ECONADAPT

The Economics of Adaptation

Funded by the European Union

Assessing the economic case for adaptation to extreme events at different scales

Onno Kuik, Paolo Scussolini, Reinhard Mechler, Junko Mochizuki, Alistair Hunt, Jacob Wellman

Deliverable number	5.1
Work Package Number	5
Submission date	January 2016
Type of Activity	RTD
Nature	R = Report
Dissemination level	Public

Document information

Title:	Assessing the economic case for adaptation to extreme events at different scales
Authors:	Onno Kuik, Paolo Scussolini, Reinhard Mechler, Junko Mochizuki, Alistair Hunt, Jacob Wellman
Other Contributors	Petra Honja
Date:	19 January 2016
Contact details	Onno Kuik, onno.kuik@vu.nl
Work Package Number	WP 5
Deliverable number	D5.1
Filename:	Deliverable 5-1 final.docx
Document history:	Draft/ Final and version number
Type of Activity	RTD
Nature	R = Report, O = Other
Dissemination / distribution level	PU = Public:
Citation:	
Copyright:	

The ECONADAPT project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 603906.

To find out more about the ECONADAPT project, please visit the web-site: www.econadapt.eu

For further information on the ECONADAPT project contact Alistair Hunt at: ecsasph@bath.ac.uk

.

Executive Summary

This report examines Disaster Risk Management (DRM) strategies of European countries with the aims of understanding how decisions are taken in the selection and design of DRM options at different scales, to examine how climate change, and its associated uncertainty, is or could be integrated into DRM strategies, and to draw lessons for decisions related to adaptation to climate change in Europe in general. The focus of choice is on disasters caused by floods.

A database of DRM investments for floods in Europe was constructed, containing 110 observations on investments/projects from 32 studies and databases, covering 16 European countries. In addition, detailed case studies of DRM policies were carried out in Austria, Czech Republic, The Netherlands and the United Kingdom.

The inventory of DRM investments in flood risk protection in Europe shows that, on average, the investments have high Benefit-to-Cost Ratios (BCR). The mean BCR of the investments is 5.9 while the median BCR is 3.0. DRM investments that enhance preparedness to disasters show the highest economic returns, while also investment that prevents floods from occurring and investments that mitigate the damage of floods show high BCRs. The data do not show a large variation in the economic efficiency of investments that were evaluated with different decision-making tools, such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria decision-making analysis (MCA), and Real Options Analysis (ROA). Evaluations of DRM investments increasingly take the potential impacts of climate change into account, even though the uncertainty due to the spectrum of future possible developments is commonly not considered.

The country case studies show the complexity of decision-making of flood risk protection at national, regional and local levels. In The Netherlands, flood protection standards for the whole country are written in law and central government and its services play a key role in overall flood risk management. In the Czech Republic, the central government has an important coordinating role in the development of the multiannual programme of flood prevention. In the UK the Environment Agency has reponsibility for managing risk from flooding from main rivers and the sea, including the approval and funding of flood risk management projects undertaken by local authorities and water drainage boards. In Austria, central government is reponsible for the designation of flood hazard areas, in coordination with the regional governemnts (Länder), and also manages a disaster fund that finances preventive measures and emergency and recovery actions. In all the case study countries, regional and local authorities play distinctive but varying roles in various elements of flood risk management (flood control, flood damage mitigation, preparedness, emergency planning and recovery).

For the assessment of long-term investments in flood protection infrastructures, most countries employ some form of cost-benefit analysis (CBA). However, other decision-making tools such as CEA, multi-criteria decision-making analysis (MCA), and Real Options Analysis (ROA) are also used, sometimes as substitutes, but in most cases, as complements. The Netherlands provide an interesting example where CBA - together with other tools – is used at the highest level of decision-making on flood protection standards, and where much more participatory and multi-criteria approaches are employed for local-level decisions on the actual design of flood control infrastructures. The use of CBA and participatory decision-making is supported by the EU Floods Directive. In practice, CBA tends to focus primarily on tangible costs and benefits such as avoided direct damage to buildings and infrastructure. In order to include intangible damages in the equation (human casualties, health, environmental damages, etc.), decision-makers often take recourse to some sort of MCA. MCA approaches can range from very simple (setting protection standards on the most stringent of four criteria such as in The Netherlands) to rather advanced (such as MCA optimisation methods used in the United Kingdom). ROA is not a substitute for CBA, but rather an extension. It has not yet entered the standard toolbox of project appraisal, but it offers interesting possibilities for the

appraisal of complex, long-term investments in flood protection. As yet, there is no single superior decision-making tool to fit all circumstances. We found that there is growing recognition across Europe, also promoted by the EU Floods Directive, that participatory approaches to decision-making should be employed, whenever this is feasible.

DRM provides a good entry point to examine the state of affairs with decision making on adaptation to climate change. Almost three-quarters of the assessments of DRM investments that we collected in our database pay attention to climate-change aspects (sea level rise, rising riverine flood risk, changing precipitation patterns, etc.). This attention starts around 2004 and the majority of studies after 2004 (80%) take climate-change impacts into account in one way or another. The way that climate change is taken into account differs across and within countries, depending on the specific context and decision-making level.

Across our case study countries, The Netherlands and the United Kingdom are actively factoring-in the effects of future climate change into flood risk management strategies, while this has yet to start in Austria and the Czech Republic, that focus on addressing existing risks of extremes. The sophistication of the approaches to factor-in the effects of future climate change ranges from simple updates of protection design standards based on one ‘most-likely’ scenario of future (climate) changes, to complex applications of ‘Dynamic Adaptive Policy Pathways’ (The Netherlands) and ‘Real Options Analysis’ (United Kingdom). The evidence suggests that the approaches have by no way settled yet: governments, government agencies and academic researchers are experimenting with approaches and are actively evaluating and developing the options. In this context, the European Commission has rightly argued that in investment projects, climate change-related risk management should be integrated into existing project lifecycle appraisal approaches to manage the additional risk from climate change. These existing approaches can vary between countries and sectors. From a practical perspective it is important that risk management approaches complement existing project appraisal processes but not replace them.

On the basis of the research in this report, some preliminary generalizations can be made regarding investments in adaptation to climate change in general. The most obvious generalization would be to adaptation of long-lived infrastructures in general (for example also with respect to mitigating public health risks from heatwaves). In addition, the high returns of investments in preparedness seem to offer some evidence that investments in preparedness to other climate-related extreme events (heatwaves, storms, droughts) might also offer comparable returns. Decision-making approaches on adaptation investments in general can benefit from the methods and tools that we found are currently being used and that are currently being developed in existing DRM domains.

Abbreviations

BCR:	Benefit to cost ratio
CBA:	Cost-benefit analysis
CEA:	Cost effective analysis
DRM:	Disaster risk management
IPCC:	Intergovernmental panel on climate change
MCA:	Multi-criteria analysis
NPV:	Net present value
ROA:	Real options analysis

Table of Contents

1 Introduction

European countries have a long history of coping with natural disaster risks. They have all developed their own ways to cope with these risks, ways that are attuned to the particular form in which natural disasters tend to manifest themselves, to the economic and technological possibilities of coping with them, and to the political and institutional culture of the country. The Netherlands, for example, have learned to cope with flood risks for over a thousand years (Tol and Langen, 2000). Nevertheless, the equilibrium between society and nature is fragile and inherently dynamic, so learning should and does continue. In particular, apart from the continued pressure posed by social and economic developments, climate change has recently added a new challenge to the management of natural disaster risks by its (present and potential) influence on the frequency and intensity of hydro-meteorological natural hazards such as floods and droughts, heatwaves, forest fires, extreme precipitation, storm surges, etc. (EFDRR, 2013).

Many European countries and local communities have developed so-called Disaster Risk Management (DRM) strategies that include strategies to cope with natural disaster risks. These strategies often include options to prevent natural disasters from happening, to mitigate their impacts when they do happen, and to quickly recover in their aftermath. DRM options can operate at different scales: from international (e.g. coordinating foreign aid in the aftermath of a natural disaster) to local (e.g. strengthening local houses to withstand flooding).

Cost-benefit analysis (CBA) is a popular and oft-advocated tool to choose between alternative DRM options. Ideally, it compares advantages (benefits) and disadvantages (costs) of options in a systematic and objective way, so that the option that provides the greatest net gain to society can be selected. The EU Floods Directive (2007/60/EC) requires that flood risk management plans “take into account relevant aspects such as costs and benefits, ...” (EU Flood Directive, 2007, Art. 3), and this has undoubtedly given an incentive to apply CBA in regions where it was not common before.

Yet, the application of CBA in the appraisal of DRM options is nothing new. In the USA, CBA of flood control projects was mandated by Congress under the 1936 Flood Control Act and has been used for evaluation of risk reduction projects since the 1950s. CBA has also often been criticized, however. Because the tool needs to express all costs and benefits in a money metric to compare them, it is sometimes argued that it is biased towards those options whose benefits are most easily expressed in money to the disadvantage of options that provide intangible benefits in the form of greater social or environmental quality. In the context of adaptation to climate change, the IPCC (2012) concluded for such reasons that the applicability of ‘rigorous’ CBA for evaluations of climate adaptation would be limited. In contrast, the UK Foresight Report on reducing risks of future disasters (UK Government, 2012) argued that, especially in times of austerity, CBA continues to be an important tool for prioritizing efficient DRM measures, but that with a shifting emphasis from infrastructure-based (hard) options to preparedness and systemic (soft) interventions, other tools such as cost-effectiveness analysis, multi-criteria analysis and robust decision-making would deserve more attention (see also, Mechler, 2016).

