide acceptance. In a top-down approach it involves accepting the foundation, negotiating the basic principles and their interpretation (e.g. sustainability) and deciding upon alternative guiding principles. In a bottom-up approach participatory planning usually involves composing and negotiating a portfolio of measures which meet the pre-set requirements.

Participatory planning has been attempted in Foresight (Office of Science & Technology, 2004) as well as in the Netherlands' planning of Room for the River measures (Rijkswaterstaat, 2005). Also Van Asselt *et al.* (2001) involved stakeholders in their study, but they found that it is difficult to involve people who are not directly affected because the study focuses on the long term beyond their life-time. Moreover, there seems to be little surplus value in involving stakeholders, as measures are not going to be very concrete and are not very likely to be implemented.

For long-term, exploratory policy analysis, there is no need to involve stakeholders. Alternative strategies should rather be very diverse, radical and visionary, in order to allow the exploration of the whole range of possibilities. Alternatives should span the playing field. Although a participatory planning process is not advised here, knowledge of stakeholders on flood risk management and on socio-economic and natural characteristics of the region and the developments in the region may be used in order to enlarge understanding of the area. Also ideas of stakeholders can be considered, but they should then be incorporated in the top-down approach.

Where to start then, and how to proceed further on?

Flood risk management strategies should contribute to society in the region (See chapter 2.4). This rather vague aim should be translated to more tangible aims and criteria. Potential aims could be:

- Flood risks should decrease in the future, or, *alternatively*,
- they may not increase in the future, or, *alternatively*,
- they may not increase faster than the GDP does.

It may be decided to use one and the same main aim for all strategic alternatives to be taken into account, or – alternatively – to define alternatives with different main aims each. The latter is done in Foresight, for example, where the protection level differs in each alternative.

Even when it is decided to adhere to one and the same main aim for all strategic alternatives, many very different sets of measures and instruments which achieve this aim could be designed. A further division – or focusing – could be achieved by specifying further aims. The advantage of such an approach is that the alternatives differ on the point of societal value given preference. This is generally regarded a better approach to designing alternatives than, for example, by opposed types of measures and instruments (e.g. non-structural versus structural measures); the latter disqualifies because means are given priority above goals (Stevers & De Groot, 1991).

Distinguishing further aims may help to further span the playing field by defining ***contrasting*** – or sometimes: opposing – strategies. The further aims are specific for each alternative. Examples (from experience in the context of the study Room for Rivers, WL | Delft Hydraulics, unpublished) are:

- the cheapest;
- the most cost-effective;
- maximum conservation of natural and cultural (landscape) heritage;
- maximum development of natural and cultural (landscape) values;
- enhancing local economic development at the most;
- interfering the least with present ownership and land use practices;
- etc.

Instead of by defining further aims related to the practice of policy planning (as above), an even more deductive – or theoretical – approach can be followed. This implies the definition of ***guiding principles*** related to, for example, 'whole system functioning' according to different philosophical prejudice. Examples are:

- resistance versus resilience (see e.g. Vis *et al*., 2001; De Bruijn, 2005);
- Taoism versus Confucianism

Thus, very different strategies can be designed, allowing that first contrasting strategies are explored, which can be refined and made more realistic later on.

How many alternatives?

When alternatives are being distinguished on the basis of different main aims, different further aims and different guiding principles, the possible number of alternatives is defined by their product. We may be confronted with a large number of alternatives, which together more or less span the multidimensional hyperspace of possibilities. For the study Room for Rivers (WL | Delft Hydraulics, unpublished), we defined 14 alternative strategies, and then decided to further disappoint the stakeholders (mind: only authorities at that stage!) who still wanted more. In this study, the number of alternatives can very easily be raised, as the Toolbox (Van Schijndel, 2005) allows rapid composition of new alternatives. But very few people were able to keep due overview over all the consequences of these 14 alternatives. In most studies, however, there are practical constraints as to how many alternative strategies can be managed, modelled and interpreted.

In practice, the human mind is not able to gain overview over more than some 7 alternatives (Haber, 1992). In most EIA studies, 4 to 5 alternatives are being developed. In Foresight, 4 strategies were designed. Vis *et al.* (2001) developed 4 alternatives – including the 0-alternative –, with 5 variants for land use change.

When alternative strategies are to be evaluated against future scenarios, an even smaller number is desirable, because each alternative strategy must be evaluated against each future scenario. Van Asselt *et al.* (2001) developed only 3 strategies in their IRMA-SPONGE project.

Procedure to further elaborate the design of the strategies

The design of a strategy – or any other kind of plan – may be tackled intuitively (as in daily life), very systematically, or primarily creatively (Stevers & De Groot, 1991). In practice, how systematically one may intend to be, designing always implies some ***creative leap*** in order to attain the overall design quality that really matters.

A systematic approach to design is closely related to the analysis of the problem. In the case of flood risk management this means it is related to the analysis of the flood risk, at present and/or in the future. Further, a systematic approach is likely to consist of several stages. After Stevers and De Groot (1991), we distinguish:

1. Stage 1: detect patterns
2. Stage 2: define guidelines and rules
3. Stage 3: remove mental blockades

The ***detection of patterns*** implies the analysis of the flood risk system in the context of the next-higher system level – being the society's sustainable development, with the criteria concerned – and consisting of interactions among the next-lower system level – being the constituents of the society, its economy, its infrastructure, its institutions (insurance; management authorities), the flood defences, etc. In addition, the recognition of functional units may help in the further design, e.g. by distinguishing between flood abatement, flood control and flood alleviation (Parker, 2000; cited by De Bruijn, 2005, p. 25), or between cause-oriented and effect-oriented, or between preventive, curative and palliative. Many other approaches to detecting patterns can be distinguished, but we make the next step. After all, we assume that a sound flood risk analysis, including the causes, pathways and consequences, and including the future development of hazard and vulnerability has already been performed.

The ***definition of guidelines and rules*** is the next step. This issue has already been touched upon above. Stevers and De Groot (1991) distinguish between an inductive approach and a deductive approach of finding design guidelines, 'laws' or design principles. The *inductive* approach relies on experience, earlier or elsewhere. Such an approach is followed by FLOODsite task 12, with respect to individual measures and instruments (Olfert & Schanze, 2007), and by FLOODsite task 13, with respect to flood risk management strategies (Hutter *et al*., 2007). A *deductive* approach implies that rules are derived from theoretical concepts or theories. For example, the island theory from ecology (MacArthur & Wilson, 1967) yielded rules for planning nature conservation areas (NATURA 2000); and economic theory states, for example, that financial policy instruments may be less effective, but are usually more efficient than regulatory instruments (example from Stevers & De Groot, 1991). An inductive approach to deriving design guidelines for flood risk management has been followed by Vis *et al.* (2001) who supposed a better coping capacity of resilient systems than of resistant systems (cf. also De Bruijn, 2005). This presumption was derived from ecology (cf. Klijn & Marchand, 2000; Clapham, 1973).

Next, despite the systematic approach, we must try to get rid of ***mental blockades*** to being creative. This makes designing a difficult task for scientists who are trained to adhere to an analytical attitude. But ***designing is a synthetic activity, not an analytical one***. Therefore, design disciplines are often being brought in to help make the '*creative leap'* (Stevers & De Groot, 1991), such as architects, landscape architects, etc. They may help to remove mental blockades, e.g. by introducing techniques such as:

- experimental design or rapid prototyping (trying very different strategies which are no more than trials)
- brainstorm (where the quantity of ideas is important and not their quality; progressive association without criticising)
- abstracting to the principle and proposing contrasting principles

2.3.3 Review of recently applied approaches

As for recently applied approaches we again refer to Foresight (Office of Science & Technology, 2004) and the perspectives-based method (Van Asselt *et al.*, 2001; Middelkoop *et al.*, 2004), because both relate strategic alternatives to scenarios. However, as both quantified the strategic alternatives primarily by generic assumptions on effectiveness of measures (e.g. as 'flood risk reduction factor' in Foresight), and *not* as comprehensive sets including geographically differentiated measures, we also refer to another IRMA-SPONGE project, viz. '*Living with floods'* by Vis *et al.* (2001; cf. also De Bruijn, 2005).

'Foresight': bottom-up

In the Foresight project (Office of Science & Technology, 2004) strategic alternatives were developed from a gross list of response measures, policies and interventions. This gross list was based on a literature review and consultation of a wide range of experts and stakeholders. It comprised about 120 possible measures, policies and interventions, which were clustered into 26 'response groups', which were again further attributed to 5 broad themes (managing the rural landscape, managing the urban fabric, managing flood events, managing flood losses, and river and coastal engineering).

First the effects of all 26 response groups in all 'futures' were assessed as a factor with which flood risks increased. The scores of the response groups on the flood risks in different foresight 'scenarios' (Office of Science & Technology, 2004) were used to define a portfolio of responses for each future. These portfolios of response groups can be regarded as strategic alternatives. Each portfolio also included a different safety standard (target level for protection), which was related to the future scenarios discussed in the former section. Thus, in Foresight 4 strategic alternatives were defined, which were each combined with (only) one future scenario each. Foresight explicitly assumes that each strategic alternative belongs to one future scenario only.

The method used in this project is thus consistent in the sense that strategic alternatives are defined in relation to future scenarios. However, the definition of 'portfolios of response' is primarily bottom-up; consequently it seems slightly haphazard and not very methodical[7].

Perspectives-based strategies (IRMA-SPONGE)

In the IRMA-SPONGE project "Development of flood management strategies for the Rhine and Meuse basins in the context of integrated river management" (Van Asselt *et al*., 2001; Middelkoop *et al*., 2004) alternative water management policies were identified for the Rhine and Meuse basins according to certain management styles. The management styles – as well as the expected future scenarios belonging to a certain perspective (as recognized in the so-called 'Cultural Theory' (Thompson *et al.*, 1990) – can be translated into policy strategies, as the perspectives determine not only the ideas about how the world functions and develops, but also determine the preferred approach to policy and management.

Thus three different management perspectives were translated into three strategic flood risk management alternatives:

- The Hierarchist or Controlist
- The Individualist or Market-optimist
- The Egalitarian or Environmental-pessimist.

In practice, the development of strategic alternatives did not receive the attention which it ought to have had, primarily because of time constraints. Therefore, strategic alternatives were simply defined

[7] Neither does it become clear whether policy making might fail when future developments would deviate from the expected; the correspondence between policy making strategy and future scenario is regarded both given and fixed.

by different emphasis on detention measures (many by egalitarians, none by individualists) and dike heightening (none by egalitarians, some by hierarchists) Also, reference was made to other IRMA-SPONGE research projects. Thus, the current Netherlands' strategy was considered a good example of a hierarchist strategic alternative, and the resilience strategies developed by Vis *et al.* (2001) were considered to be examples of Egalitarian strategic alternatives.

The effects of the strategic alternatives were evaluated both for the scenario for which they were developed (utopia) and for other scenarios (dystopia).

In this project there is a certain beauty in the correspondence of scenarios and strategic alternatives, because of their being both related to perspectives through world views and management style. This allows the recognition of utopias and dystopias, and ensures a systematic assessment of (in this case) 9 distinct combinations of scenario and strategic alternative. However, the perspectives have the disadvantage of being caricatures of real convictions, thus triggering opposition to the method and some resistance to accepting the lessons that can be drawn from the results.

'Living with floods': strategies from guiding principles (IRMA-SPONGE)

Above, we already referred to the fact that Van Asselt *et al.* (2001) and Middelkoop *et al.* (2004) used some strategic alternatives that were designed by Vis *et al* (2001) for the IRMA-SPONGE project *Living with floods.* In this project, strategic alternatives were designed and evaluated, but no scenario analysis was performed; among the assessment criteria, however, were also criteria aimed at ***assessing the performance of the strategic alternatives in view of uncertainty*** – both natural variability and more rapid or slower trends in change – viz. ***robustness and flexibility.***

Vis et al. distinguished 4 alternatives, from carrying on as before (0-alternative with autonomous development) to a very extreme one, where all the land was given back to the river and the land use pattern completely re-designed (Land & Water alternative, after DWW).

The design of the alternatives followed a number of opposites/ bifurcations, related to guiding principles:

- resistance (flood defence by technical measures: ***0-alternative/ reference***) versus resilience (flood control by technical-spatial measures)
- within resilience: 'balanced' resilience versus ***extreme resilience (3)***
- within balanced resilience: temporary storage (***compartments (1))*** versus enhanced discharge (floodways / ***green rivers (2)***)
- within compartments: few (up to an expected maximum river discharge ***(1a))*** versus many (taking into account many more uncertainties ***(1b))***
- within flood ways/ green rivers: with different land use, spontaneous development ***(2a)*** or ecological development ***(2b)*** or multi-functional ***(2c)***

The thus distinguished strategic alternatives can be regarded as different points between extremes on an axis ***from*** full ***resistance*** (flood defence) ***to*** extreme ***resilience*** (no dikes left, land use adapted to floods). Perpendicularly –or rather: slightly obliquely – to this axis are the principally different techniques of storage versus discharge and preference for a certain type of land-use.

Comparison of the approaches

In the above examples we can distinguish two principally different approaches, viz. the top-down approaches from guiding principles in IRMA-SPONGE and the bottom-up approach in Foresight. It seems the top-down approach yields more contrasting alternatives, and thus adds to insight into a strategic alternative's advantages and disadvantages.

Within IRMA-SPONGE, the perspectives' approach has the advantage of a clear relationship to preferences regarding policy making and management practice. The strategic alternatives distinguished, however, were not really designed, but rather copied. Partly, they were copied from Vis *et al.* (2001). These authors explicitly distinguished strategic alternatives related to guiding principles, thus achieving at a sufficient number of sufficiently different alternatives; i.e., for the purpose of comparing their performance and further consequences in the long term, e.g. on sustainability criteria. ***Therefore, it is advised to design strategic alternatives according to a similar approach, at least via clear and opposed guiding principles***. In case scenarios are being developed related to perspectives, it is advised to name (and design) the strategic alternatives according to these perspectives as well.

2.4 Confronting strategies with scenarios

2.4.1 Introduction

In the sections above we have discussed the development of scenarios ***of*** the future and the design of strategic alternatives ***for*** the future. The next step is to discuss the method to assess the confrontation of scenarios and strategic alternatives with each other, as visualised in table 2.2. Such a confrontation enables to assess (1) what the best strategic alternative is under one given scenario, and (2) how the various strategic alternatives for flood risk management perform under various scenarios. A similar procedure was followed in a scenario study on sustainable water management by Messner & Kaltofen (2004).

Table 2.2 Set up of the assessment of strategic alternatives under various scenarios for one future epoch, with a five-scale ranking (- - to ++) as example

Scenario / **Strategy**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Strategy 1	+	+	+
Strategy 2	+ +	-	- -
Strategy 3	- -	- -	+ +

To achieve at the scores of each combination of strategic alternative and scenario, we must first achieve an overall score for each combination of alternative and scenario on the basis of a set of assessment criteria. In this section a review of possible approaches towards a full assessment of strategic alternatives will be presented, including both the analyses of flood risks and other relevant consequences, and some conclusions will be drawn for setting up a full assessment of long term strategic alternatives for flood risk management.

First, it is repeated that flood risk management strategies are considered to contribute to the broader goal of sustainable development of regions. In order to assess the contribution of strategic alternatives to sustainable development, this broad goal is translated into assessment criteria in section 2.4.2. Section 2.4.3 discusses how to obtain indicator values and scores, and section 2.4.4 finally discusses the question of how to best present the assessment results. This section will not give an exhaustive description of all the methods available, but will focus on the rationale of achieving at an elegant, i.e. a comprehensive and understandable, assessment procedure.

2.4.2 Assessing the alternative's contribution to sustainable development

Flood risks are related to the hazard of flooding as well as to the exposure and vulnerability of a region (Chapter 2.2.2). Accordingly, flood risk management is not only about floods, but is clearly related to the characteristics and developments in a region (Hall *et al.*, 2003). Flood risk management must enable society to cope with floods in such a way that a region's well-being is maintained or can grow in the future. This is reached when flood risk management contributes to the sustainable development of the region where floods may happen (De Bruijn, 2005) (see also section 2.3.1).

Sustainable development is a development which meets the needs of the present generation without compromising the ability of future generations to meet their needs. The concept evolved after an era of industrialisation and a strong belief in technical solutions. Publications such as *Silent Spring* by Carson (1963) and '*Limits to growth'* by Meadows *et al.* (1972) raised awareness of the adverse effects on the environment. After the publication of the report Our Common Future by Brundtland *et al.* (1987) the concept of sustainable development was adopted not only by environmental groups and NGOs, but also by governmental institutions and even the business community. In 1992, Young (1992) described sustainable development in terms of the three domains (or realms) social equity, ecological integrity, and economic efficiency. This general idea was further specified and translated into the triple-P concept: *People, Planet and Profit.*

Nowadays, it is accepted in various scientific studies and consulting practices to use these three domains of sustainability in the analysis of flood risks and for the full assessment of strategic alternatives for flood risk management. Examples are the study of De Bruijn (2005) on the merits of resilience strategies for flood risk management and the report of Wade *et al.* (2006) to support actions underway as part of the new UK strategy for flood and coastal erosion risk management. ***It is here recommended to use the three domains of sustainable development as leading for the full assessment of flood management strategic alternatives under various scenarios.*** This implies that social, ecological as well as economic criteria must be defined.

Criteria (and/or related indicators) are widely used in environmental impact assessments, and have been made operational from the 1950s onwards. Just after World War II, when recovery of agricultural production and economic growth was urgent, emphasis was on the economic criteria. For instance the Dutch Deltaplan – developed after the *Watersnoodramp* of 1953 – was mainly evaluated on the basis of economic indicators. During the 1970s, growing environmental concern led to the development of Environmental Impact Assessments using environmental criteria. And since the late 1990s, social issues such as equity and gender issues gained importance. As the application of the economic and environmental criteria gradually evolved during this prolonged period, criteria that were used in the past will not be further reviewed, but instead some recent guidelines and studies will be discussed here.

Indicator framework for sustainable development

Criteria and indicators which allow to assess the level of sustainable development of different countries have been defined by the United Nations (United Nations, 1995). Through intensive collaboration between governments, international organizations, academic institutions, non-governmental organizations and individual experts, a set of criteria for sustainable development for use at the national level was developed. A theme-approach was recommended which resulted in a focus on themes and sub-themes of sustainable development. Four dimensions of sustainable development were distinguished, Social, Environmental, Economic, and Institutional, three of which clearly correspond to the triple P's (Table 2.3). Institutional criteria are more related to the means on how to reach a more sustainable society than to the resulting sustainability as such. Therefore, the relevance of the institutional theme for sustainability assessment can be disputed. In the Netherlands, this UN-scheme was proposed for use in eco-engineering (Van Oostrum, 2005).

Table 2.3 The UN Indicator Framework as an example of a comprehensive set of criteria (themes and sub-themes) and associated indicators for sustainable development

SOCIAL		
Theme	**Sub-theme**	**Indicator**
Equity	Poverty (3)	Percent of Population Living below Poverty Line
		Gini Index of Income Inequality
		Unemployment Rate
	Gender Equality (24)	Ratio of Average Female Wage to Male Wage
Health	Nutritional Status	Nutritional Status of Children
	Mortality	Mortality Rate Under 5 Years Old
		Life Expectancy at Birth
	Sanitation	Percent of Population with Adequate Sewage Disposal Facilities
	Drinking Water	Population with Acces to Safe Drinking Water
	Healthcare Delivery	Percent of Population with Access to Primary Health Care Facilities
		Immunization Against Infectious Childhood Diseases
		Contraceptive Prevalence Rate
Education	Education Level	Children Reaching Grade 5 of Primary Education
		Adult Secondary Education Achievement Level
Housing	Living conditions	Floor Area per Person
Security	Crime	Number of Recorded Crimes per 100,000 Population
Population	Population Change	Population Growth Rate
		Population of Urban Formal and Informal Settlements
ENVIRONMENTAL		
Theme	**Sub-theme**	**Indicator**
Atmosphere	Climate change	Emissions of Greenhouse Gases
	Ozone Layer Depletion	Consumption of Ozone Depleting Substances
	Air Quality	Ambient Concentration of Air Pollutants in Urban Areas
Land	Agriculture	Arable and Permanent Crop Land Area
		Use of Fertilizers
		Use of Agricultural Pesticides
	Forests	Forest Area as a Percent of Land Area
		Wood Harvesting Intensity
	Desertification	Land Affected by Desertification
	Urbanization	Area of Urban Formal and Informal Settlements
Oceans, Seas and Coasts	Coastal Zone	Algae Concentration in Coastal Waters
		Percent of Total Population Living in Coastal Areas
	Fisheries	Annual Catch by Major Species
Fresh Water	Water Quantity	Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water
	Water Quality	BOD in Water Bodies
		Concentration of Faecal Coliform in Freshwater
Biodiversity	Ecosystem	Area of Selected Key Ecosystems
		Protected Area as a % of Total Area
	Species	Abundance of Selected Key Species
ECONOMIC		
Theme	**Sub-theme**	**Indicator**
Economic Structure	Economic Performance	GDP per Capita
		Investment Share in GDP
	Trade	Balance of Trade in Goods and Services
	Financial Status	Debt to GNP Ratio
		Total ODA Given or Received as a Percent of GNP
Consumption and	Material Consumption	Intensity of Material Use
	Energy Use	Annual Energy Consumption per Capita

Production Patterns		Share of Consumption of Renewable Energy Resources
		Intensity of Energy Use
	Waste Generation and Management	Generation of Industrial and Municipal Solid Waste
		Generation of Hazardous Waste
		Generation of Radioactive Waste
		Waste Recycling and Reuse
	Transportation	Distance Travelled per Capita by Mode of Transport
INSTITUTIONAL		
Theme	**Sub-theme**	**Indicator**
Institutional Framework	Strategic Implementation of SD	National Sustainable Development Strategy
	International Cooperation	Implementation of Ratified Global Agreements
Institutional Capacity	Information Access	Number of Internet Subscribers per 1000 Inhabitants
	Communication Infrastructure	Main Telephone Lines per 1000 Inhabitants
	Science and Technology	Expenditure on Research and Development as a Percent of GDP
	Disaster Preparedness and Response	Economic and Human Loss Due to Natural Disasters

The EU has also applied impact assessments for a long time. Impact assessments related to the European Commissions' work programme have embraced an impact assessment procedure which aims to balance the three sustainability domains (social, ecological and economic), and a guideline and handbook for impact assessment have been published on this approach. The sustainability criteria, however, are not completely clear whilst the debate on how to assess sustainable development is still going on (Kristensen *et al.*, 2006).

Sustainability Impact Assessment Tools (SIAT) for ex-ante assessments to support policy decision making on multifunctional land use in European regions, are being developed in the EU-FP6 Integrated Project SENSOR. In SENSOR, impact assessment is clearly related to the triple-P concept and, similar to the UN project, an indicator framework has been made. For each of the sustainability domains various impact issues are described, and each of these issues is linked to one or more indicators. The indicators are more or less evenly distributed among the three P's: the EU SENSOR projects lists 27 indicators for the social and ecological impact issues each, and 25 for the economic impact issues (Kristensen *et al*., 2006). This is in line with Slingerland *et al.* (2003) who conclude that there is no good reason to assign more weight to one of the three P's.

Both the UN and EU-SENSOR frameworks show that there is a clear distinction between criteria and indicators. The themes and sub-themes in the UN framework and the impact issues in the EU project SENSOR are rather the criteria, which refer to the subject of assessment at a rather abstract level. Each of these criteria is associated with one or more indicators (named Impact Assessment Indicators in SENSOR), which can be measured (preferably quantified) and thus enable to determine whether a criterion is met or not and/or to which degree it is met. Any set of criteria should be comprehensive and relevant, whereas indicators must be representative and must enable to argue or measure the performance related to that criterion.

Accordingly, an equal distribution of criteria over the three sustainability dimensions is proposed, so that these receive equal (or balanced) treatment in the full assessment. Consequently, the associated indicators should have as little overlap as possible. Existing lists with key sustainability themes such as those of the UN and the EU project SENSOR provide a first indication of which criteria can be used to evaluate sustainable development (e.g. United Nations, 1995, Hoogeveen *et al.*, 2000; Delbaere, 2004; Klijn & Vulings, 2005; Olfert & Schanze, 2007; Kristensen *et al.*, 2006; Evans *et al*., 2004 a,b).

Flood risk relevance of criteria and indicators

The examples mentioned above suggest that many indicators are needed for evaluating whether strategic flood risk alternatives are sustainable or not. The UN list contains 61 indicators, while SENSOR lists a total number of 79! Some recent studies show that it is not always necessary to assess all themes, because not all criteria and indicators may be relevant in the case at stake. Instead a selection is made. In the UN project, the SENSOR project, as well as in other water related projects (e.g. Messner & Kaltofen, 2004), the most relevant indicators were selected by the stakeholders involved in the study. Policy documents may also be used to prioritise indicators (Vreke & Van Mansfeld, 2000). Below we indicate which criteria we considr most relevant in the context of flood risk management studies. As a substitute to stakeholders, and because policy documents are considered less relevant for assessments over very long (50-100 years) periods, we analysed some recent flood risk management studies to this end.

Various studies in which strategic alternatives were assessed made an attempt to apply a comprehensive set of criteria for sustainability assessment. In their IRMA-SPONGE scenario study, Vis *et al.* (2001) mention – apart from the costs of investments and expected flood damages –effects and opportunities for economic development, ecological effects and opportunities for nature development, and landscape quality. Bana E Costa *et al.* (2004) use indicators for water (N=4), soil (2), fauna and flora (1), landscape (2) and social aspects (3), together with technical ones. De Bruijn (2005) includes socio-economic effects (flood impacts, costs, economic opportunities), effects on nature and effects related to the system's sensitivity to uncertainties (robustness and flexibility). De Bruijn (2005) uses the following subcriteria for socio-economic effects: the expected flood risk, expected annual number of affected persons, recovery capacity, costs of the strategy, economic opportunities for relevant land use functions and equity. In the FLOODsite Task-12 report on ex-post assessment of individual measures, Olfert & Schanze (2007) identify many indicators for hydrological and hydraulic effects (N=8), social effects (3), economic effects (14), effects on soil and vegetation (7), limnological effects (13), and ecological effects in floodplains and on coastal shores (7). Incorporation of these indicators in the full assessment framework draws attention not only to the attended risk reduction effects, but also to the unintended effects of the implementation of a flood risk strategy. In their valley restoration feasibility study, Vreke & Van Mansfeld (2000) made a selection of indicators on the basis of both the effects of the alternatives they studied and the policy goals for the studied region. From the examples above, it follows that such an approach may be useful too in the assessment of flood risk management alternatives.

Up-and-coming criteria: robustness and flexibility

In the UK Foresight Project Summary, Wade *et al.* (2006) state that '*it is important to develop policies that can cope with a range of different outcomes – and which can adapt flexibly as the situation evolves*'. This is put forward as an argument to investigate a wide range of possibilities. However, some authors also investigate whether one strategic alternative meets the need of various outcomes and is flexible to be adapted to unforeseen circumstances. This is in line with Popper *et al.* (2005) who argue that when no more than a handful of the many plausible futures will be addressed, every choice is vulnerable to blunders and surprises. Their approach is not to look for optimal strategic alternatives, bur for robust ones that are also flexible. Also, Hoekstra (2005) mentions that robustness and flexibility are up and coming criteria, which enable to deal with uncertainty of future developments. Thus, these authors confirm the relevance of the choice of robustness and flexibility as additional criteria and support the trials to operationalise these as attempted in some recent studies (e.g. Vis *et al.,* 2001, De Bruijn, 2005, Kwadijk *et al.,* 2006).

Robustness is defined here as the ability of aflood risk system (or: strategic alternative) to cope with natural variability and unexpected events. A robust strategy performs according to its objectives, even when unexpected pressures occur. *A strategy is flexibile when the strategic alternative can easily be adapted to changing circumstances (developments slower, faster, or in another direction) and when future regret about decisions and measures implemented is unlikely* (Vis *et al.,* 2001).

Adding the criteria robustness and flexibility to the criteria related to the three P's may seem a bit unbalanced. After all, they are criteria of a higher level, relating to the whole system's (strategy's) functioning rather than to effects. Since, however, the two together express the capability of the strategic alternative to cope with uncertain events and uncertain future changes, they are relevant for assessing sustainability and should thus be incorporated. Therefore, it is advised to add these criteria to the other sustainability criteria as a new group.

Indicators for the criteria

The criteria will often be measured or expressed by indicators. Economic, ecological and socio-cultural indicators and measuring methods can be found in various reports on indicators (e.g. United Nations, 1995; Hoogeveen *et al;*, 2000, Delbaere, 2004; Klijn & Vulings, 2005; Olfert & Schanze, 2007; Kristensen *et al*, 2006, etc.). All these indicators may be arranged in a hierarchy from very simple to very sophisticated, and from very detailed to comprehensive. In the case of biodiversity, for instance, a simple indicator would be the size of a natural area, to be expressed in ha or km^2. A more meaningful approach would be to indicate the habitat function of these nature areas for certain key species. And the most sophisticated one would involve an analysis of the entire food web in the study area. Which solution is the most adequate depends on many factors, such as the availability of data, of knowledge, of modelling skills, and of time available for performing the analyses. When selecting indicators, it should be kept in mind that there is always a degree of uncertainty, and that this uncertainty increases with an increasing time horizon. Because of this large uncertainty in assessments of long-term strategic alternatives in the far future, it is not necessary to work with very detailed and specific indicators. ***In general, therefore, less detailed and more comprehensive indicators will perform adequately when assessing strategic alternatives for future scenarios with a time horizon of 50-100 years.*** In contrast, when dealing with the ex-post assessment of measures one would choose more specific indicators such as proposed by Olfert & Schanze (2007).

2.4.3 Methods for obtaining and integrating indicator scores

Many methods have been developed for integrated assessments, monetary and non-monetary, quantitative and qualitative. We will try to establish the applicability of the well-known and frequently used Cost Benefit Analysis, Multi Criteria Analysis, and 'balanced score cards'.
Before going into these formal methods of 'integration', we briefly explore the problem of obtaining indicator scores for comprehensive, and quite qualitative indicators. We especially go into the Delphi Method.

Obtaining scores for indicators

The various relevant indicators should be scored: given a value. Many indicators can be easily expressed quantitatively, e.g. in terms of money, in numbers, or area. Actually, indicators are often specifically selected because of their ease of quantification. However, ease of quantification should not make one forget that relevance for the sustainability criterion at stake is more important. And unfortunately, many relevant criteria and indicators are difficult to quantify, especially for the far future.

In such a case, one might try to achieve at some ranking, in order to make a qualitative judgement semi-quantitative. For instance, by scoring on a relatively simple 5- or 7-scale ranking (++ to --; resp. +++ to ---). For reasons of comparison across the alternatives, all these values may be scored on a positive/neutral/negative scale of measurement (Thorne *et al.*, 2007). Weighing can be done by means of classification of the values. Preferably the classes should be well described, so that they can be reproduced.

A formal method to obtain such scores is the so-called *Delphi method*. In this method hypotheses and a questionnaire are prepared by an administrator and sent to various experts. Scores and arguments provided by the experts are summarized by the administrator and this summary is sent to the experts again, who then may change their opinion in a second round after having read the arguments of other experts. When consensus is reached after two or more rounds the process may be stopped. The advantage of this method is that consensus may be reached rather fast even though the subject is complex, and that 'groupthink' is avoided, so that unforeseen ideas get the attention needed. In the original Delphi method all participants remained anonymous, but recently face-to-face Delphi methods have been developed, even locking all the participants into a room and not letting them out before they reach consensus.

In the case of planning long-term strategic alternatives for an uncertain future, it is advised to use some kind of Delphi method to obtain indicator scores.

Integration methods

Cost Benefit Analysis (CBA) is an economic, and essentially monetary metho. It is by far the one most used (Van der Heide *et al.,* 2006). CBA provides a quantitative overview of the pros and cons of alternatives. CBA is mainly an economic appraisal, which requires that all effects must be expressed in monetary terms. In its simplest form, this is achieved by only taking into account monetary indicators. Obviously, this 'narrow' approach of CBA does not qualify for a full sustainability assessment. Others try to translate all the relevant criteria into monetary terms, e.g. by applying methods such as 'willingness to pay', shadow pricing', etc. They meet massive opposition from scientists from other fields (other than economy), however, who find that any translation of the value of intangibles into monetary terms gives the economic value to much credit and thus disturbs the balance between the 3 P's.
An somewhat more recent and more 'liberal' variation to CBA, Social Cost Benefit Analysis, is also an economic method, but it does aim to include all the indirect socio-economic and ecological costs and benefits. It allows for scoring non-monetary criteria in more approriate 'own measures'. Social Cost Benefit Analysis enables to deal with the negative and positive effects of alternatives on environment and society, and thus provides a better link to the three domains sustainability. Because it allows for criteria and indicators to be exp[ressed in their own terms, it can be regarded as a transition between CBA and MCA (see below).

Multi Criteria Analysis (MCA) differs from CBA in the sense that all variables may be expressed in their own terms, and need not be of the same level of detail, because the possibility to weigh criteria is the essence of this method. MCA enables alternatives to be ranked on the bases of scores of very different indicators. It simultaneously takes into account different and even conflicting objectives that have different units of measurement, whether quantitative or qualitative. Eventually, the weighing allows to attribute different values to the various indicators. The weighing also allows to translate values into scores, so that lumping and ranking of the alternatives is possible. MCA is frequently applied in Environmental Impact Assessments. Van der Heide *et al.* (2006) argue that an MCA is easier to implement than a Social Cost Benefit Analysis, but that the MCA procedure must be transparent in order to avoid that results are manipulated. Indeed, it is often quite unclear how a ranking is achieved and because obnly the final ranking counts, the method easily provokes manipulation.

CBA and MCA are well-known and frequently used formal methods, but they do not automatically prevent misjudgements, unbalance between criteria, irrelevance of criteria, or other pitfalls of integrated assessment. A main disadvantage of these methods is that they tend to keep relevant information of differences, trade-offs etc. hidden, instead of manifest. An alternative which does not have this disadvantage is to produce overview tables or so-called '*balanced score cards'*. This method allows for inclusion of qualitative as well as quantitative indicators, whereas indicatopr scores can be sorted, judged and/or lumped. Effect sheets and score cards are often used when dealing with strongly deviating themes.

It is advised to use some kind of balanced score cards or MCA, but especially to be explicit about the criteria and indicators as well as about how they were scored.

2.4.4 The presentation of the assessment results

There are different ways to present the results of full assessments. They can be presented in tables, graphs or in pictures. To help the reader tables may be used with 'traffic light colours' such as the one shown in figure 2.5. These are especially helpful when comparing different alternatives.

An alternative is the so-called spider diagram, in which the scorings on the indicators are depicted in the form of a spider web (Thorne *et al.,* 2007, Van Mansfeld & Vreke, pers. comm.). This fashionable way of presenting is especially useful when reference values or absolute references for each indicator are available, e.g. legal standards or so. Otherwise, they are quite difficult to interpret (Figure 2.6). Often, spider diagrams depict between 5 and 8 indicators or indicator groups, but diagrams with > 20 indicators are known too.

Again an alternative is a trial to combine the fashionable diagram (actually merely a 'circular table') with colours for the judgement (Hoogeveen *et al.*, 2000; Figure 2.7).), or length. In the latter case, it is rather a circular histogram.

2.5 Concluding remarks

2.5.1 On scenarios

- We argue to follow the clear distinction between scenarios and strategic alternatives as defined in the FLOODsite *Language of Risk.*
- We advise to work with projective, exploratory scenarios.
- We suggest to build on accepted and widely used scenario studies as much as possible and to use either the two discriminate axes method or the perspectives method (in practice they work out very similar).
- We advise to distinguish no more than 4 different scenarios.
- The main drivers to be examined are climate change with its consequences for the flood hazard and economic growth, population growth and land use change with their consequences for exposure and vulnerability.
- The downscaling from qualitative narratives to quantitative scenarios for the geographical area of interest (in our case the pilots Schelde, Elbe and Thames respectively) requires due attention.

i0044-7447-33-3-141-f07

Strategy	PV of costs (€ billion)	PV of flood damage (€ billion)	Flexibility	Economic power	Ecological power	Landscape quality
0. Autonomous development	0.9	0.5	4.1	5.0	3.5	4.4
1. Compartments						
a. up to 18,000 m³ s⁻¹	1.0	0.6	6.9	5.3	4.0	5.2
b. up to 20,000 m ³ s⁻¹	1.6	0.3	6.7	4.7	4.1	5.3
2. Green river						
a. spontaneous development	8.0	0.0	4.8	3.3	7.7	6.6
b. ecological development	8.0	0.0	4.8	3.4	8.0	6.6
c. multifunctional development	3.0	0.1	4.7	5.7	6.7	6.7

1 Qualitative scores are assigned between 0 (utmost bad) and 10 (perfect).
2 Emotional values are not included. Emotional values may be accounted for by applying a weighting factor (greater than 1) for the score on flood damage.
3 When the compartmentalisation strategy is fully implemented more compartments must be constructed resulting in still higher costs.

Figure 2.5 The use of colours in a balanced score card for mutual comparison of strategic alternatives: the figures refer to either a quantative absolute scale or to a ranking on a 10 point scale (1 – 10) (from Klijn et al., 2004).

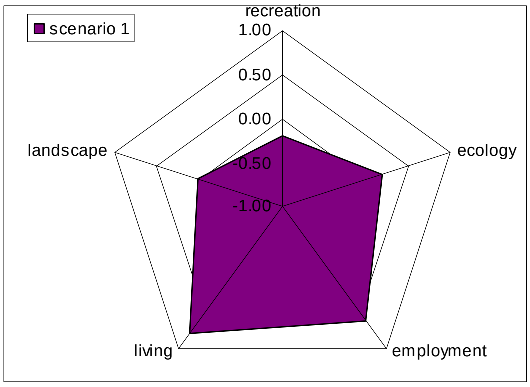


Figure 2.6 Spider diagram depicting lumped scores on five indicators group (source: Van Mansfeld & Vreke, pers. comm.)

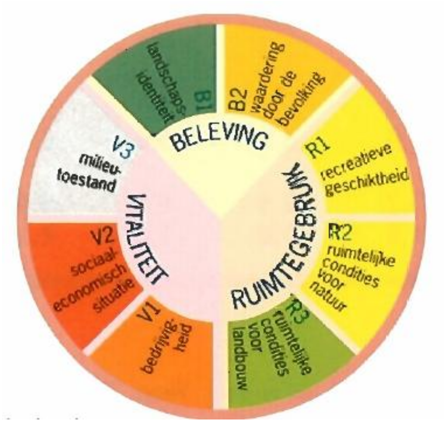


Figure 2.7 Hoogeveen et al. (2000) presented their set of indicators groups and indicator scores as coloured segments of a circle. Note that no figures are presented but just colours indicating the positive/neutral/negative scale of measurement

2.5.2 On strategic alternatives

- We argue to design strategic alternatives by content (of goals, aims, measures and instruments) only; in contrast to strategies which also comprise process (institutions, responsibilities, timing, etc.).
- We advise to design no more than 4 strategic alternatives; perhaps 3 suffice, but a zero-alternative is quintessential for reference purposes.
- We advise to design strategic alternatives according to a top-down approach, defining clear and opposite guiding principles, such as resistance versus resilience, and/or by specifying different objectives (economy versus ecology, people versus material damage, etc.).
- In case scenarios are being developed related to perspectives, it is advised to name (and design) the strategic alternatives according to these perspectives as well: a controlist's, an egalitarian and a market-optimist's strategy.
- All strategic alternatives should consist of combinations of structural and non-structural measures/instruments; and all alternatives should aim at both hazard control and vulnerability reduction – although their respective shares may deviate substantially.

2.5.3 On criteria for full assessment

- We advocate the recognition of the three domains of sustainability – people, profit and planet – as leading for the selection of criteria for a full assessment of flood management strategic alternatives under various scenarios.
- We advise to add the criteria robustness and flexibility to the other sustainability criteria in order to cover the issue of 'coping with uncertainty'..
- We propose an equal distribution of criteria and associated indicators over the three sustainability fields, so that they receive a balanced treatment in the assessment.
- A general level of abstraction of the indicators and a simple and practical method to obtain indicator values– for all indicators – suffices for the purpose of evaluating long term flood risk strategies under various scenarios for the far future.
- We advocate using a sort of Delphi method to obtain scores for qualitative/semi-quantitative criteria/indicators which rely on expert(s') judgement.
- For the integrated assessment, balanced score cards or some very explicit form of Multi Criteria Analysis can be used.
- It is advised to present the results in a visually attractive way.

3. Method

3.1 Introduction

This chapter proposes a procedure and methods for defining and assessing long-term strategic alternatives in the context of an uncertain future. The procedure and methods are based on the conclusions of the reviews in the previous chapter. In the next chapters on the pilots, the adequateness of the procedure and methods will be tested by applying them to real-world cases.

The procedure and methods are to be used by institutes or organisations who help policy makers to develop long-term strategies. The procedure may also serve as a kind of checklist for policy makers. It shows which steps are required to establish what the implications of continuing the current flood risk management strategy are and to compare these with the implications of other strategic alternatives.

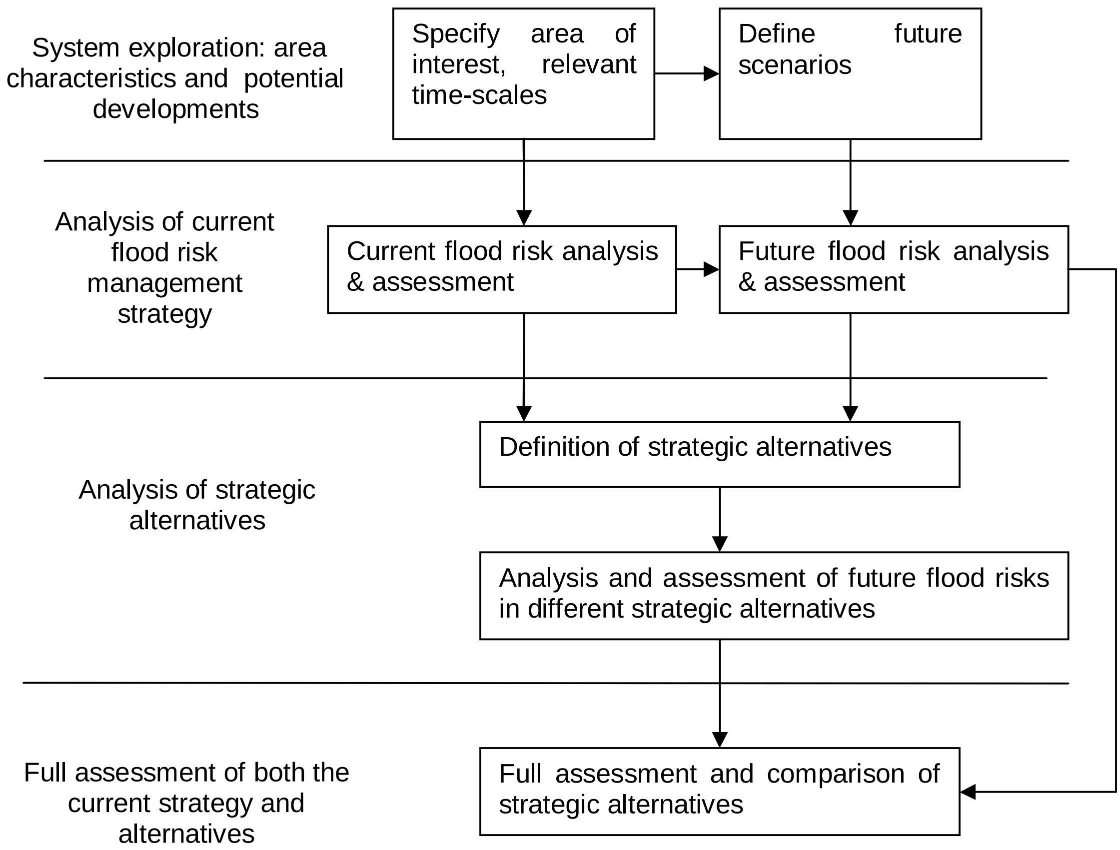


Figure 3.1 Schematic overview of the method for developing and assessing long-term flood risk management strategies in view of uncertain futures (The blocks represent the different steps within the method. The arrows represent the connections between different step).

Figure 3.1 provides a schematic overview of the procedure. Although, in reality, management planning is a cyclic process, figure 3.1 depicts it as a linear process which starts with an explorartion of the flood risk system and ends with a full assessment of strategic alternatives. In practice, alternatives may be adapted when unfavourable results are obtained or additional alternatives may be added halfway. Also, various iterations between design and analysis are likely. However, in order to clearly show the main procedure and relationships the figure is kept simple. The steps of figure 3.1 will be briefly described below, while in the next sections the the methods to apply will be discussed in more detail.

System exploration
First, the area of interest is to be defined and the flood risk system to be described as specified in section 3.2. Next, different future scenarios are to be developed, which serve to explore what the future might look like if the current flood risk management policy were to be continued or if alternatives were to be implemented. Scenario development is discussed in section 3.3.

Analysis and preliminary risk assessment of the current flood risk management strategy
The current flood risk is analysed by studying flood probabilities and flood impacts. When the flood risks are known, they can be assessed on societal acceptability in order to establish whether the flood risk is a concern. This has to be done for the current situation as well as for the future (see section 3.4).

Analysis and preliminary risk assessment of strategic alternatives
If the flood risks are not acceptable now or in the future, various strategic alternatives for flood risk management may be developed (see section 3.5). The resulting risk should be analysed and assessed across different future scenarios in the same way as that of the current flood risk management strategy.

Full assessment of the strategic alternatives in view of uncertain futures
Finally, all the relevant effects of implementing the different strategic alternatives for flood risk management are to be assessed for different future scenarios. This comprehensive impact assessment of alternatives not only includes an assessment of flood risks, but also all the other consequences of the alternatives for the man-environment system in which the alternative is to be implemented. This overall assessment involves a scoring by a set of sustainability criteria (see section 3.6). This means that both the intended effects in terms of the changed flood risk and the unintended side-effects of implementing the strategic alternative on social, economic and ecological functioning of the system are taken into account.

Although the procedure as presented in Figure 3.1 suggests that the full assessment is the last activity, it is strongly advised to choose the criteria and indicators for the assessment in the beginning of the project. This is because the design of strategic alternatives cannot be done independently from the societal objectives for sustainable development.

3.2 System characterisation

First, the area of interest must be defined, both geographically and conceptually. Conceptually the definition is according to the definition of a flood risk system: a system of people and their property in a flood-prone environment. This system of interest thus primarily consists of the flood-prone area – a river valley, a floodplain area or a coastal plain–, but often the water bodies which form the hazard are included. The flood risk system comprehends the physical (relief/ physiography and technical structures) and the socio-economic subsystem in the area (De Bruijn, 2005). There are various reasons to include both the flood-prone areas *and* the water bodies, and to include also socio-economic aspects:

- Firstly, measures to influence flood risks may be taken in and along water bodies but also in the flood-prone areas;
- Secondly, for selecting a strategic alternative for flood risk management the effects of the alternative on natural and socio-economic functioning must be taken into account. Therefore, the most important socio-economic and physical characteristics of the system must be known.