For the case of the European Union, a common strategy for decision making has not yet been adopted. Further, it is not clear which tools are used by the various state members, and which practices seem to yield the most promising results. Improving understanding in this direction is crucial in view of the development of a unitary framework. The initial objective of Task 5.1, as stated in the Description of Work, was to develop an improved protocol for comparative economic analysis of options for adapting and improving disaster risk management (DRM) to near future changes in extreme weather events. While this is a commendable objective, we believe, after reviewing the academic literature and the empirical evidence on decision making on DRM in selected (case study) countries, that it is still too early to develop such a protocol. We have therefore decided to moderate our ambitions somewhat and put the emphasis of the work on better understanding how decision making on DRM is evolving in Europe and how this could provide lessons for decision making on adaptation to climate change in general.

This report therefore has the following three main aims.

- The first aim of this report is to understand how decisions are taken in the selection and design of DRM options in European countries at different scales. Who is involved and what (appraisal) tools are used to guide these decisions? Since CBA is largely employed in project appraisals in other decision-making contexts, we are particularly interested in its role as a tool for DRM, both procedurally and substantive.
- The second aim is to examine how climate change, and its associated uncertainty, is or could be integrated into European DRM strategies.
- The third aim is to draw lessons for decisions related to adaptation to climate change in general.

To achieve these aims, we have followed two lines of research. **First**, we have assembled a new inventory of DRM investments in Europe, focussed on flood risk reduction, that presents an overview of types of investments, their size, the decision-making tools that were applied to evaluate them, and performance indicators such as their Benefit-to-Cost Ratios (BCR). **Second**, we have carried out case studies on decision-making on flood risk management in four EU Member States: Austria, Czech Republic, The Netherlands and the United Kingdom. These case studies focus on decision-making at different levels (national, regional and local) and examine if and how decision-making on flood risk management at these different levels takes climate change into account. The case studies were carried out by national experts, mostly based on existing documentation. For the case study on the Czech Republic, knowledge from existing documentation was augmented by a number of face-to-face interviews with key decision-makers.

After providing a brief introduction to DRM and presenting an overview of the common procedures and tools in decision making in DRM (Section 2), we present the new inventory of DRM investments in Europe over the period 1991-2015 (Section 3). Section 4 presents the case studies on decision making at different levels (national, regional, local) on flood risk management in four European countries. We draw concusions from the research in Section 5.

2 Decision making in Disaster Risk Management

2.1 Introduction

Disaster risk management can be said to comprise the following distinct four ex-ante stages and one ex-post stage (the fifth) (Smith, 1996; Timonina et al. 2013):

1. risk identification and analysis;
2. risk prevention;
3. risk preparedness;
4. risk sharing and financing; and
5. disaster management (response, reconstruction and rehabilitation).

In the risk identification and analysis stage the risks are identified and quantified. A natural disaster is always the product of a physical event and the socio-economic system on which it impacts. Paraphrasing Okuyama and Sahin (2009, p.4): a climate extreme is the occurrence of the physical event per se, and disaster is its consequence on society. The consequence is dependent on the extent of exposure of people and assets to the hazard and the vulnerability of the society that is affected (Ariyabandu, 2001; Kron, 2005). With respect to the economic damage of disasters, it is common to distinguish between direct, indirect and intangible effects (Hallegatte and Przyluski, 2010).

Risk prevention can take many forms, e.g. strengthening dikes and river embankments, regulating building codes and land use planning, implementing pro-active economic incentives, education, training and awareness raising. Damage can be mitigated by risk preparedness measures such as investments in early warning/communication systems, shelter facilities and evacuation plans. Risk sharing facilities and government calamity funds are important instruments to mitigate individual hardship. Risk sharing facilities can provide incentives for enhancing private resilience. Ex-post disaster management can be divided in immediate responses (humanitarian assistance and clean-up) and longer term reconstruction and rehabilitation.

The literature presents alternative classifications of DRM options. A brief tabulated overview of some classifications of flood risk management options can be found in Annex A of this report. In the remainder of this report we classify flood risk management options into options that reduce the probability of flooding (flood control: ‘hard’ and ‘soft’ options), that reduce the potential consequences of flooding (land-use planning, flood-proofing of buildings and infrastructure, early warning, emergency plans), and that focus on recovery after a flood has struck.

2.2 Decision-making procedures and tools

The shift towards iterative, bottom-up approaches to disaster risk management increasingly supplants traditional appraisal procedures and tools that are used to assess the effectiveness and efficiency of DRM strategies and projects such as CBA (Mechler et al. 2008).

The large variety of project appraisal procedures and tools that exist can be classified into a number of groups (de Ridder et al. 2007). Rayner and Kuik (2010) distinguish: (1) assessment frameworks; (2) participatory tools; (3) scenario analysis tools; (4) multi-criteria analysis tools; (5) cost–benefit and cost-effectiveness analysis tools; (6) accounting tools, physical analysis tools and indicator sets, and (7) model tools.

1) **Assessment frameworks** can be considered 'procedural tools', in the sense that they do not carry out a particular kind of analysis, but are procedures designed to connect to a decision-making process, and within which a range of different analytical tools can be applied (Finnveden et al. 2003). Examples include the EU's Impact Assessment system, Environmental Impact Assessment, Strategic Environmental Assessment and Integrated Sustainability Assessment.

2) **Participatory tools** can be used in decision-making processes with the aim of involving stakeholders in policy development. They can be defined as 'methods to structure group processes in which non-experts play an active role in order to articulate their knowledge, values and preferences' (van Asselt and Rijkens-Klomp 2002: 168). There is a great variety of such methods and techniques, stemming from a broad range of disciplines, including focus groups, consensus conferences and repertory grid techniques. Stagl (2007) outlines how deliberative and participatory elements can be introduced into a range of traditionally less participatory tools, including multi-criteria analysis and forms of monetary valuation.

3) **Scenario analysis tools** include tools for defining and developing scenarios and interpreting the results. In essence, scenarios are constructed to assist in the understanding of possible future developments of complex systems (van der Heijden 2005). Tools assigned to this category include, for example, Delphi and cross-impact analysis (Helmer 1977), and scenario workshops (Andersen and Jaeger 1999).

4) **Multi-criteria analysis (MCA)** tools support comparison of different policy options on the basis of a set of criteria. Within this group at least three subgroups of MCA tools can be distinguished: (1) compensatory MCA tools, which allow compensation between different criteria, such as the multi-attribute value theory (Keeney and Raiffa 1976); (2) non-compensatory MCA tools, which do not, e.g. the dominance method (Jankowski 1995); and (3) partial compensatory MCA-tools, which allow for compensation between a limited number of criteria only (Brans and Vincke 1985). More recently, within this tool group evolutionary multiobjective optimising methods have gained momentum (Srinivas and Deb, 1994).

5) **Cost-benefit analysis (CBA)** monetises expected positive and negative impacts of a policy. The monetised results can be used to justify acceptance or rejection of a policy proposal by simply comparing costs with benefits (Pearce et al., 2006). The group **CBA tools** include techniques such as contingent valuation and hedonic pricing that are used to monetise certain impacts for which no market value exists. The **cost-effectiveness analysis (CEA)** tool is also included in this group because, like CBA, it is rooted in economics and plays a role in analysing policy options. However, unlike CBA, CEA cannot determine whether the benefits of different policies outweigh the costs (Pearce et al. 2006). CEA focuses on the cost-side of policy options, with the aim to find the most cost-effective option, i.e., the option that can deliver a pre-specified target at least costs.

6) **Accounting tools, physical analysis tools and indicator sets** are used for elucidating the physical side in an assessment, rather than the economic (Adriaanse et al. 1997). Three subgroups are distinguishable in this group:

i) accounting tools, e.g. measures of economic welfare, which add the physical dimension to common economic accounts;

ii) physical analysis tools, which can be used to calculate certain physical quantities such as an ecological footprint;

iii) indicator sets which can be taken together to assess something specific within a broader assessment. Indicator sets can, for instance, be designed to measure poverty, hunger or economic competitiveness.

7) **Model tools**. Models are simplified representations of complex real-world phenomena that try to simulate real-world processes based on, or calibrated to, empirical information and with some relevance to actual policy decisions. Three categories of models can be distinguished: (1) socio-economic (e.g., general economy models); (2) bio-physical (e.g., climate models); and (3) integrated models (e.g., land-use models).

3 Current practice: A database of DRM investments and decision-making tools

3.1 Introduction

This chapter presents a new inventory of DRM investments in Europe. The inventory is meant to help identifying commonalities and differences across contexts and identify which factors (variables) motivate different decision rules concerning DRM and adaptation investments. The inventory provides an overview of types of investments (flood control, flood damage mitigation, preparedness, and recovery), the size of these investments, decision tools applied to evaluate these investments ex-ante or ex-post (if available), and a number of other variables decribed below. In addition, Benefit-to-Cost ratios (BCR) and other performance indicators are presented, where available.

Existing inventories of DRM investments of this kind have largely focused on investments in developing countries or globally (Mechler et al., 2014; Mechler, 2016; Shreve and Kelman, 2014; Hawley et al. 2012). In contrast, the present inventory is specifically focused on Europe, and therfore allows for studying the EU context in higher detail. In our search for evidence, we have made use of the aforementioned inventories and also of databases that are constructed in other Work Packages of the ECONADAPT project (WP1 and WP6). In addition, we have searched the existing grey and academic literature for additional studies. Due to linguistic limitations of the researchers, we have only collected studies in the English, Dutch, Spanish and German languages. To somehow restrict the scope of the research into the vast mole of material available, we have focussed on studies on risk management in the context of floods, although we also found some studies for other hazard types.

3.2 The database

At present (September 2015), the database contains 110 observations on DRM investments/projects from 32 studies and databases across 16 European countries over the period 1991-2015 (see Table 1).

Table 1 Disaster risk management (DRM) database for Europe

Study/database	Country	Hazard	# observations
STUDIES			
Holub and Fuchs 2008	**Austria**	**Flood, Mass movement**	**2**
Projectconsortium MKBA Sigmaplan 2004	**Belgium**	**Flood**	**1**
Fošumpaur and Satrapa 2011	**Czech Republic**	**Flood**	**1**
Klimatilpasning 2006	**Denmark**	**Flood**	**1**
Copenhagen Climate Adaptation Plan	**Denmark**	**Flood**	**1**
Zhou et al. 2013	**Denmark**	**Flood**	**1**
Boettle et al. 2013	**Denmark**	**Flood**	**1**

Porthin et al. 2013	**Finland**	**Flood**	**1**
Saint-Geours et al. 2015	**France**	**Flood**	**1**
Poussin et al. 2015	**France**	**Flood**	**1**
Forster and Kneis 2005	**Germany**	**Flood**	**1**
Gocht 2004	**Germany**	**Flood**	**1**
Generalplan Küstenschutz 2011	**Germany**	**Flood**	**1**
Meyer 2012	**Germany**	**Flood**	**3**
Kontogianni et al. 2014	**Greece**	**Flood**	**4**
OPW et al. 2010	**Ireland**	**Flood**	**27**
Riza 2005	**Netherlands**	**Flood**	**4**
Grontmij 2007	**Netherlands**	**Flood**	**1**
Kind 2011	**Netherlands**	**Flood**	**21**
Gersonius et al 2012	**Netherlands**	**Flood**	**2**
Jha et al. 2012	**Poland**	**Flood**	**1**
Balesteros 2013	**Spain**	**Flood**	**1**
Larsson 2012	**Sweden**	**Flood**	**4**
Fuchs 2006	**Switzerland**	**Mass movement**	**4**
Thompson et al. 1991	**UK**	**Flood**	**7**
Gersonius et al. 2013	**UK**	**Flood**	**2**
Woodward et al. 2013	**UK**	**Flood**	**1**
EWASE 2008	**Spain, Germany**	**Flood**	**3**
DATABASES			
CIRCLE-2	**Netherlands, Switzerland**	**Flood**	**2**
OURCOAST	**Bulgaria, Cyprus, Greece, Netherlands**	**Flood**	**7**
PROCOAST	**Denmark**	**Flood**	**1**

The database presents a snapshot of DRM investments and projects in Europe. By the very nature of the method of research, such a database cannot be exhaustive and we do not claim that it contains a representative sample. Indeed, the body of literature searched is not exhaustive, as information on investments and the decision-making aspects thereof is generally sparse and unstructured. Analysis of the data will therefore only suggest some trends and hints to possible correlations.

The data suggest that the economic case for DRM can be made in Europe. The mean benefit to cost ratio (BCR) of the investments is 5.9 (N=84). The database contains some extremely high BCRs and the frequency distribution in Fig. 1 suggests that the distribution of BCRs is skewed to the right. With a little imagination, the sample distribution suggests a draw from a lognormal population of BCRs.

In a skewed distribution, the median is often the preferred measure of central tendency. The median BCR of our sample is 3.0. This is very much in line with BCRs in the USA and global surveys of DRM investments, where average BCRs of 4.0 (MMC, 2005) and 3.7 (Mechler et al., 2014) are reported for DRM investments for all kind of hazards. We recognize however, that it is possible that our samplying strategy, as those of the studies we cite, incurs in a systematic positive bias of the BCRs of investments, as it could be that successful investments and projects are more frequently reported upon in official documents, and therefore have a higher change of being represented in our database (publication bias).

The database distinguishes between different types of DRM. As was discussed in Section 2.1 above we make a distinction between options that reduce the probability of flooding, that reduce the potential consequences of flooding, and that focus on recovery after a flood has struck. Options that reduce the probability of flooding (flood control) can be divided in 'hard' options such as dike heightening, flood walls, embankments, etc. 'Soft' options includes 'room for the river' investments (such as restoration of floodplains, retention polders, by-passes), beach nourishment, etc. In the options that reduce the potential consequences of flooding (flood damage mitigation) we distinguish between flood-proofing of houses and infrastructure, urban drainage improvements, etc. Options to enhance 'preparedness' are early warning systems, emergency planning, etc. Finally, as a recovery measure risk financing is included.

The data allow us to calculate seperate mean BCRs for hard and soft flood control, flood-proofing, and preparedness.[1] Preparedness has the highest mean BCR (10.8), followed by flood damage mitigation (BCR = 8.5), hard flood control (4.1) and soft flood control (1.6). A high average BCR for preparedness is also reported by Hawley et al. (2012), but in contrast to our findings they report a higher BCR for soft flood control than for hard flood control. Not much weight should be put on this difference, as the sample of studies from which Hawley et al. (2012) and we draw conclusions is not representative and therefore selection bias is likely to be high.[2]

Furthermore, much of the criticism that is raised against the standard application of CBA in this area (see for example Mechler et al. 2014; Shreve and Kelman 2014) is applicable to the studies included in our database: difficulties of taking account of 'intangible' social and environmental effects; improper treatment of uncertainty; doubts about the discounting of future benefits; and concerns of bias towards 'hard infrastructure' all apply to most considered studies, although a number of studies have tried to address one or more of these critical issues in innovative ways.

---

[1] The database only has one observation on risk financing, so we have not included this observation here.

[2] The database contains 21 observations on soft flood control measures.

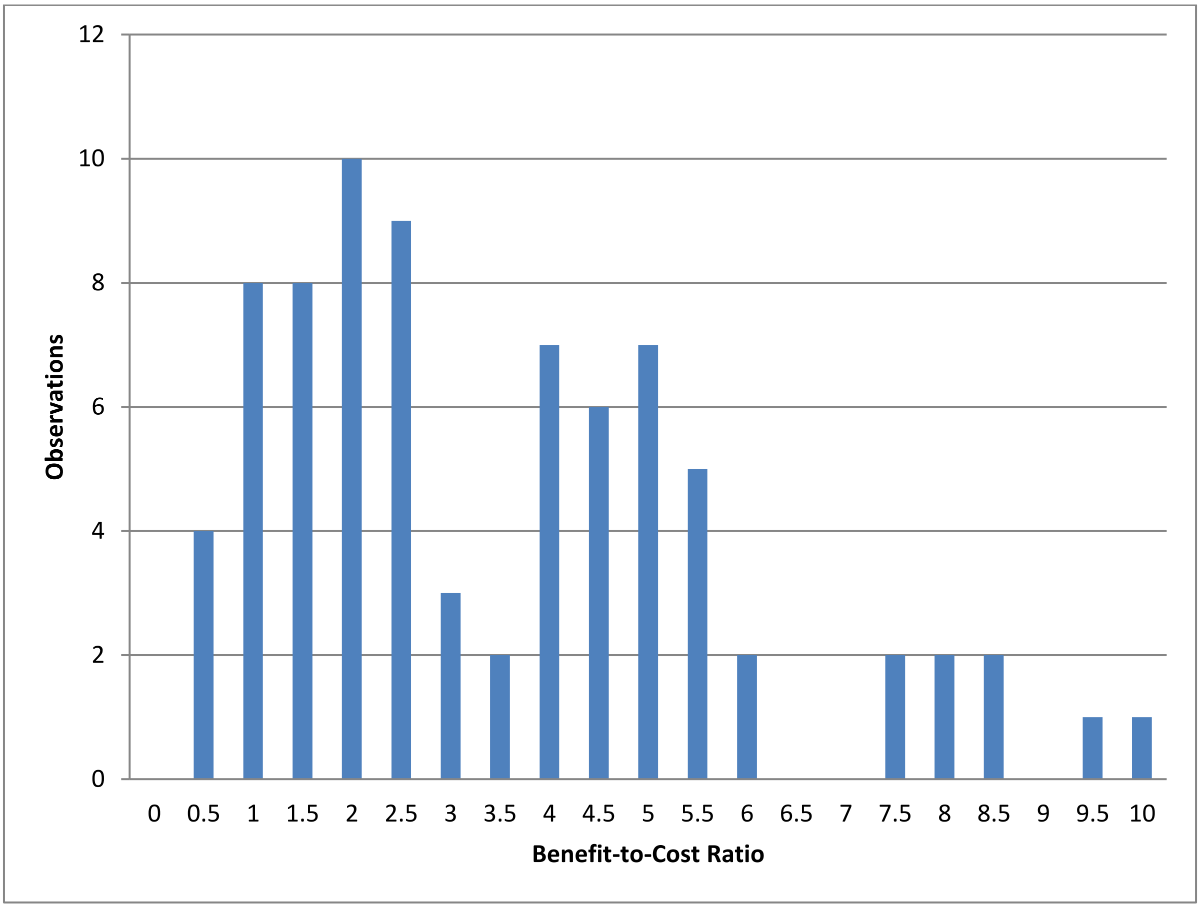


Figure 1 Frequency distribution of BCRs of DRM investments in Europe (the distribution is only shown for BCR's between 0 and 10, larger BCR's are not shown because they would negatively affect the readability of the graph).