The flood risk system must cope with external pressures which may consist of rainfall or of inflows from upstream water bodies or of extreme sea conditions or of combinations of those three. These external pressures may be considered as disturbances. The reaction of the flood risk system to these disturbances, especially the reaction of the socio-economic subsystem, is important for flood risk managers. The reactions may be:

- No reaction: water levels in the system go up, but no flooding occurs. (e.g. when a flood wave occurs in diked rivers and the dikes hold). Normal life continues;
- Small reactions: floods occur, but their impact is small. One might think of flooding of recreational areas in winter time, evacuation of cattle from farm land, etc.
- Catastrophes: uncontrolled floods occur and cause large-scale devastation and panic. Recovery is likely to be slow.

Flood risk managers may influence the reaction of the system to disturbances by measures which prevent reactions (raising embankments etc.) or by measures which reduce the severity of reactions (land use adaptation, flood early warning, etc.) (De Bruijn, 2005).

Space and time scales

First the system must be delineated geographically and a relevant time horizon must be chosen. Based on the occurrence and consequences of recent historic floods the boundaries of the area of interest can be selected. The system boundaries should preferably correspond with a water body (hazard) and its flood-prone area, usually a river floodplain or coastal plain. It may, however, be necessary to limit the system that is being studied for practical reasons such as time and data availability.

The time horizon for the strategic alternatives must be sufficiently far away to avoid interference with short-term policies. Since long-term strategic alternatives will be rather visionary and not very detailed, the time-scale will be at least 30 to 100 years. The alternatives will be evaluated in terms of sustainability and thus a timeframe of some 50-100 years is required for a meaningful analysis. The flood risks may be calculated for a few relevant time-moments within that long time-frame (e.g. after 20 years when all existing plans are implemented, after 50 years and at the end of the time-horizon). The selection of these moments depends on the expected developments in the system. Next to these future moments, also the current state of the system must be studied.

For these spatial and temporal frames further information must be collected on land use, flood protection levels, developments in land use, and main economic and demographic developments.

Elements to include in the system description

In FLOODsite risk is defined as probability * consequence or as a combination of hazard, exposure and vulnerability. The system description should, therefore, at least cover these elements: the hazard by flood levels and probabilities; the exposure by flood propagation velocities, routes and surface area; the vulnerability by characteristics of all receptors which may be harmed by a flood (e.g. population, property, ecosystems) to be translated into consequences by combination with exposure (yielding e.g. damage or loss of life).

Summarizing: when the system's spatial boundaries and time horizon are clear, the system must be described in more detail, comprising at least:

- A description of the most important *hazard* characteristics (e.g. discharge regimes, tides, surge levels, rainfall intensities etc.);
- The physiography of the flood-prone area (is it a valley, low-lying polder areas or a mountainous area) and currently present defence structures such as embankments, bypasses, dike rings or other obstacles etc., as these determine the *exposure* characteristics (depth, rise rate, etc);
- Population and land use in the area and the main economic activities *(vulnerability)*;
- Recent historic floods and their consequences;
- Expected changes in land use, demography, and other relevant changes.

For each case study other land use functions and developments may be important. Therefore, no more specific requirements are set here. When all elements mentioned above are described and the hazard, exposure and vulnerability characteristics are known, a flood risk analysis complying with the EU-Directive on Flood Risk Assessment is possible.

3.3 Scenario development

3.3.1 Introduction

Section 3.3 provides insight in the development of future scenarios, proposing how these may be built-up to reflect a range of possible futures. As with strategic alternatives (Section 3.6), the development approach is to adopt a guiding principle which shapes the scenario building, i.e. a top-down approach. A useful analogy is that of baking a cake. The top-down approach assumes the end-product is known, e.g. a lemon cake, whereas a bottom-up approach would be: given these ingredients, what type of baking could come out? In order to assess the strategic alternatives in the context of a range of possible futures, some four future scenarios are required.

For reasons of clarity, we repeat the definition of scenario, being "all future ***autonomous*** developments, i.e. all future developments which ***are not purposefully influenced*** by flood risk managers and related policy instruments".

In Chapter 2, the key criteria identified for the development of scenarios (Section 2.2 and 2.5) include:

1. scenarios should be projective, i.e. the reasoning runs from the past, through the present and into the future;
2. scenarios will only include autonomous developments;
3. scenarios should be consistent, distinguishable and practical (maximum of four);
4. scenario drivers will include (i) hazard changes such as climate and land subsidence and ii) vulnerability changes such as economic growth, population growth and land-use change;
5. scenarios should be exploratory and may include both trends and unpredictable developments; and
6. scenarios will need to be down-scaled to the area of interest.

In long-term flood risk management planning, scenarios are merely a means in the research method. This means that most effort should be spent on the design and assessment of the strategic alternatives and that the effort put in the development of the scenarios should be limited. It is advocated to use existing, accepted and widely-used scenarios from other studies where possible, with due consideration of the above review criteria. This might include scenarios as discussed in Chapter 2, e.g. from RIVM (2005) or Foresight (Office of Science and Technology, 2004), as well as those from the IPCC on climate change.

Use of existing scenarios

In the cases later in this report, we primarily build on the scenarios distinguished in Foresight, but as far as the method is concerned, any set of existing and widely accepted scenarios might do. In Foresight, four scenarios are distinguished, namely: World Markets, National Enterprise, Local Stewardship and Global Sustainability. The storylines associated with these (Table A-1, Chapter 2) may form the basis for building the four future scenarios and can be used to quantify future trends and to define unpredictable developments to ensure consistent and distinguishable scenarios[8].

[8] Note that a distinction between our approach and that adopted in Foresight is that in Foresight the emission scenarios are not directly related to the scenarios.

A future scenario represents a possible future realisation of a combination of autonomous developments such as climate change, population growth, urbanisation, land use, etc. The uncertainties associated with predicting these developments and their possible combinations are significant and the longer the period, the greater the associated uncertainty. Even so, consideration of possible change provides an understanding of the rate of change in flood risk and promotes long-term thinking. Thus, the four scenarios form the remote corners of a multi-dimensional hyperspace, which they envelop. This complements the assessment of the strategic alternatives in the context of 'all possible' future scenarios.

Spatial and temporal scale

Spatial and temporal scales are an important issue in the definition of scenarios. As scenarios refer to all autonomous developments in an area, they must be defined at one spatial scale level above the area of interest, and one only!. For example, knowledge of population growth at the level of Great Britain is not relevant for the flood risk management strategy along the Thames, when all people tend to migrate to London. In contrast, when population development is fixed at the level of a quarter, the adequateness of spatial planning measures cannot be assessed because the people cannot be moved to higher grounds as the population development is regarded an autonomous process: a given.

As the area of interest may be large or small, for example a national or local scale flood risk management strategy, an appropriate 'down-scaling' may be needed. In a national assessment, the level of detail for the analysis is likely to be less to ensure the approach is feasible. It is therefore appropriate to use national or regional values for items such as GPD which reflect economic growth or population growth. For local, more detailed studies, a downscaling may be needed

The time scale of interest is variable, but there is also the issue of uncertainty. Climate change is a slow process and sea-level rise even more so; this knows considerable time-lag as the system at stake is a worldwide system which reacts slowly but steadily. This results in a relatively high level of predictabilty, in contrast to socio-economic developments. Especially land-use change cannot even be estimated far beyond the next 20-30 years. After that, anything may happen. As the study is exploratory, it is advised to adopt some discrete moments in time and to just assume: WHAT IF …in the various scenarios. After all, the scenarios are just a means to explore the possible futures, not the likely future. In order to build-up a picture into the future, multiple snapshots may be used. This concept is explored in more detail in task 18 of the FLOODsite project (Mc Gahey *et al.*, 2008). For practical purposes, the number of epochs to consider should be restricted, e.g. to 3: present day, medium term (e.g. 2030-40), and long-term (e.g. 2100).

3.3.2 Building scenarios

The first step in achieving at quantitative scenarios is to identify all possible and relevant drivers which may cause a change in the system. In previous studies (e.g. Office of Science and Technology, 2004), these are referred to as 'drivers of change'. A summary of possibly relevant drivers of change and the associated factors is provided in Table 3.2. The final column provides examples of the type of parameters which may be altered to reflect the change in the system model[9]. Having identified the relevant drivers of change, the next step is to determine how these will behave in the four scenarios.

Storyline and scenario development

When developing scenarios for a certain area the qualitative 'storylines' must be translated into quantitative assumptions. These assumptions can then be used for the flood risk analyses of the future situations. For this, the following steps are undertaken:

[9] Note that these examples will vary for different models.

- Describe the scenarios for the area of interest in qualitative terms: this is termed 'storyline development' (builds on Table A-1, Chapter 2);
- Next, identify the parameters which are relevant to the particular flood risk system, as, conceptually, the storyline merely describes the 'full picture'. For example, changes in the number of single headed households may be relevant for the consistency of the total scenario picture, but it will not be translated to a figure in the flood risk analysis. (Its potential effect: more houses and thus a different land use map may be incorporated);
- Once selected, these drivers of change should be classified into qualitative and quantitative parameters – this is largely based on the specific modelling method and data, as items can only be changed quantitatively if they are represented quantitatively within the model. For example, lack of public preparedness for flooding may be reflected through a reduction in the measure of social vulnerability if represented in the model (Table 3.1 may be used as a guide);
- The qualitative drivers may then be used to add context to the scenarios, i.e. to add to the 'storylines';
- The quantitative parameters may then be altered based on the likely trend for the given scenario. For example, under the National Enterprise scenario, for the driver Market Forces it is anticipated that property values will rise and people will purchase more household goods, and this may be represented through an increase in the residential damages by a factor of 2.

It should be noted that a given scenario applies to the present day through to 2100. Although the analysis is taken at a discrete epoch e.g. 2030, this is simply the snapshot at which the system is assessed in the context of that scenario. This is important when building the scenarios, as a particular change e.g. large-scale urbanisation may not happen in that particular year – but may occur at any point in time through to that year. Although this may seem obvious, it is emphasised to ensure that the appropriate data are gathered through time, i.e. the search is not limited to changes within the selected epoch.

Table 3.1 Summary of the drivers of change and related factors

	Driver of change in flood risk	**Affected factors**	**Parameters for risk analysis (examples)**
Climate	1. Climate change due to emissions or natural processes	Temperature	Model boundary conditions,
		Precipitation	Model boundary conditions
		Sea level	Model boundary conditions
		River discharges	Model boundary conditions
		Wind	Model boundary conditions
Socio-economic/institutional	2. Population growth	No. of people	Population map
	3. Public attitudes / preparedness change	People exposure & social vulnerability	Population at risk, fatality rate, recovery rate
	4. Market forces	Economic growth / decline	Land use map or depth damage curves
		Land use change	Land use map or depth damage curves
		Rise / decline in land value	Depth- damage curves
	16. Science, engineering & tech.	Vulnerability of people e.g. buildings, electronics, other	Depth damage curves
	5. Legislation (on environment / natural areas agricultural practices)	Land use change	Land use map, hydraulic roughness, river cross-sections, depth-damage curves etc.
		Soil characteristics, evaporation	Rainfall runoff parameter changes
Physical changes	5. Ground level movements	Morphology	Ground model
		Land subsidence	Condition Grade, Crest Level
		Plate tectonics	Ground model
	8. Sediment movement & veg. growth / changes	Conveyance capacity	Hydraulic roughness, model cross-sections
	18. Defence deterioration (no Flood risk management)	Strength of flood defences	Breach growth, failure characteristics

3.4 Analysis and assessment of current and future flood risks

3.4.1 Analysis of current flood risk

Flood risk measures

In FLOODsite, flood risks are defined as a function of hazard, exposure and vulnerability, or as the (integrated/ summed) product of flood probabilities and consequences. To calculate risks we thus need information on both the probabilities of flooding and of the corresponding consequences. How this is done depends on the available data, models and time.

Risks can be quantified by different measures, as extensively described in the FLOODsite report on task 9 (Messner *et al*., 2007). A summary of the most relevant overall (lumped/ comprensive) risk measures is shown in table 3.2 (after De Bruijn, 2005 and Jonkman *et al.*, 2003). Some risks can be expressed in monetary terms, for example the economic risk which can be indicated by the expected annual damage (EAD). For others, especially risk to intangibles such as fatalities, health impacts, ecological flood impacts, etc. other measures and indicators are proposed (cf. Messner *et al*., 2007), in our case: individual risk, group risk, number of affected persons, and ecological risk. Intangible impacts such as stress, loss of personal belongings (e.g. photographs), and health impacts are difficult to quantify. By considering the number of people living in flooded areas (*the affected people*) in the EANAP, some indication of this kind of impacts is obtained.

Table 3.2 Possibly relevant measures of risk: categories and indicators

Measure of risk	**Indicator**	**Abbreviation**	***Unit***
Individual risk (P_d)	Probability of dying due to a flood	P_d	*(1/year)*
Group risk to people	Expected Annual Number of Fatalities	EANC	*Number of fatalities per year*
	Fn curve: relationship between number of fatalities and the probability of an event	Fn-Curve	-
Health and psychological risk	Expected Annual Number of Affected Persons	EANAP	*Number of persons per year*
Economic risk	Expected Annual Damage	EAD	*€ per yr*
Ecological risk	No standard measure, case specific	-	-

In risk analysis studies two types of fatality risks are often distinguished: individual risk and group risk or societal risk. The measure of individual risk is used to determine the *probability* of dying due to accidents at, amongst others, airports, transport routes and hazardous installations. The Dutch Ministry of Housing Spatial Planning and Environment (VROM) has set the individual risk standard for populated areas at 10^{-6} per year. This individual risk can also be determined for floods. It is then equal to the probability of dying due to a flood (P_d). This probability is calculated by multiplying the flood probability and the fatality rate (the probability of dying if a flood occurs). Jonkman (2007) found that on average the fatality rate during a flood is 1%. In cases where the fatality rate is 1% and the individual risk standard is 10^{-6} per year, the flood probability of an event should thus be smaller than 10^{-4} per year.

Group risks may be assessed differently from individual risks, requiring another way of measuring, especially when infrequent large numbers of fatalities are considered less acceptable than more frequent small numbers of fatalities. To allow for such an assessment group risks may be expressed in FN-curves, and not only by the indicator of mean number of fatalities per year (EANC). The EANC merely gives the average annual number of fatalities due to floods in the system considered, but does not allow for weighing rare large events more heavily than more common small events. FN-curves do allow for such weighing as they relate the number of casualties to the frequency of occurrence of that number. Beckers *et al*. (2008) elaborately explored and discussed the use of FN-curves and other means of expressing group risk of floods.

As to economic risks, one might also consider weighing small and large damages differently. It is much more difficult for individuals and society as a whole to cope with rare large damage than with frequent small damages, even though the EAD may be the same. Therefore, in addition to the EAD, one might consider the use of additional measures to characterize risk, for example:

- A measures to express the ease of recovery from a flood, e.g. recovery rate (see De Bruijn, 2005);
- The expected damage resulting from an event which just exceeds the design level;
- The 'worst-credible' damage, considering physical maxima of rainfall, discharge or flood+ storm surge height;

Floods may also result in ecological impacts. No clear measures for such impacts were found, and a complication is the fact that floods also have substantial positive ecological effects. Many floodplain ecosystemes rely on frequent flooding for their well-functoning. According to the EU-Flood Risk Directive, measures for ecologiacl risk must be considered, however. This may have to be done qualitatively.

Relative risk figures: scaling

In addition to the absolute value of flood risks, more information is needed when different case study areas are compared or when one system state is compared to a system state in another year. It may not be considered fair to compare the absolute value of economic risks and fatality risks of different systems or one system in different epochs, because the damage is not distributed over the same number of inhabitants and the different regions are not equally wealthy in all periods (De Bruijn, 2005). Therefore, additional figures are proposed, such as the EAD as a percentage of the GDP of the relevant socio-economic system in which the flood-prone area is situated;

Uncertainties

Flood risk analyses involve many uncertainties. The input data are uncertain, the models involve model uncertainties, the assumptions used are uncertain, the analyses are usually not complete and the analyses of future situations are inherently uncertain. However, these uncertainties do not necessarily prohibit to draw conclusions. Although the exact figures may be wrong, the order of magnitude may be right and the differences between alternatives may also be significant. It is important to explain clearly which assumptions were made, where uncertainties are large and what effect they may have.

3.4.2 Assessment of current flood risk

When the risks are quantified, it must be assessed whether they are acceptable. The acceptance of risks by society can usually not be clearly motivated. Risk assessment is highly subjective and strongly depends on societal preferences and values. Societies which are risk-avoiding will accept lower risks than societies which are not. Furthermore, the acceptance of flood risks depends on whether floods are an issue with a high priority. If there are other important issues which need funding, higher flood risks may have to be accepted. Also disasters and near-disasters will trigger public opinion and enhance investments in flood risk lowering. Additional factors include the costs of reducing risks, the benefits of living in flood-prone areas and the distribution of the flood-related costs and benefits over different groups and individuals.

The question which flood risk is acceptable has, however, been asked in all times. Despite this being a normative question which should not be answered by scientists, scientists may provide arguments, facts and/or methods to help policy makers to decide which risk is acceptable. As for methods, risks can be assessed by:

- Comparison with risk standards/ agreements / or legal requirements;
- Comparison with other risks;
- Comparison with GDP and number of inhabitants (see below);
- Comparing costs to reduce risk with the risk reduction (Cost-Benefit analysis).

Risk standards/ legal requirements

In some countries there are risk standards provided in law. In the Netherlands, for example, the Law on Flood Defense prescribes for each flood-prone area the probability of the conditions on which the design of embankments must be based. The probability for the densely populated western coastal area is 1/10,000, while for the areas along the rivers in the eastern part of the Netherlands probabilities of 1/1250 per year are prescribed. These probabilities were derived from a risk analysis, although they now relate to hazard conditions only. The areas with the highest potential damage have the highest protection level, while the areas with less potential damage have lower protection levels. There are, however, no flood risk standards prescribed by law.

Comparison with other risks

Flood risks may also be compared to other risks to assess whether they are too high. When comparing risks due to different causes it is important to take into account the voluntariness of the risk and the benefits for the risk takers. Generally, higher risks are accepted for activities which are voluntary and offer benefits to the risk takers such as for example smoking, mountaineering and motor driving. The probability to die due to those activities varies around $5 * 10^{-3}$ to $1 * 10^{-6}$ (Ministerie van VROM, 1989). For involuntary risks without direct benefits, such as risks associated with nuclear power plants and chemical factories, safety standards are generally 10^{-6} or higher. In areas where large parts are flood-prone and inhabitants have no real option to choose where they live (such as in the Netherlands) flood risks are often considered involuntary and bearing the flood risk does not offer a clear direct benefit to the individual. In situations where people clearly choose to live in a dangerous location the flood risk can be regarded voluntary.

For the mutual comparison of group risks equation 3 is sometimes used (Van der Most *et al.*, 2006), with $P(x)$ being the accepted probability of an event with x fatalities, c a constant, and a being the slope of the line. If a equals one, the relationship is linear and one fatality every year is considered as serious as 10 fatalities once in every 10 years. If a is 1.5 an event with 100 fatalities should occur 1000 times less frequently then an event with one fatality. Van der Most *et al*. (2006) shows examples with group risks of about 0.1 to 0.2 fatalities per year on average.

$$P(x) = c \cdot x^{-a} \qquad \text{(Eq. 3)}$$

Comparison with the GDP and number of inhabitants

To assess flood risks it is possible to compare economic risk with the GDP and/or group risk with the number of inhabitants of the relevant area. This is usually the nation or region. The risk is then calculated as the percentage of the GDP and the fatalities and affected persons are expressed as a percentage of the total population in a country (De Bruijn, 2005). De Bruijn (2005) showed that although flood risks caused by river floods in Cambodia are much lower than in the Netherlands, when they are expressed as a percentage of the GDP it becomes clear that thye are a more serious problem in Cambodia than in the Netherlands. In Cambodia they are 34 % of the GDP, while the flood risks along the non-tidal part of the Rhine River are only about 0.2 % of the Dutch GDP. Similar analyses could be carried out for the number of affected persons and the expected number of fatalities.

TEXTBOX: Acceptability of flood risks

Acceptance of individual risks
Vrijling et al. (1998) provides a formula for the acceptable probability of failure (P_{fi}) of embankments which depends on how voluntary the risk is (expressed by the factor β_i), ranging from completely voluntary to involuntary, and the probability of dying in case of a flood ($P_{d|fi}$) (see equation 3 below). This formula provides the acceptable probability of failure from the view of individual risks. Vrijling et al. (1998) assume that the probability of dying in case of a flood ($P_{d|fi}$) is 0.01. In this case the acceptable probability of failure of embankments is thus 10^{-2} per year if floods are considered a neutral risk and 10^{-4} per year if floods are considered an involuntary risk.

Table 3.3The value of the policy factor β_i as a function of voluntariness and benefit (Source: Vrijling et al., 1998)

β_i	Voluntariness	Direct benefit	Example
100	Completely voluntary	Direct benefit	Mountaineering
10	Voluntary	Direct benefit	Motor biking
1	Neutral	Direct benefit	Car driving
0.1	Involuntary	Some Benefit	Chemical factory
0.01	Involuntary	No Benefit	LPG-station

$$P_{fi} = \frac{\beta_i .10^{-4}}{P_{d|fi}} \qquad \text{(Eq. 3)}$$

Acceptance of societal risks
For the acceptance of societal risks equation 4 is often used (Van der Most et al., 2006). *P(x)* is the acceptable probability of an event with *x* fatalities, *c* is a constant, and *a* is the slope of the curve. If *a* equals one, the relationship is linear and one fatality every year is considered as serious as ten fatalities once in every 10 years. If *a* is 1.5 an event with 100 fatalities should occur 1000 times less frequently then an event with one fatality. Van der Most et al (2006) show examples with group risks of about 0.1 to 0.2 fatalities per year on average.

$$P(x) = c \cdot x^{-a} \qquad \text{(Eq. 4)}$$

To evaluate societal risk Vrijling et al. (1998) consider the expected number of fatalities ($E(N_{di})$), the voluntariness of the risk (factor β_i) and the risk aversion index of society (factor k) (see Equation 5). The concept of risk aversion is reflected in the standard deviation. Relatively small accidents are more easily accepted than one single rare accident. Vrijling et al. (1998) proposed to use a β_i of 0.01 (involuntary risk) and a ‘k factor’ of 3 (risk averse) for the assessment of societal flood risks in the Netherlands.

$$E(N_{di}) + k.\sigma(N_{di}) < \beta_i .100 \qquad \text{(Eq. 5)}$$

It has to be stressed that Vrijling does not include all factors that influence the assessment of flood risks, and for the factors that are included different choices can be made as well. Ultimately, flood risk assessment remains a social and political issue, which may be informed by different technical measures and comparisons.

Assessment based on cost-benefit analyses

Whether it is economically sensible to invest in lowering flood risks may be established by cost-benefit analyses. If the optimum protection is reached, the remaining risk could be considered acceptable – at least from an economic point of view, which is not necessarily the same as a societal point of view! In such cost-benefit analyses the costs of measures are compared with the achieved risk reduction. The risk reduction resulting from a certain strategic alternative is found by comparing the risk in the do-nothing situation with the risk resulting from implementing the strategic alternative.

It is difficult, if not undesirable, to include casualties in a cost-benefit analysis. Moreover, attention should be paid to distributional issues.

Even if it is not clear whether current flood risks are acceptable, it is worthwhile to consider alternative strategies for flood risk management, because flood risks are expected to increase in the future. By comparing and evaluating the current and alternative strategies, scientists can help decision makers to decide whether the current strategy is acceptable.

3.4.3 Analysis and assessment of possible future flood risks

Not only the current flood risks, but also the expected future flood risks must be analysed and assessed. To do this, the same procedure as described in the previous section is to be used, but the flood risks are analysed and assessed for situations in the future as they result from different future scenarios and continuation of the current strategy. This current strategy may require maintenance and even recurrent upgrading of flood defence and control infrastructure – as in the Netherlands –, or allow for deterioration of the defences – as in the UK. Such characteristics of the current strategy should be taken into account and may also influence the costs of continuing the current strategy in various future scenarios (compare the pilots Schelde and Thames in chapters 4 and 5).

3.4.4 Summary of flood risk analyses and assessment steps

When analysing and assessing flood risks the following steps should be carried out:

1. Determine the risk measures as shown in table 3.2 (EAD, EANAP, P_d, EANC and if relevant an FN curve and/or the ecological risk) for the present and future situations;
2. Consider whether other measures besides risk are relevant to the specific case study and calculate if relevant (e.g. recovery rate, damage from the worst credible event, etc.).
3. Determine the risk as percentage of the GDP and the number of fatalities and affected persons as percentage of the number of inhabitants;
4. Compare the risk figures with available risk standards (if any), with other risks (e.g. due to chemical plants);
5. Draw conclusions on the acceptability of the flood risks now and in the various possible futures.

At the end of this it may still be impossible to conclude whether the current flood risk management strategy results in acceptable flood risks in the long-term or not. This is because acceptability is such a subjective item. However, the procedure yields clear quantitative information which may enhance the discussion on long-term flood risk management.

3.5 Development of strategic alternatives

3.5.1 Introduction

A strategic alternative is a coherent set (or ‘portfolio’) of flood risk management measures and related policy instruments for the future. In long-term flood risk management planning, alternatives are defined for the next 20 to 100 years.

As discussed in chapter 2, strategic alternatives should be visionary; they are defined by a top-down approach in which stakeholders do not need to be directly involved. The alternatives should show policy makers what would happen if their policy would remain unchanged and what the future might look like if they would change the direction of their policies. Long-term strategic alternatives do not provide us with very detailed plans which are ready to be implemented on local level. In contrast, they are quite extreme, clear images resulting from the application of a certain idea into flood risk management. For practical reasons, the number of alternatives should be limited to about three to five.

The following sections explain the use of guiding principles to develop strategic alternatives and discuss how alternatives can be defined using a long-list of measures and instruments. Finally, section 3.6.5 summarizes the method to develop alternatives in the case studies.

3.5.2 Use of guiding principles

Chapter two proposed to define strategies based on guiding principles, since this will allow us to use a top-down approach and to develop clear visionary strategies. With one primary principle one could develop two or three strategies. If more strategies are needed, secondary guiding principles may need to be used.

As primary guiding principle one could use:

- 'world-views' especially on the issue of how mankind should relate to (manage, control, gouvern, dominate, etc) his physical environment (the 'planet') and his fellow-men (the 'people') (see section 2.3, especially the text-box on the world-views according to Thompson);
- The concepts of resilience and resistance.

Use of world views as guiding principles

World views may be used as guiding for developing strategic alternatives. The differences in those views are then used to select different types of measures and develop different, contrasting strategic alternatives. In the full assessment the alternatives will be assessed against all future scenarios, also scenarios which may rather match a completely different world view. This will provide insight in the functioning of strategies in scenarios for which they were not designed.

The world views as discussed in chapter 2 can be used to develop strategic alternatives. Instead of using world views it is also possible to use only one element from these world views as guiding principle for alternatives, such as the preferences of people for nature, economy or social equity. A strategic alternative which is designed for a society with preference for nature would contain other measures than a strategic alternative which tries to maximize economic profits. The first would probably require more space for natural flooding processes and plea for adaptation to natural variability, while the latter is expected to focus on flood defence and constraining natural behaviour.

Another element of world views which may provide guidance to the development of alternatives is the different expectancy concerning the influence (power) a flood risk manager may have (belief in technology, legal regulations, etc.; compare the Controlist's view with that of the Fatalist's). If flood risk managers are supposed to have power over nature only, measures will be limited to flood defences and flood control measures. If flood risk managers are expected to also be able to influence people's behaviour and land use, also other measures and instruments may be incorporated a in strategic alternative.

Use of resilience and resistance as guiding principles

Resilience and resistance can be used as guiding principles for the definition of strategic alternatives too (De Bruijn, 2005; Vis *et al.*, 2003). These principles are based on a systems approach. Together, they define the reaction of *a system* to disturbances. In flood risk management, resistance can be defined as the ability of the system to prevent floods, while resilience is defined as the ability of the system to recover from floods somewhere within the system (De Bruijn, 2005). The resistance of the system thus determines which flood waves or which water levels can still occur without causing floods, while the resilience determines the ease of the system to recover from flood impacts (see textbox 3.1). Most systems have both resilience and resistance. The resistance of the system enables the system to withstand the more frequent events, while the resilience determines the ability to recover from floods which do occur. Both resilience and resistance together determine the systems ability to cope with floods.

Resilience and resistance (after De Bruijn, 2005)
Resistance can be quantified by the ‘reaction threshold’: the highest discharge or water level, or the most extreme precipitation event which does not cause floods. The resistance of a system can be increased by raising the reaction threshold. In systems with a high resistance extreme events will not cause floods. However, events which are beyond the reaction threshold may cause disasters.

Resilience can be described and quantified by three aspects (see figure 1):
- The magnitude of the reaction, or, in this case, the flood impacts;
- The graduality of the increase of reaction with increasingly severe disturbances;
- The recovery rate.

The resilience of a system can thus be increased by reducing flood impacts, by increasing graduality or by increasing the recovery rate. In general, in resilience strategies no sudden catastrophies will occur but damage will increase gradually with disturbance. In a resilient system floods do result in adverse impacts, but these impacts are not catastrophic and they are soon recovered from.

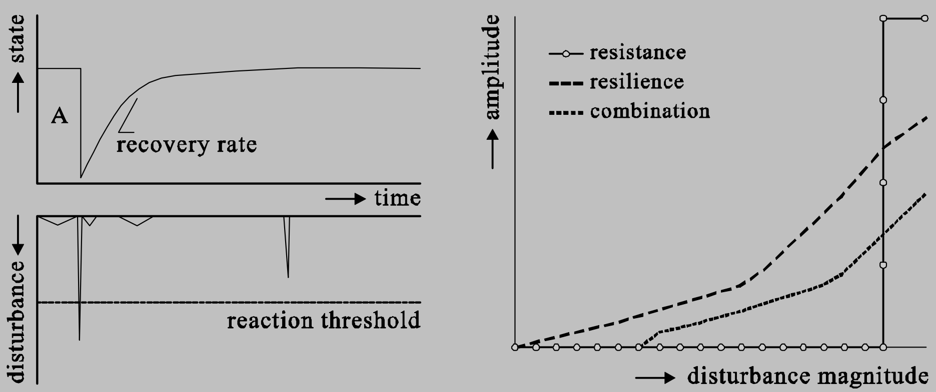


Figure 1. Left: The hypothetical system of this picture has resistance to cope with small disturbances. Therefore, no reaction to these disturbances is visible. To cope with larger disturbances, the system has resilience. The degree of resilience depends on the magnitude (A) of the reaction and the recovery rate

Right: The relationship between reaction amplitude (the same as reaction magnitude) and disturbance magnitude for a resilient and a resistant system and a system that has both system characteristics (source: De Bruijn, 2005)

Two examples for respectively a lowland river and an estuary are provided: In flood risk management of lowland rivers the system consists of the lowland river stretch and the adjacent flood-prone area and includes society within this area (see figure 3.2). Peak discharges coming from the upper river may act as disturbances on the functioning of this system. If the system is negatively affected by these high discharges, its resilience determines the rate of recovery. If the resistance of the system is sufficiently high, peak discharges will pass through to the tidal area without causing any damage. In estuaries the system may consists of the estuarine water bodies and the adjacent flood-prone area. Disturbances from outside may consist of surges and extreme discharges from the inflowing rivers. Depending on the system’s resilience and resistance, these high water levels and discharges may be resisted or they may cause floods from which the system must recover.

An elaborate review on the origin and meaning of resilience is provided by De Bruijn (2005).

Decision makers may choose measures which enhance the resilience or the resistance of the system, or both, in order to make the system able to cope with these disturbances. Resilience strategies for flood risk management are defined as strategies that increase the system property ‘resilience’ and resistance strategies as strategies that enlarge a system’s resistance. *Resilience strategies can be understood as strategies that allow floods, but aim at minimizing flood impacts, maximizing recovery rates and ensure a gradual increase of flood impacts with increasingly severe events*. They aim at increasing the capability of a system to recover from flood impacts. In contrast, *resistance strategies can be understood as strategies which prevent that events below a certain threshold cause floods*.

The two strategies apply different combinations of measures, although the same measures may be used in both resilience and resistance strategies. Resilience strategies try to direct floods to the less vulnerable areas and to limit the flood extent by, for example, compartmentalisation or to lower flood impacts by, for example, measures such as flood-proofing and land use regulations. They can also focus on the increase of the recovery rate by, for example, insurances and enhancing preparedness. Resilience strategies involve both structural and non-structural measures. In resistance strategies, in contrast, flood protection by means of structural measures dominates.

For an exploration of possible long-term strategic alternatives for flood risk management a wide range of options must be studied. The distinction of an extremely resistant and an extremely resilient alternative, as well as a strategy which has both resilience and resistance, guarantee this wide range. Next to these alternatives also the current flood risk management strategy and a do-nothing strategy should be considered.

Using secondary guiding principles

Sometimes, one primary guiding principle is not sufficient to explore a wide range of possible alternative strategies. To create more strategic alternatives a sensible secondary guiding principle must be selected. One might use the contradiction between optimizing for economy versus optimizing for ecology as Vis *et al.* (2001) and De Bruijn (2005) did and define different resilience strategies. For defining different resistance strategies one might use the distinction between a concentrated defence and a long-defence line (a flood barrier versus embankment strengthening along the whole length of the river). As secondary guiding principles also many other concepts may used. Which one is sensible, is case specific.

3.5.3 Selecting measures for the strategic alternatives

The strategic alternatives comprise of combinations of measures and instruments. The measures and instruments of which the alternatives are composed can be selected from the long list of “all” options scored on effectiveness for the area involved. Measures and instruments only include those that influence the flood risk system. Each alternative is a set of technical, regulatory, financial, and communication measures. This section discusses how different measures can be selected and combined in order to develop resilience or a resistance strategy. The findings of FLOODsite Task 12 are used.

As a start a long list of measures characterised by their aimed effect and their character is provided (table 3.1). The guiding principle of the strategy guides into the direction of a certain measure type. Based on this preference and the effectiveness of the measure a selection of promising measures is made.

Measures with different aims and character

Measures and instruments can be distinguished by their ***(sub)aim (***see table 3.4)**.** They may reduce flood probabilities or alternatively, flood impacts. Flood probabilities can be reduced by measures and instruments which focus on *flood abatement* and aim to prevent or reduce hazards, or by measures which focus on *flood defence* and aim to prevent floods. This latter category includes measures as embankment raising as well as measures which create room for the river or Estuary in order to prevent floods. Flood impacts can be reduced by *controlling flood patterns* in such a way that the least vulnerable areas become flooded, by *adaptation and regulation of the land use* in the flood-prone area or by improving *preparedness* or *distribution* of the impacts over more people. In the context of the SPRC model, flood abatement measures focus on the source term, flood defense measures and measures which control flood patterns cope with the pathway term and measures aiming at land use adaptation and regulation or on increasing preparedness affect the receptor term.

In river floods for example, the following chain of event results in flood impacts:
- Intensive or prolonged rainfall in combination with specific local circumstances can cause flood waves in a river;
- These flood waves may cause floods in the downstream area;
- If these floods conflict with economic activities, negative flood impacts will occur.

Measures and instruments may focus on the first chain and aim to prevent rainfall to cause peak flows in the river *(flood abatement)*, or they may aim at preventing these peak flows to cause floods *(flood defence)*, or they may aim at alleviating the impacts of floods when they do occur *(flood impact reduction)*. In the case of sea or estuarine floods the chain of events is comparable with the one for river floods. In the case of sea floods storms may cause high water levels and high waves. Local circumstances (sand banks, wetlands etc) may cause an increase of wave heights or a decrease of wave heights before they reach the coast. Defensive works at the coastline may prevent the waves or high water levels to cause floods and flood alleviation measures and instruments may reduce flood impacts in the case of flooding. The general idea that measures and instruments may influence different steps within the chain of events applies to all flood types.

Measures and instruments can be of different ***character.*** Distinguished are (Hooijer *et al,* 2002; Ölfert & Schanze, 2007):
- Technical measures (detention basins, dikes, etc.)
- Regulatory instruments (zoning, legal instruments, etc.)
- Financial instruments (burden sharing, subsidies, financial compensation, insurance, etc.)
- Communicative instruments (warning, awareness raising (brochures, DSS, mass media), etc)

Selection of measures for the resistance and resilience strategy

With the help of Table 3.4 and our understanding of resilience and resistance we can now define strategies. A resistance strategy aims at flood prevention. We start therefore with considering measures which aim at *flood defence,* such as embankments and barriers. First, all measures within this category are scored on effectiveness for the specific study area. Then they are ranked according to their score (see textbox 3.2 for an example of the lowland part of the Rhine River).

A resilience strategy aims to prevent sudden catastrophes and enhances recovery. We start therefore with measures which *control flood patterns in such a way that* the least vulnerable are flooded most frequently, while flooding of the more vulnerable areas is prevented. We then add measures that aim at reducing flood impacts by *adaptation and regulation of the use* of the flood-prone area and add measures that enhance recovery by improving the *preparedness* of the inhabitants and by *impact distribution.* When measures of different character are available, first structural measures are considered, then regulatory, financial and communicative instruments are added. Within each group of measures, the measures are ranked according to their effectiveness.

The strategy which has resilience and resistance elements but both in a lower degree than the extreme resilience and resistance strategy, can be developed by taking elements of both strategies and combine them according to the estimated effectiveness of the measures. This is done based on knowledge of the area and its developments.

Table 3.4 List of flood risk management measures and instruments according to aim, subaim and character

Aim	Subaim	Character	Name
Flood probability reduction	'Flood abatement' or flood prevention	Structural	• Conservation tillage • Dams/reservoirs • Reforestation • Restoring meanders in brooks and rivers • Retention in upstream catchment • Retention of water in cities • Wave breakers
		Regulatory	• Wetlands conservation/rehabilitation • Coastal wetland protection
	Flood defence & control	Structural	• Embankment construction/strengthening • Flood barrier • Mobile flood wall • Coastal sand supply • Bypasses • Connect rivers to existing lakes • Dredging rivers • Embankment relocation/realignment • Floodplain lowering • Removing obstacles to lower hydraulic roughness • River bed widening
Flood impact reduction	Control of flood patterns	Structural	• Compartmentalisation of areas • Detention areas/calamity polders • Floodway • Ring dikes along villages/cities • Mounds
	Adaptation & regulation of use of flood-prone area	Structural	• Flood proofing
		Regulatory	• Building restrictions • Land use zoning • Regulations on storage of toxics/chemicals • Adaptation of recreation functions • Adaptation of agricultural practices
		Financial	• Fines for damage increasing behaviour • Subsidies for flood proofing or other measures
	Distribution of flood impacts	Financial	• Damage compensation • Governmental relief funds • Insurances
	Preparedness	Communicative	• Crisis management • Education of inhabitants • Evacuation plans • Flood forecasting • Flood risk maps • Flood warning systems • Radio/Television information channel

* This list was developed for FLOODsite task 12.

When more than one resilience or resistance strategy is developed based on a secondary guiding principle, the list of measures and their scores on effectiveness is also useful. One could for example develop a resilience strategy with mainly measures aiming at adaptation and regulation of land use and one with mainly measures aiming at controlling flood patterns. As explained in section 3.5.1 for each case study also other secondary guiding principles can be used.

Explanation of the selection of measures based on the degree of resilience and resistance for the lowland river part of the Rhine River

A *resistance strategy* for the lowland part of the Rhine River would consist of measures in and along the river bed. Dike strengthening would be the main measure, while at some locations also removing obstacles, lowering the winter bed, lowering the summer bed (dredging) could be considered (see table T1).

A *resilience strategy* for the lowland part of the Rhine River would consist of compartmentalisation and differentiation of flood protection levels. The least vulnerable parts of the area could be used as detention areas while the most vulnerable areas should have the highest protection level. Combined with compartmentalisation and flood probability differentiation land zoning would further reduce flood impacts. The most frequently flooded area might benefit from building restrictions or land use changes, while in the least frequently flooded area all types of land uses could be allowed. Preparedness measures are added to reduce flood impacts and enhance recovery (see table T2).

In the Rhine River a *combined strategy* would consist of embankment maintenance to guarantee for example a protection against 1/1000 year events, while during more rare events measures as compartmentalisation and flood probability differentiation guide flood waters to the least vulnerable areas.

Table T1 List of flood risk management measures and instruments aiming at flood defence. Their effectiveness and feasibility are scored for the lowland river Rhine*

Measures and instruments	***Effectiveness***
Embankment constructing / strengthening	++
Removing obstacles to lower hydraulic roughness	+
Dredging/cleaning river beds	++
Floodplain lowering	+
Bypasses	+
Embankment relocation	++
River bed widening	+
Flood barrier	--
Coastal sand supply	--
Connect rivers to existing lakes	--

*(scored by an expert, the values serve as an example; values are not based on exhaustive calculations)

Table T2 List of flood risk management measures and instruments. Their effectiveness (E) scored for the lowland

river Rhine*. The +/- are relative scores compared with other measures with the same aim

(Sub)Aim	***Measures and instruments***	***E***
Flood regulation	Detention areas/calamity polders	++
	Compartmentalisation of areas	++
	Floodway	+
	Ring dikes around villages/cities	+
	Mounds	0
Adaptation & regulation of use of flood-prone area	Land use zoning	++
	Flood proofing	+
	Building restrictions	+
	Regulations on storage of toxics/chemicals	+
	Adaptation of agricultural practices	0
	Adaptation of recreation functions	0
	Fines for damage-increasing behaviour	0
	Subsidises for flood proofing or other measures	0

Selection of measures for different world views

When world views are used as guiding principles, one could select measures as follows:

- For world views or scenarios based on the idea that market forces should regulate society a selection of cost-efficient measures which allows economic use of flood-prone areas should be made. Mainly flood defence measures would then be selected. Regulatory measures and instruments which restrict economic possibilities will probably not be considered. Technical and financial measures may be selected as well.
- For world views or scenarios in which people feel responsible for the poor, the socially weaker people and for nature, other measure selections are expected. In such worlds people would prefer measures which do not harm nature. They may select first regulatory then communicative, financial and finally structural measures.

If the power of flood risk managers is used as criterion, and flood risk managers only have power over water bodies and shores, then measures will be limited to structural measures in and along water bodies. At the other hand, if flood risk managers also have power to change spatial planning, then also flood-abatement measures as conservation tillage, measures which aim to control flood patterns, and measures which try to adapt and regulate the use of flood-prone areas should be considered.

3.5.4 Summary of procedure to develop strategic alternatives

The method to develop long term strategic alternatives discussed in this section can be summarized as:

- Choose a primary guiding principle: either use ‘world views’ as guidance or use resilience and resistance as guiding principles.
- Define extreme strategies according to the primary principle: for example an extreme resistance strategy in which preferably measures are used which aim at flood defence and an extreme resilience strategy in which preferably measures are used which aim at flood regulation, adaptation or regulation of use of the flood plain, measures that increase preparation and focus on flood impact distribution;
- If more strategic alternatives are needed, select a secondary guiding principle and select measures based on that principle to develop additional strategies.

When the strategic alternatives have been developed they can be analysed and assessed across different future scenarios in a similar way as the current strategy was analysed across these scenarios (see chapter 3.4).

3.6 Full assessment of strategic alternatives

In section 2.4 a review was provided on how to perform a full assessment of strategic alternatives. From this review it was concluded that :

- the assessment criteria should cover the three sustainability domains (People, Planet, Profit) as well as criteria for the capability to cope with uncertainties, comprehending uncertainty about natural variability (requiring robustness) and uncertainty about gradual change (requiring flexibility).
- The criteria and indicators should be distributed equally over these sustainability domains, so that they receive a balanced treatment in the evaluation.
- A general level of abstraction of the indicators and a simple and practical method to obtain indicator values suffices for the purpose of evaluating long term flood risk strategic alternatives.
- Either the Delphi method or a Multi Criteria Analysis are suitable for obtaining and integrating scores. The results should be presented in a simple and understandable (preferably visually attractive) way.

These conclusions are used to propose a framework for a full assessment in this section.

Criteria for a full assessment

We propose to use the set of criteria shown in table 3.5 in order to duely cover the three domains of sustainable development, viz. people, planet and profit, as well as criteria which specifically pertain to 'dealing with uncertainties'. Also, both the intended effects of flood risk management are covered by criteria for all three sustainbility domains, and the unintended side-effects of implementing measures and instruments to these three domains

Table 3.5 The framework of criteria and indicators for a full assessment

Sustainability field	**Criterion**	**Indicators**
People (socio-psychological effects)	Casualty risk	EANC (casualties/yr)
	Personal intangible flood impacts (stress, loss of personal belongings, illness, etc.)	EANAP (affected persons /yr)
	Equity	-
Planet (ecological effects)	Landscape quality	-
	Nature	-
Profit (economic effects)	Implementation costs	Present value of costs (€)
	Economic risk	Present value of risk reduction compared to the do-nothing strategy (€), OR EAD (€/yr)
	Economic opportunities	-
Sensitivy to uncertainties	Robustness	-
	Flexibility	-

With respect to '*people*', the expected casualty risk, the expected personal intangible effects (covering, among other things, stress, illness and loss of personal belongings) and effects on social equity are proposed. As indicators for the first two criteria the expected annual number of casualties (EANC) and the expected annual number of affected persons (EANAP) may be used. The criterion 'equity' needs to be considered only, if a strategic alternative causes the differences between rich and poor people to increase (e.g. due to insurance costs) or if the persons who benefit from the strategy are different from the ones who suffer from the disadvantages and costs of the strategy. Since no clear indicator for equity is known, it may be scored qualitatively.

For '*planet*' the criteria 'effects on nature' and 'effects on landscape quality' are proposed. Both may be scored qualitatively, or quantitatively (e.g. by comparing areas available for nature in different strategies). Nature may be negatively affected by for example pollution due to floods, by salt in the flood water, or by the measures itself: if the area available for nature becomes smaller.

The sustanability domain of '*profit'* is covered by the criteria: costs, economic risk or economic risk reduction, and economic opportunities. The economic opportunities criterion expresses whether the strategic alternative enhances or decreases the land use possibilities of the region or the economic option value. If floods occur more frequently, or if a smaller area is available for economic use, economy may be negatively affected. If, however, the area becomes safer, or suitable for other land use types, it may be more attractive for investors and the strategic alternative would score positively on this criterion.

The *sensitivity of the strategic alternative to uncertainties* is scored by the criteria 'robustness and flexibility'. Strategic alternatives resulting in systems that are able to cope with disturbances are called robust and those that can be adapted to all kind of circumstances are flexible (De Bruijn, 2005). Robustness thus relates to the sensitivity to unexpected events (events which the strategy is not designed for). In order to assess a system's robustness, one might ask:

- What would happen if the storm duration is longer or if peak water levels are higher than expected?
- What if certain structures fail, or if important people are not available, or if information services fail?
- What if people do not behave as required when evacuation of an area is required?
- Etc.