The data show little variation in BCR values across different decision-tools that have been used to evaluate the DRM investments. Investments that were evaluated with 'robust' decision making tools (mainly Real Options Analysis, (ROA)) have the highest BCR (7.9), followed by MCA (5.8) and CBA (4.6). In a number of recent project evaluations (for example the Thames Estuary 2100 plan (Woodward et al., 2013)), both MCA and ROA were used. In recent studies, we see the emergence of MCA optimisation, which is used to generate so-called Pareto-efficient frontiers of project options. These are basically indifference curves, where it is impossible to improve on one evaluation criterion without incurring negative consequences for the other evaluation criteria (Woodward et al. 2013; Saint-Geours et al. 2015).

Recent years saw an increase of the application of ROA to assess DRM options, but apart from the Thames Estuary 2100 plan, these applications have remained largely in the academic domain and have not significantly spread to the standard public policy assessment domain. In this respect it is interesting to note that the Dutch Economic Assessment Agency requires that assessments of structural flood risk investments report the first-year Net Present Value (NPV) next to the NPV over the lifetime of the project (RIZA, 2005). The idea is that even if the lifetime NPV of an investment is positive, the investment can be postponed if the first-year NPV is too low. This can be seen as a simplified approach to ROA analysis.

Almost three-quarters of the assessments of DRM investments in the database pay attention to climate-change aspects (sea level rise, rising riverine flood risk, changing precipitation patterns, etc.). This attention starts around 2004 (Projectconsortium MKBA Sigmaplan, 2004) and the majority of studies after 2004 (80%) take climate-change impacts into account in one way or another. Usually, only one – 'most–likely' – climate change scenario is used to evaluate the

DRM investments against. In the next chapter we will explore the attention to climate change in more detail for the case study countries.

3.3 Conclusions

We have constructed a database of DRM investments in Europe. The database is not exhaustive, and it is not a representative sample. With these limitations in mind we can draw some preliminary conclusions based on the quantitative exploration of the collected data:

- The economic case for DRM investments in Europe, at least for flood risk management, can be made. On average, the investments have high benefit-to-cost ratios.
- DRM investments that enhance preparedness to disasters show the highest economic returns.
- The data do not show a large variation in the economic efficiency of investments that were evaluated ex-ante with different decision-making tools.
- Evaluations of DRM investments increasingly take the potential impacts of climate change into account, even though the uncertainty due to the spectrum of future possible developments is commonly not considered.

4 Current practice: Case studies

4.1 Introduction

To understand how decisions are taken in the selection and design of DRM options in European countries at different governance scales, who is involved, and what (appraisal) tools are used to guide these decisions, we have carried out case studies in four EU Member States: Austria, Czech Republic, The Netherlands and the United Kingdom. The selection of the case studies was partly motivated by the available expertise in the ECONADAPT consortium, and partly by the desire to represent different geo-physical regions, and differences in risk cultures, governance and data availability. The case studies were carried out by national experts, mostly based on existing documentation. For the case study on the Czech Republic, knowledge from existing documentation was augmented by a number of face-to-face interviews with key decision-makers. The case studies start with general background information on flood risk and the flood risk management for the particular country. Then the case studies examine decision-making on DRM investments and projects on national, regional and local scales of governance. Finally, the case studies examine if and how climate change is taken into account in decision-making.

4.2 Austria

4.2.1 Background

Floods are one of the costliest natural disasters in the Federal Republic of Austria, which is characterised by steep mountainous regions exposed to the continous hazards of heavy rainfalls, avalanches and mudflows, and by low-lying and built-up urban areas exposed to costly floods. Due to its highly mountainous topography, only approximately 38% of the country's land area is suitable for permanent settlement; as such population and economic activities have tended to concentrate on river valleys and basins that are prone to flood risk (BMLFUW, 2015a). A number of structural and non-structural measures have therefore been taken throughout Austria's history to anticipate, adapt to, reduce, and prepare for flood risks (Lebensministerium, 2006).

Flood risk had traditionally been managed locally with limited use of intensive engineering and hydraulic works until the mid 19th century. Since the late 19th century until the early 20th century, considerable public works projects have been conducted to control the country's flood risks. While during the war periods disruptions of economic and social life significantly curtailed river regulation and management, the years since the 1970s saw a strong emphasis on flood risk reduction investments, connected to a longer-term view of risk management, along with investment into damage repair (Hembeleton-Hamann, 2007).

In a shift towards more comprehensive flood risk management, traditional practices such as straightening and confining of flood channels without sufficient retention areas have been abandoned, and incorporation of considerations about flood risk into land-use zoning has been promoted. Flood risk reduction works are now seen as an integrated part of larger river system planning in which revised guidelines emphasise the importance of integrated and participatory planning of river-basins. Currently, the ten guiding principles of flood risk management in Austria include (Lebensministerium, 2006):

- Highlighting the responsibility of stakeholders and the limits of protection
- Promoting knowledge and awareness of hazards
- Safeguarding appropriate use through spatial planning
- Promoting incentives for taking individual precautions
- Recognising negative developments that are relevant to flood protection
- Coordination of public planning
- Protective measures where necessary
- Extension of emergency planning and disaster protection measures
- Safeguarding financial provisions
- Improving early warning systems

Despite continued efforts to manage the country's flood risk, recent years have seen repeated incidences of large scale floods in Austria. The estimated economic damages from the recent flood events of August 2002, August 2005 and June 2013 are reported around 2,445, 515 and 866 million Euros respectively (Thieken et al. 2014). These events have triggered increased public and private efforts on flood protection measures through the country. Following the 2002 flood event, for instance, federal and provincial governments introduced flood protection measures worth 2.9 billion Euros, targetted at protecting human lives and properties. In 2007, another agreement between federal and provincial governments came into force which required flood protection investment worth 21 million Euros. Until 2016, it is expected that further flood protection investment totalling 570 million Euros will be realized along the Danube, March and Thaya rivers (Hahn 2009).

4.2.2 Decision-making on DRM projects and investments

4.2.2.1 Introduction

The administrative structure of Austria is based on three levels consisting of:

- One federal government
- Nine provincial governments (Länder)
- 2,358 municipalities

In addition, next to these three official levels of government, the Austrian municipalities are organized according to 99 administrative districts (Bunderskanzleramt 2009).

Flood protection in Austria is managed through a complex set of authorities shared across federal, provincial, district and municipality scales (Table 2).

Table 2 Roles and Responsibilities of Federal, Provincial, Local Governments. Adapted from Clar and Steurer (2014).

Federal	Provincial	Local	Legal basis
Active flood protection			
Building of water regulating infrastructure (e.g. flood protection dams, broadening or aligning of water courses) together with risk zone planning.	Maintenance and protection of buildings and their uses. Torrent control measures	Definition of flood-threatened areas within local land use plans	Buliding law; water law; and nature and landscape conservation
Passive flood protection			
Fullfilment of EU requirement. Defining innundation zones of HQ 30, HQ 100. Formulation of spatial planning interest and goals Modification of water lines and immediate catchment areas	Determining local spatial planning Definition of retention areas Coordinating land use demands Execution of water law	Execution of water law Waste water dsiposal	Building law; water law; environmental law and EU Framework Directive

Responsibilities and roles of flood risk investment are codifed across a number of laws, which specify mandates for federal, provincial and municipal governments. In general, the Federal government is in charge of the development and management of water regulating infrastructures, while provincial and local governments are in charge of spatial planning and water resources management at their respective scales.

4.2.2.2 National and provincial levels

Designation of flood hazard areas and the implementation of land-use planning are the main instruments used to manage the risk of floods in Austria. The Federal government is in charge of specifying areas in danger of erosion and avalanches (§ 11 of the Forestry Act) and inundation (§§ 3 and 48 of the Austrian Water Rights Act). Overall regional spatial planning falls under the responsibility of provincial governments (Länder); therefore, coordination is an important element of overall flood planning in Austria (ELLA n.d.).

To foster development and sharing of flood risk information, the Federal Ministry of Agriculture Forestry Environment and Water Management (BMLFUW) has worked closely with the Austrian insurance companies (Austrian Insurance Association: VVO) and developed a nationwide zoning system for natural disasters (HORA-Flood Risk Zoning Austria). Hazard maps are available for the country's river system spanning across more than 25,000 km^2, for the 30-year, 100-year and 200-year flood events (Stiefelmeyer and Hlatky, 2008). The freely accessible risk maps of HORA allow investors, residents and concerned citizens to obtain an estimation of the potential flood hazards surrouding their properties. For areas nearby water courses, data on a

125 m grid is overlaid with available statistics such as the national population census, land-use and cultural asset locations to allow for easy access and examiniation of high risk areas (Hornich, 2013). While the hazard zone is delineated by the federal government, the responsibility for disemminating forecasting rests with the governor of each province (Nachtnebel n.d.).

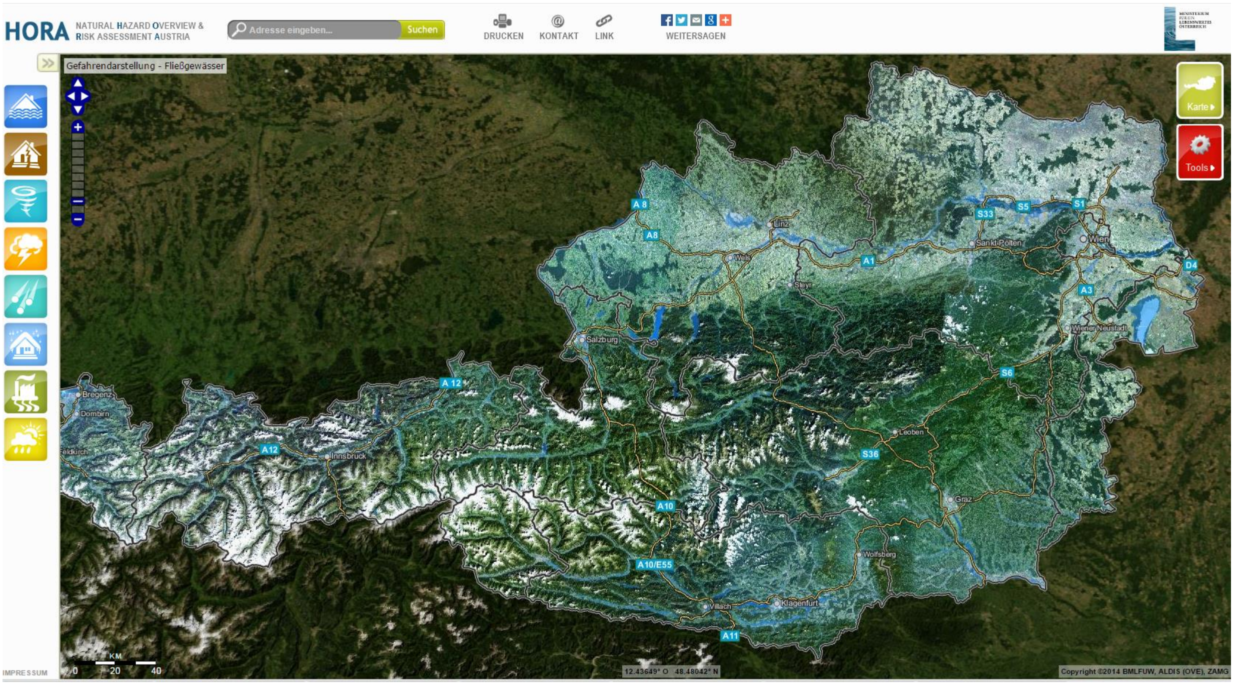


Figure 2: HORA Online Platform. Source: HORA website http://www.hora.gv.at/

Following the EU-Water Framework Directive, assessments of costs and benefits are mandatory for water management protection and water development projects above 1 million Euros in Austria. For projects above 0.11 million but less than 1 million, simplified CBA is performed. For maintenance and upgrading projects worth less than 0.11 million Euros, CBA is not mandatory. Full-scale CBA requires economic benefits and costs of intangible assets (social, ecological and cultural) together with tangible assets associated with the whole life-span of a proposed project. Comprehensive CBA in Austria includes the following 15 inputs and steps: 1) geo information; 2) characteristics of flood scenarios; 3) hydrodynamic modeling; 4) socioeconomic information; 5) vulnerability assessment; 6) damage potential estimation; 7) benefit estimation, 8) cost estimation; 9) BCR and sensitivity analysis; 10) assessment of people exposed; 11) assessment of intangible effects; 12) overall assessment; 13) comparison of alternative and choice of 'optional alternative'; 14) description of residual risk and 15) report and documentation (ICPDR 2014). To faciliate standardised implementation of CBA, BMLFUW has developed guidelines as well as templates for detailed CBA assessment (BMLFUW 2015b).

The responsibility for recovery and reconstruction after flood events generally falls under provincial jurisdiction, as the Austrian constitution does not specify the responsibility for federal government. However, in case of severe natural disasters, exceptions are made in the form of special legislation to extend additional support necessary to accelerate recovery and reconstruction. In 1951, for example, a large scale avalanche necessitated a special law to raise sufficient funds for local recovery. Following consecutive large-scale floods that occurred in

1965 and 1966, the country's first permanent disaster fund, known as 'Katastrophenfonds' was set up, based on the the law 'Katastrophenfondsgesetz 1966' (BMF, 2012).

The Federal Ministry of Finance takes charge in the management of resources allocated for the country's disaster fund, while BMLFUW, along with the Federal Ministry for Transport, Innovation and Technology (bmvit), and the nine Austrian Länder take charge of the implementation of hazard mitigation. Within the BMLFUW, the 'Austrian Service for Torrent and Avalanche Control' ('Wildbach und Lawinenverbauung', WLV) and the 'Federal Water Engineering Administration' ('Bundeswasserbauverwaltung', BWV) are responsible agencies for flood protection. The Viadonau (Österreichische Wasserstraßen-Gesellschaft mbH) is the responsible unit within the bmvit.

The fund is largely financed through taxation on federal income, labour wage, capital yield on dividends, and corporate income. Additional resources are drawn from investments and repayments of Austrian hail insurance. While the fund accrued interest until 2013, it is no longer invested, and is instead treated as an accounting component. Figure 3 shows annual deposits to the disaster fund over the period 2002-2014.

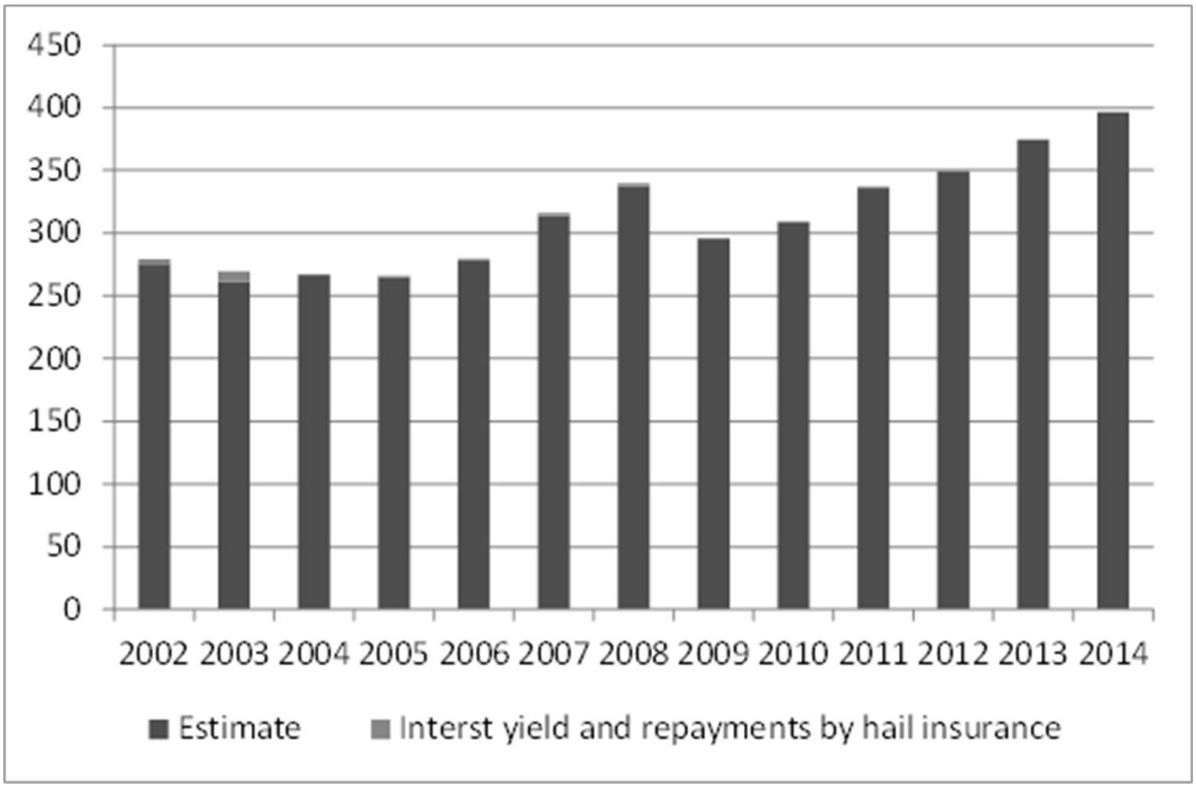


Figure 3: Deposits to the Austrian disaster fund 2002-2013 (million EUR), based on bi-annual reports of the Austrian disaster fund (see e.g. BMF, 2014 for the reporting period 2012-2013).

According to the prevailing version of the disaster fund law, the disaster fund's annual resources are currently allocated for the following purposes:

- Preventive measures (73%)
- Recovery and rebuilding from exceptional catastrophic events (18%)
- Equipment for fire departments (9%)

Because disaster management in Austria lies within the competences of the nine Länder, these are the first authorities to extend financial assistance for recovery of assets owned by natural and legal persons (with the exception of regional and local authorities, i.e.

‘Gebietskörperschaften’) in case of extraordinary catastrophic events. The federal government then refunds provinces up to 60% of the financial assistance (in line with the maximum level assistance according to § 3 Z 3 lit. a KatFG 1996). An impaired private party may receive assistance worth approximately 20-30% of the incurred damages, in some cases of extraordinary hardship up to 80%.

4.2.2.3 Local level

In addition to overall flood risk planning that takes place at both federal and provincial levels, local level participation is important, especially in terms of spatial planning and other flood risk management interventions. While spatial planning laws are introduced generally at the regional level, additional risk management measures such as restriction of land use in retention areas, etc are often implemented by local authorities (ELLA n.d.).

Furthermore, technical flood protection measures are also designed at the municipal level in collaboration with engineers and consultants. In many cases, a number of municipalities form a ‘water board’ to work together to plan and build structural flood protections (Ceframe 2013). These water boards receive collective financial and technical support from the relevant provincial or federal authorities. In addition, voluntary fire fighting units at local levels play an important role in the case of emergency, assisting in rescue, cleanup and other response and recovery operations.

4.2.3 (How) is future climate change taken into account?