Flexibility is defined as (1) the possibility to adapt to changes in due time, whilst (2) minimizing future regrets resulting from irreversible decisions and/or effects (free after Vis *et al.*, 2001 and Kwadijk *et al.*, 2006). A strategic alternative is thus flexible when it can be adapted to *changing circumstances* in time, but not too late, as that might also cause huge regrets. Strategic alternatives which require little investments, or which may be adapted in time since they are implemented stepwise and strategies which do not cause irreversible changes are thus considered as being more flexible than others. Changing circumstances may involve climate change, economic growth, changing societal preferences, etc. To assess the system's flexibility, the following questions may be put:

- Is it possible to phase measures and investments with changing circumstances and conditions?
- Is it possible to undo measures without irreversible effects and without capital losses resulting from investments that cannot be recovered?

The criteria and indicators and the level of detail applied must be adapted to the needs of the case study in consideration.

The quantitative indicators which may used for the criteria are presented in table 3.5 as well. For the criteria where no indicators are mentioned a qualitative approach is needed. For those criteria, it is advised to use the Delphi-method.

The Delphi method

The Delphi method consists of several steps:

1. Independent experts are selected to be member of the expert panel. Invited people must be experts in the field of one or more of the envisaged criteria, and together they have to cover the entire set of criteria for full assessment.
2. The experts read and discuss the strategic alternatives, scenarios and assessment criteria to compare their understanding.
3. Agreements are made on the assessment method:
    a. Which scenarios are scored and for which time epochs?
    b. What is the scoring reference? (the current status, the current policy or the expected effects of the do-nothing alternative in the different scenarios?)
    c. What is the scoring procedure and time-table?
4. All experts individually score the different alternatives for the future scenarios and time epochs agreed on.
5. Scores are distributed, compared and discussed and motivations behind the scores are collected.
6. The experts are asked to reconsider their scores.
7. Step 6 and 7 may be repeated several times until concensus is reached. (or alternatively: the mean and range of the scores are determined).

Finally, the scores of the strategic alternatives on the assessment scores must be presented in a clear way, analysed and discussed and conclusions must be drawn. It is recommended to try to answer questions such as:

- Which strategic alternative scores best on the people aspect, which one is best for the planet aspects, the profit aspects and which one is least sensitive to uncertainties?
- What is the effect of the different future scenarios on the scores of the strategic alternatives?
- Are there strategic alternatives which score well in all future scenarios?

Summary of the full assessment method

1. Select the assessment criteria which are relevant for the case study and together cover the three sustainability fields people, planet and profit and the sensitivity to uncertainties.
2. Select relevant indicators for the criteria.
3. Calculate the values for the quantitative indicators.
4. Use the Delphi-method for the criteria for which no quantitative indicators can be found.
5. Present the scores, analyse and discuss them and draw conclusions.

4. The Schelde Estuary

In this chapter the methods discussed in the previous chapters are applied on the Schelde Estuary. This chapter discusses the Schelde River Basin, scenarios for future change in the area, current and future flood risk analysis, and strategic alternatives for flood risk management. Finally, the strategic alternatives are assessed against sustainability criteria.

4.1 The case study area

The Schelde Estuary consists of the Schelde catchment and the Westerschelde Estuary and its flood-prone area. The Schelde River flows from France through Belgium until it reaches the Westerschelde in the Netherlands. This Westerschelde is a wide estuary connected to the North Sea (see figure 4.1). The average discharge of the Schelde into the Westerschelde is 127 m^3/s. The water levels in the Schelde River downstream of Gent and in the Westerschelde are dominated by the tides. The tidal difference in the Westerschelde increases from west (3.86 m) to east (4.83 m) and near Antwerpen it even reaches 5.20 m (ARCADIS *et al.*, 2004). Critical water levels for the Schelde Estuary occur when severe storm surges coincide with high tides.

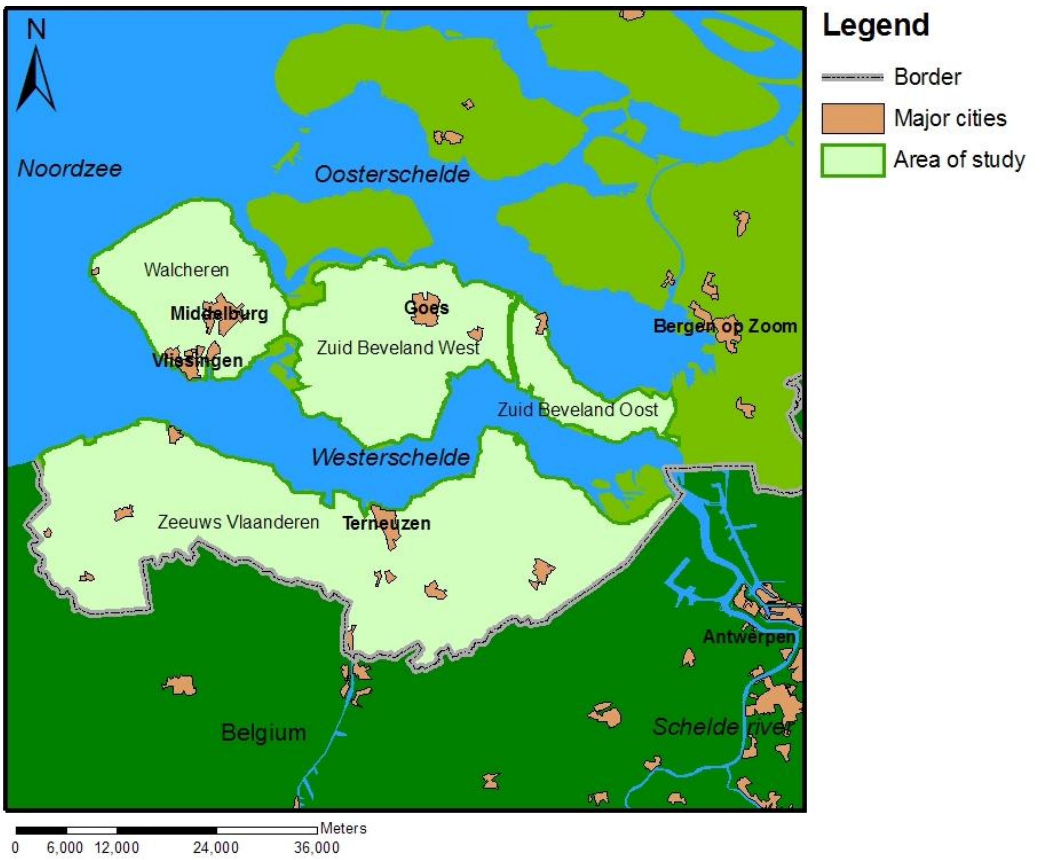


Figure 4.1 Overview of the Schelde River and Westerschelde Estuary (the study area is bright green)

This case study focuses on the Dutch part of the Schelde Estuary and includes both the Westerschelde and its flood-prone area. The study area is bounded by the Oosterschelde water body (North), the Kreekrak Canal (East, not visible in map) and the Belgium-Dutch border (South). The Schelde River which flows into the eastern part of the Westerschelde Estuary has a negligible effect on the water levels and discharges in the Westerschelde during extreme events. The effect of measures in and along the Westerschelde on water levels in the Schelde River, however, may be relevant. Strategic alternatives which include large changes in land use or economic activities may also have trans-boundary effects on land uses and population. It would, therefore, be interesting to study the whole Schelde Estuary including the tidal Schelde River. However, for practical reasons this study focuses on the Dutch part only. In section 4.7 the meaning of the conclusions for the Belgium part will be discussed in a qualitative way. The remainder of this section will describe the Westerschelde and its flood-prone area.

The flood-prone area around the Westerschelde mainly consists of low-lying polders. It is divided into different dike rings which are separated from each other by high embankments or higher areas. The four dike ring areas are called Walcheren, Zuid-Beveland-West, Zuid-Beveland-Oost, and Zeeuws-Vlaanderen (see figure 4.1). There are many ancient embankments present in the flood-prone area which currently function as secondary embankments. If these hold during floods, they will significantly affect the flood extent and flood depths in the different subareas.

The land use functions of the flood-prone area are residential area, industries, transport, agriculture and nature. Tourism and fisheries are also important for the economy in the region. The industry is mainly located near the harbours of Vlissingen and Terneuzen. The Westerschelde itself is important for navigation: many large ships pass through on their way to the harbour of Antwerpen in Belgium (see figure 4.1). The intertidal areas along the shores of the estuary host fauna and flora-rich salt marshes and provide feeding grounds for birds and resting areas for the increasing population of seals. In the research area has about 300,000 inhabitants.

In 1953 a North Sea storm coincided with high tides and many embankments could not hold. The resulting flood caused a lot of damage and casualties in the Netherlands, and some damage in Belgium. This flood triggered the development of the Delta Plan which included the raising of embankments along the Westerschelde to withstand sea conditions with a probability of 1/4000 a year.

The system described in this section changes in time. Slow natural geological processes occur and human actions such as removing of polders and dredging still affect sedimentation processes. Further dredging of the Westerschelde together with expected sea level rise will result in further changes in the morphology of the Westerschelde in the future. Next to changes in the physical system characteristics, also large socio-economic changes are expected. Population may further increase and agriculture may become less important for the area. All these changes will be discussed in more detail in section 4.2.

4.2 Future scenarios

4.2.1 Introduction

Scenarios on future developments are used to calculate future flood risks. The four future scenarios described in chapter 2 and 3 are downscaled and quantified for the Westerschelde Estuary. The four scenarios are:

- *World Market:* An internationally oriented world that focuses on liberty with a minimal role for policy;
- *National Enterprise:* A nationally oriented and individualistic world that has a state-centered policy;
- *'Global Sustainability':* An internationally oriented world that has strong social and environmental goals with strong governance;
- *'Local Stewardship':* A co-operative world that focuses on local solutions with a strong and local governance.

These scenarios concern the socio-economic development of the Netherlands and are assumed to behave independent from developments in climate. There are two reasons for this: (1) the effect of emissions on climate change is still uncertain and the model uncertainty of General Circulation Models (GCMs) as used by the IPCC is larger than the uncertainty due to unknown greenhouse gas emissions until 2050 (KNMI, 2006), (2) even if the Netherlands focuses on a nationalistic, social and green world and greenhouse gas emissions are reduced, in the rest of the world green house gas emissions may still increase. The climate change scenarios are, therefore, combined with the socio-economic scenarios in such a way that four different scenarios for flood risk developments are created; a worst case, a best case and two in the middle.

Table 4.1 gives an overview of the resulting scenarios. Although climate change is added to the socio-economic scenarios, the names are kept the same as in the Foresight project (see chapter 2).

Table 4.1 Overview of combined socio-economic and climate change scenarios

	World Market	**National Enterprise**	**Global Sustainability**	**Local Stewardship**
Climate change	High	Medium/high	Medium/Low	Low
Economy	High growth	Average growth	Low growth	Very low growth
Demography	High increase	Average	Low increase	Low decrease

The scenarios affect climate, the physical system, economy and demography. All these changes may influence the flood risk in this system, either by changing the hazard or by changing the vulnerability. Table 4.2 shows the importance of changes in various factors which determine the flood risk in the Schelde Estuary. A factor is found important when it is expected to change and when this change influences the flood risk in the long term.

Table 4.2 Flood risk drivers and their importance in the Schelde Estuary (-- not important at all, ++ very important)

Class	**Group**	**Factor**	**Importance**
Hazard	Climate	Precipitation change	-
		Temperature change	-
		Sea level rise	++
		Change in storm field	+
	Physiography	Vegetation change	-
		Morphology change	+/-
Vulnerability	Economy/demography	Economic change	++
		Land use change	++
		Population change	++
	Physiography	Land subsidence	-

As for climate change mainly the sea level rise and the change in storm field will influence the flood hazard in the Westerschelde Estuary. Precipitation and temperature change will affect the discharge patterns, which is not significant compared to sea level rise and storm surges in the Westerschelde Estuary. Higher upstream discharges as a result of changing precipitation and temperature patterns will not significantly influence the water levels in the estuary during high tides (see appendix A).

Not only the climate changes, but also the physiography and the economy of the system itself change. Relevant changes in physiography may be changes in channel vegetation, changes in morphology and land subsidence. No significant long-term changes in channel vegetation are expected in the

Westerschelde. However, significant changes in morphology are expected. From 1800 humans have intervened in the system by claiming land from the sea, dredging, etc. This is still affecting the flood propagation and the difference between high and low tide, and results in an increase of flood hazards. Moreover, the Westerschelde is currently being deepened to allow larger ships into the harbour of Antwerpen. The effect of this deepening on extremely high water levels is estimated at +5 cm within 5 years (ARCADIS *et al*., 2004). It is uncertain what degree of changes can be expected in the future. It is very difficult to predict changes in morphology and its effect on flood propagation and high water levels. Besides, little is known on the impact of feedback mechanisms (De Kramer, 2002). The effect of measures on morphology and the resulting high water levels has to be taken into account when measures are about to be implemented. For now it is not included in the study.

Land subsidence also affects flood risks. Polders could subside with respect to the embankments as a result of peat oxidation or clay settlement. The expected average subsidence of Zeeland as a result of oxidation and settlement is 10 cm in 100 years. As a result of tectonic movement the coastal zone of the Netherlands will subside a few centimeters in 100 years (Kors *et al.*, 2000). These figures are small, especially compared with the uncertainties in water depths in the flooded areas. This land subsidence has not been taken into account in this research project.

Economic change is closely related to demographic change. The economy usually grows with an increase of the population, international cooperation and market orientation. These changes will partly influence in the land use and therefore also the potential damage and the potential number of casualties within an area.

In the next sections the described developments will be quantified in order to take them into account in the flood risk analyses.

4.2.2 Hazard development until 2100

Climate change

Climate scenarios for the Netherlands were recently published by the Royal Dutch Meteorological Institute (KNMI, 2006). The well-known IPCC climate projections (IPCC, 2000) have been downscaled to the Netherlands by adding Regional Climate Model (RCM) output and local observation series (see table 4.3, figure 4.2 and textbox 4.1). The most pessimistic KNMI scenario is combined with socio-economic scenario of highest growth. This is expected to result in a worst case scenario regarding flood risk.

Table 4.3 Sea level rise (cm) as projected by KNMI (2006), relative to 1990

KNMI scenarios	W+	W	G	G+
2050	35	25	15	20
2100	85	60	35	40

Climate change may affect the storm field, an important trigger for storm surges in the Westerschelde. A storm field is a combination of wind speed, wind direction and a low pressure field at sea. It is highly uncertain whether the number and strength of storms will increase in the future. Model calculations show no significant changes in the number of storms coming from the North-West, relevant for surges near the Dutch coast (KNMI, 2006). For this study it is assumed that only sea level rise increases the flood probability. Higher sea levels do not only threaten the areas along the Westerschelde but also those Belgium areas along the Schelde River (Beersma, 2004).

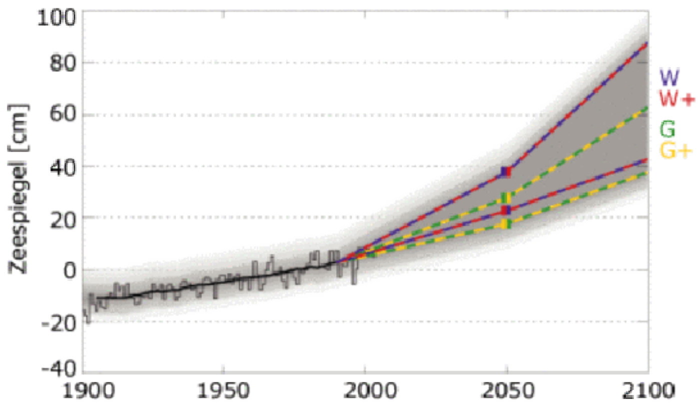


Figure 4.2 Sea level (cm) observations and projections for the Netherlands (KNMI, 2006)

To prepare the model boundary conditions for simulating flood events water level series are needed (see section 4.3). High water levels in the Schelde Estuary are caused by combinations of storm surges and high tides. The high water levels in the Westerschelde are not sensitive to the amount of discharge from the Schelde River (see appendix A). Relevant variables to consider when describing relevant sea conditions for flooding are thus astronomic tiding, storm surges at the North Sea, wind directions and wind speeds and the interaction between these variables. Of these variables the maximum, duration and time profile needs to be understood. IMDC (2005) did a statistical analysis on these variables in order to combine them into sets of variables with a certain probability. They did this analysis for the current situation, for 2050 and for 2100. Figure 4.3 shows that the maximum water level which currently has a probability of 1/4000 a year, will occur about every 10 years in 2100 according to the worst scenario. However, according to the most positive scenario in terms of flood risks, the current 1/4000 water level will occur every 350 years in 2100.

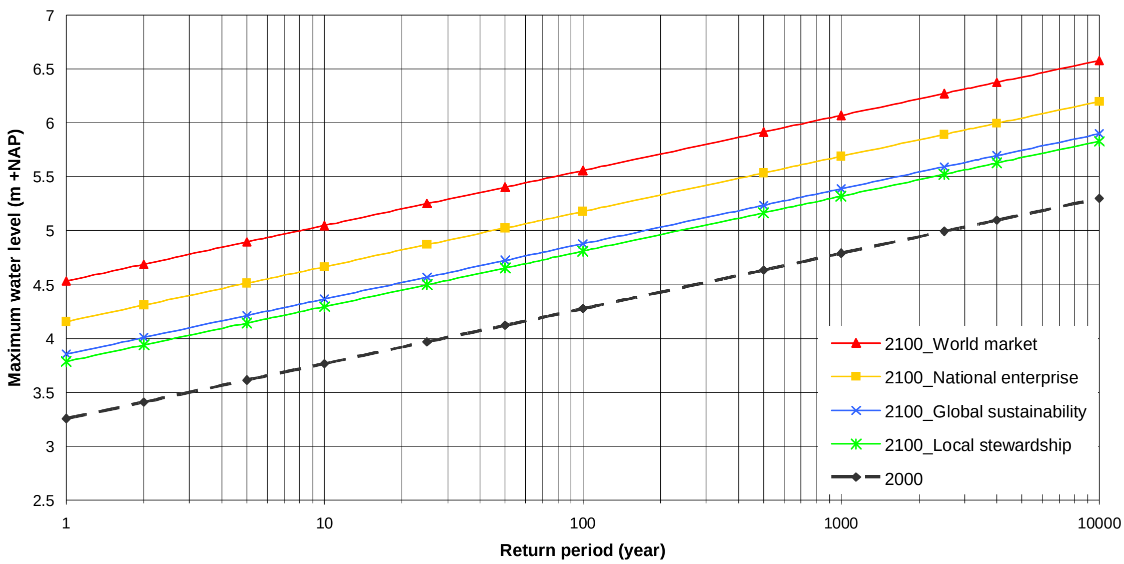
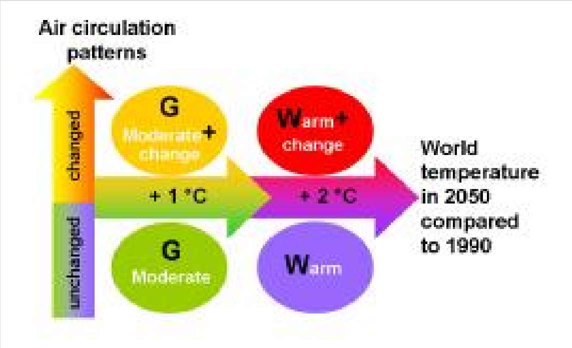


Figure 4.3 Maximum water levels near Vlissingen as a function of the return period, derived from IMDC (2005)

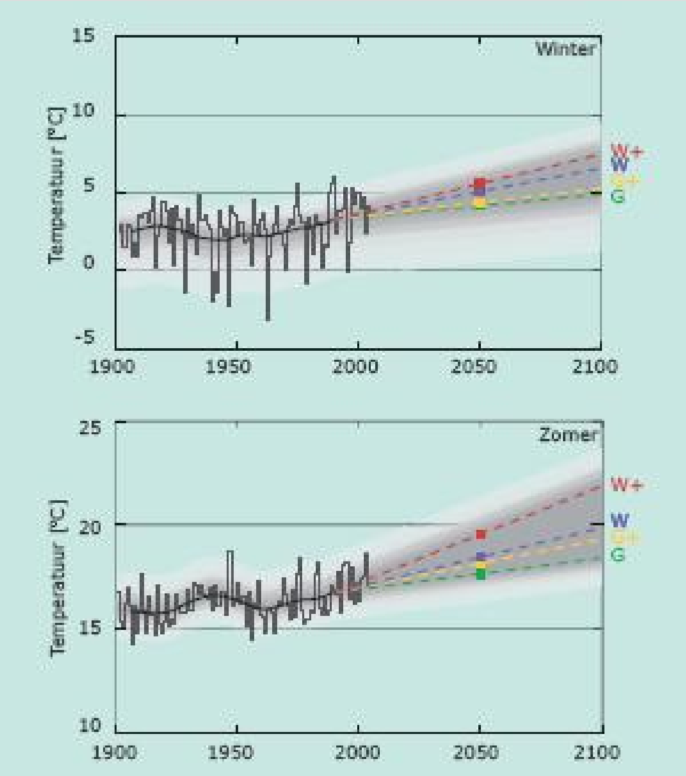
TEXTBOX 4.1 KNMI climate scenarios 2006

The scenarios that are addressed in this study are a group of general climate change scenarios constructed by KNMI for the Netherlands for 2050 and 2100 (KNMI, 2006).

The criterion for discriminating the actual four scenarios is based on the GCM projections and two anticipated circulation regime changes. A strong change of circulation induces warmer and moister winters and increases the likelihood of dry and warm summers. Both regimes are presented for the global temperature increases, producing a total of four scenarios (see figure 4.6). Figure 4.7 shows observed and projected temperatures in winter and summer for the four scenarios.



Schematic overview of the four KNMI'06 climate scenarios for 2050 (KNMI, 2006)



Observed temperatures in winter (upper) and summer (lower) in the Netherlands and projections until 2100 (KNMI, 2006)

4.2.3 Vulnerability development until 2100

Population change in the Netherlands until 2050

Population change is generally caused by a set of social and cultural trends that influence fertility, mortality and migration. Fertility and mortality are closely related to economic growth. Female education, income and day-care are the main determinants for fertility, while for mortality income, lifestyle and access to medical services is mainly important. Migration is influenced by the attractiveness of the Dutch economy in terms of labour market conditions and policies concerning asylum and family migration. (De Jong & Hilderink, 2004). De current population number of the Netherlands is about 16 million persons.

The principles and numbers below are copied from the demographic scenario study by De Jong & Hilderink (2004). All planning agencies in the Netherlands currently base their long-term studies on these scenarios. The scenario labels in this study are slightly different from the ones used in FLOODsite. The original labels are specified between brackets.

In the World Market (‘Global Economy’) scenario a high economic growth is combined with European integration which results in cooperation in trade, investments and a high migration level. People have money to spend on healthy food and day-care. For the Netherlands this means healthy people and a high birth rate.

- Migration balance: 50,000 persons (positive = immigration)
- Life expectancy: 82 (m) and 85 (f)
- Fertility: 1.9 kids per woman
- Total population in the Netherlands in 2050: 20.3 million persons

National Enterprise (‘Transatlantic Market’) focuses on cooperation with the US more than within Europe. The economic growth is quite high, but the social security is low. Immigrants are not welcome in Europe. This results in a low migration level in the Netherlands. There is a large difference between the rich and the poor. Only the rich people can afford health care.

- Migration balance: 25,000 persons
- Life expectancy: 80.5 (m) and 83.5 (f)
- Fertility: 1.7 kids per woman
- Total population in the Netherlands in 2050: 16.8 million persons

‘Europe’ is growing in the Global Sustainability (‘strong Europe’) scenario. Because of high solidarity and strong influence of the government, the social security system works well. There is a medium migration level. Health care is cheap and women can easily combine kids with work.

- Migration balance: 35,000 persons
- Life expectancy: 82 (m) and 85 (f)
- Fertility: 1.9 kids per woman
- Total population in the Netherlands in 2050: 19.2 million persons

The Local Stewardship (‘regional communities’) scenario is characterized by low economic growth and expansion of the EU, but the level of international cooperation is low. Immigrants are not very interested in the Netherlands and even Dutch people leave the country to find better jobs elsewhere. Health care is organized by the government, but only the basic needs can be covered. Although elderly can watch over the kids, some people do not have enough money to have kids.

- Migration balance: 10,000 persons
- Life expectancy: 79 (m) and 82 (f)
- Fertility: 1.6 kids per woman
- Total population in the Netherlands in 2050: 15.1 million persons

Population change in the Netherlands until 2100

As discussed above, De Jong & Hilderink (2004) provided population figures for the Netherlands in 2050. However, for the current study also demographic numbers for 2100 are required. The United Nations (UN, 2004) recently carried out a scenario study about the world population until 2300. Also figures for the Netherlands can be extracted from that research. Figure 4.4 shows that three scenarios are distinguished: high (23.1 million people), medium (15.9 million people) and low (10.7 million people). The population scenarios for 2050 (De Jong & Hilderink, 2004) are also included in this figure. When the two studies are compared for 2050, it turns out that the medium scenario of UN (2004) corresponds best with the National Enterprise scenario of De Jong & Hilderink (2004), the low scenario corresponds best with the Local Stewardship scenario and the high scenario corresponds most with both the World Market and Global Sustainability scenarios. The World Market scenario population figure for 2050 lies clearly above that of the high scenario of UN (2004) in 2050. However, for the World Market scenario 2100 population figure the high scenario figure has been used anyway, since it is not expected that the total population of the Netherlands will grow above the provided figure of 23.1 million in 2100. Table 4.4 shows the figures used in the current study.

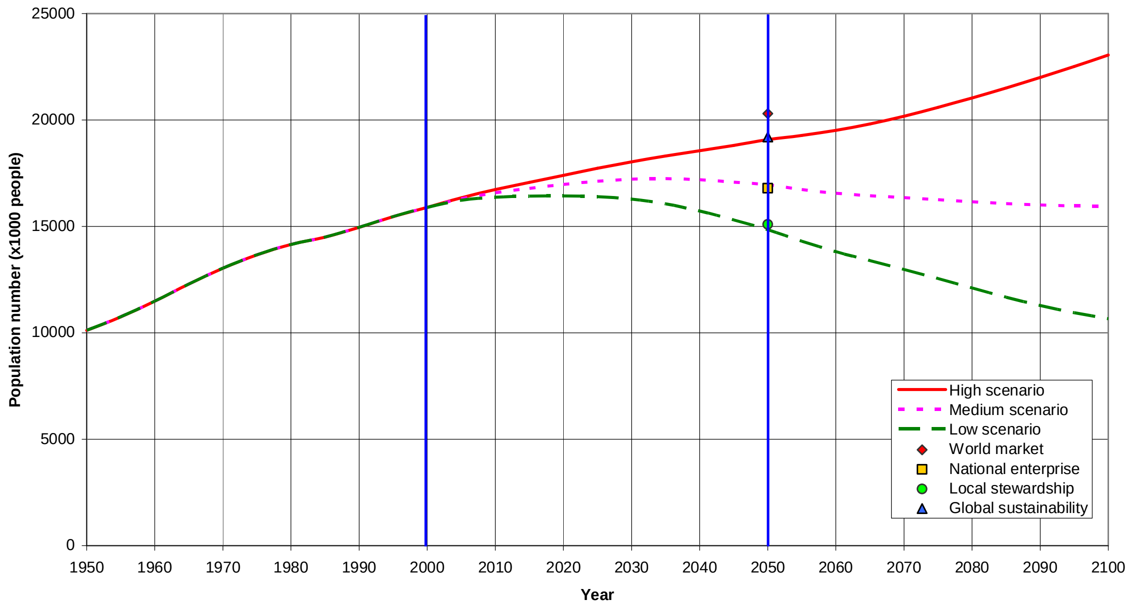


Figure 4.4 Projection of the Dutch population until 2100

Table 4.4 Population number (million people) in the Netherlands in 2050 and 2100 (reference: 15.8 million people in the year 2000)

	World Market	National Enterprise	Global Sustainability	Local Stewardship
2050	20.3	16.8	19.2	15.1
2100	23.1	15.9	23.1	10.7

Population in Zeeland in 2050 and 2100

For the current study not the population figures for the Netherlands as a whole are required, but those for Zeeland. Therefore, the population figures in table 4.4 need to be downscaled to population figures for Zeeland. In 2000 about 2.3% of the 15.8 million inhabitants of the Netherlands lived in Zeeland. These were 0.37 million people. The case study area has currently about 300,000 inhabitants. A recent study on population decline (Derks *et al.*, 2006) predicted that in 2046 Zeeland will have 0.33 million inhabitants and the Netherlands 16 million. Based on this prediction, it is assumed that in 2050 and 2100 2.1% of the population of the Netherlands will live in Zeeland. This results in the population figures shown in table 4.5.

Table 4.5 Projections of population number (million people) in 2050 and 2100 for Zeeland (reference: 0.37 million people in the year 2000)

	World Market	National Enterprise	Global Sustainability	Local Stewardship
2050	0.43	0.35	0.40	0.32
2100	0.49	0.33	0.49	0.22

Economic change

The economic growth in a country can be represented by the change in gross domestic product (GDP). GDP is affected by productivity and employment growth. More market competition leads to more innovation and, therefore, in more productivity. Employment growth is also related to population growth. Dutch planning agencies carried out a scenario study for the future development of the Netherlands (Janssen *et al.*, 2006). Future developments until 2040 are projected in four scenarios that are comparable to the scenarios used in this study. Janssen *et al.* (2006) describes the following developments regarding economic growth for the four scenarios:

- *World Market:* Population growth and personal responsibility plus global economic integration lead to higher productivity. This results in the highest economic growth scenario;
- *National Enterprise:* Personal responsibility and low social security leads to high participation. Market competition with US leads to productivity. Population, however, does not grow very fast;
- *Global Sustainability:* Because of international competition, the market is large and the productivity is high;
- *Local Stewardship:* Compared to the first two scenarios, there is less competition, less innovation and a low productivity. The unemployment level is quite high and participation is low because of a high level of social security.

Table 4.6 shows the economic figures provided for 2040 by Janssen *et al.* (2006). In this research these figures were extrapolated towards 2100 (see table 4.7). For reference: The average annual GDP growth in the Netherlands from 2000 to 2005 was 3% (CBS, 2006).

Table 4.6 Economic growth index numbers for 2040 relative to 2001 (source: Janssen et al., 2006)

	2001	World Market	National Enterprise	Global Sustainability	Local Stewardship
Productivity	100	224	209	179	160
GDP	100	272	209	184	132
GDP per person	100	221	195	156	133

Table 4.7 Projected average GDP growth (% per year) in the Netherlands until 2100

	World Market	National Enterprise	Global Sustainability	Local Stewardship
GDP growth	2.5	1.9	1.5	0.7

Land use change

Both population change and economic change influence land use change. Flood damage is affected by land use change, therefore, it should be considered in the flood risk analysis. It is difficult to find land use maps corresponding with the four future scenarios. MNP produced land use maps for 2040 based on two of the four scenarios which are used in the current study (Klijn *et al.,* 2007). These maps will be used to get an idea of possible developments in 2050. For the other two scenarios and for 2100, however, economic growth figures will be used only. Economic growth expresses itself into two components: more companies, houses and other buildings, which will be visible in future land use maps and secondly in an increase of production and an increase of vulnerable possessions and objects present in those buildings (e.g. computers, DVD players etc.). This second component will not become visible in the land use. In this research economic growth figures only or alternatively, both future land use maps and figures for the second component of economic growth will be used (see section 4.3.2).

Summary

Table 4.8 summarizes the most relevant autonomous developments in the Westerschelde Estuary that are projected for 2050 and 2100.

Table 4.8 The most relevant figures for the province of Zeeland derived from the four scenarios

Indicator		World Market	National Enterprise	Global Sustainability	Local Stewardship	2000
2050	GDP growth per year (%)	2.5	1.5	1.9	0.7	3
	Population (million people)	0.43	0.40	0.35	0.32	0.37
	Sea level rise (cm)	35	20	25	15	-
2100	GDP growth per year (%)	2.5	1.5	1.9	0.7	3
	Population(million people)	0.49	0.49	0.33	0.22	0.37
	Sea level rise (cm)	85	40	60	35	-

4.3 Flood risk analysis

4.3.1 Analysis of the current flood risk

To calculate flood risks, insight in the consequences of the wide range of possible sea conditions must be obtained. This section describes the approach followed to calculate current flood risks by discussing the elements shown in Figure 4.5. The method here is based on the guidance in section 3.4.

Analysis method

Flood risk consists of combinations of probabilities of events and their consequences (see section 2.2.2). Ideally, flood risks are determined by simulating all possible combinations of storm and discharge conditions with breach locations by a hydrodynamic model of the entire area, followed by the calculation of the corresponding flood impacts. Since the number of possible combinations is almost infinite and because the impacts of storms on embankments are uncertain, such an approach is not feasible. Therefore, a simplified method was adopted: a limited number of representative storms and discharges is selected. These selected events are combined with assumptions on breach locations and breach growth and then simulated with a 1D2D model to obtain the corresponding inundation depths. A damage model is used to calculate damage numbers and number of casualties and affected persons in the flooded area. The probability of the selected events and the resulting flood impacts are then combined into flood risks (See figure 4.5). The assumptions used in the analysis are summarized in table 4.9 and discussed below.

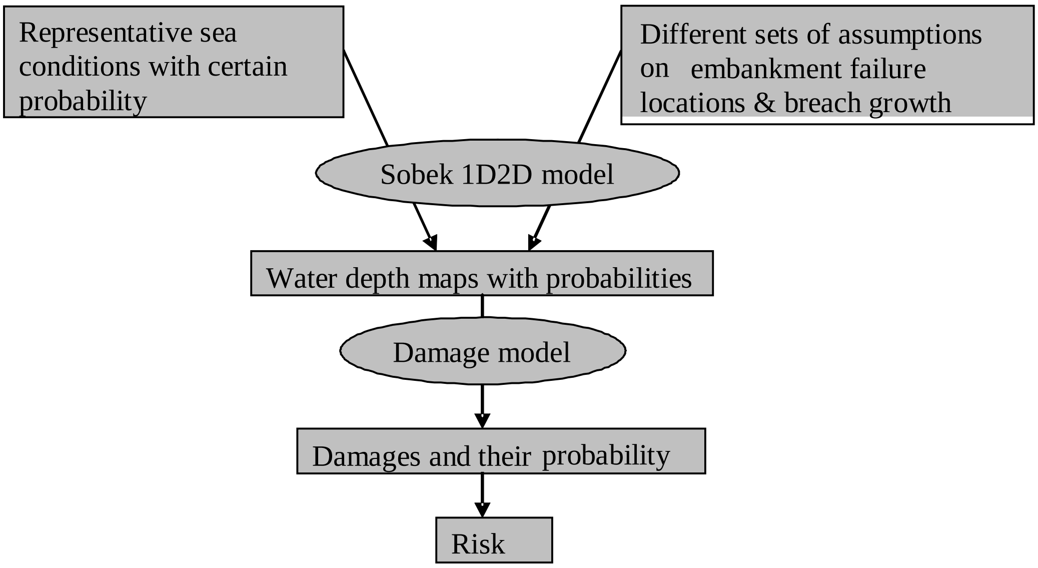


Figure 4.5 Risk analysis approach for the Schelde case

Selection of representative extreme sea conditions

Because it is impossible to consider the whole domain of possible extreme sea water level conditions, this project uses a selection of representative events. These events should give insight into the consequences of all possible conditions. The selection of events is based on the composite approach of IMDC (IMDC, 2005). To study the flood risk corresponding with the current situation, only those conditions with probabilities of 1/10,000 and 1/4000 a year were used. Larger probabilities were not considered, because the current strategy prescribes that embankments must be able to withstand sea conditions with a probability of 1/4000 a year. Of course lack of maintenance and all kind of uncertainties and unforeseen circumstances may cause floods during less extreme circumstances. However, it is also thinkable that conditions with a probability of 1/4000 do not cause floods. As for now we take a 1/4000 probability as a threshold for the current situation.

Breach locations and breach growth

Extreme sea conditions may cause breaching of embankments. It is uncertain where embankments will break, at what moment they will break and how many breaches will occur during extreme conditions. Therefore, different sets of assumptions on the breach locations, number of breaches and the breach growth process were used. For breach locations, we first considered the known weak spots, such as structures in embankments, sandy deposits in embankments, the connecting locations of dune- and embankment defences, low embankment spots etc. However, this did not result in sufficient locations within our research area. We, therefore, chose to simulate breaches occurring at favourable locations and at unfavourable locations. Favourable is here seen from the viewpoint of damage. Favourable locations are thus rural areas, while the unfavourable locations are situated near cities and industrial areas (See figure 4.6). For severe events we added breach locations in such a way that in each subarea one breach occurs (a subarea is a polder separated from other subareas by embankments). Embankments are assumed to fail when the water level reaches the 1/4000 year water level. If an embankment fails the breach is assumed to grow to a width of 200 m with a grow rate according to the formula of Van der Knaap.

Next to all failure locations in the outside embankments, there is also a possibility that the sluices in the Canal of Walcheren fail which may be followed by a breach in the embankments of that Canal. Since this sequence of events results in the flooding of the city of Middelburg, it is incorporated in the analysis (see location 1b in figure 4.6). In this project, secondary embankments are expected to remain intact.

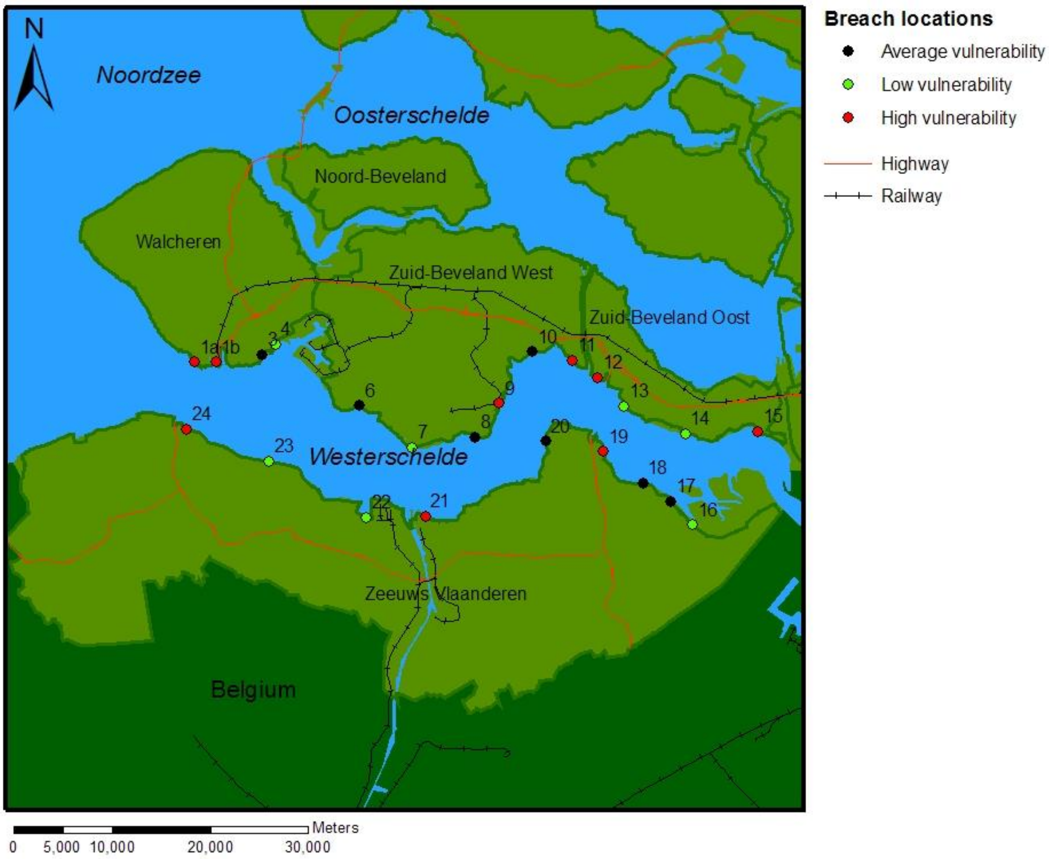


Figure 4.6 Studied embankment failure locations (the green ones cause relatively little damage, the red ones result in higher damages and the black ones are in between)

Table 4.9 Summary of assumptions used

Subject	**Assumptions**
Range of possible sea conditions considered	• Damage corresponding with sea conditions with a probability smaller than design probability is calculated by assessing the damage corresponding with two probabilities (for the current strategy P = 1/4000 & P = 1/10,000 were used). These together are supposed to represent all possible events. • Sea conditions with a probability P larger than the design flood probability (currently 1/4000 a year) do not result in damage.
Breach growth	Breaches grow to 200m wide following the formula of Van der Knaap
Failure locations	We used different sets of assumptions: • One set in which embankments only break at locations with a relatively low vulnerability due to 1/4000 year conditions and also at moderately vulnerable conditions at 1/10,000 year conditions; • One set in which embankments only break at locations with a relatively high vulnerability due to 1/4000 year conditions and also at moderately vulnerable conditions due to 1/10,000 year conditions; • One set in which embankments break at all locations both in case the 1/4000 event occurs and in case the 1/10,000 year event occurs.
Secondary embankments	They do not fail.

Modelling flood patterns and damage

The effects of extreme sea conditions are modelled with a Sobek1D2D model. This model contains both the Westerschelde and the flood-prone areas. The Westerschelde is schematized as a quasi-2D by simulating flow through the main channels and interlink those channels by many 1D branches. The flood-prone area is schematized by a 2D grid. Boundary conditions for this model are water level as a function of time at Vlissingen and the discharge from the Schelde River. The model simulates the flood pattern and the resulting maximum water depths. The model schematisation is discussed in more detail in appendix A.

The water depth maps resulting from the Sobek-1D2D model are used as input in the Standard Dutch Damage Module (Kok *et al.*, 2005) to assess the corresponding flood damages. This damage module calculates direct and indirect damage, but does not include damage related to water quality, cleaning, evacuation and rescue.

The number of affected people (persons who live in the flooded area) and the number of casualties (killed persons) are also calculated by the same damage module (Kok *et al.*, 2005). The number of casualties depends among others on:

- the evacuation efficiency and behaviour of people;
- the time between the moment of breaching and the arrival of the water;
- water rise velocity, flow velocity and water depths;
- Whether flooding occurs in winter or summer, during daytime or night time, at a weekend or at a working day.

The number of casualties and affected persons was estimated based on the simulated water depths. No information on flow velocities, water level rise and other factors was used. The results should thus be considered as an indication. It was assumed that between 25% and 75% of all inhabitants are evacuated. These figures are drawn from Klijn *et al.* (2007).

Calculating risks

Finally, flood risks were determined by combining flood probabilities and damages. It is very unlikely that all subareas will become flooded when the 1/4000 sea conditions are reached. Therefore, different sets of assumptions with different failure locations were used to assess the flood risk (see also table 4.9 and 4.13). For sea conditions with a probability of 1/10,000 per year it is assumed that at many more locations failures occur.

4.3.2 Analysis of future flood risk

The future flood risks are assessed by using future scenarios (see section 4.2). Table 4.8 in section 4.2 summarized the expected changes in each scenario.

Climate change

Climate change has been implemented by using the statistical method of IMDC (2005). The sea level change in each scenario has been translated to boundary conditions for varying probabilities (see section 4.2.2).

Economic growth

To account for land use changes and economic growth the damage figures found for 2000 were increased with the economic growth percentage corresponding with each scenario (see table 4.8). It was thus assumed that economic growth occurs in the whole region and that locations where investments are concentrated in 2000 will grow fastest. Furthermore, it was assumed that damage increases linearly with economic growth.

In addition, two socio-economic scenarios were analysed in more detail for the current strategy. This second approach does not assume that economic growth occurs homogenously over the area. Instead, the economic growth number is divided into two components and future land use maps are used. The first component is that economic growth which becomes visible in land use maps, because it relates to new constructions, such as new houses, companies, roads and other objects. The second component realtes to an increase in productions, possessions and services. This component of economic growth is not included in land use maps and must thus be incorporated seperately when future land use maps are used. To take into account land use changes, the future land use maps for 2040 available in Klijn *et al.* (2007) were used and considered representative for 2050. Figure 4.7 shows the current land use and the land use in 2040 according to the World Market scenario. The second component was included as a homogenous percentage called a 'growth factor'. This growth factor was calculated by subtracting the economic growth component 'new buildings and roads' from the total economic growth (see table 4.10).

Table 4.10 The growth factor for the increase in damage due to increase in possessions, production and services for two scenarios for the period 2000-2040 (Source: Janssen et al., 2006)

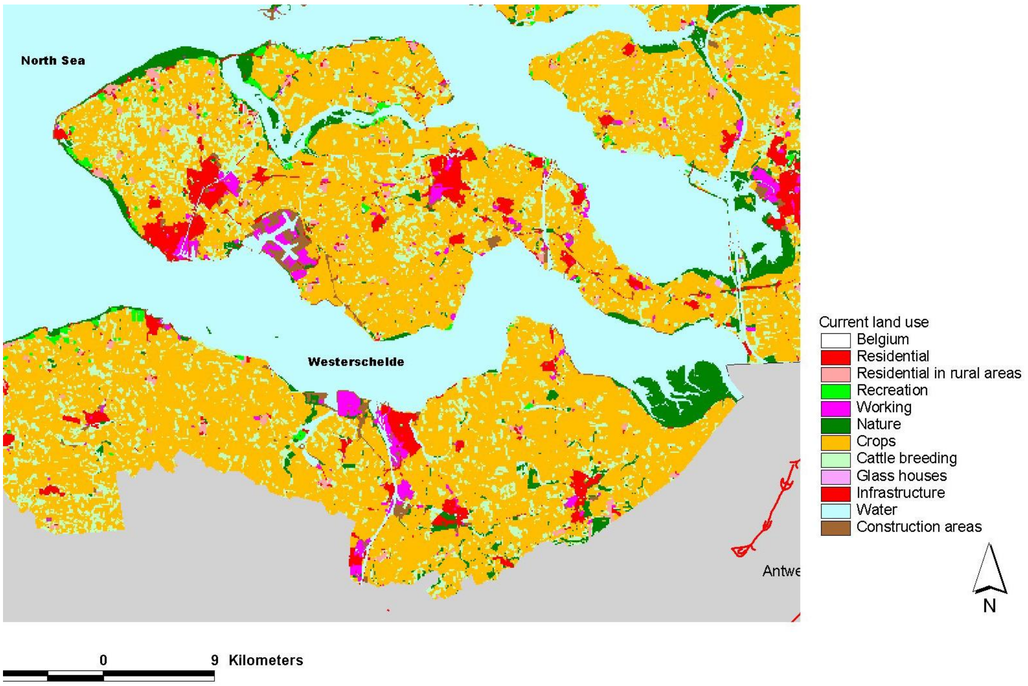
Scenario	World Market	National Enterprise
Average annual increase in GDP	2.6	1.9
Annual increase due to new constructions (%)	1.0	0.5
Growth factor (%/year)	**1.6**	**1.4**

Population growth

Population growth is incorporated in the casualty assessment and assessment of the number of affected persons only. It is carried out by increasing the figures found corresponding with future water depths but with population data of 2000 with the population growth percentages of each scenario.