Given limited knowledge and high uncertainty regarding future impacts of climate change on flood hazards, the current Austrian adaptation strategies are targeted at addressing the existing risk of extremes. The adaptation strategies are also designed to be flexible and robust, with emphasis placed on ‘no-regrets’ and ’win-win’ measures (Lebensministeirum 2013). Uncertainty of future climate change is therefore not presently incorporated into flood risk planning in Austria (based on personal communication with an expert of BMLFUW).

The process for developing the Austrian climate adaptation strategies began in 2007 among BMLFUW and the nine Länder. From 2008-2011, sectoral level recommendations for the following 14 areas are made: 1) Agriculture, 2) Forestry, 3) Water Resources and Water Management, 4) Tourism, 5) Energy, 6) Construction and Housing, 7) Protection from Natural Hazards, 8) Disaster Risk Management, 9) Health, 10) Ecosystems/Biodiversity, 11) Transportation Infrastructure and Selected Aspects of Mobility, 12) Spatial Plannning, 13) Business, Industry and Trade, 14) Cities. The drafting of recommendations involved a series of participatory sessions including approximately 100 organisations representing various areas of interest. Based on these inputs, the first draft of policy paper ‘The path to a National Adaptation Strategy-First Draft’ was released in July 2009. This was followed by a publication of a second draft in October 2010. In the areas of hazard management the following actions have been recommended:

- Promotion of Hazard and Risk Awareness, self-sufficiency of the population and the development of consulting models
- Promotiong of sustainable spatial development strategies including increased consideration of hazard zone mapping and risk presentation
- Promotion of water retention in the catchment and the reactivation of natural flood plans, particularly as a contribution to precautionary land use
- Promotion of research on the impact of climate change on extreme events and on changes in the natural environment and human use thereof
- Promotion of risk management with inclusion of appropriate risk transfer mechansims
- Promotion of technological property protection measures (permanent and temporary) as a contributing factor to self-sufficiency

- Promotion of forecasting (early) warning and measuring systems (Lebensministeirum 2013).

4.3 Czech Republic

4.3.1 Background

The Czech Republic is vulnerable to natural disasters caused by hydro-meteorological events, especially river flooding. A large flood in 1997 started discussion on new flood-control management in the country. A major, devastating disaster occurred in 2002 due to extreme precipitation in Central Europe (Toothill 2002; Kundzewicz at al. 2005; Kundzewicz et al., 2010; Genovese 2006). Water levels rose up to 3 meters in unprotected areas. 15 people were killed and 220,000 citizens were evacuated. In total 1.6 million people suffered from the floods, 100 towns and villages were flooded and another 350 were partially flooded on the Vltava, Berounka and Labe rivers (Toothill 2002). Total economic damage in the Czech Republic has been estimated around 3-3.6 billion Euros (Toothill 2002; Genovese 2006). Around one third of the damage was concentrated in the capital city of Prague. Especially the districts of the Lesser Town (Malá Strana), the Old Town (Staré Město), the Jewish Quarter (Josefov) and Karlín suffered heavy losses (Genovese 2006).

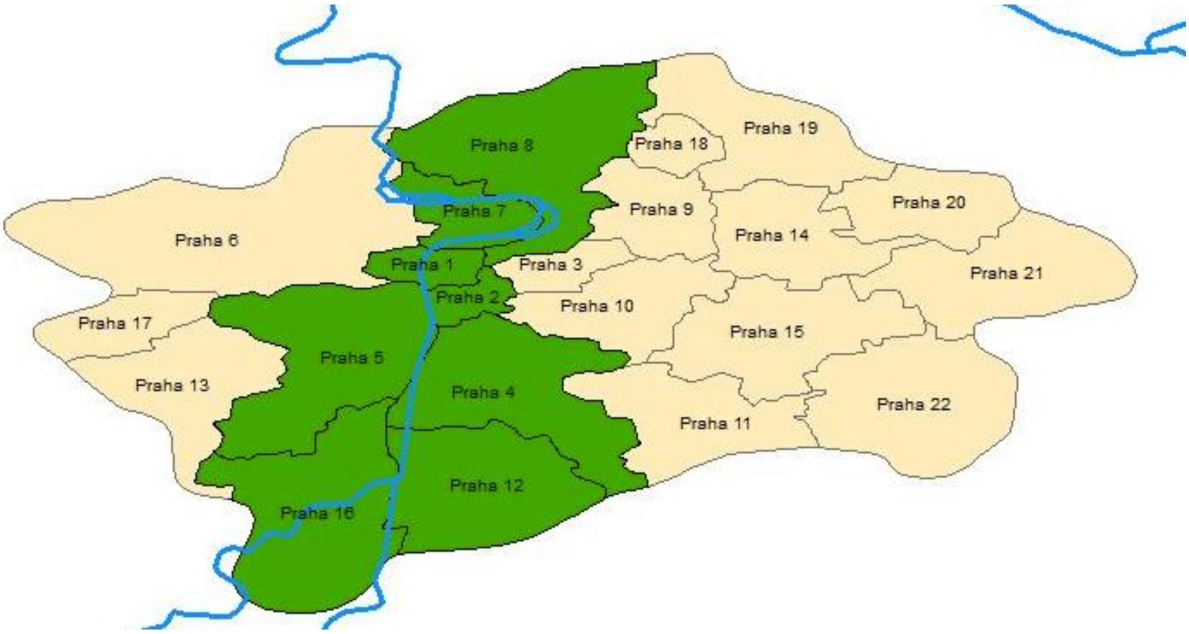


Figure 4. A map of the river Vltava and districts of Prague. Lesser Town (Malá Strana) is in Praha 1 and 5; Old Town (Staré Město) and Jewish Quarter (Josefov) are in Praha 1; Karlín is in Praha 8. Source: Spiegel 2014.

At the time of the floods of 2002 the Czech Republic did not have sufficient experience to protect citizens from extreme flooding (Spiegel 2014). In an ex-post evaluation of the 2002 flood, Sklenář et al. (2006) noticed:

> "*Unfortunately the hydrologic monitoring network was insufficiently funded in the last century. During the flood most of the river gauge stations were destroyed, and could not transmit or even record data during the unexpectedly high water levels. Although a meteorological forecast was available and quite accurate, hydrological forecast was not fully available in the later stages, because most of the models were out of range and on-line data were hardly available later during the event. Rating curves were not accurate enough or did not exist for high discharges on most of the rivers affected. All*

the simulations and measures until 2002 were carried out for the highest flood rated as Q100 The flood 2002, rated as approximately Q 500 has changed the attitude of all the authorities involved." (Sklenář et al. 2006, p.159).

As a response to these devastating floods, and because of the need to transpose European law, the Flood protection strategy of the Czech Republic and the Flood plan of the Czech Republic have been developed in 2000 and 2005 respectively. In the same period, 'The plan of flood protection of the City of Prague' was developed to protect the city of Prague and as a requirement of the 'water law' (no. 254/2001). The main inspiration of the plan came from the flood protection plan of the city of Cologne in Germany. The main flood protection measures of the plan are the construction of a movable barrier along the Vltava River in the historic city centre of Prague and construction of dykes and dams in the northern and southern outskirts of the city.

Since 2002, the Czech Republic has experienced six major flood events with substantial damages, the last one in 2013. Apart from these large flood events, the Czech Republic is experiencing around 60 to 100 flash floods yearly, causing damages to municipalities located mainly in the upper parts of watercourses, in the mountain areas and in the foothills (Czech Hydrometeorological Institute 2013).

4.3.2 Decision-making on DRM projects and investments

The general policy context of flood protection in the Czech Republic is described in Deliverable 6.1 of the ECONADAPT project (Scussolini et al. 2015). We summarize the description here.

The legal concept of flood protection in the Czech Republic is set such that every citizen is responsible for protecting his own property and life from flood, as set in the Czech National Flood Protection Strategy (2000). The citizens cannot claim any flood damages from the government or other public entities. The properties that are subject to flood risks may be insured so that the owner does not have to bear the full costs of a possible inundation. However, while the damages that are covered by insurance have substantially increased since 1997, the overall practice of the insurance companies is to cover only around 1% of the insured amount, and many insurance companies do not cover flood risks in floodplains. In some cases after a major flood there is a one-off subsidy measure by the government that covers some flood damage.

Flood protection planning is widely developed by the public sector, and accounts mainly for flood protection measures that affect larger areas in the river basins. Local administrations play a role in regulating development in floodplain areas (administratively defined areas that may be flooded in case of inundation), both by setting the territorial plan of the municipality, and by participation in the building-permit process. According to the Water Act (no. 254/2001; as amended by Act no. 150/2010), property development (for other than water management purposes and necessary transport constructions) is forbidden in so called 'active zones' of floodplain areas, which are the most vulnerable areas within floodplain zones.

Flood protection management is assured by flood protection authorities (during the flood, these include a flood committee and integrated rescue system), which follow flood-event management plans.

The key documents on a European level that deal with water management are the EU Water Framework Directive (2000/60/EC) and the EU Floods Directive (2007/60/EC). While the first aims at long-term sustainable water management, based on a high level of protection of the aquatic environment in all surface and groundwater bodies and at ensuring their sustainable use, the second directly focuses on the reduction and management of flood risk. On the national level, these goals are transposed and embodied in the Water Act (no. 254/2001; as amended by Act no. 150/2010) and are also reflected in the main planning documents in the river basin districts; each of them contains a 'Scheme of the measures' section, with descriptions of specific proposed adaptation measures. At present, also the 'Flood risk management plans' that follow from the EU Floods Directive are being prepared. Together with the actualisation of Plans of the river basin districts, they will be finished by 22 December 2015.