Analysis

The analysis of future flood risks is carried out in a similar way as the analysis of the current flood risk. First flood patterns corresponding with certain sea conditions are calculated, secondly the corresponding damages are estimated and finally the probabilities of the sea conditions and the damages are combined to flood risks. For all future combinations of strategies and scenarios it was assumed that embankment failures occur at all breach locations as indicated in figure 4.6.



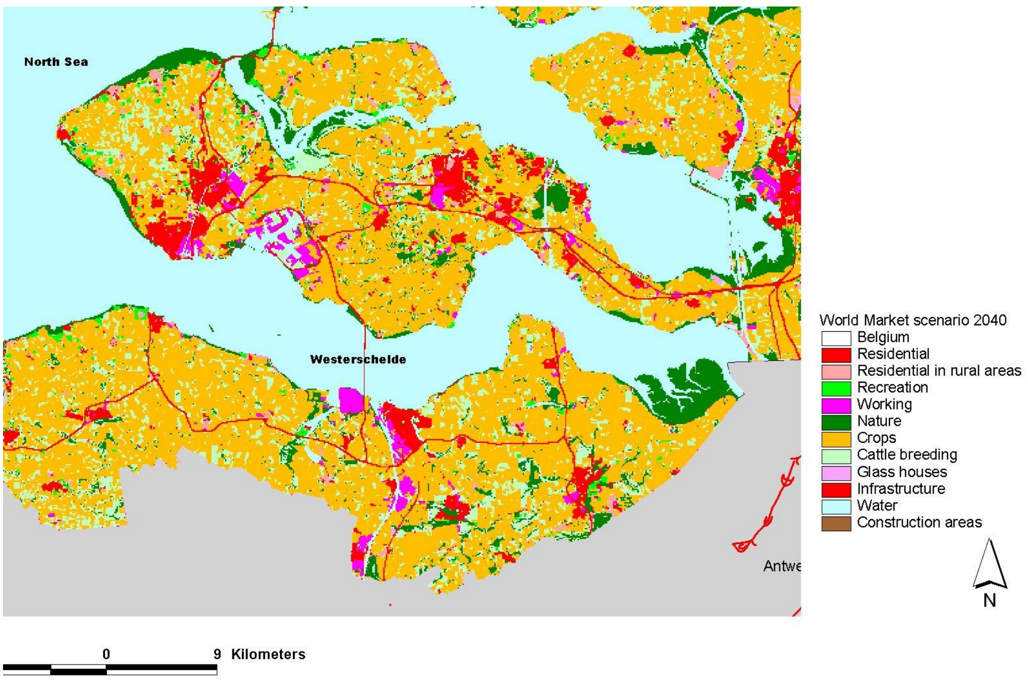


Figure 4.7 Current land use and future land use (2040) according to the World Market scenario (Janssen et al., 2006)

4.4 Current flood risk management strategy

4.4.1 Description of the current flood risk management strategy

The current flood risk management strategy of the Westerschelde Estuary can be summarized as follows:

> *Embankments are strong and high enough to protect against water levels and wave conditions up to a probability of 1/4000 a year.*

Every five years the conditions corresponding with a probability of 1/4000 a year are revised with the latest data and knowledge available and the embankments are evaluated against design criteria. Climate change expectations are incorporated in the design criteria. If the embankments are considered too weak, they are improved or raised. The current flood risk management strategy is thus a resistance strategy (see section 3.5), which only involves flood defence measures.

4.4.2 Current flood patterns, damages, casualties and risks

To be able to analyse this strategic alternative it was assumed that in this alternative no dike breaches and thus no flooding occurs due to events which are less severe than the 1/4000 year event. If the 1/4000 year event or more severe events occur, then embankments break at some locations. For sea conditions with a probability of 1/4000 years it is expected that failure will occur at a few locations only. Sea conditions with a probability of 1/10,000 per year are assumed to cause breaches at more locations.

Figure 4.8 shows the resulting water depths for the situation in which one dike failure occurs in each subarea and the sea conditions correspond with the 1/10,000 year conditions. It shows that most areas become flooded to a depth of about 1.5 to 3.5 m. Almost no secondary embankments are overflown. Those that are overflown face small water depths and low flow velocities. Therefore, they were assumed to remain intact.

Table 4.11 shows that the damage due to floods along the Westerschelde varies between 61 and 2196 M€ depending on the number of breaches, failure locations and the boundary conditions. Differences in the choice for the location of breaches result in a factor 27 in difference in flood damage, while different boundary conditions result in small differences only.

Table 4.11 Resulting damages for the current strategy

P(sea conditions)	***Failure locations***	***Damage (M€)***
1/4000	Least vulnerable	61
1/4000	Most vulnerable	1709
1/4000	Moderately vulnerable	207
1/4000	All	1977
1/10,000	Least vulnerable	68
1/10,000	Most vulnerable	1886
1/10,000	Moderately vulnerable	242
1/10,000	All	2196

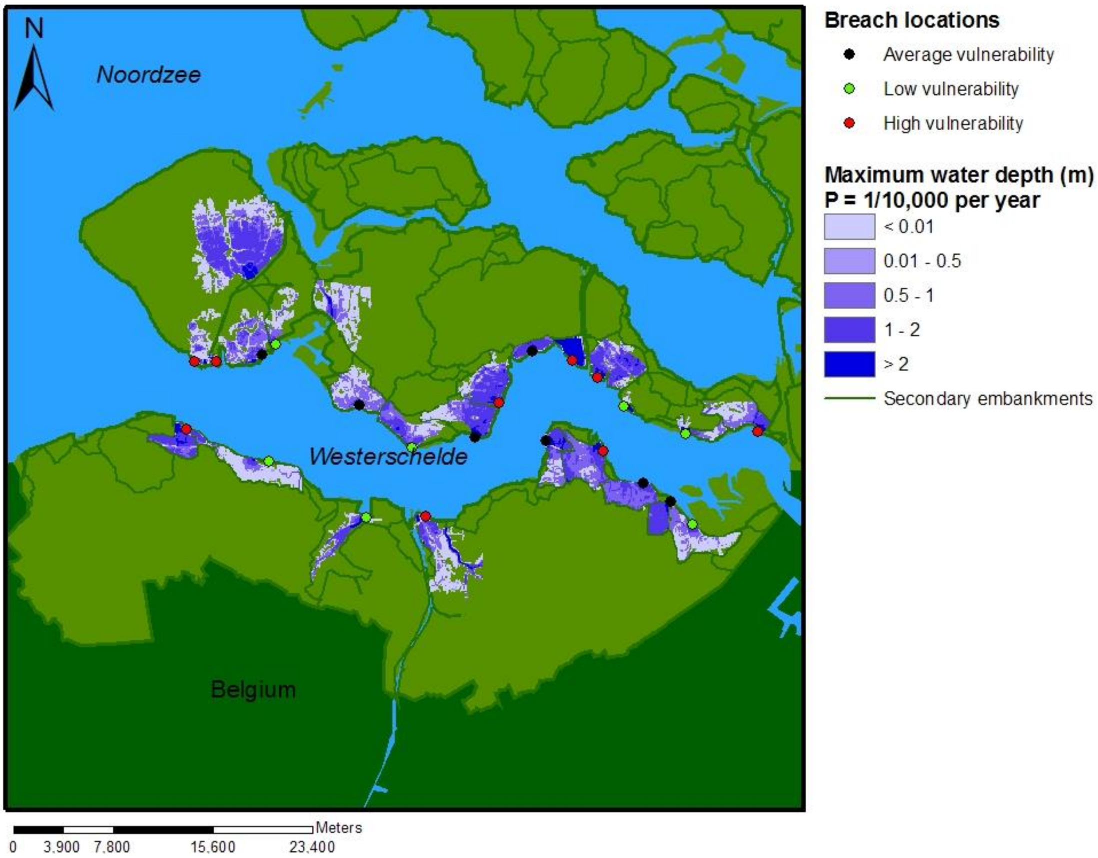


Figure 4.8 The water depths resulting from breaches at all locations mentioned in figure 4.6 and sea conditions corresponding with a probability of 1/10,000 a year

The resulting risks

The risk is expressed by the Expected Annual Damage (EAD), the Expected Annual Number of Affected Persons (EANAP), the Expected Annual Number of Casualties (EANC) and the individual risk.

Table 4.12 and figure 4.9 show the *EAD per subarea*. The EAD for the areas behind the breaches vary from 0 to 165 k€/ year. This 165 k€/ year is the EAD of the area around the city of Middelburg. Breach location 21 is situated near the city of Terneuzen.

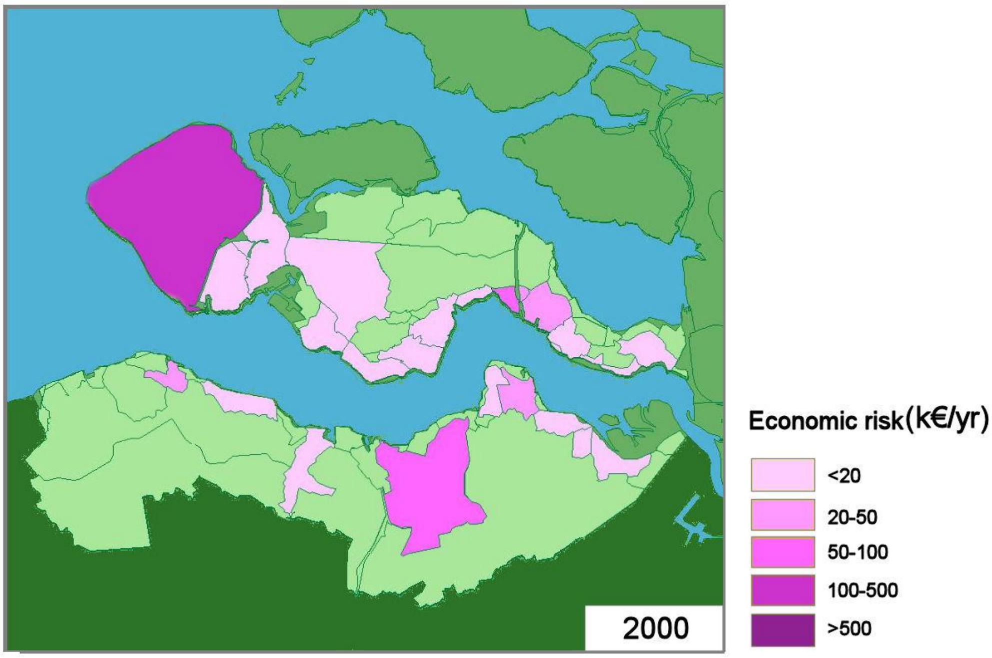


Figure 4.9 EAD (k€/yr) for the different polder areas behind the breach locations

Table 4.12 Damage and EAD per breach location (the locations of the areas are shown in figure 4.6)

Breach location	**Damage (M€)**		**EAD (k€/yr)**	**EAD (%)**	**Area (%)**
	(P = 1/4000)	**(P = 1/10,000)**			
1a &b*	633	668	165	31	21
3	30	51	11	2	5
4	3	4	1	0	2
5	10	17	4	1	5
6	44	46	11	2	5
7	29	31	8	1	4
8	47	49	12	2	5
9	72	75	18	3	5
10	31	32	8	2	1
11	194	209	51	10	2
12	123	129	32	6	6
13	1	1	0.2	0	0
14	3	3	1	0	1
15	25	29	7	1	4
16	7	8	2	0	5
17	19	20	5	1	2
18	12	12	3	1	4
19	82	87	21	4	5
20	14	15	4	1	3
21	402	494	117	22	5
22	7	8	2	0	2
23	10	12	3	1	5
24	179	195	48	9	3
SUM	1977	2196	*533*	*100*	*100*

*Breaches 1a and 1b both threaten the same subarea

The resulting EAD for the whole area depends on the number of breaches that occurs and on the breach locations. In order to determine the total EAD of the system as a whole, different sets of assumptions with different failure locations were used (see table 4.13). The resulting EAD varies between 0.06 and 0.53 M€/year. The difference between these figures is about a factor 10.

Table 4.13 EAD corresponding with different assumptions on failure locations due to events with probabilities of 1/4000 and 1/10,000 a year (see for failure locations figure 4.6)

Breach locations considered		**EAD (M€/yr)**
P = 1/4000	**P = 1/10,000**	
Only the *less* vulnerable	Less and moderately vulnerable locations	0.06
Only the more vulnerable	Moderately vulnerable and highly vulnerable locations	0.50
All locations	All locations	0.53

Table 4.14 shows the expected number of affected persons per year and the expected number of casualties per year. This table shows that the houses of about 265,000 people become flooded during a flood event and that on average about 0.08 to 0.2 casualties per year occur.

Table 4.14 Expected Annual Number of Affected Persons (EANAP) and the Expected Annual Number of Casualties (EANC) if breaches occur at all locations shown in figure 4.6

	Probability of sea conditions		**(Number/yr)**
	1/4000	**1/10,000**	
EANAP	71208	75869	19
EANC if 75% of the population is evacuated	254	327	0.08
EANC if 50% of the population is evacuated	508	655	0.15
EANC if 25% of the population is evacuated	761	982	0.23

The resulting individual risk was found by multiplying the flooding probability with the probability of dying. The probability of flooding is assumed 1/4000 per year. The corresponding probability of dying corresponding with the 1/4000 flood event is equal to the number of casualties divided by the number of affected persons: $508/71208 \approx 0.0071$. The individual risk in the flooded area is thus $1/4000 * 0.0071 = 1.8*10^{-6}$.

4.4.3 Future flood patterns, damages, casualties and risks

This section discusses the effects of the assumed future changes mentioned in table 4.8 on the flood risks in 2050 and 2100.

The flood patterns corresponding with future sea conditions with probabilities of 1/4000 and 1/10,000 have been simulated with the Sobek1D2D model (see section 4.3.2). The previous section showed that the different sets of assumptions on breach locations resulted in risk figures which all have the same order of magnitude. For the future, therefore, only one assumption was used, namely: breaches are expected to occur at all locations mentioned in figure 4.6. The resulting flood pattern for 1/10,000 year sea conditions in the World Market scenario is provided in Figure 4.10.

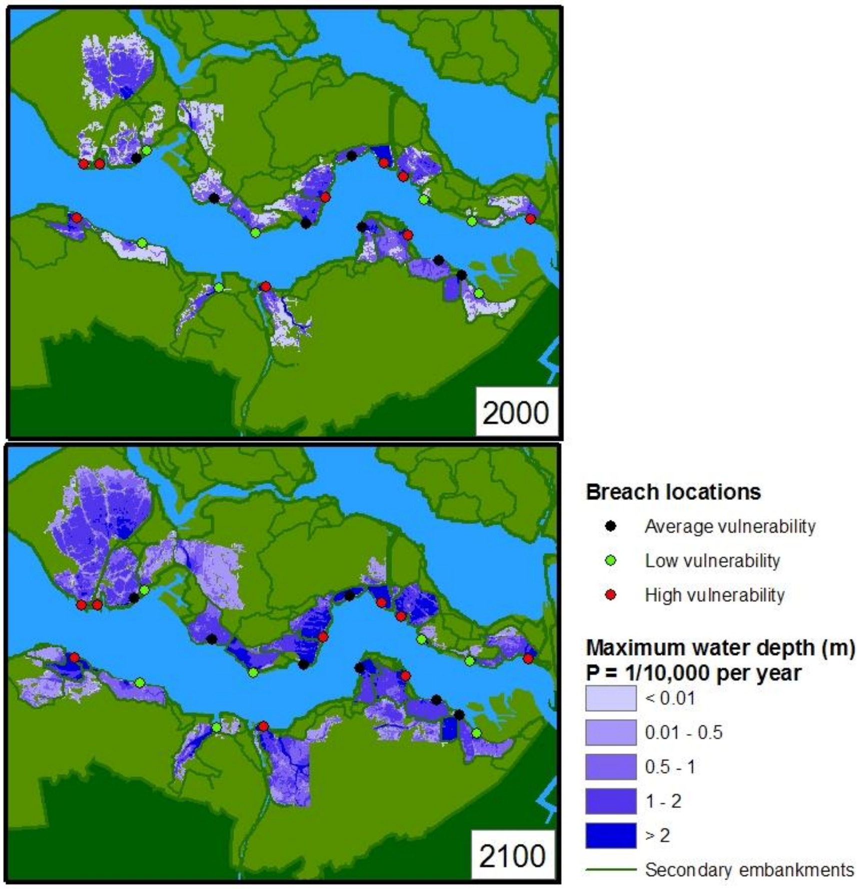


Figure 4.10 Resulting flood pattern corresponding with sea conditions with a probability of 1/10,000 a year in 2000 and 2100 (World Market scenario)

Resulting risk figures

The resulting EAD values are presented in figure 4.11 and in the tables 4.15 and 4.16. The tables show that the EAD increases due to sea level rise and economic growth. In this alternative, the contribution of economic growth is much larger than the contribution of sea level rise. This is caused by the adaptation of the height of the embankments in order to maintain the flood probability at 1/4000 per year. The differences in increase in risks between the different scenarios are large. In the Local Stewardship scenario the EAD increases from 0.53 M€/yr in 2000 to 1.5 M€/yr in 2100. In the World Market scenario, however, the EAD increases from 0.53 to 14 M€/year (see table 4.16).

Table 4.16 contains two figures for both the World Market and National Enterprise scenario. The figure between brackets indicates the resulting EAD when future land use maps for 2050 are used instead of a uniform economic growth percentage (see explanation in section 4.3.2). The resulting figures of the two approaches differ substantially, but the differences between the two scenarios 'National Enterprise' and 'World Market scenario' remain the same in both approaches. Since the differences between the two approaches are quite large, it is recommended to use future land use maps also for the other scenarios. The differences between the EADs in both approaches is caused by the developments and economic growth, which do not occur homogenously over the area in the second approach. According to the future land use maps economic development concentrates in areas which do not become flooded from the Westerschelde, such as the area around the city of Goes.

Table 4.15 Current and future EAD (M€/yr) calculated by assuming that only the sea level changes in the future

Year	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	0.53	0.53	0.53	0.53
2050	0.77	0.70	0.66	0.63
2100	1.2	0.96	0.80	0.77

Table 4.16 Current and future EAD (M€/yr)in which both sea level rise and economic growth are accounted for

Year	World Market*	National Enterprise*	Global Sustainability	Local Stewardship
2000	0.53	0.53	0.53	0.53
2050	(2.1) 2.6	(0.8) 1.8	1.4	0.90
2100	14	6.3	3.5	1.5

* The figures between brackets show the risks calculated by using land use maps for 2040 as described in the text above

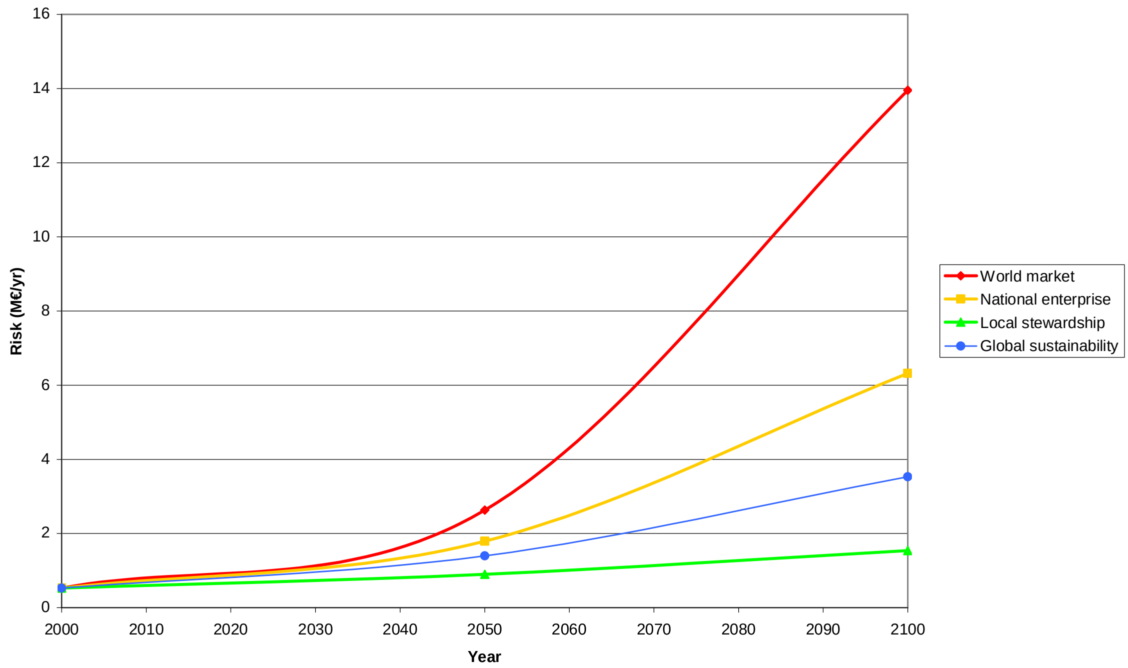


Figure 4.11 Increase in EAD from 2000 to 2100 in the different scenarios

Casualties and affected persons

Table 4.17 shows the EANAP and EANC for the different future scenarios in case 50% of the population is evacuated in time.

The individual risk or the probability of being killed corresponding with the 1/4000 flood event is equal to the number of casualties divided by the number of affected persons. The resulting individual risk is about $2.2*10^{-6}$ to $4.2*10^{-6}$

Table 4.17 Expected Annual Number of Affected Persons (EANAP) and the Expected Annual Number of Casualties (EANC) when 50% of the inhabitants is evacuated or in a shelter

		World Market	National Enterprise	Global Sustainability	Local Stewardship
2050	EANAP	24	23	22	22
	EANC	0.29	0.23	0.22	0.19
2100	EANAP	32	29	24	24
	EANC	0.55	0.37	0.33	0.23

4.4.4 Costs and other effects of the current strategy

Costs
The investment for the current strategic alternative mainly consist of costs to raise the embankments. To estimate this costs, the following assumptions were made:

- The length of the shoreline is estimated roughly at 170 km;
- The embankments are raised in two steps (in 2050 and 2100). In reality it takes about 30 years to plan and implement embankment strengthening measures;
- The first raising takes place in 2000, following the National Enterprise sea level rise scenario to derive the embankment height. This corresponds with a raising of about 40 cm for the first 50 years.
- The second raising takes place in 2050. At this time it is presumably known which sea level rise scenario did occur and will occur in the coming 50 years. For the next raising step the scenario is followed, resulting in a raising of 90, 50,20 and 15 cm for WM, NE, GS and LS respectively;
- Costs for maintenance are not taken into account.

In the Netherlands the investment costs of raising the dikes with 1 meter is usually estimated at 1.7 – 3.2 M € per km. As we are dealing with unstable soils and tidal areas, the maximum of 3.2 M € per km seems a reasonable estimate for the Westerschelde Estuary. Besides structural costs, unpredicted costs and costs for planning and implementation need to be accounted for. The Dutch Directorate for Public Works and Water Management usually works with a factor of 2.5 to account for extra costs. Based on this the total costs of raising the dikes with 1 meter are estimated at 8 M € per km for this study. The resulting costs in the different scenarios are presented in Table 4.18.

The costs are compared with the reduced flood risks. Both costs and reduced flood risks are translated to present values. The risk reduction corresponding with the current strategy was calculated by comparing the EAD in this strategy with the EAD in the do-nothing alternative (see chapter 4.5). The differences were discounted to the Present Value with equation 1.

Table 4.18 shows that the current strategy is only cost-efficient in the World Market scenario. It must be noted, however, that the implementation of this strategy in reality will be different then the one anlysed here. Dike raising may occur in more than two steps, and it will probably not occur exactly in 2050 and 2050. This will affect the cost-benefit analysis. Furthermore, the EAD reduction will be slightly different in reality: just before dike raising the failure probability may exceed the 1/4000 years, while just after dike raising a lower failure probability is expected. This effect is shown in Figure 4.12. These aspect were not taken into account in the risk calculation. The resulting figures should, therefore, be considered as an indication. They can be used for comparison only and not for design or optimization of measures.

Discounting formula: $$R_0 = \sum_{t=1}^{t=100} \frac{R_t}{(1+r)^t} = \sum_{t=1}^{t=100} \frac{R_t}{(1+0.025)^t}$$ (Equation 1)

With: R = Risk reduction (M€), R_0= Present Value of the risk reduction from 2000 to 2100, r = discount rate (2.5%).

Table 4.18 Present value of costs and reduced EAD (in M€) for the current strategy in each scenario

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Risk reduction	3203	470	89	46
Costs (raising in two steps)	878	727	607	578
Difference	2325	-257	-518	-532

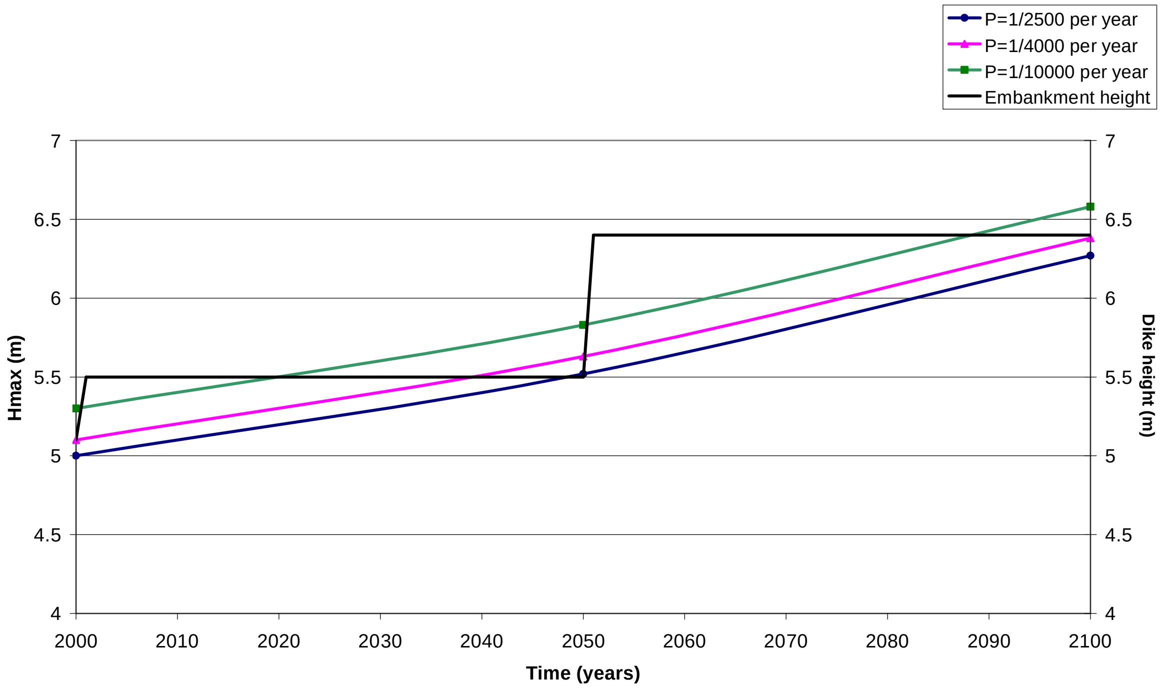


Figure 4.12 Schematic view of embankment heights and sea level rise (maximum water level) in time according to theWorld Market scenario

Other effects

The strategy does not influence land use developments or socio-economic developments, nor does it influence nature values purposefully. Developments are expected to continue autonomously as discussed for the different future scenarios in section 4.2.

4.4.5 Assessment of the current strategy

As was explained in chapter 3, risks can be assessed by:

- Comparison with risk standards/ agreements / or legal requirements;
- Comparison with other risks;
- Comparison with GDP;
- Comparing costs with the risk reduction (cost-benefit analysis (CBA)).

In the Netherlands the safety standards as provided in the Law on Flood Defence prescribe the probability of the design conditions on which the design of embankments is based. For the Schelde Estuary the probability of the design conditions is 1/4000 a year. This 1/4000 a year probability was not directly derived from a certain accepted level of risk. No norm differentiation within our research area is present. No risk standards in law are thus available for comparison.

There are individual risk figures of other types of risk available with which we can compare our risk figures. The calculated individual risk in this case study is currently $1.8*10^{-6}$. In future this increases to $4.2*10^{-6}$. A common risk figure used in the industry is 10^{-6} (see chapter 3.4). This means that the individual risk due to flooding is higher than the industrial norm and would thus not be accepted according to that norm. The order of magnitude, however, is the same.

The societal risk is expressed by the EANC currently is 0.08 to 0.2 casualties per year and increases to about 0.23 to 0.55 casualties per year in 2100. There are no clear standards to compare these numbers with.

The current EAD is about 0.0001% of the GDP of the Netherlands. Flooding in this area of the Netherlands thus not threatens the economy of the Netherlands as a whole. The same is expected to apply for the future.

The current alternative could also be assessed by comparing the costs with the risk reduction achieved in this alternative. The calculations of the Present value (PV) of the reduced risk and the costs in the previous section show that only if the World Market scenario becomes reality dike raising to this level is cost-efficient. If one of the other scenarios becomes reality, maintaining this safety level is too expensive. In this cost-benefit analysis the reduction in the number of expected casualties was not taken into account.

Continuing the current strategy thus results in a high number of expected casualties compared to safety standards for the industry and on economic grounds it is too expensive (unless the World Market scenario becomes reality). It is, therefore, worthwhile to study alternatives for the future.

4.5 The 'do nothing' reference

Description

In this alternative the risk is calculated in case no measures are taken at all. Embankments and dunes are thus not raised or strengthened. They are, however, maintained and managed. In reality this is not considered a feasible option in the Netherlands. In this study, it is used for comparison purposes only.

The embankments are currently designed to withstand circumstances with a probability of 1/4000 a year. In the future, the probability corresponding with the current design water levels will increase due to sea level rise (see figure 4.13). In the World Market scenario, for example, the design water levels will correspond with a probability of about 1/400 a year in 2050 and 1/15 a year in 2100. Table 4.19 shows the future probabilities of the current design water levels for all scenarios. The flood risks corresponding with the do-nothing alternative are assessed by increasing the probabilities of the events calculated in section 4.3.2 (current flood risk) and correcting the damages for economic growth and the expected number of casualties for population growth.

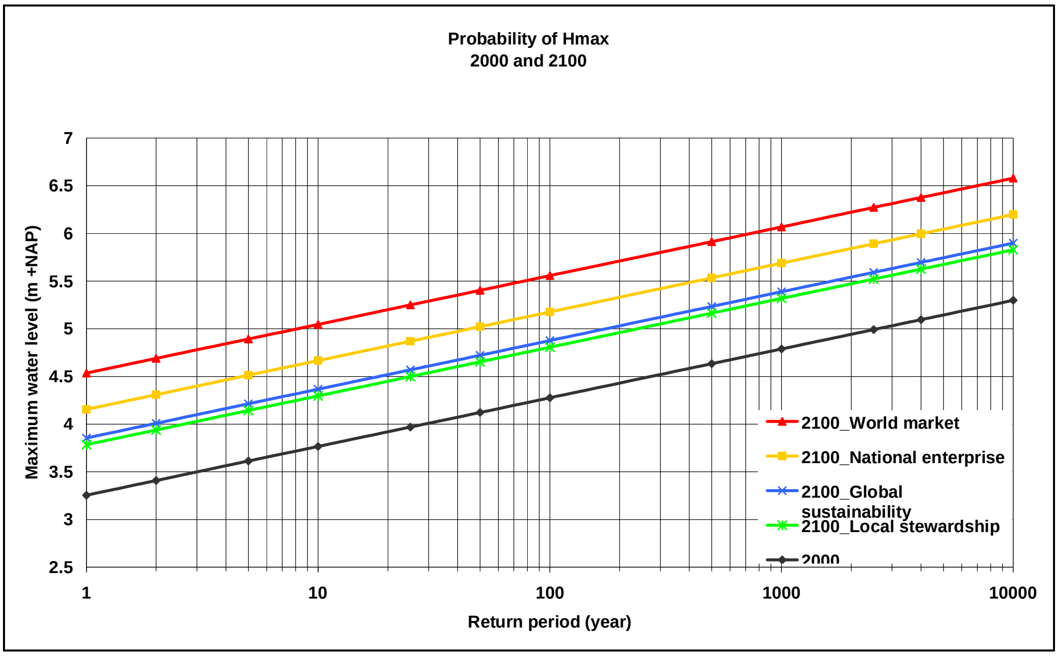


Figure 4.13 Increasing return periods of maximum water levels at Vlissingen in 2100, according to four scenarios (This figure is equal to figure 4.3)

Table 4.19 Future probabilities of the water level at Vlissingen of 5.10 m + NAP that currently has a probability of 1/4000 per year

	WM	NE	GS	LS
2050	1/400	1/800	1/1000	1/1500
2100	1/15	1/70	1/300	1/400

Resulting risk

Tables 4.20, 4.21 and 4.22 show that the flood risks increase enormously if embankments are not raised. This increase is caused by both climate change and economic growth. While continuing the current strategy resulted in an EAD in 2100 of about respectively 14, 6, 4 and 2 M€/yr in the four scenarios World Market, National Enterprise, Global Sustainability, and Local Stewardship, these risks in the do-nothing alternative would become respectively 2670, 277, 42 and 13 M€/yr.

Expected costs and other effects

The costs of this strategy are 0 (if maintenance costs are neglected). This strategy seems very unrealistic: if floods would occur as frequently as assessed here, people will increase their protection, or they will change the land use or adapt their land use functions to lower the damage. It is not expected that people will allow disastrous floods frequently without doing anything to improve the situation. Because this strategy is unrealistic, it is not evaluated. It is only used for comparison of other strategies.

Table 4.20 Future EAD (M€/yr) in different scenarios for the strategic alternative 'do nothing'

Year	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	0.53	0.53	0.53	0.53
2050	23	8.3	4.8	2.2
2100	2700	280	42	13

Table 4.21 Future Expected Annual Number of Affected Persons (EANAP) in different scenarios for the strategic alternative 'do nothing'

Year	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	19	19	19	19
2050	230	110	79	52
2100	7500	1300	350	190

Table 4.22 Future Expected Annual Number of Casualties (EANC) in different scenarios for the strategic alternative 'do nothing' (assuming that 50% of the people is evacuated or in a shelter)

Year	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	0.15	0.15	0.15	0.15
2050	2.3	1.0	0.71	0.45
2100	95	15	3.6	1.9

4.6 Strategic alternatives

4.6.1 Introduction

To develop strategic alternatives it is advised to use a top-down approach in which guiding-principles are used (see chapter 3.6). For the Schelde case the resistance / resilience guiding principle has been used to develop strategic alternatives. Two resistance alternatives are considered and two alternatives with a higher degree of resilience were studied (see table 4.23). To be able to distinguish different resistance strategies the location where resistance is applied is used as secondary guiding principle. To distinguish different resilience strategies the degree to which spatial planning occurs autonomously is used (see figure 4.15). In resilience alternatives, the fact that floods may occur is more consciously present than in the resistance alternatives. Therefore, the guiding principle describing whether spatial planning occurs autonomously or follows flood risk management is used in the more resilient alternatives only. In the resistance alternative spatial planning will not be significantly influenced by flood risk management.

The strategic alternatives are discussed below. The current strategy was discussed in the previous sections.

Table 4.23 Overview of the strategic alternatives for the Schelde Estuary

	Name	**Guiding principles**	**Description**
0	Current policy	• Resistance along long lines	Maintaining the once in 4000 years protection level by raising embankments
1	Flood surge barrier at Vlissingen	• Resistance concentrated at one location	Providing a once in 10,000 years protection level by a barrier
2	Risk approach & no spatial planning	• Increase of resilience • Spatial developments occur autonomous, flood protection levels follow	Flood protection level differentiation based on flood consequences, spatial developments occur autonomously
3	Risk approach & spatial planning	• Increase of resilience • Flood patterns control spatial developments;	Protection level differentiation and spatial planning are combined in order to lower flood risks.

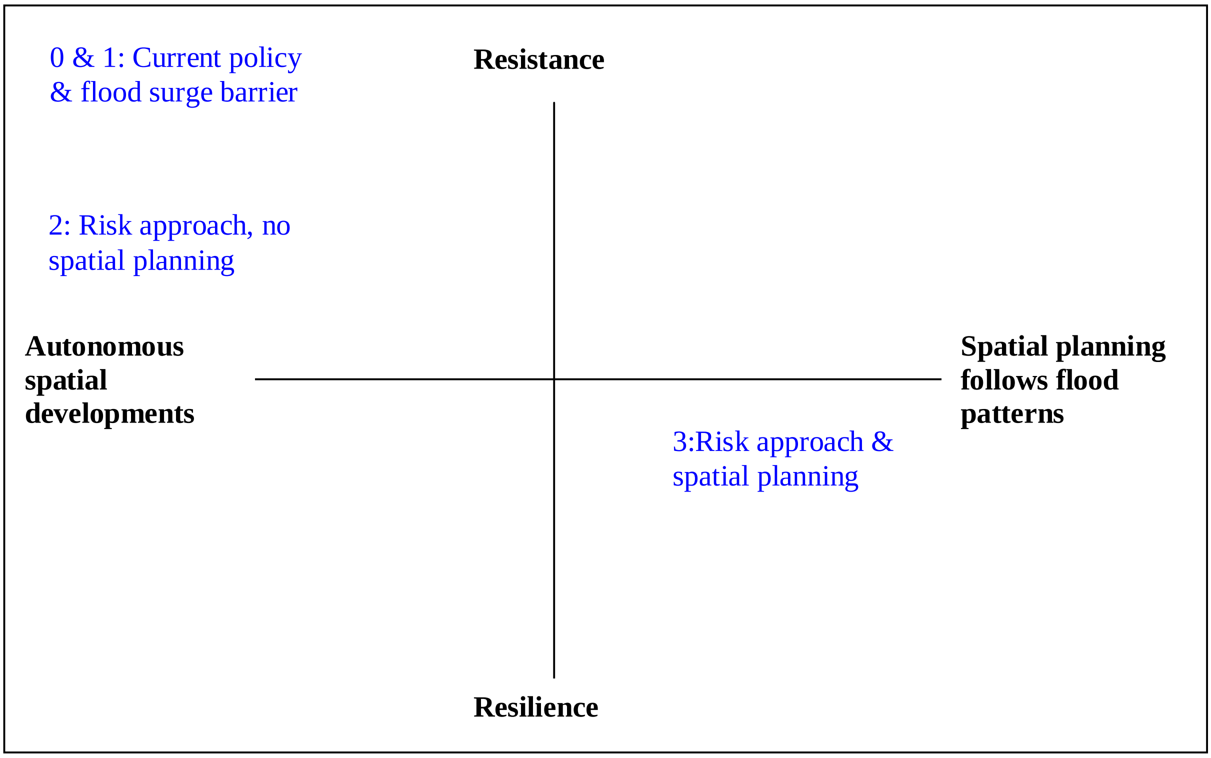


Figure 4.14 The 4 strategic alternatives placed across axes which represent the two guiding principles used (the do-nothing strategy is not shown here)

4.6.2 Alternative 1: A storm surge barrier near Vlissingen

Description

This alternative incorporates a storm surge barrier near Vlissingen (see figure 4.15) to prevent high water levels in the Westerschelde. The design of the barrier is very sophisticated: in normal situations it is open to large sea vessels passing through, while at extreme situations it is closed. The strategy also includes dike raising of the dike stretch which is situated at the sea-side of the proposed storm surge barrier.

This alternative is a resistance alternative just like the current strategy, because both aim at flood prevention. While in the current alternative the resistance is located at the embankments along the Westerschelde, in this alternative resistance is concentrated at the flood surge barrier.

Basic assumptions made to be able to anlyse this alternative are:

- The storm surge barrier is able to withstand future conditions with a probability of 1/10,000 years in 2100. This requires the barrier to withstand water levels of 6.20m at Vlissingen and to be sufficiently strong to withstand high waves.
- When conditions are more extreme, the flood surge barrier will not function anymore.
- The 1/10,000 year event in 2100 in the National Enterprise scenario was used for the design. This level lies above the 1/10,000 year event in 2050 in all scenarios and the 1/10,000 event in 2100 in the scenarios Global Sustainability and Local Stewardship. If these scenarios become reality, flood protection levels will thus be higher than the 1/10,000 a year.
- Embankments along the Westerschelde are maintained to withstand the current 1/4000 year conditions.
- No floods occur below design conditions. More severe conditions will result in failure of the barrier and flooding in areas of the Westerschelde Estuary.

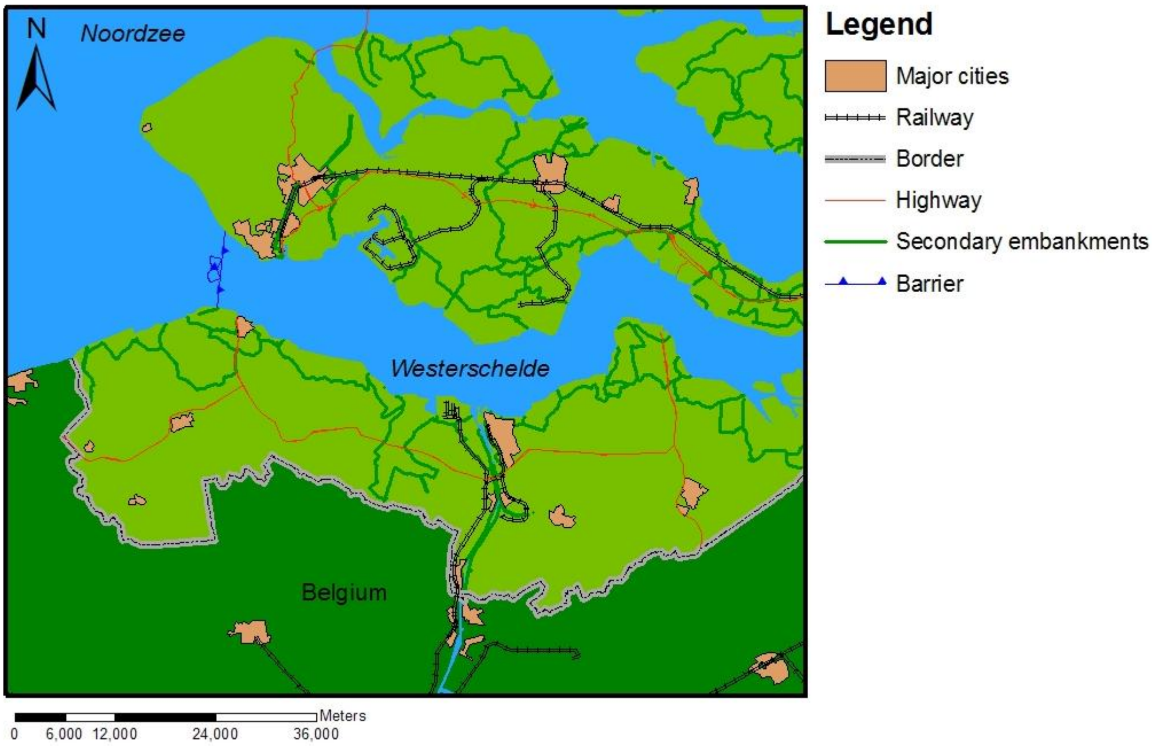


Figure 4.15 The location of the flood surge barrier at Vlissingen.

Resulting risk

For this strategic alternative the flood probability differs per scenario. In the World Market scenario the flood probability is higher than designed and in the other scenarios it is lower, due to the lower sea level rises than anticipated. The resulting flood probabilities are presented in table 4.24.

Table 4.24 Flood probabilities in the different scenarios (Flood barrier alternative)

Year	**World Market**	**National Enterprise**	**Global Sustainability**	**Local Stewardship**
2050	1/50,000	1/100,000*	1/100,000*	1/100,000*
2100	1/2,000	1/10,000	1/40,000	1/50,000

*If the flood probability found is smaller than 1/100,000 it was changed to 1/100,000. Smaller probabilities of failure of the barrier seem very unrealistic (the barrier may also fail due to other unknown causes than overtopping)

The resulting EAD, EANAP and EANC in different future scenarios for the Dutch area is presented in the tables 4.25, 4.26 and 4.27. Next to the risk reduction in the Dutch Westerschelde Estuary, this storm surge barrier will also result in risk reduction in the Belgium part of the Schelde Estuary. Currently, flood risks in Belgium are estimated to be about 10 M€/yr (Blankaert *et al.*, in press).

Table 4.25 Future EAD (M€/yr) in different scenarios for the strategic alternative 'Storm surge barrier at Vlissingen'

Year	**World Market**	**National Enterprise**	**Global Sustainability**	**Local Stewardship**
2000	0.53	0.53	0.53	0.53
2050	0.19	0.07	0.06	0.04
2100	29	2.6	0.45	0.15

Table 4.26 Future Expected Annual Number of Affected Persons (EANAP) in different scenarios for the strategic alternative 'Storm surge barrier at Vlissingen'

Year	**World Market**	**National Enterprise**	**Global Sustainability**	**Local Stewardship**
2000	19	19	19	19
2050	1.8	0.90	0.94	0.87
2100	77	11	3	2

Table 4.27 Future Expected Annal Number of Casualties (EANC) in different scenarios for the strategic alternative 'Storm surge barrier at Vlissingen'

Year	**World Market**	**National Enterprise**	**Global Sustainability**	**Local Stewardship**
2000	0.15	0.15	0.15	0.15
2050	0.02	0.01	0.01	0.01
2100	1.2	0.15	0.04	0.02

Expected costs and other effects

The costs of the storm surge barrier were estimated based on the total costs of two storm surge barriers built in the recent history: the Oosterschelde barrier (built in 1986) and the Maeslant barrier (built in 1997). The design of the new barrier will be more sophisticated in order to allow the passage of large ships to Antwerpen. The Oosterschelde barrier cost about 2.5 B€ (www.deltawerken.com). The Maeslant barrier cost about 0.5 B€ (www.deltawerken.com). Taking into account an inflation rate of 2% per year, the total costs to build a storm surge barrier near Vlissingen were estimated at 3.8 B€. The costs of dike raising of the stretch at the sea-side of the storm surge barrier and possible extra costs for dredging in the navigation channel due to increased sedimentation are considered negligible compared to the high costs of the barrier.

This cost figure is compared with the present value of the risk reduction in all scenarios. This risk reduction is found by comparing the EAD resulting from this strategic alternative with the EAD in the do-nothing alternative. Table 4.28 shows the present value of the costs and the EAD reduction for the Netherlands.

Table 4.28 shows that this alternative is not cost effective in any scenario. However, the alternative also causes significant risk reduction in Belgium, especially in Antwerpen. For a fair analysis the advantage of the barrier for Belgium should be considered as well. Current flood risks in Belgium were estimated as 10 M€/yr (Blankaert *et al.*, in press). If floods would be prevented completely, then the risk reduction in Belgium up to 2100 would be about 800 M€ if 2% annual economic growth is assumed. The resulting risk reduction would then be 4100 M€ for the World Market scenario which means that the alternative would become cost-efficient. In the other scenarios the alternative would still be too expensive. For the large city of Antwerpen, the storm surge barrier may be an interesting alternative. The alternative, dike raising, may be very difficult in a city such as Antwerpen.

Table 4.28 The Present Value (M€) of the risk reduction and costs in the 'Storm surge barrier' alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Risk reduction	3300	500	160	70
Costs	3800	3800	3800	3800

This alternative will have side effects. The differences between low- and high tide will be reduced and the sedimentation and erosion patterns may change in the Westerschelde. This is expected to affect nature negatively. The navigation channel in the Westerschelde may need to be dredged more due to increased sedimentation resulting from the reduced tidal differences. Navigation will still be possible, even of large ocean-going vessels. Since the navigation opening will be small, some negative effects are expected. No effects on land use developments and socio-economic opportunities of the land use are expected.

4.6.3 Alternative 2: Risk approach, no spatial planning

Description

In the alternative '*Risk approach, no spatial planning'* embankments along each subarea are raised if the risk becomes unacceptably high. In order to do so, the currently present secondary embankments that divide the area into subareas get an official status. Land use developments are considered to occur autonomously and flood protection standards thus *follow* these developments. This alternative is interesting because a risk based approach is considered seriously in the Netherlands.

For this alternative it was assumed that embankments would be raised if that is cost-efficient. For each subarea it was studied whether the costs of embankment raising were equal or lower than the expected risk reduction which was obtained by this embankment raising. If this was the case, then the embankments were raised.

This strategy maintains a high level of resistance, but resilience is also increased because sudden catastrophes are less likely in some areas. Urban areas are protected best, thus extreme events are expected to flood mainly rural areas. Because flood extents are limited by secondary embankments and because consequences are probably smaller due to norm differentiation, this alternative is considered more resilient than the current one.

Analysis

It is not feasible to consider which level of embankment raising would be cost-efficient for each subarea and at what moment embankments should be raised. In this project, therefore, a simplified analysis approach has been followed, in which a fixed embankment raising is evaluated at two moments in time (2000 and 2050).

For 2000 there are two options for each subarea. Depending on the cost-efficiency:

- Either the embankments are raised to the required 1/4000 year protection level for 2050 in the National Enterprise scenario (with about 0.4 m);
- Or, the embankments are not raised at all and remain on the current 1/4000 protection level.

In 2050, this procedure is repeated:

- Either the embankments are raised to the required 1/4000 protection level for 2100 in the National Enterprise scenario (with about 0.9 m in areas where no embankment raising occurred in 2000 and with 0.5 m where embankments were also raised in 2000);
- Or they are not raised.

Figure 4.16 shows which compartments were selected for embankment raising in 2000, in 2050, and in both years.

In this procedure it was assumed that the National Enterprise scenario is most likely and decisions are based on this. If another scenario becomes reality, then the embankments which are raised will not protect against the 1/4000 year water level for that scenario. In the Local Stewardship scenario the obtained flood probability is lower, whereas in the World Markets it is higher.

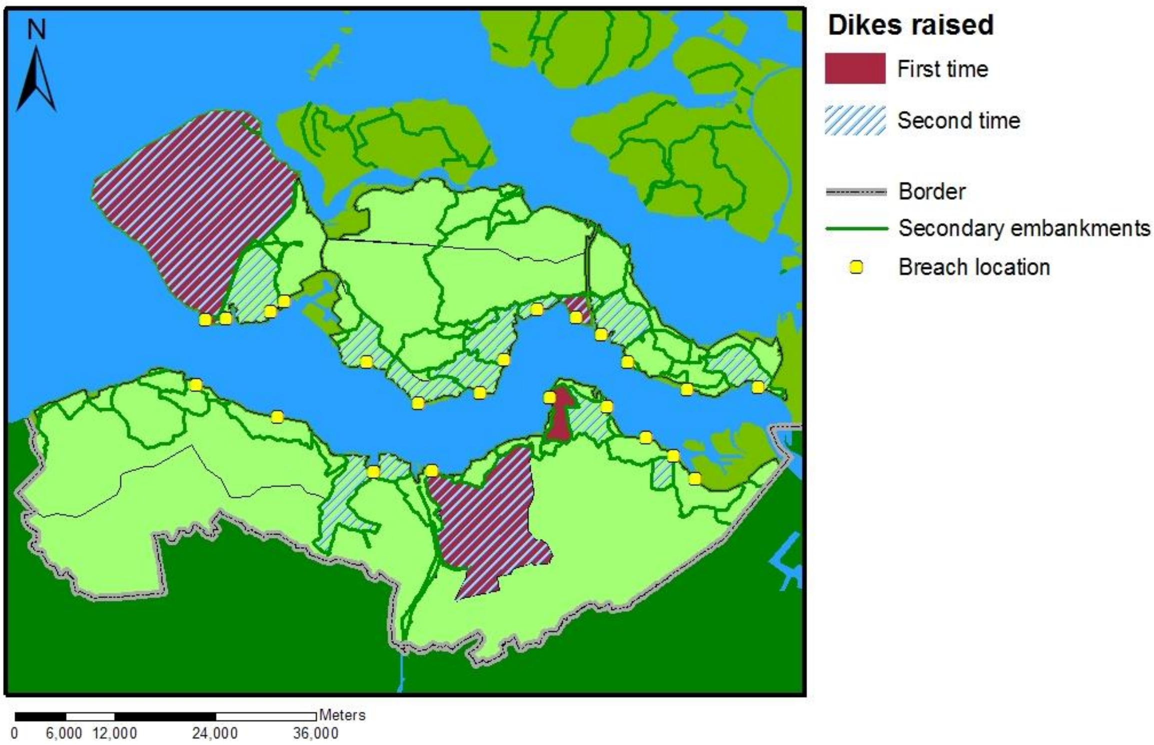


Figure 4.16 Subareas selected for dike raising in 2000 and 2050 [10]

[10] Not all subareas were analysed. Only those areas in which breach locations are drawn were considered.

Resulting risk

Tables 4.29 and 4.30 and figure 4.17 show the resulting EAD values for this strategic alternative. Table 4.31 and 4.32 show that the resulting expected annual number of casualties (EANC) and affected persons (EANAP) lie in between the figures of the strategic alternatives 'dike raising' and 'do nothing'.

Table 4.29 EAD (M€/yr) in 2050 for all scenarios for three strategic alternatives.

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	2.6	1.8	1.4	0.9
Do nothing	23	8.3	4.8	2.2
Risk approach	14	3.9	2.2	1.0

Table 4.30 EAD (M€/yr) in 2100 for all scenarios for three strategic alternatives

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	70	6.3	1.0	0.3
Do nothing	2660	280	40	13
Risk approach	290	26	8.9	3

Table 4.31 Expected Annual Number of Casualties (EANC) in 2050 and 2100 for the 'risk approach, no spatial planning' alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	0.15	0.15	0.15	0.15
2050	0.47	0.37	0.25	0.25
2100	11	0.85	0.63	0.31

Table 4.32 Expected Annual number of Affected Persons (EANAP) in 2100 for the 'risk approach, no spatial planning' alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	34	28	27	22
Do nothing	4600	81	200	34
Risk approach	1600	46	75	25

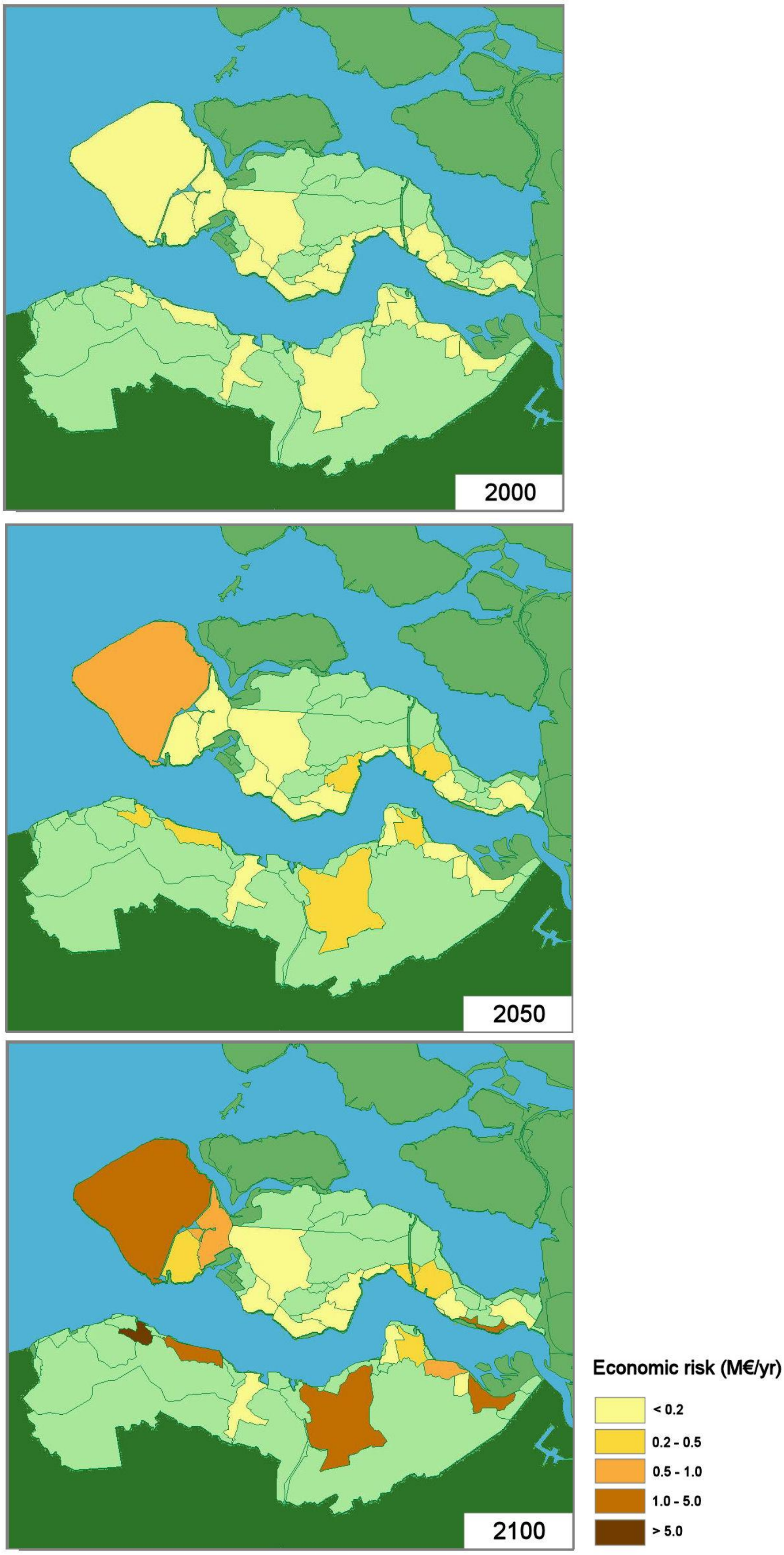


Figure 4.17 EAD (M€/yr) per subarea in the National Enterprise scenario in 2000, 2050 and 2100, according to the strategic alternative 'risk approach, no spatial planning'

Costs

The technical costs of raising embankments with 1 meter were estimated at 3.2 M€/km length. Based on that figure it was decided to raise embankments or not. This figure does not include the extra costs for planning and implementation. In the calculation of the total costs of the strategic alternative this figure for embankment raising was multiplied with a factor of 2.5 to include planning costs.

Table 4.33 shows the present value of the costs and the reduced risks (reduced compared to the do-nothing strategy) in M€. Table 4.32 shows that both the World Market and National Enterprise scenario are cost efficient, but the other two scenarios are not. Their costs are much higher than the resulting benefit of risk reduction. In those scenarios sea level rise and economic growth are less than in the anticipated National Enterprise scenario, while the economic growth is less than anticipated. In those scenarios dikes are thus raised too much, which is costly. In reality, however, the embankments may be raised at the time needed. This will increase the cost-benefit ratio of the strategic alternative.

Table 4.33 Present value of reduced risks and costs (M€) for the 'risk approach, no spatial planning' alternative, for 2000, 2050 and in total (discounted back to 2000)

		World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	Costs	53	53	53	53
	PV reduced risk	80	27	43	15
2050	Costs	600	600	600	600
	PV reduced risk	11200	150	1000	55
Total	Costs	230	230	230	230
	PV reduced risk	3300	70	350	30

Other effects

Land use will develop autonomously. Thus economic opportunities of the land, nature and sea functions as fishery and navigation are not affected by this strategy.

In reality people may change this strategy according to developments which are occurring. They may, for example, decide to raise embankments already in 2040 if sea level rise is higher than expected. Or they might calculate the optimal dike height per subarea in terms of cost-benefit. Since allowing all these options would make an analysis infeasible, these have not been incorporated. They must, however, be kept in mind, when the alternative's flexibility is scored.

4.6.4 Alternative 3: Risk approach & spatial planning

Description

While in the previously described alternative the protection levels follow spatial development, in the alternative 'risk approach & spatial planning' flood protection levels are used to guide spatial developments. Spatial developments do not occur autonomously, but they are planned in such a way that vulnerability is reduced.

This alternative consists of a combination of norm differentiation, embankment strengthening and widening, construction of secondary embankments and land use planning. Embankments of the area which are currently vulnerable areas are made highest, those of the rural areas lowest. The current land use determines thus which subareas are protected best. In future, land use developments are also directed towards these heavily protected areas. The areas which are more rural currently will thus remain more rural, also in the future.

Areas which would get a high future risk if nothing was done (in the do-nothing-strategy) are given a higher flood protection level in this strategy (see figure 4.18). These are the subareas in which the cities of Middelburg, Terneuzen and Breskens are situated and relatively small areas which may face high water depths in case of flooding. In this strategy economic investments are controlled. Economic investments concentrate around the existing cities of Vlissingen, Middelburg, Terneuzen and Breskens and in the areas which are not directly adjacent to the Westerschelde. In the remaining coastal areas, economic investments are only allowed if they are carried out in such a way that flood impacts do not increase. New buildings can thus not use the first floors, or they should be build on mounds or other solutions must be found. If no new investments were made, then economic growth is limited to an increase in production and possessions of the investments that are already present. Figure 4.18 shows which compartments were selected for better protection and in what areas the spatial development is restricted.

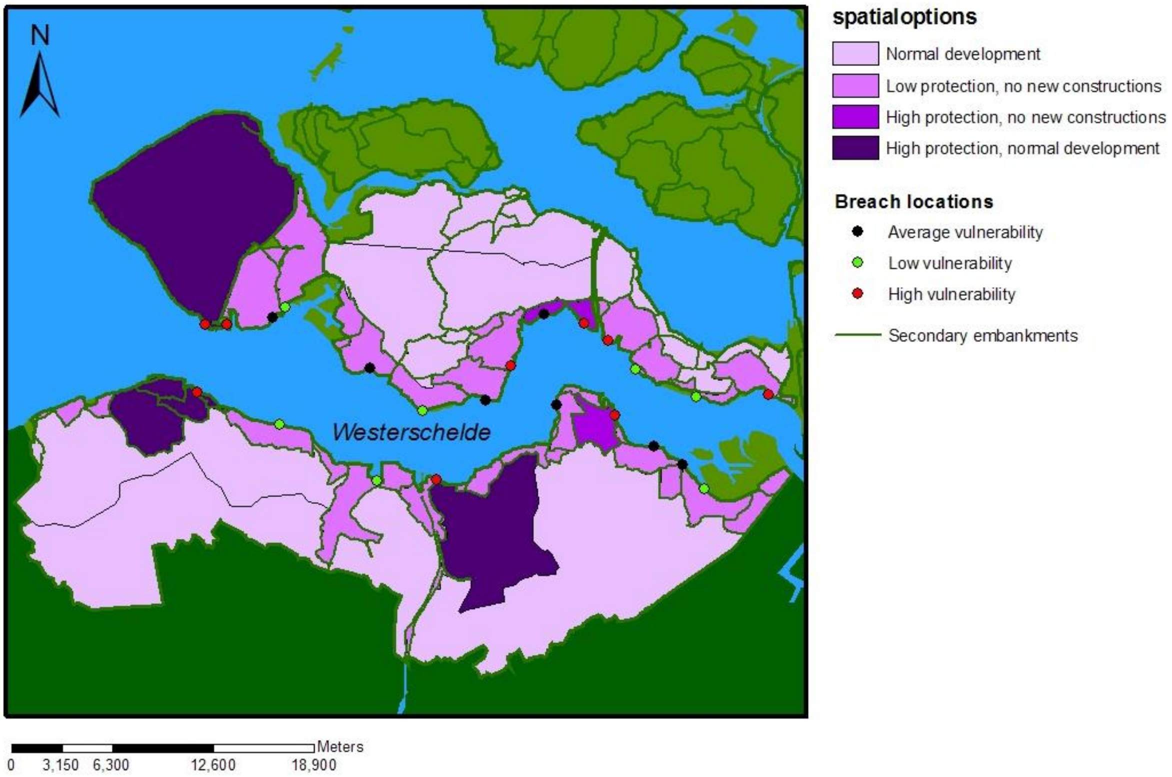


Figure 4.18 The flood protection level and spatial development regulation level in the various compartments (no new construction means: no new constuctions which increase the potential damage, new constructions with an adapted building style are allowed)

Analysis

To be able to analyse this alternative a simplified elaboration approach was followed. The areas with a high protection level are protected against the once in 4000 years condition in 2100 according to the National Enterprise scenario, while the remaining areas have a flood protection level of 1/500 a year in 2100 according to the National Enterprise scenario. The embankments along the areas with a future protection level of 1/4000 are raised with 0.9 m, while the ones raised to 1/500 are raised with 0.4 meter. To calculate the influence of restricted spatial development, the economic growth is divided into two elements: increase in production and possessions and new constructions. Table 4.34 shows the distribution of economic growth over the two components.

Table 4.34 The two components of economic growth for the four scenarios (all in % per year)

	World Market	National Enterprise	Global Sustainability	Local Stewardship
GDP growth	2.5	1.9	1.5	0.7
New constructions	1	0.5	0.5	0
Increase in production	1.5	1.4	1.0	0.7

Resulting risk figures

Table 4.35 and 4.36 show the resulting EAD values for the strategic alternative 'risk approach & spatial planning'. The risk in 2050 is comparable to that of the current strategy in 2050. In 2100 is the the EAD figure in the World Market scenario for the spatial planning alternative much higher than for the current strategy.

Figure 4.18 shows the resulting EAD of this strategy in the National Enterprise scenario. Even though the dikes of breach locations 1 and 21 are raised, the risks there are highest of all compartments. In all areas in which the spatial planning was restricted, the EAD remains below 1 M€/yr.

Table 4.35 EAD (M€/yr) in 2050 according to three strategic alternatives, in four future scenarios

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	2.6	1.4	1.4	0.9
Do nothing	23	8.3	4.8	2.2
Spatial planning	3	1.4	1.2	0.8

Table 4.36 EAD (M€/yr) in 2100 according to three strategic alternatives, in four future scenarios

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	14	6.3	3.5	1.5
Do nothing	2663	277	42	13
Spatial planning	73	13	4	2

Table 4.37 Expected Annual Number of Casualties (EANC) in 2050 and 2100 for the spatial planning alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
2000	0.15	0.15	0.15	0.15
2050	0.33	0.25	0.21	0.19
2100	25	0.38	0.91	0.25

Table 4.38 Expected Annual Number of Affected Persons (EANAP) in 2100 for the spatial planning alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
Current strategy	34	28	27	22
Do nothing	4600	81	200	34
Spatial planning	1500	28	72	21

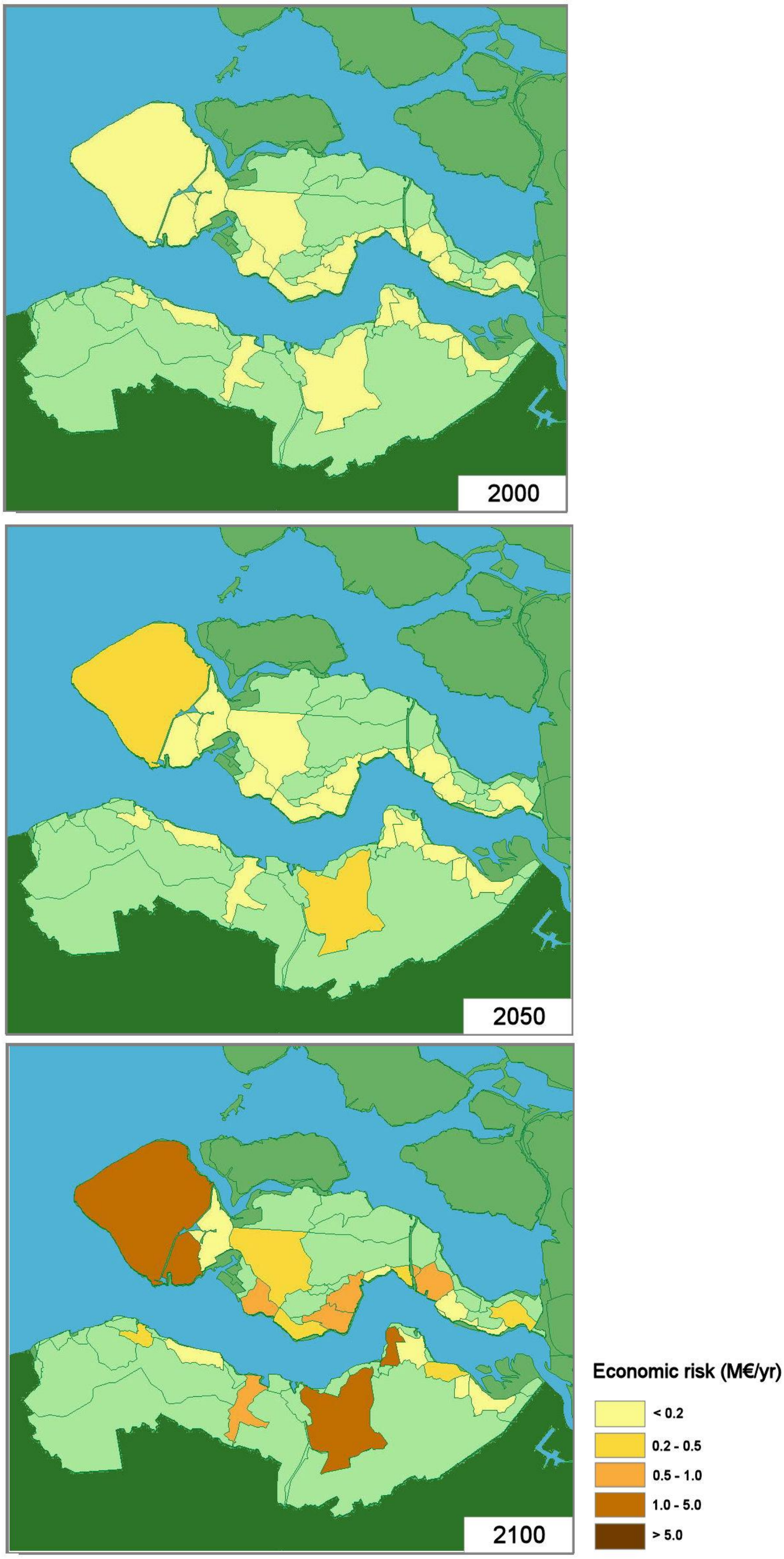


Figure 4.19 Resulting EAD in 2000, 2050 and 2100 in the National Enterprise scenario, according to the spatial planning strategy

Costs

The costs of the spatial planning alternative consist of the dike raising. The cost figures for raising 1 km dike length with 1m are the same as for the previous strategic alternative. Table 4.39 shows the present value of both the costs and the reduced risk (compared to the do-nothing strategy). The spatial planning alternative is cost-efficient in the National Enterprise and World Market scenario. In the other two scenarios the costs for dike raising are higher than the reduced risk. The economic disadvantages of not allowing some areas to develop have not been incorporated in the cost figures.

Table 4.39 Present value of costs and reduced risks (M€) in 2100 for the spatial planning alternative

	World Market	National Enterprise	Global Sustainability	Local Stewardship
PV Cost	450	450	450	450
PV reduced risk	3100	470	130	48

Other effects

This strategic alternative results in a landscape with clustered economic activity and large rural areas. The people living in areas where economic investments are restricted may feel discriminated. They have economic disadvantages and they also get a lower flood protection level on the long-term. However, all people, both in the cities and in the rural areas will need to pay less for embankment raising than they have to do in other strategic alternatives. Since economic developments are restricted land use change to less economic valuable land use types may become feasible. Nature and land scenery may benefit of this economic devaluation. It is expected that economic growth for the region in total is not suffering much, but that the growth is distributed over the area slightly differently.

4.7 Full assessment of the strategic alternatives

4.7.1 Criteria, indicators and scoring method

Criteria and indicators

Chapter 3 advises to assess the strategic alternatives by criteria related to the three sustainability domains people, planet and profit and to add criteria which involve the system's sensitivity to uncertainties. Table 4.40 shows the criteria and indicators used for the Schelde Estuary.

Table 4.40 The framework for the full assessment of long term flood risk management alternatives

Sustainability field	Criterion	Indicator
People (socio-psychological effects)	Casualty risk	EANC (casualties/yr)
	Personal intangible effects as stress, illness, loss of personal belongings, etc.	EANAP (affected persons/yr)
	Equity	- (score between -3 and +3)
Planet (ecological effects)	Effects on nature	- (score between -3 and +3)
	Effects on landscape quality	- (score between -3 and +3)
Profit (economic effects)	Implementation costs	Present value of the costs in M€
	EAD and Economic risk reduction	EAD in M€/yr, risk reduction: Present value in M€
	Economic opportunities	- (score between -3 and +3)
Sensitivity to uncertainties	Robustness	- (score between -3 and +3)
	Flexibility	- (score between -3 and +3)

To express the effects on *'people'*, the expected number of casualties, the expected personal intangible effects such as stress, illness, loss of personal belongings and effects on equity are proposed. As indicators for the first two criteria the expected annual number of casualties (EANC) and the expected annual number of affected persons (EANAP) are used. These have been analysed for each strategic alternative. No clear indicator for equity is known. Therefore, it will be scored qualitatively on a scale from -3 to +3. A combination of a scenario and an alternative scores a -3 if equity strongly decreases compared to the current situation and a +3 if it increases much. If equity is not affected, the strategic alternative scores a 0. In the Schelde system equity is affected in those alternatives in which:

- Protection level differentiation is proposed: this means that different inhabitants are not protected equally well anymore.
- People better move away to safer areas: this will be more easy for the richer people with more job opporunities.
- Some villages are more restricted in their development then others by spatial planning restrictions.

It must be kept in mind, however, that strategic alternatives which decrease equity might easily be combined with compensating measures. These measures may then result in an alternative which does not affect equity.

To determine the effects of strategic alternatives on *'planet'* or on nature the criteria 'effects on nature' and 'effects on landscape quality' are used for the Schelde Estuary. Both are scored qualitatively on a scale from -3 to +3 in a similar way as explained for the criterion equity in the previous paragraph. Nature affects can be considered by looking at the Dutch nature aims of surface area (the more the better), naturalness, diversity and connectivity. This means for the Schelde Estuary that the area of sandbanks, shoals and swamps, the naturalness of tidal prism and geomorphological processes, diversity of ecotypes, and the salt-fresh water gradient are important. Nature in the Schelde basin may be negatively effected by pollution due to floods, by salt in the flood water, or by the measures itself: if the area available for nature becomes smaller or if nature becomes less diverse this is negative. This may for example be the case in strategic alternatives which affect the tidal difference, the salt-freshwater gradients or the sediment distribution in the Schelde Estuary. Both nature and land-scape quality may also be affected by spatial planning in the alternatives. If a strategic alternative enhances possibilities for a network of connected nature areas the alternative scores positively on 'effects on nature' and if it maintains the typical land scenery consisting of open polders with secondary embankments it may score positively on 'land scenary'. The criteria 'effects on nature' and 'effects on landscape quality' are, unfortunately, rather subjective.

The *economic effects* of the strategic alternatives are assessed by the criteria: costs, economic risk, and economic opportunities. The costs and economic risks have been determined for all strategic alternatives. The economic opportunity is scored qualitatively on a scale from -3 to +3 in a similar way as discussed above.

The *sensitivity of the strategic alternative to uncertainties* is scored by the criteria 'robustness and flexibility'. Both are scored qualitatively on a scale from -3 to +3 in a similar way as the other qualitative criteria. Robustness relates to the sensitivity to unexpected events. It is assessed by answering questions, such as:

- What would happen if the storm duration is longer or if peak water levels are higher than expected?
- What if a storm surge barrier would not close or if an embankment fails, if ships sail into structures, if evacuation does not occur efficiently and panic occurs, if important people are not available, or if information services fail?

Flexibility scores better if a system still functions well even if all kind of circumstances have changed or if it is easy to adapt a strategy to changing circumstances. The flexibility of a strategy is thus large if it is very unlikely that future regret will occur.

Scoring method

The strategic alternatives are scored for each scenario for the period ranging from 2000 to 2100. The criteria were assessed for each combination of scenario and strategic alternative in the previous sections. Only the criterion ‘flexibility’ was scored independent of the scenarios, since this criterion was found to be dependent on the strategic alternative alone. All criteria which cannot be scored quantitatively are scored qualitatively by comparing the current situation with a future situation (a combination of the implementation of a strategic alternative and a future scenario).

The scoring of the qualitative criteria was done by using the Delphi approach. A group of experts discussed the alternatives and criteria and then scored the strategic alternatives. The scores were discussed and the experts were asked to reconsider their scores.

4.7.2 Results of the assessment

The ranges and means of the scores of all alternatives per scenario are found in table 4.41. Because this table provides a lot of information at once, it is quite complex. To help the reader, therefore, the worst to best scores are coloured with shades from red to green resembling the ‘traffic light colours’. The scores are explained, motivated analysed and discussed below. Table 4.42 and 4.43 summarize the scores for groups of criteria and for scenarios.

The people aspects

The two strategic alternatives ‘Continuing current policy’ and the ‘Storm surge barrier’ score best on the people’s aspects. They are expected to result in the least casualties and affected persons and they are the most equitable. The Storm surge barrier alternative even lowers the annual expected number of casualties and affected persons below the current figures (see table 4.41). The ‘Spatial planning alternative’ scores worst on equity, but this low score may be prevented by compensation measures from the government. The low scores on equity in the alternative ‘Spatial Planning’ is explained by the unequal distribution of advantages and disadvantages. Some people will be better protected than others and some will have more opportunities for economic growth than others. The rich or highly educated people may have more opportunities than the poor with little education to leave the less favourable parts of the area.

Not only the strategic alternatives, but also the scenarios influence the scores on the assessment criteria. The scenario ‘World Market’ generally creates the worst scores on the people aspects, while the Global Sustainability and Local Stewardship scenarios result in the best scores on these aspects in most alternatives. The low score in the World Market scenario is caused by the high population growth and high sea level rise and the focus on economic growth and market forces in that scenario.

The ‘planet aspects’

The strategic alternative ‘Storm surge barrier’ scores worst on the nature and landscape scenery, while the Spatial planning alternative scores best. The strategic alternatives ‘Risk approach’ and ‘Spatial planning’ both result in an improved situation for nature compared to the current status. The ‘Storm surge barrier’ alternative results in less tidal differences and thus in a smaller area of valuable tidal swamps. The ‘Spatial planning’ alternative is expected to create opportunities for connected nature areas and for better landscape planning and thus scores best.

The final future situation for nature and land scenery strongly depends on the scenario which becomes reality: the Local Stewardship results in the best scores, followed by the Global Sustainability. In the World Market scenario all alternatives score worst on the criteria nature and land scenery.

Table 4.41 Complete overview of all scores of all strategic alternatives on all criteria in the four scenarios over the period 2000 to 2100 (for the qualitative criteria the average score is provided, while the range of scores is added between brackets)

Indicator**	Scenario	Do Nothing	Current policy	Storm surge barrier	Risk approach	Spatial planning
EANC (0.2)	WM	95	0.5	1	20	5
	NE	15	0.4	0.2	3	2
	GS	4	0.3	0.0	2	1
	LS	2	0.2	0.0	1	1
EANAP (19)	WM	7500	32	77	800	200
	NE	1300	30	11	120	61
	GS	350	25	3	75	33
	LS	190	24	2	45	28
Equity	WM	-2 (-3-0)	-0.3 (-1-0)	-0.3 (-1-0)	-2	-2.5 (-3- -1)
	NE	-1.2 (-2-0)	0.0	0.0	-1 (-2-0)	-1.7 (-3-0)
	GS	-0.7 (-2-1)	0.2 (0-1)	0.2 (0-1)	-0.8 (-1-0)	-1.3 (-2-0)
	LS	-0.5 (-1-0)	0.3 (0-1)	0.3 (0-1)	-0.2 (-1-0)	-1.0 (-2-0)
Nature	WM	-0.8 (-2-0)	-1.3 (-2-0)	-2.5 (-3 - -1)	-0.7 (-2-1)	0.5 (-1-2)
	NE	0.2 (-1-1)	-0.5 (-1-0)	-2.0 (-3 - -1)	0.2 (-1-2)	1.2 (-1-3)
	GS	0.5 (0-2)	0.2 (-1-1)	-1.5 (-2-0)	0.8 (-1-2)	1.7 (-1-3)
	LS	1 (0-2)	0.3 (0-1)	-1.3 (-2-0)	0.8 (0-3)	2.2 (0-3)
Landscape quality	WM	-0.5 (-2-0)	-1.8 (-3- -1)	-1.7 (-3-0)	-0.8 (-2-0)	0.3 (-1-1))
	NE	-0.2 (-1-0)	-1.0 (-2 – 0)	-1.0 (-2-0)	-0.5 (-1-1))	0.7 (-1-2)
	GS	0.3 (0-1)	-0.5 (-2-1)	-0.5 (-2-1)	0.3 (-1-2)	1.2 (-1-3)
	LS	0.7 (0-2)	0.3 (-1-2)	-0.3 (-1-1)	0.8 (0-3)	1.5 (0-3)
Costs	WM	0	900	4000	200	450
	NE	0	700	4000	200	450
	GS	0	600	4000	200	450
	LS	0	600	4000	200	450
EAD (0.53) / Risk reduction*	WM	2700 /0	14 / 3200	29 / 3300	291 / 3300	73 / 3100
	NE	280 /0	6 / 470	3 / 520	26 / 350	13 / 470
	GS	42 /0	4 / 89	0.5 / 160	9 / 170	4 / 130
	LS	13 /0	2 / 46	0.2 / 68	3 / 31	2 / 48
Ec. opport.	WM	-1.7 (-3-1)	1 (0-3)	1.8 (1-3)	0.5 (-1-3)	-0.2 (-2-2)
	NE	-1.3 (-2-0)	0.7 (0-2)	1.3 (1-2)	0.8 (0-3)	0.0 (-1-1)
	GS	-1.3 (-2 - -1)	-0.2 (0-1)	0.8 (0-1)	0.7 (0-2)	-0.3 (-1-0)
	LS	-0.8 (-2- 0)	0.3 (-1-0)	0.3 (-1-1)	0.0 (-1-1)	-0.8 (-2-0)
Robustness	WM	-1.7 (-3 - 0)	-0.7 (-2- 0)	-1.0 (-3-1)	-0.7 (-3-1)	-0.5 (-3-1)
	NE	-1.0 (-2-0)	-0.3 (-1-0)	-0.8 (-2-1)	-0.5 (-3-1)	0.0 (-3-2)
	GS	-0.8 (-2-0)	0.0 (-1-1)	-0.3 (-1-1)	-0.2 (-2-1)	-0.2 (-3-1)
	LS	-0.2 (-1-1)	0.3 (0-1)	-0.3 (-1-1)	0.0 (-2-1)	0.5 (-3-3)
Flexibility	-	0.5 (-2 -3)	0 (-1-2)	-3	1.2 (0-3)	1.5 (1-2)

* Risk reduction compared to the do-nothing alternative, ** The units of the criteria are provided in table 4.40.

The 'profit aspects'

The Storm surge barrier alternative is most expensive, but it also results in the lowest Expected Annual Damage criterion while the risk approach and spatial planning score best on costs and result in an EAD which is comparable with the EAD in the 'Current policy'. The figures must be considered with care and in combination with the other criteria: both the EAD and costs only include tangibles. All kind of very important intangible advantages and disadvantages are excluded from these figures. The economic opportunities are best in the Storm surge barrier alternative. However, the spreading in scores on that criterion is large and the experts do not even agree on the direction of change of the economic opportunities.

Table 4.41 also shows that the effect of different scenarios on the profit related criteria is much larger than the effect of different strategic alternatives. In the World Market scenario the profit criteria score best, while in the Local Stewardship they score worst.

Effects on the ability to cope with uncertainties

The Do-nothing strategic alternative results in the lowest robustness and the Spatial planning alternative in the highest robustness. However, spreading of the scores is large. The Storm surge barrier alternative also scores relatively low, because in that alternative the safety depends on the well-functioning of one barrier. If the barrier does not close, floods may occur. In the Risk approach and Spatial planning alternatives only certain compartments will become flooded in case of a dike failure. In the Spatial planning strategic alternative these are probably the least vulnerable compartments.

The different scenarios result in different scores on robustness. The World Market scenario results in the lowest robustness, while Local Stewardship results in the most robust system. This is explained as follows: if a flood risk management strategy fails, consequences are largest in the World Market scenario and smallest in the Local Stewardship scenario.

The Spatial planning strategic alternative is the most flexible one, while the Storm surge barrier alternative is the least flexible. Once built, this storm surge barrier is not adaptable and if it was built and not needed, a lot of money is wasted. The other strategic alternatives can be adapted in time if climate or socio-economic changes are different than anticipated.

Overview over all strategic alternatives

If profit and economic values are considered important, then the Risk approach and Spatial planning alternatives seem reasonable (see table 4.42). If, on the other hand, people aspects are considered most valuable, the Storm surge barrier and the Current policy are good alternatives. Favouring the planet aspects or valuing a low sensitivity for uncertainties will result in a preference for the Spatial planning strategy.

Table 4.42 Summary of scores of the strategic alternatives on the different sustainability aspects

Alternative / Aspect	Do nothing	Current policy	Storm surge barrier	Risk approach	Spatial planning
People	---	++	+++	-	-
Planet	++	--	---	+	+++
Profit	---	-	--	+++	+
Sensitivity for uncertainties	---	-	---	+	++

Table 4.43 summarizes all criteria per scenario. It was determined by comparing the scores of the different strategic alternatives for one scenario and then translating them in plusses and minuses for the different groups of criteria. Next the plusses and minuses of the different strategic alternatives for a scenario were added. The resulting plusses and minuses show which strategic alternative scores best in a certain scenario. A plus thus not necessarily means that the strategic alternative scores well, but only that it scores better than the other alternatives.

Table 4.43 shows that in the World Market scenario the Current strategy or the Risk approach increase sustainability most, while in the other scenarios the Spatial planning alternative scores better on the sustainability aspects. The scenarios thus affect the results significantly: if the World Market scenario becomes reality and economic growth is high, then there is a lot of value to protect and a lot of money available for protection. A more resistant strategy such as the Current strategy seems then sensible. If, at the other hand, there is less economic growth and climate changes less and there is more attention for nature and land scenery then a cheaper strategy which more opportunities for nature and land scenery development should be considered. A strategic alternative with more resilient components, such as the Spatial planning strategy is then advisable. If a resistant strategy is preferred, then an alternative with dike strengthening seems more logical than the Storm surge barrier. This is cheaper, more flexible and more robust.

The Spatial planning strategic alternative scores reasonably well in all scenarios. However, it scores relatively low on the people aspects. If this strategic alternative would be considered, it would require a lot of attention for the people related aspects. Scores could be improved by better flood event management (shelters, warning and evacuation) and by compensation or support for those people who are negatively affected.

Guiding principles

The results indicates that in the Schelde Estuary the more resistant strategic alternatives score well on people aspects, while the more resilient strategic alternatives score better on the planet, profit and sensitivity for uncertainty aspects. In World Market scenarios the resistance strategies score better, while in the other socio-economic scenarios increasing the resilience of the system improves sustainability more than increasing resistance does.

*Table 4.43 Summary of scores of the strategic alternatives in the different scenarios (the strategic alternatives were compared per scenario here**

Alternative **Scenario**	**Do Nothing**	**Current policy**	**Storm surge barrier**	**Risk approach**	**Spatial planning**
World Market	people -- planet + profit -- uncertainties -	**people ++ planet - profit + uncertainties +**	people + planet -- profit - uncertainties --	**people - planet + profit ++ uncertainties +**	people - planet ++ profit - uncertainties ++
National Enterprise	people -- planet + profit -- uncertainties -	people + planet -- profit - uncertainties +	people ++ planet -- profit - uncertainties --	people - planet - profit ++ uncertainties +	**people - planet ++ profit - uncertainties ++**
Global Sustainability	people -- planet + profit - uncertainties -	people + planet - profit -- uncertainties +	people ++ planet -- profit + uncertainties --	people - planet + profit ++ uncertainties +	**people - planet ++ profit + uncertainties ++**
Local Stewardship	people -- planet + profit - uncertainties -	people + planet - profit ++ uncertainties +	people ++ planet -- profit -- uncertainties --	people - planet + profit - uncertainties +	**people - planet ++ profit - uncertainties ++**

* The green colour indicates the best strategic alternative for the scenario (determined by adding plusses and minuses)

Reference for scoring

As a reference for the scoring of the qualitative criteria the current status of the system was chosen. This resulted in a scoring of the future situation which reflects both the strategic alternative and the scenario. Since the scenarios include assumptions, also the effects of those assumptions were scored. It would have been better if instead the effects of the Do-nothing alternative in the different scenarios were determined first. These four future situations consisting of the four future scenarios combined with the Do-nothing alternative could then be used as reference for the scoring of the strategic alternatives. In that way the effect of the scenario was already incorporated in the reference and purely the effect of the strategic alternative would have been scored. Instead of the do-nothing alternative, also the Current policy could have been used as a reference.

The used procedure in which both the effects of the scenarios and the effects of the strategic alternative was scored seems to have resulted in confusion, especially for the criterion ‘economic opportunities’. Economic opportunities in a certain future state depend on the scenario which has become reality and the strategic alternative which was implemented. In the scores in table 4.42 both are incorporated. However, the economic opportunity criterion should reflect the effect of the strategic alternatives on the case study area and not the effect of the economic growth assumption. If in a certain scenario fast economic growth occurs in the Netherlands, a certain strategic alternative may still reduce or enhance this growth in the case study area compared to other areas in the Netherlands. The economic growth hampering effect of a alternative may be larger in a scenario with a high economic growth than in a scenario with a low economic growth. There is thus a difference between the scenario assumption and the effect of a strategic alternative. People using the Delfi method should be very conscious about the reference they choose and about wether they are interested in the effect of a strategic alternative or in the sustainability of a future situation (combination of scenario and alternative).

The assessment criteria

The quantitative criteria are clearly defined. The qualitative criteria are less clear. For equity the direction of the score (+ or -) is consistent although for many combinations of scenarios and alternatives somebody also scored a ‘0’ (no change). The actual figures do differ. The wide range of scores of the experts on these criteria indicate that the criteria robustness and economic opportunities were least clear. For those criteria the experts even differ in their opinion on the direction of change. They must thus be better defined e.g. by quantitative indicators, by clear questions or subcriteria.

The scoring method

The method used to score the qualitative criteria, the Delphi method, was found to be very useful: by discussing the criteria and the strategic alternatives they became more sharply defined and, therefore, more clear. The discussions also revealed the motivations of each person for his/her scores and thus tought everyone about possible effects of a strategic alternative on all criteria. The method also showed the differences in understanding of the criteria ‘economic opportunities’ and ‘robustness’ and thus the need to improve the definitions of those criteria.

4.8 Discussion and conclusions

4.8.1 Overview and discussion of the results

The Schelde case study is used as a test case for the procedure and methods proposed in chapter 3. It aims to study long-term strategies for flood risk management in the Schelde Estuary. The results may help policy makers to develop a long-term vision on flood risk management in the Schelde Estuary. All steps proposed in chapter 3 (system characterisation, analysis of the current flood risk management strategy, analysis of strategic alternatives and a full assessment of the current strategy and of strategic alternatives) were carried out. The results are discussed per step below.

System characterisation and scenario building

The studied part of the Schelde Estuary consists of the Westerschelde water body and the surrounding low-lying polder areas. These polder areas are used for agriculture, housing and industry. Currently, they are protected by embankments which are designed to withstand once in 4000 year storm surge conditions. The Belgium upstream part of the Schelde Estuary was not considered in this study, because no data could be obtained for that area. The whole Schelde Estuary should, however, be considered as one system and be studied as a whole. Measures which affect water levels in the Westerschelde will also affect Belgium flood risks. Besides, measures may also have transboundary or international socio-economic effects and effects on nature.

To describe possible future developments the global scenarios used in foresight were downscaled to the case study region and combined with climate change scenarios (see chapter 3). The four scenarios used differ significantly. They include both a population growth and a population decline, an average annual economic growth until 2100 which varies between 0.7 and 2.5% and a sea level rise of 35 to 85 cm for the coming century. The four scenarios result for each alternative in different flood risks and different assessment scores. Because the differences in results were not known beforehand, the use of all four scenarios is considered a good choice. Besides, the use of four scenarios prevent that policy makers automatically focus on the middle scenario (which occurred before when there were only 3 scenarios).

Analysis of current flood risk management strategy

The current flood risk management strategy consists of flood prevention by dike strengthening and guarantees that water levels and wave conditions with a probability of 1/4000 or larger will not overtop the embankments. The strategy was analysed by selecting representative extreme events, making assumptions on embankment failure locations and breach growth and calculating the corresponding flood depth maps. Based on those flood depth maps and land use maps the flood impacts were determined and the resulting flood risks calculated.

The resulting current flood risk was expressed as follows: on average a risk is expected of 0.53 M€/yr, 19 affected persons per year and 0.15 casualties per year. In future, these figures increase in all scenarios due to sea level rise, economic growth and (in some scenarios) population growth. The costs of the current strategy differ per future scenario. Only in the World Market scenario this strategy was found to be cost efficient. If one of the other scenarios becomes reality, costs are about two to 10 times higher than the resulting risk reduction. It must be noted, however, that in these cost and risk reduction figures only tangible aspects are incorporated. Advantages of the current strategy such as reduction of the number of casualties, affected persons or flood effects on nature are not included. If these would be included the cost-benefit ratio would become more positive. Because the future risk is much higher than current risk and because the current strategy is only cost efficient in one future scenario, it seems worthwhile to at least consider other strategic alternatives.

In the risk analysis procedure various assumptions and simplifications had to be made. The uncertainty about these assumptions and uncertainties in the used hydro-dynamic models and damage models mean that the resulting risk figures are also uncertain. The resulting flood risk indicators are, therefore, mainly used as an indication of the order of magnitude. They are relevant, since for most decisions and for comparison of strategic alternatives knowing this order of magnitude is sufficient.