To better understand the actual decision-making processes in the Czech Republic, for the present case study we interviewed a number of stakeholders on decision making in flood protection, at different administrative levels. Two groups of stakeholders were distinguished: decision makers and interest groups. Table 3 presents the interviewed stakeholders at different regional levels. Five face-to-face interviews with representatives of the stakeholders were conducted in May 2015.

Table 3 Interviewed stakeholders

<table>
<tr><th>Level</th><th>Decision makers</th><th>Interest groups</th></tr>
<tr><td>National</td><td>Ministry of Agriculture</td><td>Czech Hydrometeorological Institute</td></tr>
<tr><td rowspan="2">Regional</td><td>Regional Authority of Central Bohemia</td><td rowspan="2"></td></tr>
<tr><td rowspan="2">Prague City Hall*</td></tr>
<tr><td>Local</td><td>Zoo Prague</td></tr>
</table>

* Prague is both a region and a municipality.

4.3.2.1 National level

At the national level a number of ministries are involved in flood protection policies, namely the Ministry of the Environment, the Ministry of Agriculture, the Ministry for Regional Development, and the Ministry of the Interior.

The **Ministry of the Environment** plays a crucial role in flood risk management, and particularly its Department of Water Protection is the central authority in flood protection (Ministerstvo Životního Prostředí, 2015). Further, the Ministry is also responsible for drafting the Flood Plan of the Czech Republic (Povodňový plán České Republiky).

The **Ministry of Agriculture** acts as the coordinator of developing the Programme of Flood Prevention in close cooperation with the European Investment Bank (EIB). At present the programme is in its third phase. In the first two phases, 2002-2014, 750 million Euros were invested in a wide range of preventive measures (dykes, retention areas, river regulation and polders) integrated at the river basin level. EIB co-financing was less than 50%, while the remainder was mainly financed from State budget and the River Boards' own funds (EIB 2006; Beros 2013). In addition, the Ministry started to run a web application that includes photo documentation of the construction of the flood control structures. Currently, this program is in the third phase, which should finish in 2019. In this phase it is planned to invest another 180 million Euros (4.5 billion CZK) from national resources. The greatest emphasis in the third phase is on the retention of water in the landscape.

The selection of flood protection measures is based on a multi-criteria approach combining BCR, technical merit and environmental considerations. Priority is given to non-structural measures (Beros, 2013). The assessment of the BCR of flood protection measures is based on a risk analysis methodology to compute expected avoided damages (benefits) with/without each scheme: (i) use Monte Carlo simulation to generate sequences of annual peak flows based on probability distribution of different flood events from hydrological data in the models operated by River Boards, and (ii) combine them with expected damages associated with different flood events, based on estimated frequency-damage functions. The methodology was developed by the Czech Technical University. In the second phase of the Programme of Flood Prevention, 81 of a total of 349 flood control projects were assessed by this method (Fošumpaur and Satrapa 2011).

Fošumpaur and Satrapa (2011) illustrate the method with a case study of a flood protection project of the Budyně nad Ohří municipality in the North Bohemia region. They evaluate flood damage at the flow levels of the 10-, 20-, 50- and 100-year return period flood events of the Ohře River. They also assess the investment and maintenance costs of dikes to protect against the same four flow levels. Average annual flood risks before and after the implementation of the flood protection measures were derived from a synthetic series of yearly peak flows of 10,000 years, based on historical data. The results of the analysis are given in Table 4.

Table 4. Economic assessment of flood protection measures

Degree of protection	Risk reduction (million EUR)	Costs (million EUR)	BCR	NPV (million EUR)	Payback period (years)
10-year	**1.036**	**0.414**	**2.5**	**0.622**	**13**
20-year	**2.219**	**0.493**	**4.51**	**1.727**	**7**
50-year	**3.009**	**0.593**	**5.07**	**2.416**	**7**
100-year	**3.378**	**0.807**	**4.19**	**2.517**	**8**

Source: Fošumpaur and Satrapa, 2011.

From the perspective of relative efficiency, BCR, the optimal level of protection is 50-year (BCR = 5.07). The 100-year protection level provides, however, a higher absolute benefit (NPV = 2.517 million EUR). Considerations other than purely economic of course also play a role in determining the preferred level of protection in this case. Fošumpaur and Satrapa (2011) suggest that the evaluation serves as a strategic decision tool for flood protection that allows determining preferences in the implementation of proposed projects or the rejection of inefficient projects.

The representative of the Ministry of Agriculture contended that at present most towns have sufficient flood protection. In the Vltava river basin, protection is only insufficient in the towns of Rokycany and Kralupy nad Vltavou. The biggest problem is presently the management of the ‘active zones’: the flood prone areas. It is prohibited to construct new buildings in such areas, but existing buildings can be reconstructed. The Ministry of Agriculture provides guidelines to towns about the demarcation of active zones, but these guidelines are just recommendations, and they are not always followed. As a result, active zones are not always clearly determined, and their demarcation is subject to lobbying practices.

The **Czech Hydrometeorological Institute** (CHMU) is responsible for hydrometeorological forecasts and warnings. Flood warnings should be given 48 hours in advance. This is challenging for two reasons. First, at the time then the warning is due, the water that could potentially cause floods could be still in the form of clouds and water vapour outside of the Czech Republic. Second, at the Vltava River, which passes through Prague, actual water flows are controlled by a cascade of dams, operated by the state enterprise Povodi Vltavy. To predict peak flows correctly, CHMU needs to know exactly how the dams will be managed, which unfortunately is impeded by the sub-optimal communication between CHMU and Povodi Vltavy. This is partly due to the fact that CHMU and Povodi Vltavy fall under different ministries, Ministry of the Environment and Ministry of Agriculture, respectively.

4.3.2.2 Regional level

The **Regional Authority of Central Bohemia** is a main actor at the regional level. The role of the Regional Authority in flood risk management is defined by the Water Act, but the institution also works beyond this regulation. The Regional Authority is responsible for drafting and updating the Flood Plan of Central Bohemia. This is the main document for managing the flood events within the region. According to the Water Act, the Flood Plan has to be updated every year. The document consists of three parts: factual, organizational and graphical. The factual part includes data required for flood protection, such as information about watercourses or information about physical structures threatened by floods. The organizational part contains a list of names and addresses of all persons who are responsible for flood protection, such as patrol services. Finally, the graphical part shows maps of the floodplain areas.

When a flood occurs, the Regional Authority establishes contact with the Flood Commission. The Commission decides the course of action to take, and the geographical focus of the intervention. The Flood Commission further coordinates flood commissions of lower authorities, such as flood commissions of municipalities.

The Regional Authority also manages the so-called Runoff Condition Study. This study aims to outline the critical areas where flood protection measures should be implemented. The study acts as a recommendation, because the Regional Authority cannot directly fund the flood measures because it does not own the flood protection infrastructure. But if the owner of the flood protection infrastructure decides to implement flood protection measures, he can ask for co-financing only if all measures are in accordance with the Runoff Condition Study. The regional domain of the coordinating activity of the Regional Authority allows preventing possible negative interactions between local flood protection measures.

Once a year, the Regional Authority of Central Bohemia provides training to local authorities, including representatives from CHMU, Povodí Vltavy, and state enterprises.

4.3.2.3 Local level

According to the Water Act, the municipalities are responsible for the creation of their own flood plans. Like the regional flood plans, they need to consist of factual, organizational and graphical parts and they need to be updated every year. The most responsible person on the local level is the mayor, who acts as head of the local flood commission. During the interviews it was mentioned that this causes problems if a flood event occurs soon after a new election, when the new mayor does not yet have sufficient experience and knowledge. Each municipality must cooperate and communicate with other authorities (local and regional), especially in the case of floods affecting multiple municipalities or regions.

The **Prague City Hall** takes responsibility for implementing flood risk protection measures in the city. According to the Water Act, the authorities of the city districts are in charge, but according to the interviewee this process can be slow and ineffective, so that Prague City Hall normally takes the responsibility. Prague City Hall is responsible for preparing and updating the Prague Flood Plan, providing information during floods, and determining buildings suitable for evacuation. During a flood event, the City Hall offers its services to the Flood Commission.

Currently, the major part of the city is protected except the districts Lahovice, Lahovičky and Troja, because, as the respondent from Prague City Hall mentioned, it is not economically feasible to build flood protection in these areas. This has led to a conflict between Prague City Hall and the **Zoo of Prague** which is located in Troja, very close to Vltava river. The animal garden is protected by a flood wall that is designed for a flood with a return period of 25-30 years. During the flooding events of 2002 and 2013 this protection was insufficient. The zoo is criticised by the City Hall for the building of additional pavilions in flood prone areas. The zoo, inits turn, has commissioned an economic feasibility study from the Czech Technical University. This study criticized the analysis of Prague City Hall, and argued instead that a protection level for the zoo against a flood with a return period of 100 years would be economically feasible. The conflict has not been solved yet.

4.3.3 (How) is future climate change taken into account?

In our research and interviews we have not been able to find explicit evidence of adaptation to climate change, although the authorities seem to be aware of the potential threats of climate change. CHMU plays a central role in making long-term hydrometeorological forecasts.

4.4 Netherlands

4.4.1 Background

Flood risk policy in the Netherlands is a matter of national safety. The policy employs a so-called 'multilayer safety approach', encompassing prevention, spatial solutions (including adaptations to buildings and infrastructure), and crisis management, whereby prevention receives prominent attention (Hoss, 2010).[3] Regarding decision-making in flood risk-related investments, from the 1950s onwards, CBA has played an import role. In recent years its application area has been extended, from assisting in the update of national safety standards to the evaluation of alternative risk-reduction strategies and individual investment projects. From the mid-1990s onwards, the potential impacts of climate change on flood risk are recognised and taken on board in flood risk management through the concept of 'adaptive flood risk management'.