Analysis of strategic alternatives

In order to enhance the discussion on future flood risk management options three alternative strategies were analysed: 1) a flood surge barrier at Vlissingen, 2) a 'Risk approach & no spatial planning', and 3) a 'Risk approach & spatial planning'. These strategies differ in their degree of resilience and resistance and in their level of spatial planning of economic developments. Next to these strategic alternatives also the effects of the 'do nothing alternative' was analysed. In this alternative maintenance of existing embankments is incorporated, but no dike raising or strengtening is applied.

In the analysis of the effects of the strategic alternatives, they had to be simplified with respect to timing, height of dike raising, and continuation period. The strategic alternatives which include dike strengthening will face different dike raising phases in the coming century. The moment of dike strengthening depends on the available funds and workers, the rate of climate change, economic growth and political factors. The exact moment of the dike raising and the number of times of dike raising in the next century affects the costs of dike raising and the present value of the costs. In this exploratory study, however, the embankments were raised twice: in 2000 and in 2050. The second simplification is the height which the embankments will get after dike rising. In this research a certain fixed criterion was used for each alternative (e.g. to the 1/4000 year water level in 2050 according to the National Enterprise scenario). In reality the resulting embankment levels may differ per stretch depending on the costs of dike rising of that stretch and the value which is protected by the dike stretch. The third simplification was that the effect of the strategic alternatives was analysed as if they were continued for about a century. In reality, the strategic alternative may be changed if socio-economic developments or climate change are different from the anticipated changes. In the assessment, however, the criterion 'flexibility' was used to indicate whether a certain alternative allows a change to other strategic alternatives. The simplifications should be kept in mind when judging the alternatives, especially when scoring the qualitative criteria. The general idea of the alternatives should be assessed in the full assessment and not the simplified elaboration.

The selection of the strategic alternatives should have been done in such a way that 'all' possible types of flood risk management measures were included. However, in this case study no extreme resilient alternative was considered because it was considered unrealistic. It would have been better to include such an extreme strategic alternative to get a wider view on the range of possibilities. Such an alternative could include a large floodway which may be used for nature development or agriculture except during extreme circumstances when it should allow the flow of a large quantity of water from the Westerschelde to the Oosterschelde water body.

All strategic alternatives and the do-nothing and current policy were combined with each of the four scenarios. The combination of the World Market scenario and the do-nothing alternative seems, however, highly unlikely. It must be noted, that this alternative was only added for reference. It is not considered a serious alternative. Other combinations of scenarios and strategic alternatives are considered more realistic.

Full assessment

During the full assessment it became clear that there is a strong distinction between the quantitative and qualitative criteria. The scores on the quantitative criteria are a little uncertain, but they are generally believed in and they seem explainable. They include mainly the flood risk indicators and the costs. The scoring of the qualitative indicators, however, was much more difficult and resulted in a lot of discussion. Since *long-term* strategic alternatives were scored, the alternatives are by definition not very clearly defined and elaborated into great detail.

The method used to score the qualitative criteria (the Delphi-method) was found to be a suitable method, because the discussions which this methods brings about proved to be very valuable for developing a vision on the long-term development of the Schelde Estuary. In the discussions knowledge, motives, and personal visions both on the criteria and on the effects of the strategic alternatives became clear**.** Although the resulting scores on the qualitative criteria still show a wide spreading and are considered highly uncertain, the differences between the scores of the different strategic alternatives (the ranking) on the criteria has become clear. Since the qualitative criteria cover very important aspects of sustainability and since the scores on these criteria differ per alternative, these qualitative criteria should be included as was done here.

The qualitative criteria were scored by comparing future situations with the current status. By taking the current status as reference, the scores include both the effect of the scenario and the effect of the strategic alternative considered. If one was interested purely in the effect of the strategic alternative, the status quo in 2100 according to the do-nothing alternative for the four scenarios should have been taken as reference. The effect of the scenarios would then already be incorporated in the reference and it would not have been included in the scores. The scores would then represent how the strategic alternative would influence the general developments in the region. They could still differ per scenario.

The criteria used are considered well chosen. They cover people, planet and profit aspects and they show the sensitivity of alternatives to uncertainties. Some criteria were difficult to score:

- The current scores on the criterion 'economic opportunities' represent both the effect of the scenario and of the strategic alternative. This was confusing and it is expected that the different experts who gave the scores did not have the same approach in scoring this criterion. The criteria should show the effect of strategic alternatives on the case study area given a certain development scenario in the Netherlands.
- Land scenery proved to be a highly subjective criterion. It is, therefore, difficult to score: questions such as 'Does a flood barrier improve or deteriorate a land scenery or is its effect negligible, may be answered differently by different experts. The criterion thus needs a clear elaboration and clear rules on what land scenary is most precious.
- The resulting flood risk criterion has been expressed in two ways: by the Present value of the risk reduction and by the Expected Annual Damage in 2100. The first figure may be compared with the cost criterion. The second shows the economic risk in 2100 and can be compared to the current EAD and to other risk figures (e.g of industrial risks). It may be considered to replace the costs and risk reduction criteria by one criterion such as the cost-efficiency (reduced risk MINUS costs). However, such a criterion might be misused and considered as the most important one. In this cost efficiency, however, all kind of effects on sustainability of the system (casualties, affects on nature, sensitivity to uncertainties etc.) are not incorporated. In this case study, therefore, this criterion was not used.
- Robustness: Robustness was scored differently by the experts. The criterion is defined too vaguely and the effects of scenarios and strategic alternatives on the robustness is not clear. This should be improved.

The results of the assessment of the different alternatives show that the sustainability of a certain strategic alternative depends significantly on the future scenario which becomes reality. The preferred protection level depends on the economic growth and sea level rise. If these are higher, then there is more value to protect and more money available for flood protection. The research also showed that currently the flood protection level is already high. If only cost-efficiency is considered, the raising of embankments of most polders would not be sensible at this moment and the embankments of some polders would not even be raised in the coming century. Since the expected annual damage in the different subareas differs significantly, norm differentiation in combination with spatial planning seems to be a very interesting option for the long term.

The case study was exploratory, which means that the results cannot be used to make concrete short-term decisions on flood risk management measures. They, can, however be used to determine which direction to move in and to specify further research. The research also indicates that the current strategy is probably not the best and that doing-nothing seems unrealistic and undesirable. Studying alternatives is thus worthwhile. A combination of spatial planning and norm differentiation seems most promising.

4.8.2 Conclusions of the Schelde case study

Conclusions on flood risk management for the Schelde Estuary

- Currently, the flood risks in the Schelde Estuary can be expressed by the following average annual figures: 0.53 million Euro of damage per year, 19 affected persons per year and 0.15 casualties per year.
- If the current flood risk management strategy (dike strengthening to enable withstanding the once in 4000 year conditions) is not changed, flood risk will increase in the future due to

climate change, population change and economic changes. The future Expected Annual Damage for example may increase with a factor 3 to 30 resulting in an EAD of 1.5 to 14 M€/yr.

- The current flood risk management strategy is cost efficient if the World Market scenario becomes reality. In the other scenarios, however, the economic risk reduction is lower than the costs made for dike raising. The figures found are indicative only and they do not include intangible aspects such as the risk reduction of casualty risks.
- If from 2000 onwards no dike strengthening measures or other measures would be carried out, but if only maintenance would continue, then flood risks will increase fast from about 0.53 M€/yr to 13 or even 2700 M€/yr (depending on the future scenario).
- Three strategic alternatives were developed, analysed and assessed. These alternatives result in other flood risks, costs and in other secondary effects. The Storm surge barrier alternative scores best on social value related indicators (the ‘people’ aspects of sustainability). The Spatial planning alternative scores best on on nature value related indicators and on indicators which describe the system’s sensitivity to uncertainties, while the Risk approach alternative scores best on the profit related indicators.
- The scores of the strategic alternatives on the sustainability aspects differ per scenario. In the World Market scenario the current policy scores best, while in the other scenarios the Spatial Planning alternative scores highest.
- If all scenarios and criteria are considered, then the Spatial Planning alternative scores best.
- A flood risk management strategy which combines norm differentiation and spatial planning thus seems very promising.

Conclusions on the applicability and usefulness of the method to develop and assess long-term flood risk management strategies

- The method proposed in chapter 3 was applied in this case study and resulted in understandable and clear risk figures and assessment results. The method is thus applicable on the Schelde Estuary: the results are meaningful and useful.
- The method had to be down-scaled to be able to apply it. The scenarios should be tailor-made for the system considered, the risk analysis approach must be adapted to the characteristics of the region involved, to the available data and also the development and assessment of strategic alternative depends on the system and the available data and time. The method does guide the researcher through the whole process and offers a clear line of thinking.
- Using scenarios is considered useful to express the uncertainty about the future. It results in a range of possible effects of alternatives and it shows which strategic alternative works best even in different future scenarios.In the Schelde Estuary this was the Spatial planning alternative.
- The full assessment was based on a multi-criteria approach in which the qualitative criteria were scored with the Delphi Method. This combination resulted in a full assessment which reveals the effects of the strategic alternatives on all sustainability aspects.
- As reference for the scoring of the qualitative criteria the current status of the system was used. The resulting scores thus reflect both the effect of the scenario and the effect of the strategic alternative. This was confusing. The scoring process and results indicate that the choice of the reference for scoring the qualitative criteria is very important and must be thought throug. If the effects of the strategic alternatives only should be reflected in the scores, then the status in 2100 in the four scenarios and the do-nothing alternative should have been used as references.
- The asssessment criteria are considered well chosen, because they reflect all sustainability aspects and thus result in a complete overview of all effects of the strategic alternative under consideration. However, the criteria ‘economic opportunities’, ‘land scenery’, and ‘robustness’ must be defined more clearly in order to reach consistency in scoring.

4.8.3 Recommendations

The case study resulted in a list of recommendations both for the Schelde Estuary and for further development of the long-term planning method.

Recommendations for flood risk management in the Schelde Estuary

1. For a complete overview of flood risk management options in the Schelde Estuary both the Belgium part and the Dutch part must be considered together as one system. The effects of the proposed strategies on the Belgium part and additional measures in the Belgium part should thus be incorporated in the design, analysis and assessment.
2. An extreme resilience alternative should be added to the range of strategic alternatives considered. Such an alternative could include a kilometers wide floodway to discharge water from the Westerschelde water body to the Oosterschelde.
3. A strategic alternative which consists of a combination of spatial planning and safety standard differentiation proved to be most promising for the Scheldt Estuary. Therefore, it is recommended to study such strategies in more detail. Safety standards could be determined e.g with a cost-benefit procedure and spatial planning could be worked out to the level of future land use maps. Finally, proposals for land zoning and regulation could be made.
4. When the long-term vision is going to be translated to concrete measures the morphology of the Westerschelde must be included in a better way and additional flood simulations and probability calculations need to be made.

Recommendations for the long-term Flood Risk Management planning method

- The full assessment criteria robustness, economic opportunities and land scenary must be better defined.
- The reference for scoring the qualitative criteria should be selected conciousness and it should be clearly communicated. If the future situation is assessed, the current status could be used as reference. However, if purely the effect of strategic alternatives must be scored, then the reference should be a future status with a do-nothing strategic alternative.

5. The Thames Estuary

This chapter describes the application of the method described in Chapter 3 to the Thames Estuary. Following a brief description of the Thames Flood Risk System (included to aid understanding) the main emphasis of the chapter is on the development and evaluation of strategic alternatives in the context of different future socio-economic and climatic scenarios. The material in this chapter builds on work undertaken elsewhere in FLOODsite (e.g. HRW 2007b) and a parallel UK project, Thames Estuary 2100 (TE2100).

5.1 Introduction to the Thames Flood Risk System

The River Thames is located in the southeast of England, and the area of interest extends from greater London through to the estuary mouth. Figure 5.1 provides the extent of the flood risk area. This was derived using a TUFLOW (2D hydrodynamic) model run with an extreme (>10,000 year) tidal event under the assumption of no barriers operating and no linear defences present. The upstream limits of the tributaries were defined using output from Estuary Processes Theme (HRW, 2006b) together with the output from the extreme TUFLOW model run.

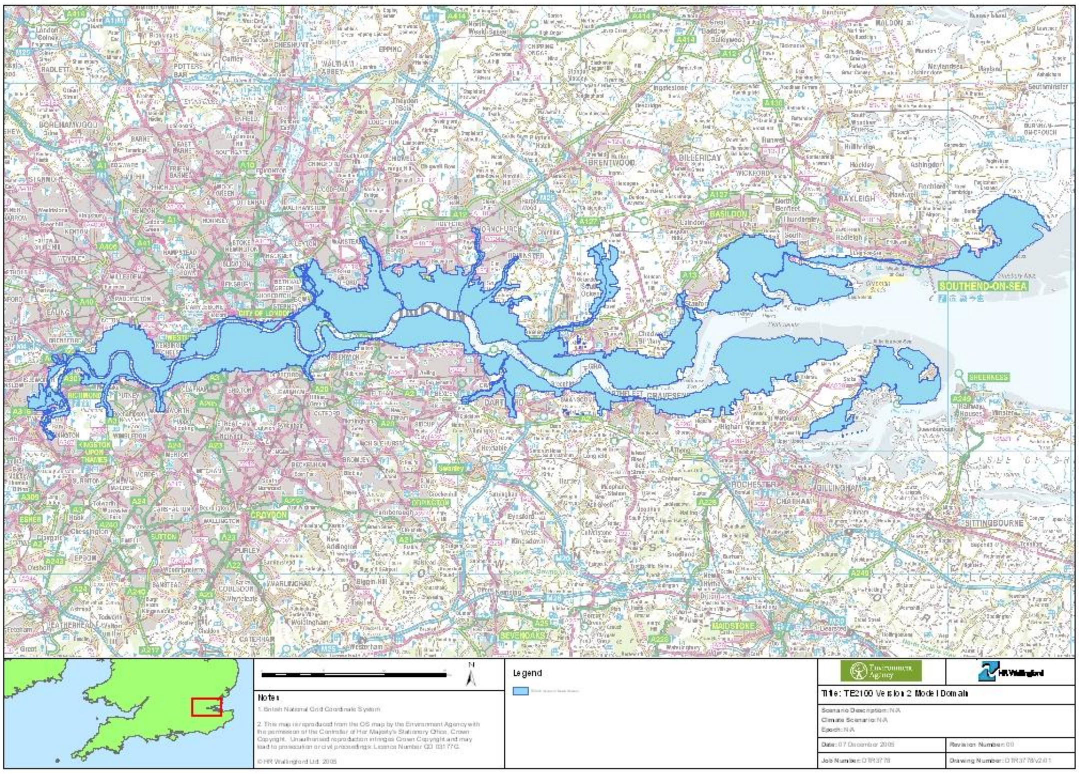


Figure 5.1 Thames flood risk area

The flood risk management system as recently been described by Ramsbottom *et al* (2006) was designed to provide a flood defence standard of 1000-years in the year 2030 for most of the tidal Thames floodplain. Exceptions include parts of west London at risk from fluvial flooding, and parts of the relatively undeveloped lower Thames marshes.

The flood risk management system consists of the following elements (see Figure 5.2):

- *The Thames Barrier*: This barrier is closed during extreme tidal events to prevent high tidal water levels upriver of the Barrier. It can also be used to reduce fluvial flood risk in West London by closing at low tide and preventing tidal water levels causing fluvial flows to 'back-up' in West London.
- *Other moveable barriers*: There are moveable barriers on the River Roding (Barking Barrier), River Darent (Dartford Barrier) and three barriers in the tidal creeks around Canvey Island (Fobbing Horse, East Haven and Benfleet Barriers). These barriers are closed during extreme tidal events.
- *Fixed flood defences downriver of the barriers*. These provide protection against tidal flooding from the tidal Thames and the associated tidal creeks.
- *Fixed flood defences upriver of the barriers*. These also provide protection against flooding, but the defence levels are lower than the downriver defences because maximum water levels are reduced by barrier operation. Maximum levels are affected by fluvial flows, particularly on the Thames and Roding.
- *Flood control gates*. There are three flood control gates that provide flood protection at dock entrances: Tilbury lock, King George V lock and Gallions lock.
- *Drainage outfalls*. There are a large number of outfalls for land drainage that pass through the fixed flood defences. The majority of these consist of tide flaps with penstocks that allow water to discharge but prevent reverse flow during periods of high tides. There are also some pumping stations. The outfalls include Combined Storm Overflows (CSOs) and outfalls from Sewage Treatment Works (STWs).
- *Frontage flood gates*. These are gates in the fixed defences that provide access to wharves and other riverside facilities. They are closed when a flood warning is received.

There are approximately 280 km of defences on the Thames with approximately 200 km of tributary defences. Some of these elements are discussed in more detail below.

Fixed flood defences

These are static defences whose primary purpose is to act as a wall against the tide. They are made of a variety of material of which the most common are earth, steel sheet piles, concrete and masonry/brick. They may be on the actual riverbank or some distance inland. Historically construction of these linear flood defences along the estuary has been carried out in a reactionary manner to flood events and as such many of the defences (in particular those in central London) show a 'stratigraphy' of raisings that often incorporates a variety of different materials. This means the defences are often fairly complex and composite in nature.

Drainage outfalls

There are tide flaps or other tide excluding structures where watercourses discharge through the tidal defences. These include both tributaries of the Thames and smaller drainage channels.

Tributaries downriver of the Thames Barrier which have drainage outfalls include the Beam River, River Ingrebourne and Mar Dyke. The only tributaries that do not have drainage outfalls are those protected by barriers (the Roding, the Darent and the creeks around Canvey Island).

Some of the tributaries upriver of the Thames Barrier have outfall structures (for example the River Crane and Beverley Brook) but others do not (for example the River Lee and the River Ravensbourne). The need for an outfall structure upriver of the Barrier depends on local conditions as the tributaries already have protection provided by the Barrier.

There are a large number of outfalls for smaller drainage channels. Typically these consist of culverts through the flood defences with a penstock chamber and tide flap. Some tide flaps are within the chamber whereas others are located at the culvert outfall. There are also a number of pumped outfalls, the largest of which is the 'Lake 4' outfall in Thamesmead with a design capacity of 10 m^3.

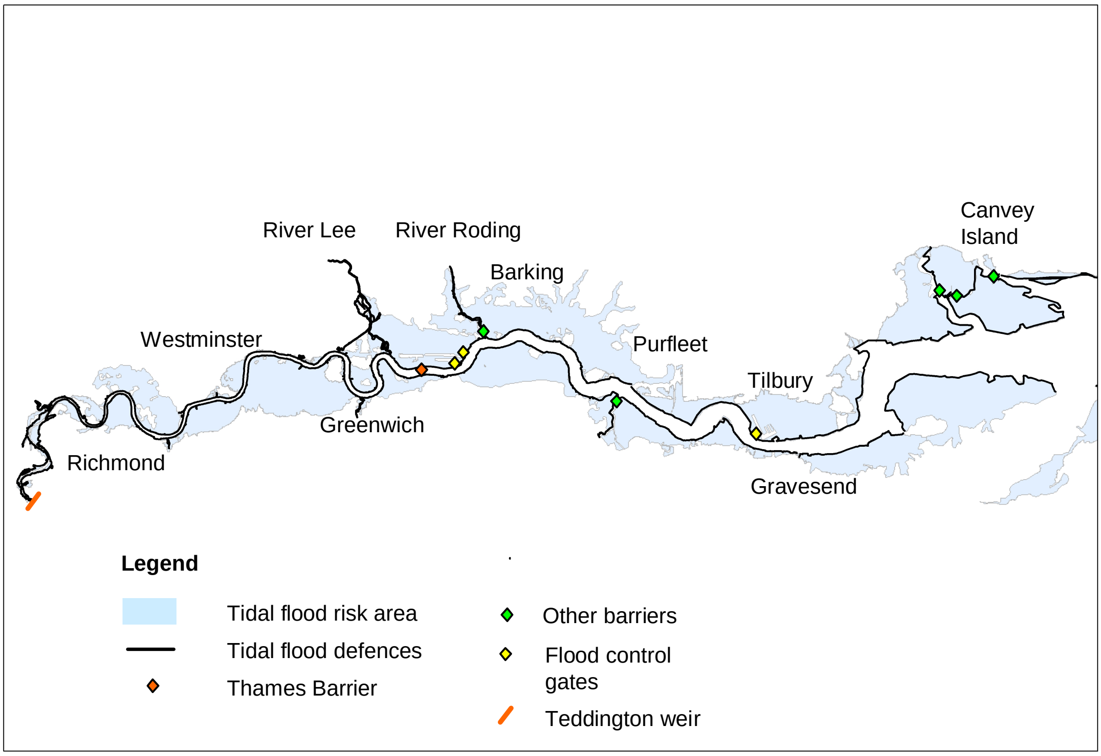


Figure 5.2 The flood risk management system

Frontager floodgates

Frontager floodgates are installed at locations where there is a purpose-made 'gap' in the tidal defence walls to allow access.

Downriver of the Thames Barrier they are usually large with various sealing devices (e.g. rubber flaps, eccentric hinges) and often a telemetry sensor to detect closure states. They allow industrial access to jetties and wharf frontages. A few of these downriver frontager floodgates are kept permanently closed (e.g. where a frontage is now 'non-working').

Upriver of the Thames Barrier they are usually smaller, and some of the openings are closed by damboards. Some openings permit public access to the foreshore but others are in private residential or commercial ownership.

Frontager floodgates are an integral part of the whole tidal defence system, and could be thought of as the 'weakest link in the chain'. The lack of closure or malfunction of one of them particularly in the downriver locations could allow extensive flooding. They are often in remote locations, and being on private area frontages are susceptible to unreported damage.

How the system works

Flood risk on the Thames occurs from the following sources:

- Occurrences of high surges and high astronomical tides leading to high sea levels: this is by far the largest source of flood risk
- Fluvial flooding on the Thames
- Fluvial flooding on tributaries with barriers
- Fluvial flooding on other tributaries and drainage channels.

Protection against extreme high tides is provided by the following elements:

- Closing the Thames Barrier
- Closing the other barriers, flood control gates and frontager flood gates
- Automatic closure of tide flaps on drainage outfalls
- The fixed flood defences

Protection against fluvial flooding on the Thames is provided by:

- Fixed defences
- Closure of the Thames Barrier at low tide to provide a storage volume upriver of the Barrier, thus minimising the risk of 'backing-up' of fluvial flows by the tide.
- Conveyance in the upper estuary reaches.

Similarly protection against fluvial flooding on tributaries with barriers is provided by flood defences (which have a lower level than on the Thames) and closure of barriers at low tide. The River Roding has limited storage compared with the potential fluvial inflows, and there is a risk of fluvial flooding upriver of the Barking Barrier.

Protection against fluvial flooding on drainage channels is provided by:

- Tide flaps, that exclude the tide
- Flood defence measures upriver of the outfall including storage, pumping stations and fixed defences

Key points regarding the system are:

- The 1000-year tide level without Barrier operation ranges from 5.03 m AOD (Southend) to about 6.5 m AOD at Richmond. This is about one metre higher than the defences upriver of the Barrier.
- The Thames Barrier reduces this level to below 4 m AOD between the Barrier and Richmond.
- The fixed defences downriver of the Barrier (with levels generally between 6 m and 7 m AOD) provide protection downriver of the Barrier.
- Water levels in the 1000-year fluvial flow exceed flood defence levels upriver of Richmond with the Barrier operating.
- If the Barrier was not operated, the fluvial flood levels would be higher by about 0.5 to 1.0m in the Teddington to Richmond area. This demonstrates the benefit of closing the Barrier to provide fluvial flood protection. This benefit is also important at lower return periods, particularly the relatively frequent events that cause flooding of undefended areas including islands on the Thames. However, this needs to be considered against cost in maintenance associated with increased frequency of operations of the barrier for fluvially driven events.

The same pattern can be observed with the 10,000-year tide, except that the levels are higher. These levels are similar to (but slightly lower than) the estimated 1000-year levels in 2050.

The flood defences upriver of the Barrier generally have levels between 5 and 6m AOD. These levels are needed to avoid frequent closure of the Barrier during 'normal' high spring tides and small (and therefore frequent) tidal surges. The interim defence raisings that were put in place whilst the Thames Barrier was being constructed also remain in some areas (Figure 5.3).

Figure 5.3 Example of the interim defence raising prior to the Thames Barrier being built (Hill, 2007)

5.2 Future socio-economic and climatic scenarios

5.2.1 Overview

This section describes the development of a series of coherent storylines for the Thames Estuary over the appraisal period present day to 2100. A key element of this is the identification, development and quantification of a range of plausible future socio-economic and climatic scenarios. These incorporate the autonomous events which the flood risk manager has no influence over, for example, sea level rise, economic growth, urbanisation etc. The outcome is four distinct storylines, analogous to the Foresight world views (Chapter 3, Text Box A), but are suitably down-scaled and implemented as appropriate to the Thames Estuary.

The appraisal period is defined as from present day through to 2100; however the risk assessment (Section 5.3) is undertaken for a number of snapshots in time to build-up a description of the change of risk through time. These “assessment points” typically coincide with the implementation of a major management intervention (Section 5.3), for example, build a new barrier in 2060. To support this free form assessment, the climatic and socio-economic scenarios are described continuously throughout the appraisal period.

Autonomy

National Enterprise

Governance/development: Weak, national closed. Continued extreme development pressure in Thames area. As objective is to maximise public or national interest, the preference is to achieve optimum FRM in terms of economic efficiency. Commercial activities are likely to be focused on bio- and nanotechnology activities with increases in susceptibility to flood damage. The industry will become specialist and concentrated, resulting in factories which may be single global producers of products with massive disruption to world stock.

Socio/economic: Population will redistribute, with more young people in Thames region. Individuals responsible for their personal flood risk - limited help from institutions and wider community. Property values will increase, and combined with increased spending on household durables, will increase susceptibility to damage.

Coastal & fluvial processes: There will be accelerated sediment transport and patterns of accretion and erosion. The lower Thames reaches and estuary mouth will, in particular, be subject to deposition. There will be increased water levels and reduced conveyance due to reduced environmental management requirements and regulation. This will also lead to concern for the intangible environmental benefits – as flood protection is prioritised. Operating authorities continue to explicitly recognise that the river has multiple users – with multiple needs – and an optimum solution is required for river management. This will be further promoted by the Water Framework Directive and Floods Directive.

Climate change: Medium-low growth with no action to [illegible]issions. Increasing and unregulated emissions from

Local Stewardship

Governance/development: Strong, local, participative. The environment will be a constraint, limiting what actions can be done and environmental enhancements will be sought. Natural forms of flood management are favoured e.g. room for rivers, managed retreat, re-creation of wetlands. Strong land-use control policy to avoid flood prone land i.e. most of the Thames region. Power further devolved to local communities and small watersheds – making integrated water management a challenge. Limited reward for entrepreneurs leads to limited innovation.

Socio/economic: Emphasis on community and equity results in increased population to support development of community facilities e.g. shops, schools, healthcare. Little new floodplain development. Flood victims are viewed as ‘sinners’ as they are based in areas belonging to the river. This view is in conflict with the ethos of community solidarity & practicalities for supporting the high Thames region population. Real income increase relatively slowly. Expected life of consumption goods increases, as does cost, but these will be less susceptible to flood damage.

Coastal & fluvial processes: Local response to local problems means that problems are dealt with in a piecemeal fashion - reinforced by reduced public funding for public services. Lack of system-scale river management leads to progressively severe river responses. Environmental concerns are considered but conflict with individuals’ perceived need for flood protection. The local emphasis leads to widespread variability in regulation - pending local enforcement.

Climate change: Low growth and low consumption, however, less effective internal action. Low innova[illegible]

Consumerism — *Communit[illegible]*

World Markets

Governance/development: Weak and dispersed. Absence of land-use controls means development tends to take place where developers expect most profit e.g. planned Olympic village on the River Lee as well as the Thames Gateway which affects East London. As the Thames region is built-up, residence and government will provide improved community defences. Commercial activities are likely to be focused on bio- and nanotechnology activities with increases in susceptibility to flood damage. The industry will become specialist and concentrated, resulting in factories which may be single global producers of products with massive disruption to world stock.

Socio-economic: Population will redistribute, with more young people in Thames region. Human impacts of flooding are irrelevant. Individuals are entirely responsible for taking actions to reduce their own personal risk, resulting in the socially vulnerable becoming more vulnerable. Property values will increase, and combined with increased spending on household durables, will increase susceptibility to damage.

Coastal & fluvial processes: There will be accelerated sediment transport and patterns of accretion and erosion. The lower Thames reaches and estuary mouth will, in particular, be subject to deposition. There will be increased water levels and reduced conveyance due to reduced environmental management requirements and regulation. This will also lead to concern for the intangible environmental benefits, as flood protection is prioritised.

Climate change: Highest national and global growth. No action to limit emissions. Price of fossil fuels may drive the development of alternatives in the long tern.

Global Sustainability

Governance/development: Strong, coordinated, consultative. Wide use of principles critical natural capital and constant natural assets. Compensatory actions for any negative environmental impacts. Preferred management strategy will be land-use control – including type of urban use. Regulators are more responsive to their perception of what stakeholders want. Emphasis on whole catchment management.

Socio-economic: The ethos of community solidarity in the face of natural disasters leads to the identification and help of the most vulnerable (defined by social terms not individual characteristics). Real income increases and spending on household durables. Real prices of household durables increase as regulations governing water and energy efficiency and recycling become increasingly rigorous.

Coastal & fluvial processes: Strong planning controls plus an emphasis on biodiversity mean a progressive retreat from river management i.e. return to natural state. Reduction in dredging to meet environment targets leads to increase deposition of sediment in the Thames mouth, reduced conveyance and greater water levels. Requirements for undertaking of compensatory actions for any negative environmental consequence will be focused on enhancement of functioning of the Thames catchment and coastal zone, rather than flood protection.

Climate change: Medium-high growth but low primary energy consumption. High emphasis on international action for environmental goals e.g. greenhouse gas emission control. Innovation of new and renewable energy sources.

Run-off: Little change to urban extent. Some increased

Interdependence

Figure 5.4 Summary of World Views for the Thames Pilot

5.2.2 Coherent storylines

The Foresight World Views are adopted in developing coherent storylines. For the Thames pilot, perhaps the least appropriate of these is the Local Stewardship, which relates to a low economic growth scenario and local devolved government structures. The Thames region coincides with England's economically vibrant capital, which has had a Gross Domestic Product growth which has been higher than the rest of the country for many years. This, together with the planned hosting of the 2012 Olympic Games in London and the Thames Gateway development (the largest regeneration project in Western Europe), suggests that the likelihood of this region having a low future growth is low. However, a Local Stewardship future is still incorporated here in the interest of developing a wide scenario range which is not based on *a priori* expectations of the region's growth.

The main drivers of change for the World Views in the context of the Thames pilot are summarised in Figure 5.4. These are classified in terms of governance/development, socio-economic aspects, coastal and fluvial processes, climate change and run-off, and build upon the storylines adopted in Foresight (2004a & b).

5.2.3 Scenario development

Scenario development involves moving from the qualitative coherent storylines, which involve a range or parameters which may not all be simulated within the risk analysis models (Section 5.4), to the more detailed quantitative parameters which are explicitly represented in the risk models. A key element here is differentiating between global parameters such as climate change that have limited dependence on regional activities in the Thames Estuary, and more localised parameters such as socio-economic change, which may be driven by regional influences, e.g. the Thames Gateway project. Thus, in developing the scenarios for the Thames Estuary, the local and global aspects are separated into two distinct axes:

- ***climate change*** represented in terms of the global emission scenario that in turn is characterised by a single continuous parameter of the rate of sea level rise (the rate of sea level rise increases as carbon emissions increase) and associated other climate changes; and
- ***socio-economic change*** represented in terms of regional growth that in turn is characterised by a single continuous parameter of housing numbers and associated other changes (population, GDP, market forces etc.)

On these axes, a 'plausible' future space can then be bounded through identifying the extremes of these ranges (Figure 5.5). For the Thames pilot, the range of climate emission scenarios is taken from three sources UKCIP02, Defra (2006) and HRW (2005). The extreme scenarios are the 'Low' and 'High++' (HRW, 2005), which are downscaled and designed specifically for the Thames Estuary region (details Section 5.4.2). For the socio-economic axis, a low, medium and high growth scenario is defined, based on historic trends and expected projections (e.g. housing, population, GDP, market forces) to inform the likely growth through to 2100 (details Section 5.4.3).

Ideally the entire scenario space (Figure 5.5) should be considered in the flood risk analysis to ascertain how a given strategic alternative (Section 5.3) performs regardless of how the future pans out - a potentially exhaustive task. For the Thames flood risk system, each strategic alternative is considered in the context of each of the 12 scenarios represented by the discrete points in Figure 5.5, i.e. unique combinations of climate and socio-economic change. The performance of each strategic alternative can then be assessed at each point and the description of the performance over the whole space may be inferred from these point measures. Integration over this entire surface allows for evaluation of a single performance measure (e.g. benefit/cost) across all plausible future scenarios (further details in FLOODsite, 2008).

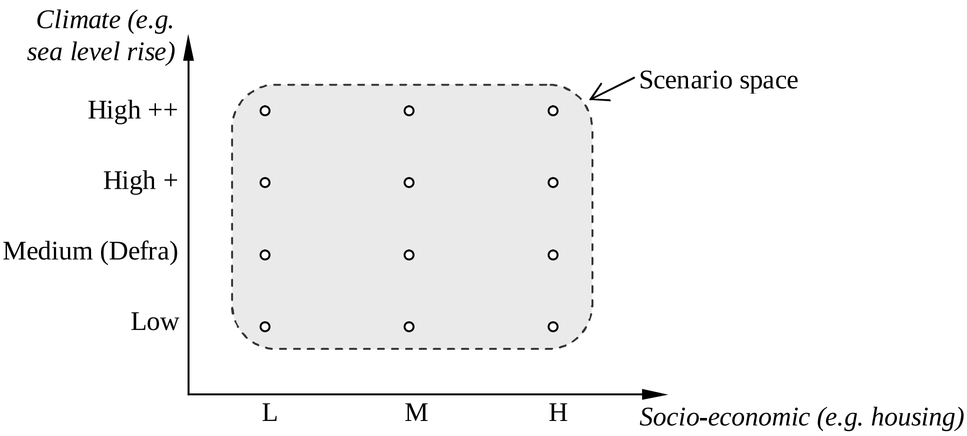


Figure 5.5 Plausible future climatic and socio-economic scenario space at time t

To illustrate the Chapter 3 philosophy, the four coherent storylines are linked to four of these discrete points, to provide four distinct scenarios for evaluating the strategic alternatives against (

Figure 5.6). The Foresight climatic and socio-economic descriptions are as follows:

- World Markets (WM) [high emissions, high growth]
- National Enterprise (NE) [med-high emissions, med-low growth]
- Local Stewardship (LS) [med-low emissions, low growth]
- Global Sustainability (GS) [low emissions, med-high growth]

The remainder of this chapter describes the development and representation of these four scenarios and the evaluation of the strategic alternatives in the context of each. The strategic alternatives are also considered in terms of the balance of these discrete points in FLOODsite (2008).

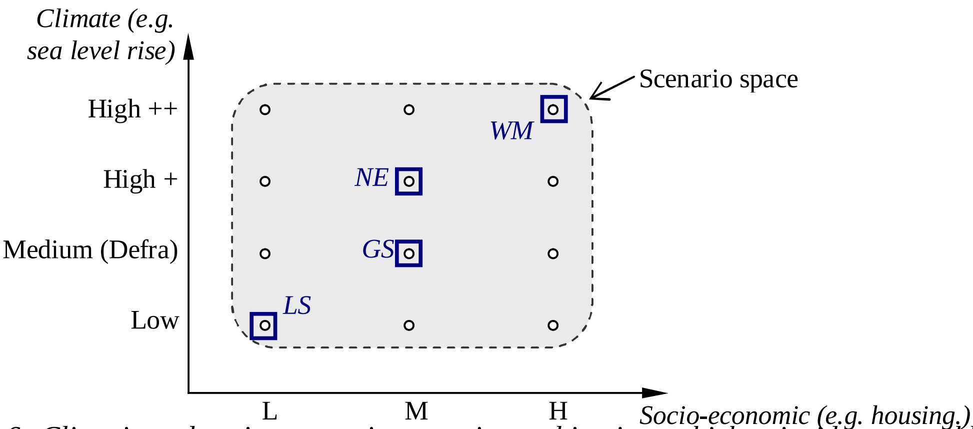


Figure 5.6 Climatic and socio-economic scenario combinations which coincide reasonably well with the Foresight World Views

Approach for representing climate change

UKCIP (2002) provides the most detailed future climate change projections for the UK, focusing on four emission scenarios, broadly representing the range of conditions which may occur in the future. These are not intended as predictions, since there is no attempt to assign a probability of occurrence to any of these scenarios. The four scenarios are designated UKCIP02 Low, Medium Low, Medium High and High Emissions.

Defra (2006) provides simple numerical 'adjustments' (Table 5.1 & Table 5.2) for various commonly used parameters, so that all such studies can be assessed on a common basis. These 'adjustments' are neither predictions nor projections, but are usually referred to as appropriate 'precautionary allowances'. This provides a fifth climate change 'scenario' which is defined as 'Medium' throughout.

Table 5.1 Regional net sea level rise allowances (Defra, 2006)

Administrative or Devolved Region	Assumed Vertical Land Movement (mm/yr)	Net Sea-Level Rise (mm/yr)				Previous allowances
		1990-2025	2025-2055	2055-2085	2085-2115	
East of England, East Midlands, London, SE England (south of Flamborough Head)	-0.8	4.0	8.5	12.0	15.0	6mm/yr* constant
South West and Wales	-0.5	3.5	8.0	11.5	14.5	5 mm/yr* constant
NW England, NE England, Scotland (north of Flamborough Head)	+0.8	2.5	7.0	10.0	13.0	4 mm/yr* constant

Table 5.2 Indicative sensitivity ranges (Defra, 2006)

Parameter	1990-2025	2025-2055	2055-2085	2085-2115
Peak rainfall intensity (preferably for small catchments)	+5%	**+10%**	+20%	+30%
Peak river flow (preferably for larger catchments)	+10%	**+20%**		
Offshore wind speed	+5%		**+10%**	+10%
Extreme wave height	+5%		**+10%**	+10%

Two further worst-case scenarios for extreme sea level rise were developed by the Thames Estuary 2100 programme team. These High+ and High++ scenarios are loosely based on physically possible (but more extreme) changes, intended to represent plausible, if unlikely, future developments. The High++ scenario was developed based on current science on ice sheet melt and rapid climate change[11]. It is intended to represent a highly unlikely but not totally implausible worst case.

For the Thames Pilot, High++, High+, Medium (Defra, 2006) 'precautionary allowance' and the UKCIP02 Low emission scenarios are adopted to provide a wide range of possible futures. The UKCIP02 Low is interpreted here as 'no change' relative to present day loads - a plausible lower scenario. The adopted fluvial and mean sea level changes at South End on Sea are summarised in Table 5.3 and Figure 5.7).

[11] Notice that the assumed sea level rise in this scenario for the Thames is much higher than in the Schelde case

Table 5.3 Climate change scenarios

Emission Scenario	Year	MSL increase (m)	Fluvial flow increase (%)
Low	2050	0.00	0
	2100	0.00	0
Medium (Defra 2006)	2050	0.31	20
	2100	0.94	20
High+ (HRW 2005)	2050	0.64	16
	2100	1.60	40
High++ (HRW 2005)	2050	1.28	20
	2100	3.20	50

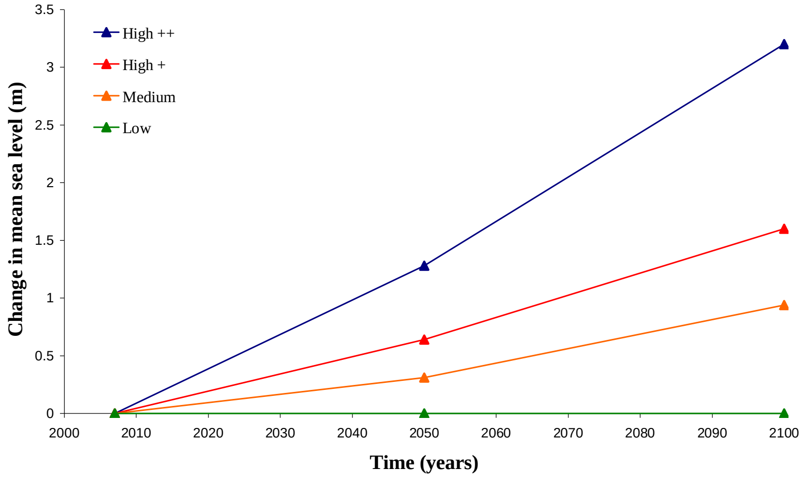


Figure 5.7 Change in mean sea level at South End on Sea for the four emission scenarios

For the system-based risk model, a change in climate is represented through a change in the extremes loading curve per linear defence (Section 5.4) i.e. a change to the in-river or coastal water level. Detailed river estuary modelling has been undertaken to ascertain the extreme loading conditions for the Thames and its tributaries under the Defra precautionary allowance (HRW 2007c), taking account of joint probabilities where appropriate. These include loadings for 2007, 2040, 2070, 2085 and 2100 and these have been undertaken for all of the strategic alternatives described in Section 5.3. The changes to the loading conditions due to the High+ and High++ scenarios were established here without undertaking further detailed river modelling. These were established through relating the change in mean sea level at South End on Sea for the given scenario (e.g. High+) and Medium (Defra 2006) case, for each return period, to produce a scaling factor per return period. This scaling factor was then applied to all the Medium extreme water levels at each linear defence to determine the equivalent High+ and High++ extremes curve per linear defence i.e.:

$$WL_{Scenarioe.g.High+} = \left(WL_{Medium} - WL_{PD}\right) * \frac{MSLrise_{/\,Scenarioe.g.High+}}{MSLrise_{Medium}} + WL_{PD} \quad (5.1)$$

where $WL_{Scenario}$ is the water level at given defence section in the estuary for a given return period and scenario. MSL is the Mean Sea Level rise at South End for the corresponding scenario. This approach is implemented for the Thames main river downstream of the barrier.

Upstream of the barrier and for all tributaries, a similar scaling factor was used based on relating the change in upstream fluvial flow of the Medium to the High+ and High++ scenarios. Here, the Medium loadings have taken joint probabilities between the main river and its tributaries into account. The tributaries downstream of the Thames barrier all have barriers or gates operating at the confluence with the main river, which means the tributary loading is fluvially driven.

An example output from Equation 5.1 is shown in Figure 5.8 for the High+ and High++ 2100 emission scenarios. These are for a linear defence located downstream of the present Thames barrier. The Low emission water levels are equivalent to present day.

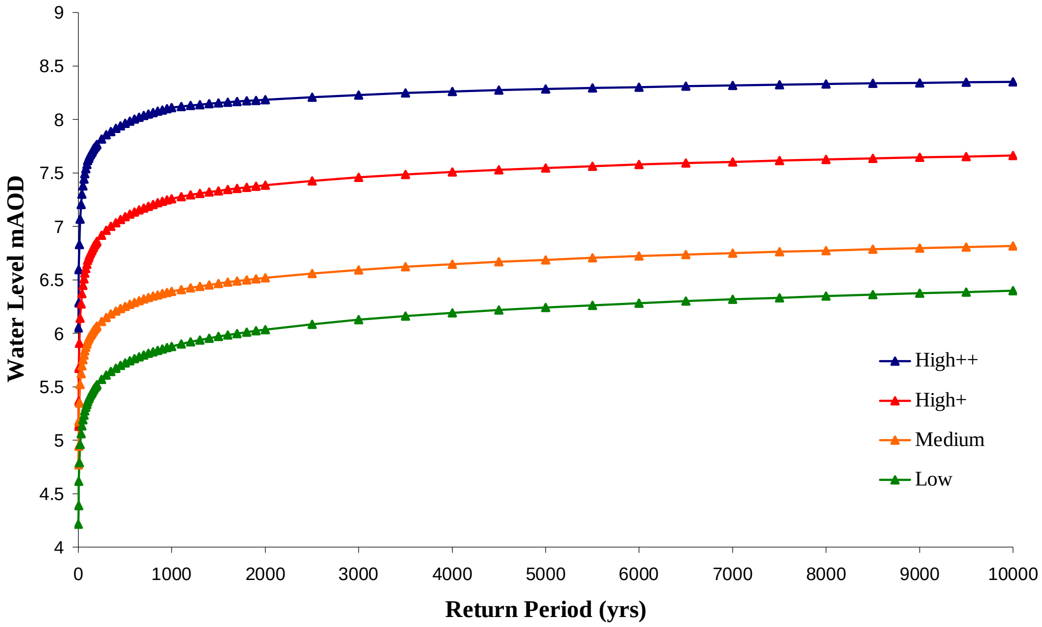


Figure 5.8 Input water levels for the four emission scenarios for a defence located downstream of the barrier (scaled from more detailed modelling completed for the Medium climate scenario)

Approach for representing socio-economic growth

The socio-economic growth is more closely linked to the actual regional developments taking place in the Thames Estuary. There have been numerous detailed studies undertaken for the London Boroughs in the Thames Estuary, covering past trends and medium-term (30 years ahead) predictions of housing, employment and population growth, including the spatial resolution of these changes (e.g. Mc Fadden *et al.*, 2007). These take due cognisance of planned developments which are already going ahead (e.g. Thames Gateway Project, 2012 Olympics) as well as spatial strategies and published plans from developers and different authorities which may go ahead.

It is difficult to determine a primary indicator for socio-economic change, but housing numbers probably provides the most direct representation of the growth. There are a variety of drivers such as economic growth, housing, urbanisation, environmental, demographics, social aspects etc. The increase in development in flood hazard areas will have implications for development within existing flood hazard areas and within the adjacent areas which are likely to become flood-prone as a result of future climate change.

For the Thames case study, the approach is to adopt the predictions for housing growth (Mc Fadden *et al.*, 2007) through to 2030 and then to develop three distinct growth scenarios – Low, Medium and High - based on no further growth (Low), direct extrapolation of the predicted curve (Med) and extrapolation of the prediction by a factor of two (High) (Figure 5.9). This approach is in keeping with that advised for scenario development (HRW 2001) in the UK's Modelling and Decision Support Framework (MDSF), which advocates a single scenario path for the short-term and multiple scenario paths for the longer term (Figure 5.10). Figure 5.11 shows the London Boroughs and the location of the existing houses in the undefended 0.01% probability Thames floodplain, i.e. present day.

The housing predictions will be used together with the predicted increases in inhabitants per house (Figure 5.12) to inform the population growth (Table 5.4). This housing and inhabitant growth information is provided spatially for most of the London Boroughs (from previous studies as summarised in Mc Fadden *et al*, 2007). To implement these changes, a GIS function is applied to present day National Property Database to increase the properties spatially based on the existing densities and housing types (e.g. Figure 5.13) and these are then used to re-derive the depth-damage curves for each Impact Zone with the RASP risk model (Section 5.4).

These housing scenarios will not be used to derive change in run-off, as this is likely to have a negligible impact for these regions.

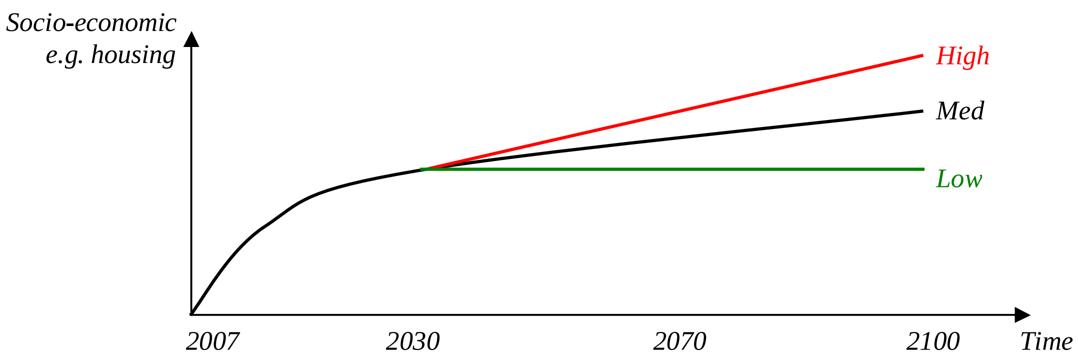


Figure 5.9 Socio-economic trends based on development

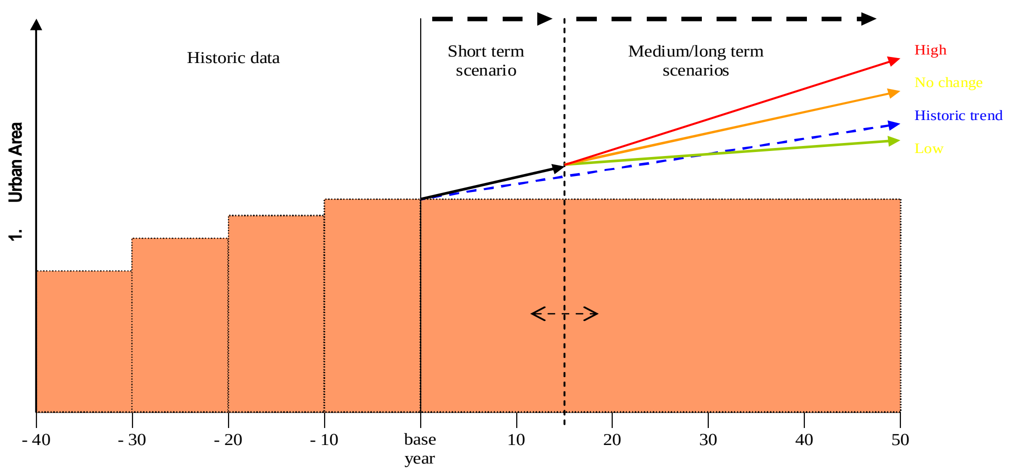


Figure 5.10 Development of scenario as advised in MDSF (HRW 2001)

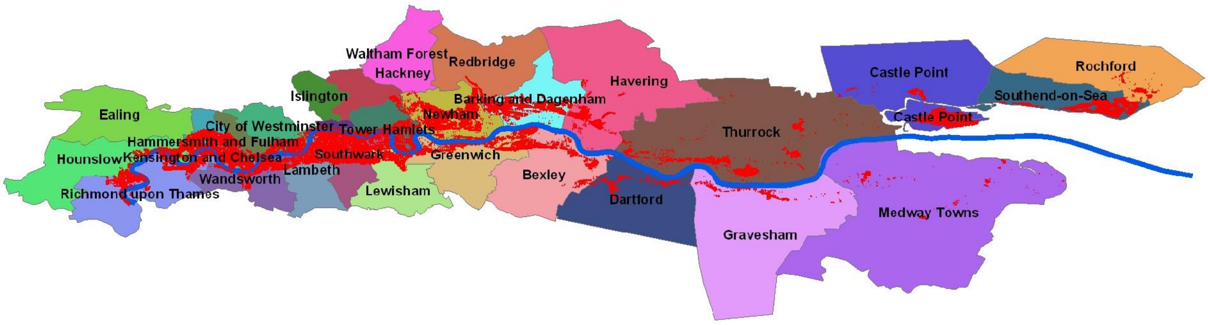


Figure 5.11 London Boroughs and location of existing houses (red) in the undefended Thames floodplain

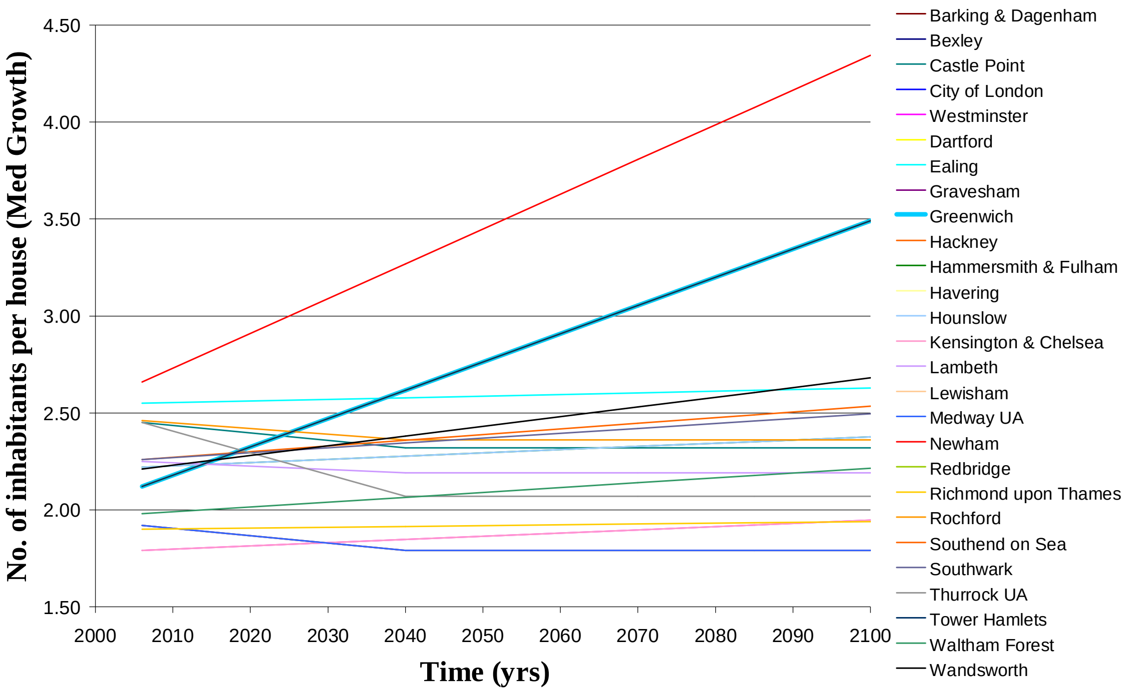


Figure 5.12 Inhabitant per house: growth curves per borough for the medium growth scenario

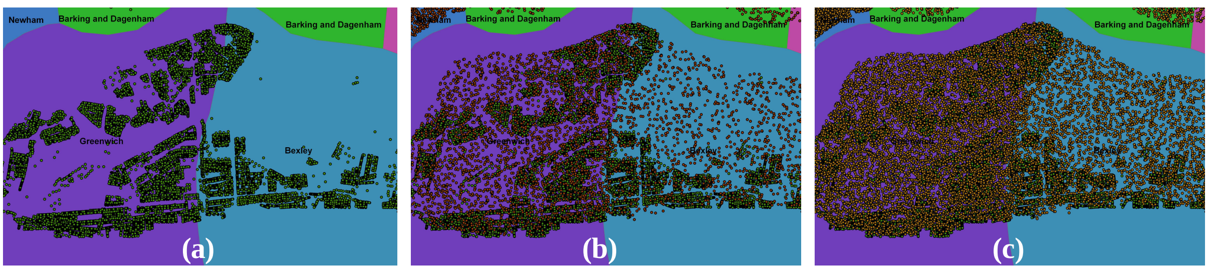


Figure 5.13 Representation of housing growth for the medium scenario in (a) present day, (b) 2040s and (c) 2100s in the Greenwich and Bexley Boroughs (within the undefended floodplain)

The aforementioned changes cover the housing and population growth; however, they do not consider changes to the commercial and residential property damages that may result from a given flood depth as described in the coherent storylines. For residential damages, this includes factors such as household durables, susceptibility to damage, and spending power (and hence the concentration of white goods, etc). For commercial areas, this additionally includes governance, advances in science and technology, legislation and regulation. Table 5.4 provides a summary of the factors applied to the damage curves to simulate the three growth scenarios.

Table 5.4 Summary of change to commercial and residential damage curves

Damages	Low (≈LS)	Medium (≈GS, NE)	High (≈WM)
Commercial (linked to sector growth)	By 2100, increase commercial damages by a factor of **8**. Linearly interpolate factor for years between.	By 2100, increase commercial damages by a factor of **15**. Linearly interpolate factor for years between.	By 2100, increase commercial damages by a factor of **20**. Linearly interpolate factor for years between.
Residential (linked to Market growth)	No change	Increased by a factor of **2** in real terms across all housing types.	Increased by a factor of **4** in real terms across all housing types.

The predicted Gross Domestic Product (GDP) directly impacts on affordability which is typically expressed in terms of Cost per GDP. For London, the predicted annual GDP growth until 2030 is 3.2 % compared with 2 to 2.5 % nationally. Thus for the Thames study, the low, medium and high growth scenarios are assumed to be associated with an annual GDP growth of 2.5 %, 3.2 % and 3.7 % respectively.

5.3 Strategic alternatives

5.3.1 Overview

This section describes the strategic alternatives for the Thames pilot study. Within the Thames Estuary 2100 study, two Policies have widely been adopted as references, the P1 and P3 Policies:

- *Policy P1*: No active intervention (including flood warning and maintenance). The 'do-nothing' policy. No work on defences and no operation of moveable structures.

- *Policy P3*: Continue with existing or alternative actions to maintain the current flood risk management regime (accepting that flood risk will increase over time from this baseline). Defences maintained at current levels and condition. Moveable structures operated.

The Chapter 3 philosophy promotes the development of resistant and resilient strategic alternatives, along with one or several reference alternatives. For the Thames pilot this results in:

1. ***Do nothing***. This is equivalent to the TE2100 P1 Policy i.e. no active intervention.
2. ***Resistant***. This involves improving the existing system through, for example, defence raising and maintenance, over-rotating the barrier and introducing limited non-structural measures.
3. ***Resilient***. This involves small improvements to the existing system (e.g. limited defence raising, increased storage, managed realignment) as well as introducing non-structural measures - all aiming to improve the flood management benefit of the floodplains.
4. ***Highly resilient***. This is similar to the Resilient option; however, numerous non-structural measures are incorporated - aiming to maximise the flood management benefit of the floodplains.

For strategic alternative 2 to 4, the P3 Policy is assumed for the present day i.e. the existing policy and, at all future dates, it is assumed that all movable structures are operating. The strategic alternatives build on those adopted in the Thames Estuary High Level Option (HLO) study (HRW 2007c). HLO 1 and 2 from TE2100 are adopted for the resistant and resilient-based options respectively. The intervention measures for 2040, 2070 and 2085 are supplemented here with additional non-structural measures.

5.3.2 Non-structural measures

The use of non-structural measures is increasingly promoted recently. With emerging guidance such as the UK Government's Department for Environment, Food and Rural Affairs' (Defra) Making Space for Water (MSfW) and the EC Water Framework Directive, there has been a move towards less heavily engineered solutions for flood risk management and recognition that the floodplains are the natural areas for the transmission of flood flows - supporting the implementation of more non-structural measures. Table 5.5 provides a list of non-structural measures that may potentially be applied in the Thames Estuary. The information on the anticipated efficiency and uptake of these measures is sparse, and this table builds on work underway in TE2100 (JBA 2005) and elsewhere (HRW 2006c, FCDPAG series). The measures are broadly divided into pre-event, during event and post-event measures.

The receptor terms in the risk analysis (Section 5.4) are modified to reflect non-structural measures as follows:

- Reduction in residential damages by a factor (may be depth specific) – RD in Table 5.5
- Reduction in commercial damages by a factor (may be depth specific) - CD in Table 5.5
- Reduced public vulnerability reflected through a percentage reduction in population in the floodplain VP in Table 5.5

In all instances, the factor in Table 5.5 is subsequently multiplied by the effectiveness and the uptake to reflect the true reduction in damage.

The feasibility of implementing different non-structural measures in the Thames Estuary is closely linked to the hazard type, i.e. tidal, fluvial or local drainage. Where tidal flooding occurs, the flood depths are significant (e.g. >2m), and thus the options are more limited. In fact, if no defences were present, the entire area would be inundated. For fluvial flooding in the reaches upstream of the barrier, the depths may be of the order 0-3 m, allowing for more options. For simplicity, the non-structural measures are assumed to be implemented throughout the floodplain i.e. no attempt is made to implement spatially diverse portfolios of measures.

Table 5.5 Summary of non-structural options and their assumed effectiveness and uptake, and model representation

Non-structural option	Effectiveness	Uptake	Change reflected in model		
			RD	CD	VP
Pre-event planning					
1. Public awareness raising e.g. flood risk maps, education of inhabitants, Radio/Television information channel	50% Limited in well defended areas where risk perception is low e.g. Thames	40%	3		2%
2. Flood Forecasting and warning	80% Improved effectiveness due to on-line systems.	50% Take-up in TE will be low due to perceived low risk.	1.05 (depths > 1m) [Ref: PAG3]		5% [Ref: PAG3]
3. Emergency planning including evacuation to high ground, crisis management	70%	30% Take-up in TE will be low due to perceived low risk.			3%
4. Development layout to facilitate safe evacuation e.g. high level access routes, reduced risk to people	75%	40% Take-up in TE will be low due to perceived low risk.			3%
5. Business contingency planning including flood recovery	70%	50%		8	
6. Land use zoning/planning e.g. development set back from defences, PPG25 sequential test	80%	50% Uptake likely to improve with e.g. PPG25	4	4	2%
7. Land use zoning/planning e.g. discourage new development in floodplain	80%	50% Uptake likely to improve with e.g. PPG25			3%
8. Flood resilient building design to minimise flood risk e.g. resilient design, multi-storeys with floodable bottom floors	80%	50% Uptake likely to improve	6 (depths < 2.5m)	6 (depths < 2.5m)	
9. Long-term planned relocation	70% Requires detailed B:C analysis to assess effectiveness.	20% Complex process - anticipated low up-take.			
10. Flood response planning (Local Authorities)			Captured in during event actions		
11. Subsidies for flood proofing or other measures			Captured in during event actions		
12. Insurances e.g. private or Government Bellwin Scheme					
13. Wetlands conservation/rehabilitation					
14. Coastal wetland protection					
15. Regulations on storage of	Not relevant for the Thames Estuary				

Non-structural option	**Effectiveness**	**Uptake**	**Change reflected in model**		
			RD	CD	VP
toxics/chemicals					
16. Adaptation of recreation functions	Limited opportunity in the Thames Estuary				
17. Adaptation of agricultural practices	Not relevant for the Thames Estuary				
18. Health and safety measures e.g. reduce impacts from flooding					
During event measures					
19. Flood fighting e.g. making breaches in secondary defences to lower levels, use of temporary demountable defences, informal defence walls, pumping water out of basements, emergency diversion of flood waters	90% Very effective. Benefits far outweigh costs.	80% Higher uptake as authorities involved	6 (depths < 1.5m)	6 (depths < 1.5m)	3%
20. Damage avoidance actions – *collective* e.g. removal of assets, erecting temporary defences, opening rest centres, operating help lines, traffic management, turning power off to areas most badly effected etc.	90% Very effective. Benefits far outweigh costs.	70% Reasonably high uptake as authorities involved	4 (depths < 1m)		2%
21. Damage avoidance actions – *individual* e.g. moving valuables, installing temporary defences, installing sandbags, moving cars, avoiding travel through the flooded areas	75% Potentially very effective. Cost of installation pays for itself within 1 flood;	60% Uptake still fairly low.	3 (depths < 1m)		
Post event measures					
22. Governmental relief funds					
23. Damage compensation					
24. Fines for damage increasing behaviour					

5.3.3 Resistant Strategic Alternative

The resistant strategic alternative builds on HLO 1 (HRW 2007c). In addition to this, flood forecasting and warning is introduced as a non-structural measure and is implemented through to 2100. Table 5.6 provides a summary of the management interventions and the timing of these. Figure 5.14 provides an overview of the spatial location of the structural changes.

Table 5.6 Resistant Strategic Alternative

Epoch	SPR	Description of intervention (Defence raising … resistant)
2040	*Source*	Re-profile channel navigation channel (West London), reduces defence loads. Managed retreat, in the Outer Estuary, reduces upstream loads.
	Pathway	Defences raised by 0.3m
	Receptor	Flood forecasting and warning
2070	*Source*	Managed retreat in the Outer Estuary, reduces upstream loads. Over-rotate the Thames Barrier, reduces upstream loads
	Pathway	Defences raised by 0.5m; Some new defences
	Receptor	Flood forecasting and warning
2085	*Source*	
	Pathway	Restore interim defences upstream of the Thames Barrier
	Receptor	Flood forecasting and warning

NB: These are introduced under a baseline assumption of P3 (routine maintenance, refurbishment of defences and barriers operating to rule)

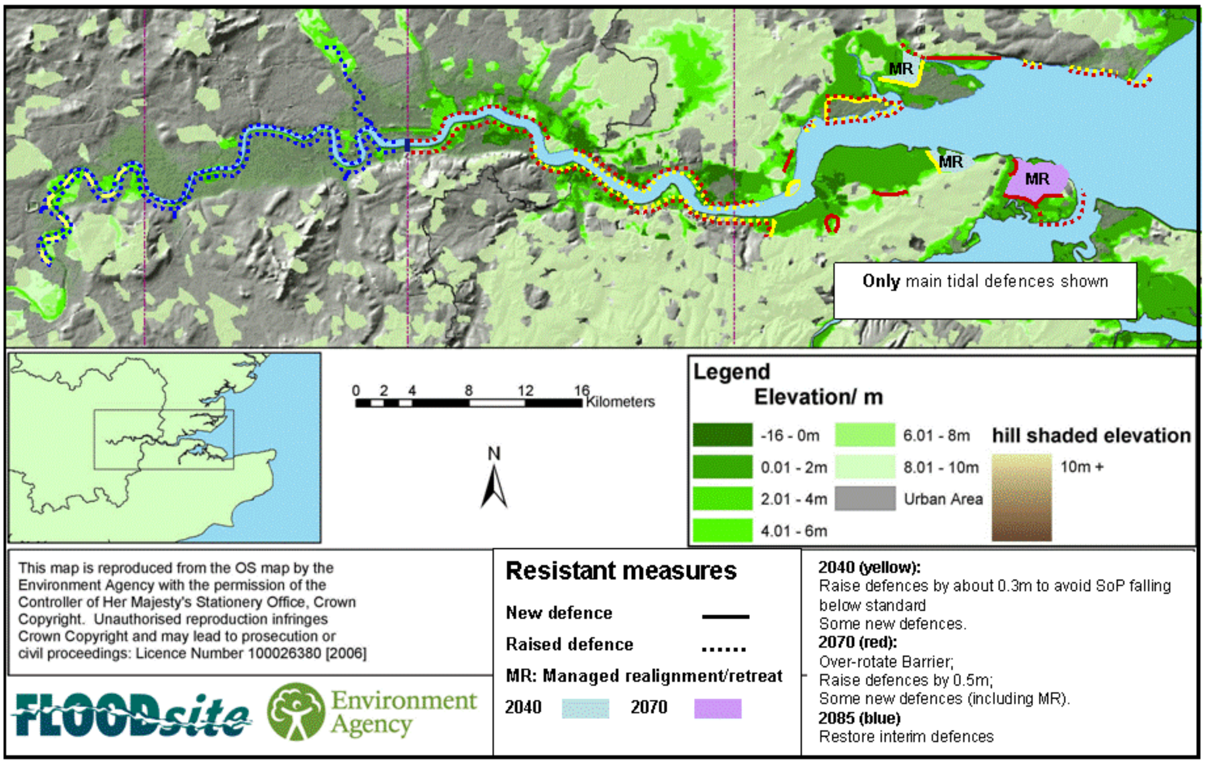


Figure 5.14 Overview of management interventions through time for the resistant strategic alternative

5.3.4 Resilient Strategic Alternative

The resistant strategic alternative builds on HLO 2 (HRW 2007c). In addition to this, a range of non-structural measures are introduced and implemented through to 2100. Table 5.7 provides a summary of the management interventions and the timing of these. Figure 5.15 provides an overview of the spatial location of the structural changes.

Table 5.7 Resilient Strategic Alternative

Epoch	SPR	Description of intervention (Storage … Resilient)
2040	*Source*	Re-profile channel navigation channel (West London), reduces defence loads. Managed retreat, in the Outer Estuary, reduces upstream loads.
	Pathway	Defences raised by 0.3m
	Receptor	Non-structural measures: 1 Public awareness raising, 2 flood forecasting and warning, 3 emergency planning, 5 Business Contingency Planning, 6 & 7 Land-use planning/zoning.
2070	*Source*	Managed retreat in the Outer Estuary, reduces upstream loads; Flood storage areas, reduce upstream loads Over-rotate the Thames Barrier, reduces upstream loads
	Pathway	Defences raised by 0.3m Some new defences, including managed retreat
	Receptor	As for 2040 - maintain
2085	*Source*	
	Pathway	Restore interim defences upstream of the Thames Barrier
	Receptor	As for 2040 - maintain

NB: These are introduced under a baseline assumption of P3 (routine maintenance and refurbishment of defences, barriers operating to rule)

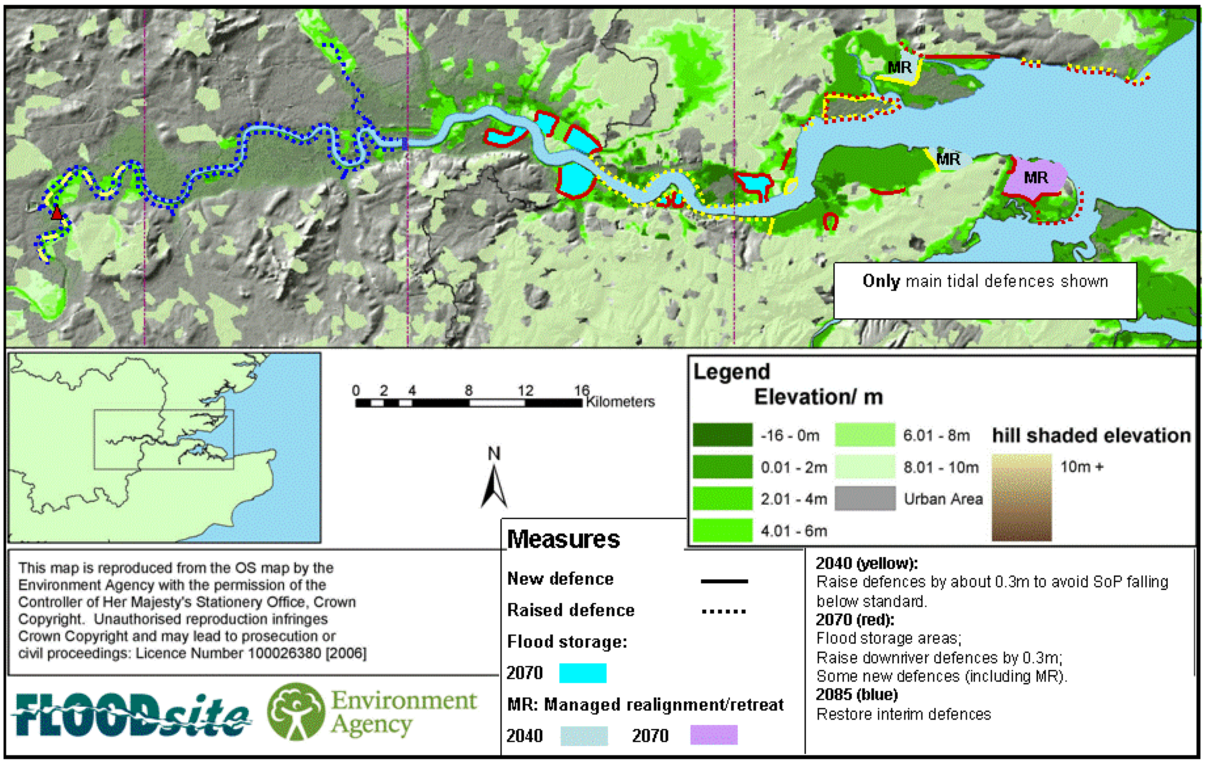


Figure 5.15 Overview of management interventions through time for the resilient and highly resilient strategic alternative (structural measures)

5.3.5 Highly Resilient Strategic Alternative (builds on HLO 2)

The highly resistant strategic alternative builds on HLO 2 (HRW 2007c). In addition to this, an extensive range of non-structural measures are introduced and implemented through to 2100.

Table 5.8 provides a summary of the management interventions and the timing of these.

Table 5.8 Resilient Strategic Alternative

Epoch	SPR	Description of intervention (Storage … Resilient)
2040	*Source*	Re-profile channel navigation channel (West London), reduces defence loads. Managed retreat, in the Outer Estuary, reduces upstream loads.
	Pathway	Defences raised by 0.3m
	Receptor	Numerous non-structural measures: Pre-event measures 1 – 11 and all during event measures 19-21 i.e. flood fighting individual, collective, authorities etc.
2070	*Source*	Managed retreat in the Outer Estuary, reduces upstream loads; Flood storage areas, reduce upstream loads Over-rotate the Thames Barrier, reduces upstream loads
	Pathway	Defences raised by 0.3m Some new defences, including managed retreat
	Receptor	As for 2040 - maintain
2085	*Source*	
	Pathway	Restore interim defences upstream of the Thames Barrier
	Receptor	As for 2040 - maintain

NB: These are introduced under a baseline assumption of P3 (routine maintenance and refurbishment of defences, barriers operating to rule)

5.4 Risk analysis methods, modelling and evaluation

To meaningfully interpret and understand the results from the flood risk analysis, it is necessary to explain the underlying data, methods and tools which underpin the flood risk model. This Section briefly describes the workings of the system model, the input data and model outputs. For a more detailed description see HRW (2007 & 2008).

The Task 24 RASP based risk engine has also been applied in the UK Environment Agency's Thames Estuary 2100 Project (TE2100), which involves the economic appraisal of different flood risk management interventions over the coming century, and given the nature and value of the assets at risk, the study is recognised as being the most significant strategic flood risk assessment ever undertaken within the UK. Given the level of importance of the study, the model has been formally reviewed by a panel of over eight experts in the field. The panel concluded the model was fit for purpose and suitable for detailed economic appraisal of options.

A System-Based Model

The RASP flood risk model (Gouldby *et al*, 2008) is based on the Source-Pathway-Receptor-Consequence concept (HR Wallingford, 2002) and is an advancement of the RASP High Level Method*plus* (HR Wallingford, 2004, see also Hall *et al*, 2003). This method involves the integration of a full range of loading conditions (extreme water levels) with the performance of defences, represented through fragility curves[12], allied to a flood spreading method, which enables economic consequences to be established.

[12] Elsewhere called failure probability curves, relating the failure probability to a certain water level or load condition

The system model includes the following components (see also Figure 5.16):

- *Sources*: 'extremes curves' which provide the fluvial (i.e. no significant wave action) and coastal (i.e. significant wave action) loading conditions to the system model;
- *Pathways*: which may be divided into two types: (i) 'pathways into the floodplain' i.e. over/through defences which are dependent on the performance of the defences and provide floodplain inflow volumes for each defence; and (ii) 'pathways across the floodplain' i.e. flood spreading which results in a probabilistic flood depth grid over the floodplain;
- *Receptors*: which include spatial information on the (value of) properties, people, habitat etc. in the floodplain which are vulnerable to flooding; and
- *Consequences*: where the pathway outputs are confronted with the receptor terms to give impacts (monetary or high/medium/low) such as economic, social or environmental damage or improvement that may result from a flood.

Figure 5.17 illustrates how the system model fits into the wider modelling process. These steps are described in more detail below.

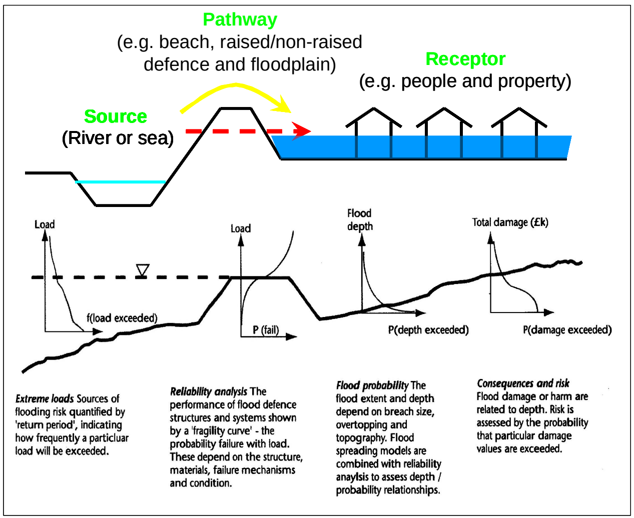


Figure 5.16 The Source-Pathway-Receptor-Consequence risk assessment framework (adapted from Sayers et al, 2002)

Base data

The essential input data to run the system model (other data is as appropriate to external models used) include:

- Extreme water levels i.e. water level and return period per defence
- Volumes into floodplain per defence for overflow and overtopping states (failed/not-failed)
- River centre line
- Ground model
- Extent of the flood risk area, i.e. 1:10,000 undefended floodplain
- Defence information (used to derive fragility) including spatial location, defence type, crest level, standard of protection (optional), condition grade, toe level, ground level
- Property data which draws on the best attributes of the National Property Database, Ordnance Survey MasterMap, Valuation Office Database and the Middlesex Multi-Coloured Manual
- Population data via inhabitants
- Any receptor data with damage and location information, e.g. infrastructure, agriculture, habitat, natural/cultural heritage, social vulnerability, etc.

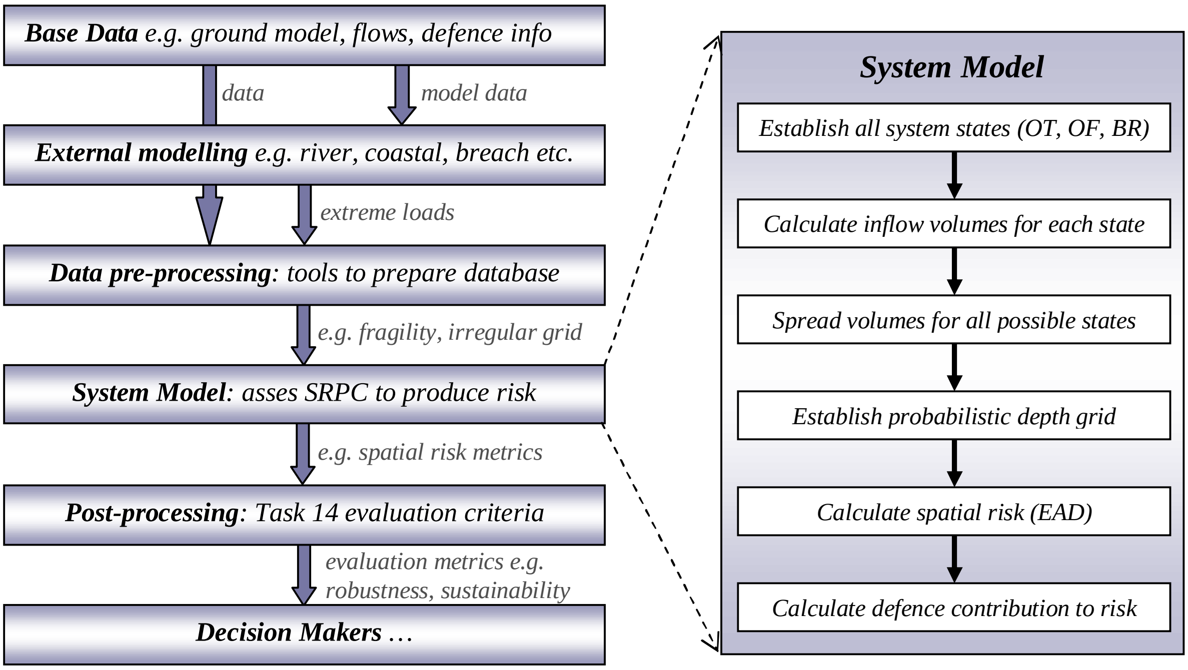


Figure 5.17 Overall modelling process

External modelling

The extreme loading conditions are derived from external modelling:

- The 1D hydrodynamic model ISIS Flow Version 2.3 is used to derive the in-river water levels for the main river and its tributaries (Halcrow, 2002);

- For the main river, a joint probability analysis is adopted using statistical modelling of extreme sea levels at Southend and extreme flows at Teddington and their dependence (EP7, TE2100). These are used together with a set of 'structure functions' (with and without the Thames Barrier open) that relate the variables to water levels at intermediate sites within the estuary, to develop extreme value probability distributions of water levels along the estuary.

- The HR PROBTOP model is used to derive volumes into the floodplain for both overtopping and overflowing (failed/not-failed) states for a range of loading events.

The outputs from the external modelling and/or data provide as inputs to the RASP model:

- for areas with *insignificant waves* - extreme total water levels for each defence with an associated return period, e.g. 100 years;
- for areas with *significant* waves - joint wave and water level conditions. These include significant wave height and still water level;
- inflow volumes to the floodplain given different failure states e.g. breach, overtopping, overflow for each extreme loading condition.

Data pre-processing

There are a number of data pre-processing steps, for example:

- creation of an *irregular grid* over the flood risk area for the flood spreading method;
- generating *generic defence fragility* curves based on the defence data attributes. ;
- generating *depth-damage* tables for residential and non-residential properties (for both saline and non-saline conditions).

System model

The conceptual backdrop for the system model is shown in Figure 5.18. This shows a river channel separated from the floodplain area (Flood Area) by a series of discrete flood defences (d_1, d_2, …, d_n). Each flood defence section has an independent and different resistance to flood loading. These are characterised by, for example, different types of structure, crest levels or condition grades. Within the Flood Areas, the water levels are calculated at Impact Zones (e.g. IZ_i, IZ_{i+1}) which are topographically driven localised watersheds. The Flood Area is further discretised into a series of Impact Cells, which is the resolution at which the risk-based calculation takes place. Any specified Impact Cell can be influenced by flood water discharged through any of the (*n*) defences around the Flood Area.

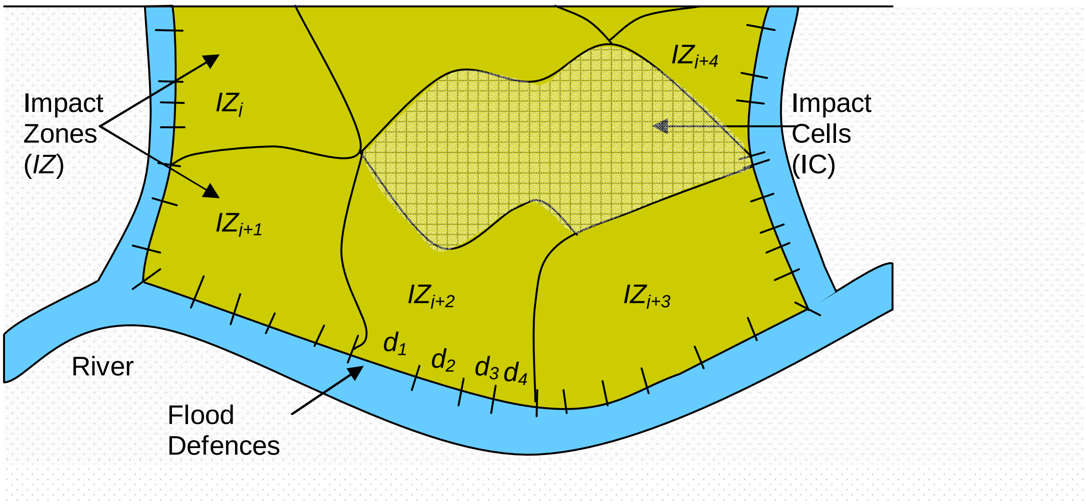


Figure 5.18 Conceptual diagram of the model backdrop (HRW, 2007)

Within this system model, the main calculation processes include:

- *Establish all system states*: within any given Flood Area, the continuous line of defence lengths forms a defence system. On any particular loading event any individual defence section is assumed to have two possible states: failed or not failed. The potential number of defence system states (combinations of failed/not failed defences within the flood area), for any specified hydraulic load, is therefore 2^n (where n is the number of defences). The failed and non-failed data for each defence is obtained from the defence fragility (for the given load), and these can be summed for each defence to determine the overall probability of that defence system state.

- *Calculate inflow volumes for each defence system state*: for each system state, the failed/non-failed status of each defence is used to allocate an inflow volume.

- *Spread volumes for all possible states*: the flood spreading is based on a Rapid Flood Spreading Model which provides water levels for each Impact Zone. Although rapid compared to other flood spreading approaches, use of this model still prohibits solution by enumeration, particularly given that the number of realisations for a defence system of say 100 defences, is of the order 2^{100}, and a range of loading events (~65 for the Thames) are to be considered. The preferred choice for solution of this problem is numerical simulation and of the available options a conventional Monte Carlo simulation is adopted. The 2^n defence system states for a given load are therefore randomly sampled such that each realisation of the sampling process provides a flood outline (or floodplain water levels)[13].

- *Establish probabilistic flood depth grid*: The next step is to establish, for each Impact Cell, the probability of exceeding any particular flood depth, under any specified loading condition. The exceedence probability is approximated from the number of realisations in the random sampling process that result in depths greater than the given flood depth, under a given loading condition, divided by the total number of realisations undertaken for that loading condition. The on-set of inundation is typically taken as zero. The unconditional annual probability is then evaluated from integrating the probabilities over the range of loading conditions.

- *Calculate risk (EAD):* the risk is calculated through confronting the receptor impacts, for example, property damages at a given depth, with the probability of flooding at that depth. This is similar to the above, where the mean economic consequence associated with a given loading condition is estimated for each Impact Cell, and then integrated over the range of loading conditions to provide the Expected Annual Damage (EAD) for that Impact Cell.

- *Calculate defence contribution to residual risk*: this process is based on establishing the relationship between the quantity of water discharged through each individual defence and the economic consequence of the event. It involves tracking the proportion of flow through each Impact Zone, from the defence to the destination Impact Zone, and then apportioning EAD in that Impact Zone (based on the volume inflow relative to total Impact Zone volume) to the defences which contributed.

Model Outputs

The system model is capable of providing a wide range of outputs that are useful for supporting decisions on long-term flood risk management planning as well as more medium term activities, such as targeting defence maintenance and improvement. Example outputs include:

- Spatial floodplain distribution of the likelihood of inundation
- Spatial floodplain distribution on the Expected Annual Damage (EAD)
- Total EAD for the flood risk area
- Annual probability of defence failures
- Contribution to residual risk (EAD) from each defence
- Contribution to residual risk (EAD) from overtopping of each defence
- Contribution to residual risk (EAD) from breaching of each defence

Additional outputs may be generated such as count of points, length of lines and area of areas affected by flooding e.g. infrastructure. The model also provides an upper and lower uncertainty bound based on the uncertainty in the defence information reflected through the fragility and in the property damage information, reflected in the damage curves.

Post-processing

The preferred evaluation criteria are summarised in Chapter 3, Table 3.5. The outputs provided for the Thames Pilot include the following flood risk indicators:

[13] An important consideration when applying Monte Carlo is the number of simulations required to stabilise the estimated quantity. The procedure adopted is to monitor the output economic damage through specification of a convergence criterion.

Economic
- Total EAD for the flood risk area in a given year (incl. upper/lower bounds)
- Total EAD relative to the 'do nothing' in a given year to illustrate risk reduction
- Present day benefits (adopting the standard Defra discount rates for the appraisal period i.e. 3.5% between years 1 and 30, 3.0% between years 31 and 75, 2.5% after year 76)
- Present day costs of planned interventions (adopting similar discount rates to those above)

Social
- People risk 1: Number of people exposed to 'frequent' flooding. This is defined as the number of people in an area with an annual probability of inundation of 1:75 of exceeding 0m depth
- People risk 2: Expected annual deaths / serious injuries. This is defined as annual probability of inundation of exceeding 1m depth multiplied by the number of people at that location.

Ecological
- Area of habitat (derived from Land Cover Map 2000) with an annual probability of inundation of 1:75 of exceeding 0.5m depth (m^2).

The following additional outputs on natural and cultural heritage could be calculated (given the datasets):

- Damage to natural heritage count within area of annual probability of inundation of 1:75 of exceeding 1m depth (no.)
- Damage to cultural heritage count within area of annual probability of inundation of 1:75 of exceeding 0.5m depth (no.)

An assessment of non-intended side-effects of the alternatives on people, economy or natural and cultural heritage has not been performed for the Thames case, in deviation of what the method of Chapter 3 proposes. And an assessment of robustness and flexibility of each strategic alternative is only performed in the context of task 18 (FLOODsite, 2008).

5.5 Results and discussion

This section provides a summary of the results. Table 5.9 shows which 82 model runs were undertaken with the model (Section 5.4). These include model runs for each strategic alternative (Section 1.3), in the context of each future socio-economic and climatic scenario (Section 1.4), for the present day, 2040, before and after the management interventions in 2070 and in 2085, and in the final year of the appraisal period, 2100.

Table 5.9 Summary of model runs for the Thames Pilot

Strategic Alternatives	**Present day**	**Future Scenarios**			
		World Markets	National Enterprise	Local Stewardship	Global Sustainability
Do nothing - P1 policy	2007	2050 2100	2050 2100	2050 2100	2050 2100
P3 Policy	2007				
Resistant		6* runs	6* runs	6* runs	6* runs
Resilient		6* runs	6* runs	6* runs	6* runs
Highly Resilient		6* runs	6* runs	6* runs	6* runs
No. of model runs:	2	20	20	20	20
Total Runs:					**82**

* includes 2040, 2070 before measures, 2070 after measures, 2085 before measures, 2085 after measures, 2100

5.5.1 Economics – EAD, benefits and costs

Expected Annual Damages

Figure 5.19 provides the total EAD through time (in £million) for each strategic alternative in the context of each future scenario for an overall comparison of the results. Figure 5.20 to Figure 5.23 provide the EAD through time for each scenario. To aid readability, the upper and lower uncertainty bounds are not included in these Figures. Table 5.10 provides the actual EAD values and the corresponding uncertainties. From these, it is apparent that the 'do nothing' option provides a substantially higher damage estimate than the three strategic alternatives - two orders of magnitude larger on the log normal axis. The total EAD values suggest that the resilient options tend to perform better than the resistant options across all future scenarios – and the highly resilient option performs better than the resilient option as expected. However, to truly understand the information, the decision makers should delve into the spatial descriptions of the probability of inundation and EAD, as there may be local/spatial variations in the tolerable or acceptable level of risk, resulting in a particular strategic alternative being favoured.

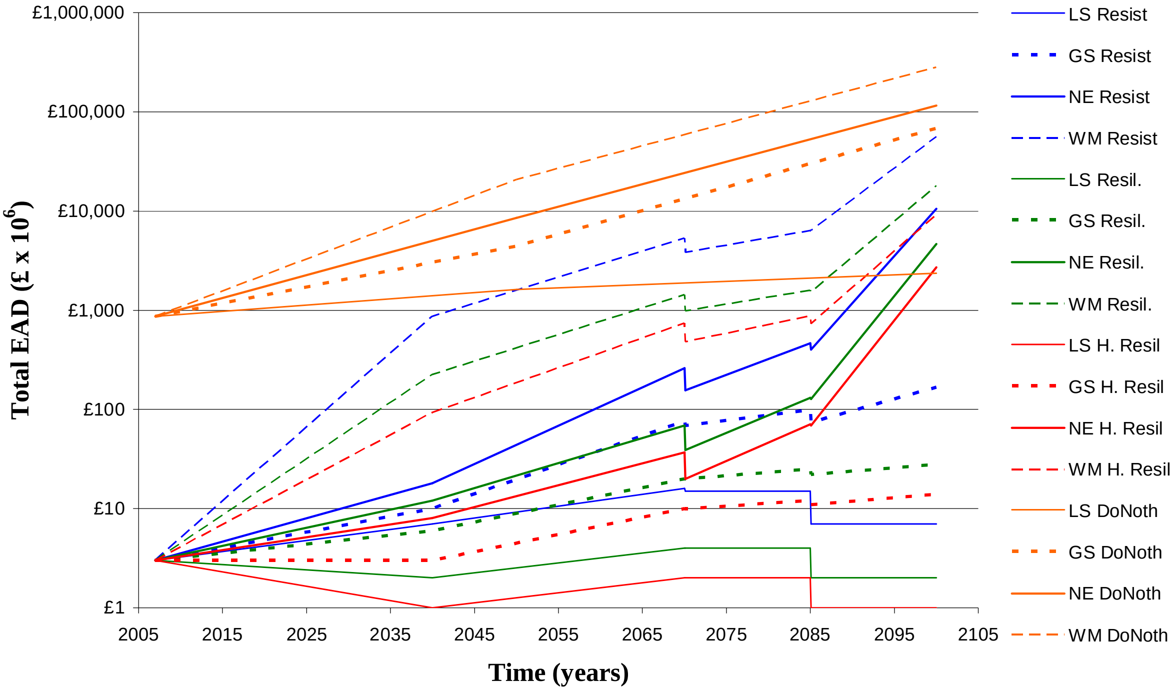


Figure 5.19 Total EAD for each strategic alternative in the context of each scenario (WM = World Markets, NE = National Enterprise, GS = Global Sustainability, LS = Local Stewardship)

Figures A1 to A30 in Appendix A include the corresponding probability of inundation spatial distribution for present day, 2040 and 2100 for each strategic alternative in the context of each future scenario. This provides an impression of where the hazard is the driving factor for the risk – and where intervening with the source and pathway may reduce the overall risk.

Figures B1 to B30 in Appendix B include the corresponding EAD spatial distribution as well as the composition of these damage values (i.e. residential versus commercial properties) by flood area for present day, 2040 and 2100 for each strategic alternative in the context of each future scenario. These provide insight into where the greatest risk contributions are made, and comparison with the probability of inundation plots provides insight into where the vulnerability may be the main cause of the high risk.

Note that in all plots, areas of solid grey are caused by one of the following: areas subject to storage or managed realignment reducing the model extent, high ground, and in the Medway Towns borough the true EAD values were not plotting correctly (i.e. cosmetic error).

Some observations from Appendix A and B include:

- Comparison of the 'do nothing' and P3 policy for the present day illustrates the substantial impact the Thames Barrier has on flooding upstream of the barrier;
- Canvey Island is the largest high risk area downstream of the barrier;
- The area on the south side of the Estuary mouth (Medway Towns borough) is subject to a higher probability of flooding but has a lower risk, as it is less developed;
- The EAD for the area on the north bank, just downstream of the barrier between the Lee and the Roding tributaries, is high in all cases - this is largely due to the high damages rather than the hazard probability (note: the proposed Olympic site is along the banks of the Lee);
- The probability of inundation and EAD for South End on Sea is high for all cases;
- The resilient and highly resilient alternatives show a marked improvement in the EAD relative to the resistant alternative in the following areas: North Bank between the Lee and the Beam tributary, South End on Sea, Gravesend and Thamesmead.

This rich volume of information (spatial, temporal, uncertainties) for the total EAD alone starts to illustrate the challenges decision makers face when developing and evaluating policies – and the strong need for decision support tools to aid the process.

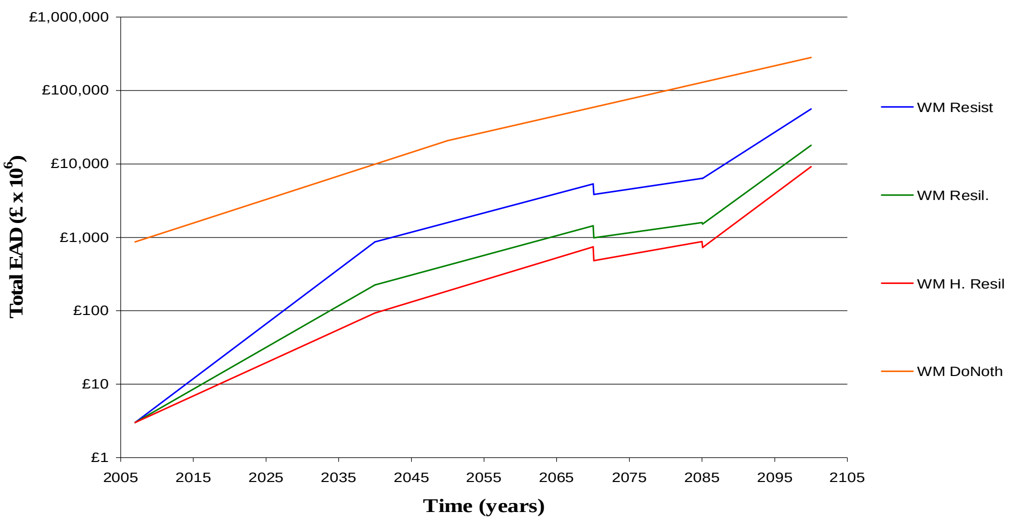


Figure 5.20 All Strategic Alternatives in the context of the World Market scenario

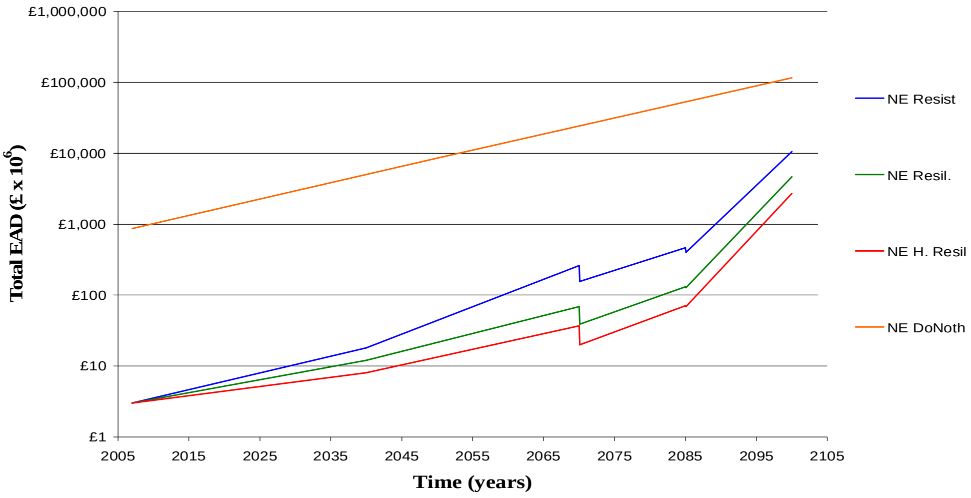


Figure 5.21 All Strategic Alternatives in the context of the National Enterprise scenario

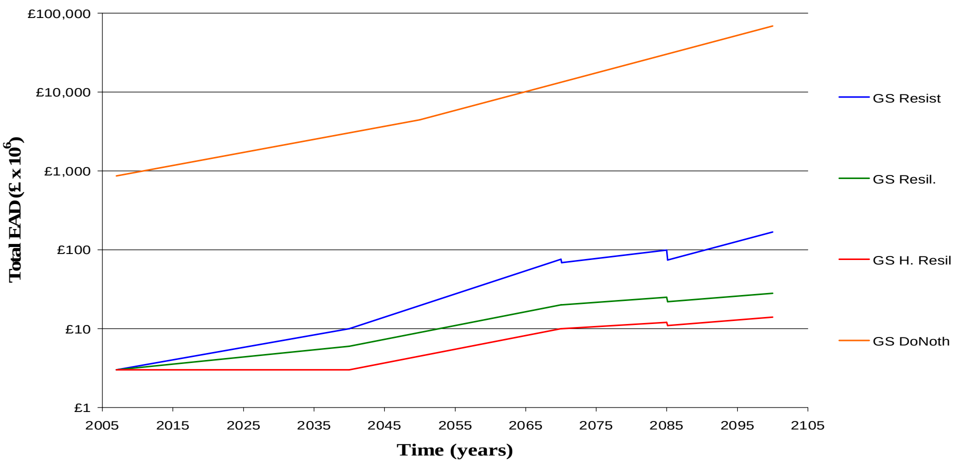


Figure 5.22 All Strategic Alternatives in the context of the Global Sustainability scenario

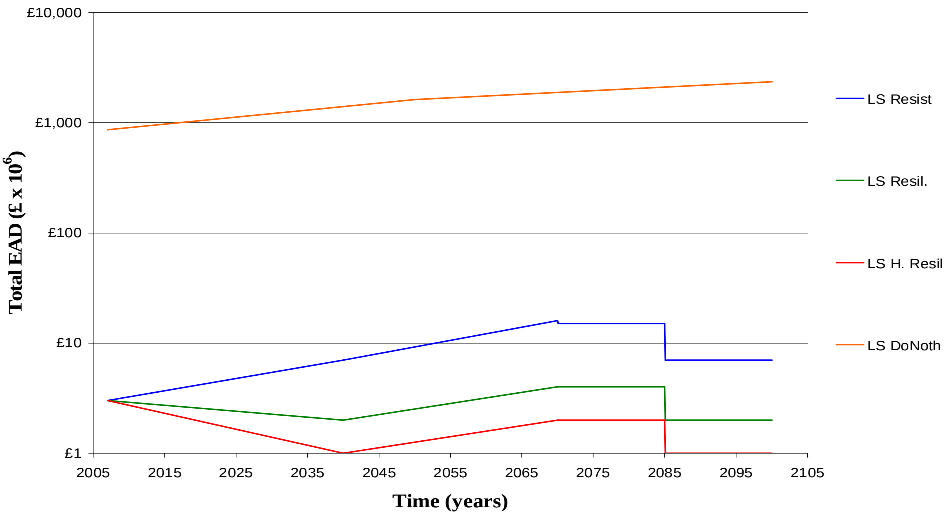


Figure 5.23 All Strategic Alternatives in the context of the Local Stewardship scenario

Table 5.10 Summary of Total EAD (£ x 10^6) for Thames Estuary at each analysis point

Local Stewardship		2007	2040	2050	2070 bef.	2070	2085 bef.	2085	2100
Expected	Do nothing	£866		£1,623					£2,358
	Resistant	£3	£7		£16	£15	£15	£7	£7
	Resilient	£3	£2		£4	£4	£4	£2	£2
	Highly Resilient	£3	£1		£2	£2	£2	£1	£1
Lower	Do nothing	£695		£1,243					£1,555
	Resistant	£2	£5		£10	£9	£9	£20	£4
	Resilient	£2	£1		£2	£2	£2	£1	£1
	Highly Resilient	£2	£1		£1	£1	£1	£1	£1
Upper	Do nothing	£1,021		£1,959					£3,030
	Resistant	£3	£9		£23	£21	£21	£35	£10
	Resilient	£3	£2		£5	£5	£5	£2	£2
	Highly Resilient	£3	£1		£2	£2	£2	£1	£1
Global Sustainability									
Expected	Do nothing	£866		£4,428					£68,645
	Resistant	£3	£10		£76	£69	£99	£74	£168
	Resilient	£3	£6		£20	£20	£25	£22	£28
	Highly Resilient	£3	£4		£10	£10	£12	£11	£14
Lower	Do nothing	£695		£2,739					£52,804
	Resistant	£2	£5		£53	£49	£74	£57	£130
	Resilient	£2	£5		£14	£14	£19	£17	£21
	Highly Resilient	£2	£3		£7	£7	£9	£8	£11
Upper	Do nothing	£1,021		£5,787					£81,450
	Resistant	£3	£14		£98	£89	£121	£90	£202
	Resilient	£3	£7		£25	£25	£30	£26	£33
	Highly Resilient	£3	£5		£12	£12	£15	£13	£16
National Enterprise									
Expected	Do nothing	£866		£8,557					£115,345
	Resistant	£3	£18		£260	£156	£465	£400	£10,495
	Resilient	£3	£12		£69	£39	£131	£127	£4,673
	Highly Resilient	£3	£8		£37	£20	£71	£69	£2,704
Lower	Do nothing	£695		£5,496					£92,227
	Resistant	£2	£11		£185	£117	£368	£318	£7,952
	Resilient	£2	£10		£51	£30	£58	£56	£3,537
	Highly Resilient	£2	£6		£28	£16	£58	£56	£2,046
Upper	Do nothing	£1,021		£10,992					£133,894
	Resistant	£3	£25		£326	£193	£549	£472	£12,776
	Resilient	£3	£14		£84	£48	£154	£80	£5,627
	Highly Resilient	£3	£10		£45	£24	£83	£80	£3,271
World Markets									
Expected	Do nothing	£866		£20,869					£280,551
	Resistant	£3	£869		£5,355	£3,849	£6,360	£6,340	£55,921
	Resilient	£3	£226		£1,435	£987	£1,584	£1,522	£17,911
	Highly Resilient	£3	£93		£742	£483	£874	£730	£9,158
Lower	Do nothing	£695		£16,747					£136,995
	Resistant	£2	£630		£4,230	£3,101	£2,586	£2,578	£46,076
	Resilient	£2	£163		£1,166	£814	£647	£620	£14,897
	Highly Resilient	£2	£65		£606	£399	£370	£318	£7,543
Upper	Do nothing	£1,021		£24,413					£367,914
	Resistant	£3	£1,084		£6,358	£4,552	£8,873	£8,843	£64,525
	Resilient	£3	£288		£1,673	£1,148	£2,186	£2,101	£20,481
	Highly Resilient	£3	£121		£862	£561	£1,190	£980	£10,559

Benefits

It is also possible to describe the change in risk under each strategic alternative relative to the 'do nothing' case i.e. the benefit. The difference between the two gives the benefit associated with the pursuit of that particular alternative. The benefits for each strategic alternative are summarised in Figure 5.24. The results broadly suggest that regardless of strategic alternative, the risk reduction achieved is as would be expected and varies significantly between scenarios.

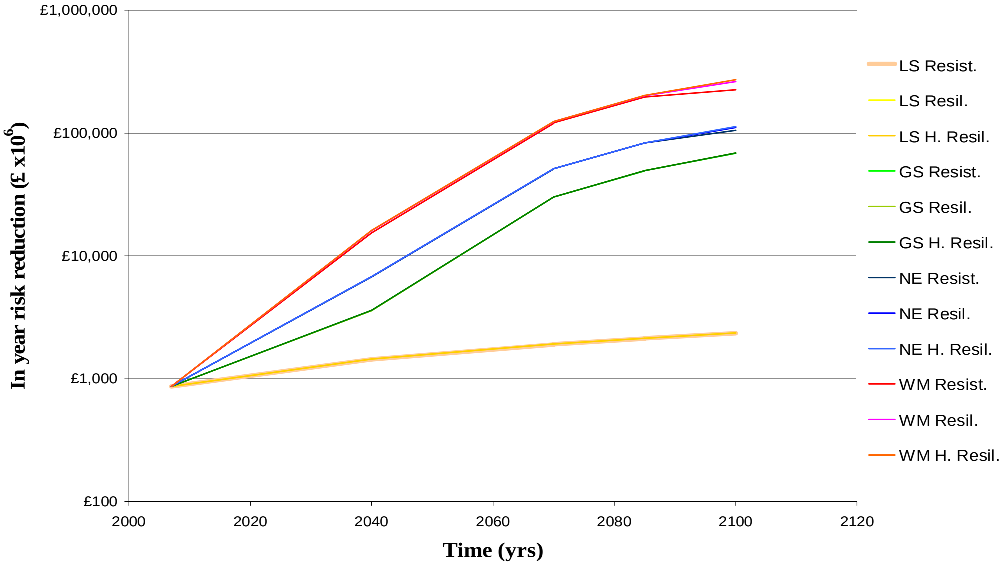


Figure 5.24 Total risk reduction for each strategic alternative in the context of each scenario relative to the do nothing case

The present day benefits are provide in Table 5.11. These are based on the standard Defra discounting rates. Based on benefits alone, the Highly Resilient strategic alternative is the most favourable.

Table 5.11 Present day benefits (£ x 10^6)

	PV Benefit	PV Cost Lower Bound	PV Cost	PV Cost Upper Bound	B:C Lower	B:C	B:C Upper	Uncertainty Band on B:C	Inremental B:C
Local Stewardship									
Resistant	£39,911	£3,031	£3,631	£4,231	9.4	11.0	13.2	3.7	2.3
Resilient	£40,016	£2,986	£3,586	£4,186	9.6	11.2	13.4	3.8	
Highly Resilient	£40,035	£3,335	£3,935	£4,535	8.8	10.2	12.0	3.2	-0.1
Global Sustainability									
Resistant	£271,714	£3,031	£3,631	£4,231	64.2	74.8	89.6	25.4	8.7
Resilient	£272,107	£2,986	£3,586	£4,186	65.0	75.9	91.1	26.1	
Highly Resilient	£272,188	£3,335	£3,935	£4,535	60.0	69.2	81.6	21.6	-0.2
National Enterprise									
Resistant	£451,339	£3,031	£3,631	£4,231	106.7	124.3	148.9	42.2	84.7
Resilient	£455,152	£2,986	£3,586	£4,186	108.7	126.9	152.4	43.7	
Highly Resilient	£456,287	£3,335	£3,935	£4,535	100.6	115.9	136.8	36.2	-3.2
World Markets									
Resistant	£1,029,228	£3,031	£3,631	£4,231	243.3	283.5	339.6	96.3	981.4
Resilient	£1,073,404	£2,986	£3,586	£4,186	256.4	299.3	359.5	103.1	
Highly Resilient	£1,082,133	£3,335	£3,935	£4,535	238.6	275.0	324.4	85.8	-25.0

Costs

Implementation costs have been estimated for the three strategic alternatives. These build on previous Thames-specific cost estimates for non-structural measures (JBA; 2005), for specific High Level Option (HLO) intervention measures (Atkins; 2006) and for linear defences (personal communication with D Ramsbottom partially informed by work of Royal Haskoning in TE2100). This information is summarised in Table 5.12.

Table 5.12 Summary of available relevant costing information for the Thames

Thames Estuary Cost Information	£/metre	Capital costs	Annual maintenance costs	Annual running costs	Periodic refurbishment (annual)	Periodic costs for 100yr period
Defences (Personal communication D Ramsbottom on Royal Haskoning work)						
Upstream smaller defences						
Replacement costs per metre	£10,000					
Raising per metre	£5,000					
Downstream Larger defences						
Replacement costs per metre	£20,000					
Raising per metre	£5,000					
Barriers (Atkins 2006)						
Thames Barrier			£2,500,000	£3,700,000	£1,400,000	
Over-rotation		£890,000				
Replace FRGs		£13,300,000				
Raise piers		£3,750,000				
Decommisioning		£417,000,000				
King George V Dock Flood Gate replacement		£24,000,000	£148,000	£228,000	£200,000	
Gallions Reach Flood Defence Gates		£300,000	£27,000	£48,000	£71,000	
Royal Docks Pumping Station		£600,000	£15,000	£0	£2,500	
Barking Barrier		£2,150,000	£355,000	£545,000	£200,000	
Dartford Barrier (existing)			£355,000	£545,000	£200,000	
Dartford Barrier (new)		£1,500,000	£180,000	£275,000	£100,000	
Tilbury Flood Defence Gate (existing)			£148,000	£228,000	£200,000	
Tilbury Flood Defence Gate (new)		£30,000,000	£185,000	£285,000	£250,000	
East Haven Barrier		£150,000	£275,000	£180,000	£100,000	
Benfleet Barrier		£300,000	£275,000	£180,000	£100,000	
Pumping Stations (Atkins 2006)						
Small (<50l/s)		£195,000	£6,000	£3,400		£345,000
Medium (50-200l/s)		£277,000	£7,000	£4,000		£552,000
Large (>200l/s)		£410,000	£8,000	£5,000		£877,000
Extra Large (10cumecs/s)		£5,800,000	£94,000	£80,100		£2,235,000
Frontage gates (Atkins 2006)						
Small (3*1.25)		£24,000	£500	£750		£76,000
Medium (7*2.1)		£71,000	£800	£750		£220,000
Large (12*2.5)		£169,000	£2,500	£750		£529,000
Outfalls (Atkins 2006)						
Small (1000mm diameter)		£59,000	£500	£100		£118,000
Medium (2000mm diameter)		£80,000	£500	£100		£180,000
Large (2*1500mm diameter)		£108,000	£1,000	£200		£248,000
New Sluices (Atkins 2006)						
Flood Storage Area		£2,123,000	£2,500	£400		£226,900
Non-structural measures (JBA 2005)						
Public awareness raising (estimate - no source)				£100,000		
Flood Forecasting and warning (EA FWIS for Thames Estuary)				£1,500,000		
Flood Forecasting and warning (EA tidal defences & flood training exercises)				£528,000		
Emergency planning - evacuation to high ground (estimate - no source)				£500,000		
Development layout to facilitate safe evacuation (estimate - no source)				£500,000		
Business contingency planning including flood recovery (estimate - no source)				£200,000		
Land use zoning/planning e.g. dev set back from defences, PPG25				£50,000		
Land use zoning/planning e.g.discourage new development				£50,000		
Flood resilient building design to minimise flood risk				£1,000,000		
Flood fighting e.g. emergency diversion of flood waters (assumes 2.5 events/yr)				£5,000,000		
Damage avoidance actions – *collective* (assumes 2.5 events/yr; 50000 houses)		£751,250,000		£100,000		
Damage avoidance actions – *individual*		£0	£0	£0		

As there are many costing elements which are common for all three strategic alternatives, rather than undertaking a complete costing, the costs for interventions which differ are determined here whereas the baseline cost is assumed £3 billion, with an uncertainty band of ± 20%. The following is also assumed:

- Capital and maintenance costs related to pumping stations, frontage gates and outfalls are common for all and covered within the £3 billion;
- Capital and maintenance costs for the barriers are the same for all and covered within the £3 billion (there are no new barriers in any of the strategic alternatives);
- Approximate annual costs for maintaining the general linear defences, which include ~490km of defence are the same for all and included in the £3 billion;

- Costs for new (e.g. managed realignment), replaced and raised defences differ for each option and are therefore explicitly costed and included;
- Costs of new sluices to storage areas are costed and included as these are only present in the resilient options;
- Costing is undertaken for all non-structural measures;
- The cost of flood proofing measures is based on 50,000 houses having protection from 2040 onwards at a cost of £15K per house (typically flood proofing varies from £10-50K per house depending on the extent, JBA 2005);
- All costs are discounted based on the Defra standard rates.

The discounted present day costs (£million), including upper and lower bands, are provided in Table 5.11. Based on costs alone, the Resilient strategic alternative is the most favourable.

The benefit/cost (B/C) ratio for each strategic alternative relative to the 'do nothing' is provided in Table 5.11, including the upper and lower bands derived from the cost information. From this, it is apparent that the Resilient option is the most favourable in terms of B/C for all futures.

An alternative means of comparing the B/C ratio is through consideration of the incremental or relative B/C of one strategic alternative relative to another (Defra, 2006) where the base is taken as the 'best' strategic alternative in terms of B/C relative to the 'do nothing'. The incremental B/C ratios relative to the base (i.e. the Resilient) are provided in Table 5.11. From this, it is apparent that the incremental benefit of moving from the Resilient to the Resistant strategic alternative is more favourable than a move to the Highly Resilient strategic alternative. For all cases, the relative B/C ratio is smallest for Local Stewardship and largest for the World Market scenario.

For a true understanding of these results, decision makers should consider the uncertainty distribution associated with the B/C ratios. For example, it may be more favourable to adopt an option with a lower B/C if the uncertainty band is narrower, particularly if the entire uncertainty band falls above the tolerable/allowable B/C ratio. For example, in Table 5.11, although the Resilient Option is favoured in terms of the overall B/C, the Resistant option has a narrower B/C uncertainty band.

This B/C analysis only considers the strategic alternatives in the context of 4 possible futures. Ideally the strategic alternatives should be evaluated in the context of the full range of plausible climatic and socio-economic scenarios (Figure 5.5) to obtain a true measure of the robustness.

5.5.2 Social – People risk

Two criteria were used to provide insight into the social impacts (evaluated for each of the present day, 2040 and 2100 model runs). The criteria where based on the 'people at risk' as follows:

- People risk 1: Number of people exposed to 'frequent' flooding. This is defined as the number of people in an area with an annual probability of inundation of 1:75 of exceeding 0m depth
- People risk 2: Expected annual deaths/serious injuries. This is defined as annual probability of inundation of exceeding 1m depth multiplied by the number of people at that location.

Table 5.13 and Table 5.14 provide the outputs for people risk 1 and 2 respectively. For all cases, the number of people exposed to frequent flooding is high in 2100, with up to ~4 million at risk for three strategic alternatives in the worst case scenarios and just under 6 million at risk for the 'do nothing'. The resilient options show less people at risk of frequent flooding than the resistant option, which is explained by non-structural measures such as flood warning and evacuation planning reducing the floodplain population exposed during events.

The expected annual deaths/serious injuries are substantially less for the strategic alternatives than for the do nothing, and as above, the resilient alternatives provide a lower expectation than the resistant alternative.

Table 5.13 Number of people exposed to frequent flooding

	GS	WM	NE	LS	Year
Existing Policy	659,438	659,438	659,438	659,438	2007
	2,620,806	5,695,616	2,926,352	659,323	2100
Resistant	863	863	863	863	2007
	5,817	128,570	9,180	9,053	2040
	85,046	4,404,114	1,210,516	1,267	2100
Resilient	863	863	863	863	2007
	5,838	91,501	15,015	1,225	2040
	42,424	3,947,645	963,658	779	2100
Highly Resilient	863	863	863	863	2007
	5,838	105,332	15,013	1,225	2040
	42,513	3,949,878	962,932	12,464	2100

Table 5.14 Expected annual deaths / serious injuries

	GS	WM	NE	LS	Year
Existing Policy	25,347	25,347	25,347	25,347	2007
	886,994	3,919,997	1,576,508	25,396	2100
Resistant	69	69	69	69	2007
	244	14,238	365	355	2040
	1,574	409,831	115,781	42	2100
Resilient	69	69	69	69	2007
	244	8,588	551	81	2040
	995	579,376	190,264	39	2100
Highly Resilient	69	69	69	69	2007
	245	13,757	551	82	2040
	995	579,879	189,723	213	2100

Figures C1 to C6 in Appendix C and Figures D1 to D6 in Appendix D provide maps of People risk 1 and 2 respectively. These include each strategic alternative in the context of the Global Sustainability future scenario for present day and 2100. The following can be observed from these:

- The present day P3 Policy, which results in ~863 people at risk of frequent flooding, shows that these are located in very small isolated locations upstream of the barrier (Figure C1).
- The present day 'do nothing' case shows many people at risk of frequent flooding upstream of the barrier, which is fully expected due to the assumption of no movable structures operating (Figure C2).
- The 2100 'do nothing' case shows a substantial degree of the floodplain population at risk of frequent flooding upstream of the barrier – as well as highlighting the people risk 1 at Canvey Island - downstream of the barrier (Figure C6).
- The resistant strategic alternatives shows that Canvey Island is the most at risk of frequent flooding, whereas the resilient options substantially reduce the risk in this area (Figures C3-C5).

These observations on the spatial distributions are similar for the second People at risk criteria.

5.5.3 Ecological risk

The ecological impacts are measured based on the area of habitat with an annual probability of inundation of 1:75 of exceeding 0.5 m depth (m^2). This is established for 2040 and 2100 for all cases. The habitat is derived from the Land Cover Map 2000. Table 5.15 and Table 5.16 provide a summary of this indicator, expressed as a percentage of the total present day habitats. The areas with greater than 50% affected are highlighted in red and those with 20 to 50% affected are highlighted in yellow.

Some initial observations from these include:

- the areas of barley, arable bare ground, intensive grassland, grass and rough grass are impacted in all cases;
- the resilient option results in a lesser amount of heath and heath gorse being impacted;
- the resistant option reduces the amount of swamp which is impacted.

The more detailed Land Cover Map class description is included in Appendix E.

5.5.4 Unintended side-effects

The most dominant unintended side-effect of the strategic alternatives in the Thames Estuary is increased floodplain development as a result of improved defences, for example, defence raising or improvements to the Thames Barrier. These more heavily engineered solutions promote a sense of safety in the floodplain, resulting in increased development. This effect is largest for the Resistant strategic alternative – as would be expected. This effect should ideally be reduced within the overall management response, through for example, awareness raising with developers, planners and general public as well as changes in planning policy.

5.6 Conclusions

The Chapter 3 methodology has been applied to the Thames pilot study for the appraisal period 2007 to 2100. Four coherent storylines based on the Foresight World Views were developed and appropriately downscaled for the Thames region to simulate the details of the future socio-economic and climate scenarios on an estuary scale (Section 5.3). Four strategic alternatives were developed and evaluated in the context of these different futures - the Resistant, Resilient, Highly Resilient and Do Nothing alternative – in terms of economic, social and ecological risks. The management intervention measures for these alternatives are planned for 2040, 2070 and 2085 and hence the model was evaluated before and after the planned interventions as well as in the present day and the year 2100. The RASP-based model (Gouldby *et al*, 2008) was adopted to simulate the flood risk system, including source, pathway and receptor, and providing the overall hazard (probability of inundation) and risk (e.g. Expected Annual Damages). A range of indicators was calculated for each strategic alternative, in the context of each future scenario, covering economic, social and ecological risk, including:

- Total EAD for the flood risk area in a given year (incl. upper/lower bounds)
- Total EAD relative to the 'do nothing' in a given year to illustrate risk reduction
- Present day benefits and costs (of planned interventions) (incl. upper/lower bounds)
- People risk 1: Number of people exposed to 'frequent' flooding defined as the number of people in an area with an annual probability of inundation of 1:75 of exceeding 0m depth
- People risk 2: Expected annual deaths / serious injuries defined as annual probability of inundation of exceeding 1m depth multiplied by the number of people at that location. Area of habitat (derived from Land Cover Map 2000) with an annual probability of inundation of 1:75 of exceeding 0.5m depth (m^2).

Table 5.15 Area of habitat as a percentage of the existing habitat with an annual probability of inundation of 1:75 of exceeding 0.5m depth for present day and 2040s

LCM Class & Description	Existing area	P3	DN	Resistant - 2040				Resilient - 2040				Highly Resilient - 2040			
	m^2	2007	2007	GS	WM	NE	LS	GS	WM	NE	LS	GS	WM	NE	LS
11 Deciduous	11,191,669	1.0%	26.8%	1.5%	8.3%	3.7%	3.7%	1.5%	8.3%	3.8%	0.9%	1.6%	8.3%	3.8%	0.9%
21 Coniferous	1,520,266	16.1%	36.9%	19.9%	39.4%	27.7%	27.7%	19.9%	39.4%	27.7%	16.3%	19.9%	39.4%	28.0%	16.3%
41 Barley	29,221,439	2.7%	11.0%	4.6%	29.7%	14.1%	14.1%	4.6%	29.7%	14.3%	2.7%	4.6%	29.8%	14.5%	2.7%
42 Arable bare ground	30,705,329	3.1%	20.1%	4.8%	15.2%	9.1%	9.1%	4.9%	15.2%	9.1%	3.2%	4.9%	15.3%	9.2%	3.1%
43 Orchard	1,491,699	1.0%	5.7%	1.8%	14.5%	6.1%	6.1%	1.8%	14.6%	6.2%	1.0%	1.9%	14.5%	6.6%	1.0%
51 Grassland intensive	37,450,924	3.6%	27.0%	5.8%	31.3%	18.9%	18.9%	5.8%	31.3%	19.1%	3.7%	5.8%	31.3%	19.4%	3.7%
52 Grass (hay/silage cut)	23,185,444	7.4%	19.4%	17.0%	42.3%	30.1%	30.1%	17.0%	42.2%	30.3%	7.6%	17.1%	42.3%	30.4%	7.5%
61 Rough grass (unmanaged)	15,905,558	2.3%	28.0%	4.2%	22.5%	14.2%	14.2%	4.2%	22.5%	14.4%	2.4%	4.2%	22.5%	14.6%	2.4%
71 Calcareous	16,486,548	11.8%	35.0%	15.4%	42.0%	32.0%	32.0%	15.4%	42.0%	32.3%	12.0%	15.6%	42.0%	32.5%	12.0%
81 Acid	2,146,335	0.0%	48.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
101 Heath dense (ericaceous)	367,555	0.0%	56.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
102 Heath gorse	265,837	0.0%	43.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
111 Swamp	635,737	0.0%	28.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
131 Water (Inland)	6,944,557	10.5%	34.5%	9.7%	23.1%	20.2%	20.2%	9.7%	23.1%	20.2%	8.2%	9.7%	23.1%	20.3%	8.2%
161 Inland rock	3,251,530	0.0%	22.8%	0.6%	11.7%	4.7%	4.7%	0.6%	11.7%	4.7%	0.0%	0.6%	11.7%	4.6%	0.0%
171 Suburban/rural developed	50,741,430	0.3%	25.5%	1.1%	6.0%	2.7%	2.7%	1.1%	6.0%	2.7%	0.3%	1.1%	6.0%	2.7%	0.3%
172 Urban resid./commer.	141,632,439	0.2%	38.4%	0.9%	3.6%	2.0%	2.0%	0.9%	3.6%	2.0%	0.2%	0.9%	3.5%	2.0%	0.2%
191 Shingle	125,053	0.0%	0.0%	0.0%	23.9%	0.0%	0.0%	0.0%	23.9%	0.0%	0.0%	0.0%	23.9%	0.0%	0.0%
211 Mud	2,939,630	2.3%	8.1%	5.4%	53.7%	19.5%	19.5%	5.4%	53.6%	19.2%	2.3%	5.4%	53.7%	19.4%	2.3%
212 Sand	3,502,859	13.0%	13.9%	18.6%	50.6%	30.8%	30.8%	18.8%	50.5%	30.9%	13.0%	18.8%	50.8%	31.0%	12.8%
221 Sea	443,162	0.7%	1.8%	0.7%	52.6%	41.5%	41.5%	0.7%	52.6%	41.5%	0.7%	0.7%	52.6%	42.1%	0.7%

Legend

> 50% habitat type affected (red)
20-49% of habitat type affected (yellow)

Table 5.16 Area of habitat as a percentage of the existing habitat with an annual probability of inundation of 1:75 of exceeding 0.5m depth for 2100s

LCM Class & Description	**Existing area**	**Resistant - 2100**				**Resilient - 2100**				**Highly Resilient - 2100**				**Do Nothing**			
	m^2	GS	WM	NE	LS	GS	WM	NE	LS	GS	WM	NE	LS	GS	WM	NE	LS
11 Deciduous	11,191,669	9.9%	44.8%	44.8%	1.0%	6.6%	43.3%	38.5%	0.9%	6.5%	43.2%	38.7%	0.9%	54.0%	71.6%	67.5%	26.8%
21 Coniferous	1,520,266	17.5%	48.6%	48.6%	1.1%	13.8%	52.1%	44.3%	1.1%	13.8%	52.1%	44.3%	1.1%	81.4%	87.3%	92.8%	37.0%
41 Barley	29,221,439	26.8%	64.5%	64.5%	1.3%	23.3%	61.4%	60.0%	1.2%	23.2%	61.4%	60.0%	1.2%	61.3%	81.3%	81.7%	11.1%
42 Arable bare ground	30,705,329	13.6%	69.4%	69.4%	1.3%	10.9%	53.5%	52.5%	1.2%	10.9%	53.5%	52.4%	1.3%	56.7%	71.6%	78.4%	20.1%
43 Orchard	1,491,699	7.6%	56.5%	56.5%	1.2%	4.8%	43.9%	43.1%	0.8%	4.8%	43.7%	43.0%	1.2%	35.3%	69.6%	59.2%	5.8%
51 Grassland intensive	37,450,924	28.7%	66.3%	66.3%	0.7%	24.0%	60.7%	59.2%	0.5%	24.0%	60.7%	59.2%	0.6%	73.8%	88.3%	88.3%	27.0%
52 Grass (hay/silage cut)	23,185,444	40.5%	72.3%	72.3%	9.8%	35.4%	68.3%	67.5%	9.7%	35.3%	68.3%	67.5%	9.8%	74.2%	88.1%	87.6%	19.6%
61 Rough grass (unmanaged)	15,905,558	25.0%	73.0%	73.0%	3.2%	21.4%	60.5%	57.0%	3.2%	21.3%	60.5%	57.1%	3.2%	62.3%	83.9%	76.1%	28.0%
71 Calcareous	16,486,548	29.9%	65.0%	65.0%	2.0%	28.3%	49.9%	48.6%	1.7%	28.2%	49.9%	48.6%	1.9%	78.1%	89.6%	87.6%	35.1%
81 Acid	2,146,335	0.0%	50.6%	50.6%	0.0%	0.0%	40.7%	36.7%	0.0%	0.0%	40.7%	37.4%	0.0%	60.0%	68.3%	71.7%	48.7%
101 Heath dense (ericaceous)	367,555	0.0%	52.5%	52.5%	0.0%	0.0%	63.2%	30.4%	0.0%	0.0%	63.2%	30.4%	0.0%	76.4%	93.5%	80.6%	56.9%
102 Heath gorse	265,837	0.0%	54.3%	54.3%	0.0%	0.0%	52.8%	37.7%	0.0%	0.0%	52.8%	37.7%	0.0%	64.2%	91.0%	81.7%	43.8%
111 Swamp	635,737	0.0%	43.4%	43.4%	0.0%	0.0%	57.9%	38.4%	0.0%	0.0%	57.9%	38.4%	0.0%	50.7%	80.3%	59.0%	28.3%
131 Water (Inland)	6,944,557	24.4%	66.7%	66.7%	9.8%	24.0%	71.7%	60.3%	9.7%	24.0%	71.7%	60.3%	9.8%	70.6%	79.7%	89.3%	34.8%
161 Inland rock	3,251,530	6.5%	68.3%	68.3%	0.6%	5.7%	58.8%	54.5%	0.6%	5.7%	58.8%	54.5%	0.6%	54.3%	80.0%	76.1%	22.8%
171 Suburban/rural developed	50,741,430	6.7%	52.2%	52.2%	0.9%	2.9%	53.9%	46.0%	0.9%	2.9%	53.9%	46.0%	0.9%	54.4%	77.4%	72.3%	25.5%
172 Urban resid./commer.	141,632,439	2.8%	41.3%	41.3%	0.8%	2.0%	53.6%	34.9%	0.7%	2.0%	53.6%	34.9%	0.8%	65.9%	80.6%	78.4%	38.3%
191 Shingle	125,053	22.1%	64.4%	64.4%	0.0%	22.1%	54.7%	54.7%	0.0%	22.1%	54.7%	54.7%	0.0%	37.8%	78.6%	54.7%	0.0%
211 Mud	2,939,630	61.4%	74.2%	74.2%	1.6%	51.6%	72.9%	72.7%	1.5%	51.6%	72.9%	72.7%	1.6%	85.6%	96.8%	95.3%	8.3%
212 Sand	3,502,859	66.4%	76.4%	76.4%	8.6%	47.5%	76.7%	76.3%	7.7%	47.3%	76.7%	76.3%	8.2%	89.2%	98.3%	97.6%	13.9%
221 Sea	443,162	70.5%	78.9%	78.9%	0.7%	65.2%	82.3%	78.8%	0.7%	65.2%	82.3%	78.8%	0.7%	76.3%	93.7%	85.8%	1.8%

Legend

> 50% habitat type affected	(red)
20-49% of habitat type affected	(yellow)

A full evaluation of non-intended side-effects of implementing the alternatives was not performed, nor of the robustness or flexibility of the strategic alternatives, in contrast to what was promoted in Chapter 3. In this sense, the Thames case differs from the Schelde case, as it put more emphasis on the role of probabilistic calculations of risk indicators, but instead only little on the side-effects of implementing the measures related to the alternatives; this can be regarded as a choice for more depth on risk at the expense of breadth of assessment.
The main non-intended side-effect was briefly discussed, illustrating the importance of people's perception of flooding and which areas of the floodplain are 'safe'. Also robustness was given some attention in the discussion on benefit/cost ratios, where the Resilient Strategic Alternative was considered the most robust as it had the most favourable benefit/cost ratio across all climatic and socio-economic scenarios considered. The flexibility of the Strategic Alternatives was not considered here, but is addressed in FLOODsite's Task 18 report. Both robustness and flexibility of the Thames alternatives are given more attention in the context of FLOODsite's task 18 report.

The main findings from the Thames Estuary case study are as follows:

- *Building Strategic Alternatives*. Developing and evaluating the performance of strategic alternatives for long-term flood risk management in the context of an uncertain future is a challenging task. The method framework trialled here provides a top-down approach to developing the alternatives, based on resilience and resistance-based principles. While these are useful in that a wide range of potential management interventions (structural and non-structural) is considered, they should not be applied without a fundamental understanding of the flood risk system and the existing infrastructure, e.g. main drivers of change (e.g. sea level rise), the likely timing of these (e.g. critical in year x), etc. Ideally, an initial, more general, study should be undertaken to ascertain these critical spatial and temporal points to aid design of the strategic alternatives.

- *Evaluating the 'best' option*. The results are intended to provide an evidence-base to decision makers. While consideration of individual elements, say the EAD at a particular spatial location and point in time may favour a particular option, it is not possible to draw an overall conclusion as to the best option. For example, consideration of the benefit/cost ratio suggests the Resilient strategic alternative is more favourable, whereas consideration of the uncertainty bands suggests the Resistant strategic alternative may be preferable as the bands are narrower.

- *Richness of information*. The shear volume and richness of the available information (e.g. spatial/temporal resolution; consideration of all defence system states; risk attribution; uncertainty etc) illustrates the challenges decision makers face when developing and evaluating policies – and the strong need for decision support tools to aid the process. Decision support tools are needed to manage the information, to assist the user in exploring what-ifs, to provide high-level outputs, whilst still allowing users to delve into the detail if required and to generate visual aids to improve understanding and interpretation of results (e.g. maps of where people or habitat at risk are located).

- *Multi-stage decisions*. The timing and nature of the interventions over the appraisal period is essential to FRM in the long term. A decision made today may impact what options are available at a future date. For example, the Resistant option may be favoured today if it performs well in all possible future scenarios; however, it may result in substantial infrastructure investments, the benefits of which may not be felt should the actual future be, say, similar to the Local Stewardship description. This highlights the importance assessing flexibility i.e. the ability of a given strategic alternative to be adapted to change. FLOODsite (2008) explores the notion of a decision 'pathway' tool, where a decision is made at some future point(s) based on how the future has actually panned out (e.g. did the expected climate or demographic change occur?) and how the system has reacted to the changes. This would provide the flood risk manager with a powerful tool to help define a strategy which is flexible, in the sense that it is a ‘no regrets’ policy.

- *Measuring sustainability*. Design and implementation of sustainable long-term solutions is essential to FRM in the long term. Chapter 3 highlights the need to ensure that the three pillars of sustainability (economic, social and ecological) are assessed in some manner as well as up-and-coming criteria such as robustness and flexibility. The criteria comprise the impacts of floods to people, economy and natural/cultural heritage as a results of a given strategic alternative; however, assessing the sustainability of alternatives also requires evaluating the unintended side-effects of implementing (the measures of) a strategy, as well as its robustness and flexibility. In the Thames case, the risk to economy, people and ecology is covered, but the side-effects of implementing measures is not. Robustness is only partly measured through the performance of a given strategic alternative in the context of all considered scenarios, with the benefit/costs as the indicator. Flexibility has not (yet) been taken into account, but is considered in Task 18 (FLOODsite, 2008).

6. Conclusion and recommendations

6.1 Introduction

This report aimed to provide guidance on the design and assessment of comprehensive long-term flood risk management strategies in the context of an uncertain future. Successively, existing methods were reviewed, a general method was proposed and the method was tried in cases. The cases serve to:

- try the method and to help finalization of the method;
- to illustrate how the method can be used;
- and to show its value by delivering results which support policy-makers to develop a long-term view on flood risk management for the region involved.

This chapter gives the conclusions and recommendations on these methodological guidelines as well as on the experiences with its application. Section 6.2 provides conclusions related to the long-term planning method. Section 6.2 gives recommendations for further research and for policy-makers.

6.2 Conclusions on the methodological framework

The stepwise -procedure

The method to develop and assess long-term flood risk management strategies relies on purposeful combinations of *different contrasting future scenarios*, on the *development of top-down visionary strategic alternatives* and *an full assessment* of the contribution of the strategic alternatives to the sustainable development of the society and ecosystems in the region involved across all future scenarios. The method consists of the following steps:

- System exploration (area characteristics and potential developments). This step includes the development of tailor-made scenarios for the region involved;
- Analysis and preliminary assessment of the current flood risk management strategy;
- Development and analysis of strategic alternatives;
- Full assessment of the current strategy and strategic alternatives.

The three elements scenario’s, strategy development and the full assessment, are incorporated in these steps. The most important findings on the use of scenarios, the development of strategic alternatives and their full assessment are discussed below.

On the use of scenarios

Since the future is inherently uncertain no long-term future predictions are possible. To cope with future uncertainty it is advocated to use contrasting future scenarios which together span the field of ‘all’ possible future developments. Scenarios describe autonomous developments in the world or region in which the case study area is situated. Autonomous developments are those developments which do not purposefully change flood risks. Consistency amongst the developments is guaranteed thorough a story-line which describes the full future picture. Based on the story-line those parameters are identified which need to be changed to visualize the effects of the scenario on the studied system. For long-term flood risk management studies these include flood hazard related parameters (probabilities of discharges/ water levels /rainfall), and vulnerability related parameters (land use / damage functions/ population figures).

The use of scenarios was found to be useful, because:

- it shows that the functioning of the strategic alternatives differs per future scenario;

- it thus shows that taking into account the uncertainty about the future is important, since strategic alternatives may function well in one scenario, while they are less preferable in others;
- there are strategic alternatives which function reasonably well in all future scenarios or which can easily be adapted to different scenarios.

The method in chapter 3 and the applications in the case studies show how scenarios can be used in long-term flood risk management planning. Since scenarios are rarely used in long-term flood risk management and since the assessment of the functioning of strategic alternatives across different scenarios is a new approach, the method developed here and its applications are useful for policy-makers.

On the development of strategic alternatives

In order to show possible ways of coping with flood hazards and their effects different strategic alternatives need to be defined and assessed. These strategic alternatives must be visionary and clearly different. Therefore, it is advocated to define them in top-down approach by using guiding principles to select combinations of measures and instruments. As guiding principles world views or for example the concepts of resilience and resistance may be used.

The case studies show that strategic alternatives are a good means to illustrate alternative possibilities for long-term flood risk management and their effects. The strategic alternatives are useful when developing a vision on where long-term flood risk management should be heading for. This vision facilitates choices for the middle and short-term flood risk management.

On the full assessment of sustainability criteria

To assess the functioning of the strategic alternatives in different possible future scenarios a set of criteria has been defined. Together they show the contribution of the strategic alternatives on the sustainability aspects ‘people’, ‘profit’ and ‘planet’ and ‘sensitivity to uncertainties’ in different future scenarios. The assessment follows a Multi-Criteria Analysis approach in which both quantitative and qualitative criteria are incorporated. The qualitative criteria are assessed with a Delphi-approach. The use of MCA and Delphi approach together enables to show the effect of strategic alternatives on all relevant aspects of sustainability, also on those aspects which are very relevant, but difficult to quantify.

Robustness and flexibility are both very important criteria since they reveal the sensitivity of strategic alternatives to uncertain events and changes. Flexible strategic alternatives mostly function well across a range of future scenarios or they can be easily adapted if future developments differ from the ones anticipated. Future regret is thus less likely when such strategic alternatives are being adopted. Robust strategic alternatives are less sensitive to uncertain events such as very extreme water levels, mall-functioning of structures, malfunctioning communication systems, unforeseen behaviour amongst the inhabitants etc. Both robustness and flexibility were incorporated in the full assessment, scored for all strategic alternatives and evaluated. However, the precise elaboration differed per case. Also within cases their meaning was sometimes not clear to all experts. Although important progress has thus been made on the robustness and flexibility criteria, their definitions are not sufficiently clear and operational yet.

The qualitative criteria need a reference for scoring. If one is interested in the effects of the strategic alternative only and not in the effects of the scenario, as reference a future status in each of the used scenarios must be used and compared with the future status in the same scenarios but after implementation of the strategic alternative. If the current status is used as reference the future combination of scenario and strategy is scored. The reference for scoring must thus be consciously chosen.

6.3 Recommendations

6.3.1 For further scientific research

The following is recommended for further scientific research:

- Apply the method en develop and assess long-term strategic alternatives for flood risk management.
- Develop a method which allows making decisions on when to change to another strategy and the effects of choices on options for the future. Questions relevant for this topic are:
  - How could we incorporate ‘decision-pipelines’ in the analysis and assessment of long-term flood risk management?
  - How could we use this to improve our knowledge on ‘breakpoints’ (when developments are such that a certain strategy is not functioning any more);
  - Can this analysis in-time replace the assessment criterion ‘flexibility’ and how?
- Develop the concept of robustness further.
- Further develop methods to combine or weigh the scores of the different alternatives in the different scenarios to find which strategic alternative scores best in what scenario and which strategic alternative is best across all scenarios.

6.3.2 For practitioners and policy makers

We recommend practitioners and policy-makers to do the following:

- Develop a long-term flood risk management vision in order to better motivate short- and middle-term decisions and to prevent future regret. Thus: think back from the future.
- Study the effects of the continuing the current strategy and the effects of strategic alternatives in the long term.
- Flexible tailor-made strategies seem to work better in an uncertain future. See for example the spatial planning strategy in the Schelde Case study area.

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