The Netherlands is by its geographical disposition notoriously exposed to extreme flooding. More than half of its land area faces flood risks, putting two-thirds of its population and 70 % of its GDP at risk (Eijgenraam et al., 2014). In the west and north, the country borders the North Sea and many coastal regions are below sea level, including the most densely populated areas of the so-called Randstad megalopolis that comprises the cities of Amsterdam, Rotterdam, The Hague and Utrecht. From the east and the south, the rivers Ems, Rhine, Meuse and Scheldt enter the country. In 1953, a huge flood occurred in the southwestern part of the country, killing more than 1,800 people and causing massive economic damage. After this disaster, in 1958, a high-level state committee, the Delta Committee, was commissioned to recommend a flood protection strategy, which resulted in the Delta Works – a huge multiannual investment program that closed river mouths and sea arms, strengthened existing dikes and built new ones (Husby et al., 2014). On the request of the committee, the mathematician Van Dantzig designed an algorithm to determine optimal dike heights based on the equilibrium between marginal investment costs and marginal expected avoided flood damage (van Dantzig, 1956). The first Delta Act of 1958 included flood protection standards for coastal areas, that were partly based on the work of Van Dantzig. As of 1970s, safety norms were assigned to rivers and since 1996 all water safety norms have been written in law (Bötger and Te Linde, 2014). The Water Act (Stb. 107, 2009) determines flood protection standards for all dike-ring areas (polders) in the Netherlands.

In 1993 and 1995, high discharges of the Rhine and Meuse rivers led to critical situations, and in 1995 more than 250,000 people were evacuated because they were considered to be at elevated risk of flooding (Eijgenraam et al., 2014). One consequence of these events was that the extreme discharge probability distribution of the Rhine river was reassessed and this led to to higher probabilities of extreme discharge levels. In 2002, the € 2.2 billion 'Room for the River' project was started to adapt the water defence system to the new discharge distribution, and, as a second objective, to improve the spatial quality of the river basins.

With the renewed attention for flood risk, the flood protection standards also came under scrutiny. As they were based on van Dantzig's work in the 1950s, the question arose if they could possibly be outdated. Population had almost doubled and GDP had increased fivefold (Eijgenraam et al., 2014). Moreover, the standards of the 1950s did not take account of the possible impacts of climate change and sea level rise. As a response to these concerns, the Minister of Infrastructure and the Environment launched the project 'Flood protection for the 21st century' to update the legal standards for flood protection. Also, in 2008 a second Delta

---

[3] In the Dutch policy-context, 'prevention' means 'prevention of flooding'. This is different from the use of 'prevention' in the EU policy-context where 'prevention' refers to 'prevention of damage', mostly because of land-use planning arrangements (see also Annex A of this report).

Committee was installed to advise the government on strategies for integrated flood risk management and fresh water supply until 2100. On the advice of this committee, a Delta Programme was launched in 2010, chaired by the Delta Commissioner, to foster protection against high water and keep the freshwater supply up to standard (Delta Commissioner, 2010). In September 2014, the Delta Commissioner presented proposals for updated flood protection standards to the Parliament (Delta Commissioner, 2014).

The Delta Programme reflects the current thinking on flood risk reduction management in the Netherlands. This management is called adaptive and integral. It is called 'adaptive' in the sense of remaining flexible to take account of future possibilities, insights and circumstances. We will return to this aspect of flood risk management in Section 4.4.3 when discussing adaptation to climate change. The management is called 'integral' in the sense that water safety solutions should try to serve multiple interests and to realign with different spatial developments. We will return to this 'integral' dimension further in Section 4.4.2.3 when discussing local implementation of flood protection measures. In addition, the Delta Programme tried to broaden risk reduction management from the traditional flood prevention approach, reflected in the new protection standards, to mitigation of the consequences of a flood (for example through restrictions on spatial development), and ex-post disaster management. This approach corresponds to the 'multilayer safety concept' that we mentioned above.

An important tool to realign spatial developments with water and flood management is the soc-alled 'water test': a legal obligation for government bodies (at national, regional and local levels) that either develop or have the authority to decide on a spatial plan, to involve the relevant water management authority early on in the process of plan development and to follow a procedure (the water test procedure) that aims to ensure that water management interests are taken into account in the preparation of a spatial plan. The water management authority can be the national water management agency (Rijkswaterstaat) for the North Sea, large rivers and lakes, water boards for regional waterways and sometimes ground water, or Provinces for ground water. The legal basis of the water test is the Act on Spatial Planning (Wro, 01-07-2008). According to experts in the field, the water test has led to a better understanding and more cooperation between water managers and spatial planners, but it is not yet fully effective because spatial planners are not *obliged* to folow the advice of water managers and in practice there is hardly any impact on the *selection* of planned development sites (Van Rijswick et al. 2015).

At a final note, it should be noticed that flood insurance hardly exists in the Netherlands. After the big 1953 coastal flood, insurers delared that the Netherlands was uninsurable for flood events. The main reason is that Dutch floods are typically low probability – high impact events with limited possibilities to spread risks. There is an insurance policy for crop damages due to heavy rainfall and since 2012 a flood insurance policy has been offered covering damages up to 75,000 Euros, but uptake has been very low. In recent years, the discussion on (mandatory) flood insurance was revived, but it is far from settled yet (Van Rijswick et al. 2015). Government may provide disaster relief for extraordinary damages at an incidental base under the 2010 Security Regions Act (Van Rijswick et al. 2015).

4.4.2 Decision-making on DRM projects and investments

In analysing decision-making and the use of CBA in the Netherlands, a distinction can be made between the national level where decisions on flood protection standards are taken, and where measures are designed, and the regional/local level where individual flood protection measures are implemented. For decision-making at the national level, we briefly examine decision-making on flood protection standards 50 years apart: in the first Delta Committee of 1958, and in the second Delta Committee and the Delta Programme of 2008 that led to the new set of flood protection standards that were adopted in 2014. At this level, we also look at the first selection of flood protection measures into so-called programmes of measures of the Room for the River programme. To understand how decision-making at the regional/local level works, we will look at an individual Room for the River project in the municipality of Nijmegen.

4.4.2.1 National level

Up to the 1980s, the rational planning model was dominant in the Netherlands. To support this planning model, use was made of traditional decision-support tools such as CBA and MCA. CBA was for example used in decision-making in the major Dutch flood protection plan from the 1950s, the Delta Plan. From the 1970s onwards, the rational planning model and its decision-support tools came under increasing criticism. It was argued that most (if not all) public policy problems were too complex and ill-defined to be adequately addressed by this model (Lindblom, 1990; Hisschemöller and Hoppe, 1995; Kørnøv, 2000). By the 1990s, a consensus amongst academics and practitioners in The Netherlands emerged that policy makers should no longer use traditional planning and decision support tools such as CBA and MCA (Mouter, 2014), and attention shifted to participatory and process-based methods. However, as the interactive planning perspective is very attractive at first sight, in Dutch practice it facilitated (or did not obstruct) the construction of some extremely expensive transport infrastructure projects that made “few people really happy” (de Jong and Geerlings, 2003). Analysing the interactive planning perspective, de Jong and Geerlings (2003) concluded that in Dutch practice at least, it often led to irrational decisions. A government committee in the Netherlands investigated the decision-making processes around two major infrastructure projects of the 1990s and concluded that “decision-making for these major projects in that period was based on a combination of impulses such as fear, hope and belief instead of research findings, debate and creativity” (Annema et al., 2007 p. 127).

As a response to these apparent failures of the current planning process, a large research project on the economic effects of infrastructure projects, OEEI, was initiated which resulted in a set of guidelines for carrying out transport appraisals with CBA (Eijgenraam et al., 2000). Since then, CBA for large infrastructure projects (both transport and spatial) has become compulsory, and the the CBA also needs to be reviewed (’second opinion’) by the CPB economic assessment agency. Recently, the OEEI guidelines were updated (Romijn and Rennes, 2013). But as Mouter (2014) remarks, the return of CBA in spatial-infrastructure planning has not meant a total relapse into the rational planning model. Both the ‘rational planning perspective’ and the ‘interactive planning perspective’ are blended into the Dutch planning and decision-making model after the year 2000. This ‘blend’ is visible in planning and decision-making practice for flood protection measures.

As we wrote above (Section 4.4.1), the first modern flood protection standards in the Netherlands for the coastal provinces were partly based on the work of van Dantzig (1956), who determined optimal dyke height from the equilibrium between marginal investment costs and marginal expected avoided flood damage. A CBA of the Delta Plan in comparison to the alternative of strengthening existing dikes was carried out by Tinbergen (1961).

The second Delta Committee that was installed as a response to the near-flooding of 2003 and 2005 (see Section 4.4.1 above), advised on an update of these flood protection standards in the light of the growth of exposed population and assets, and projected sea level rise. The Committee adopted the first Delta Committee’s risk-based approach and advised that the new standards should be based on three factors: 1) the probability of individual fatality due to flooding, 2) the probability of large numbers of simultaneous casualties, and 3) economic and other damage (to landscape, to natural and cultural heritage values, to the country’s reputation and to society). To achieve this aim the committee tentatively advised that protection levels for all dike rings should be increased by a factor of ten (e.g., if the current protection level was 1/1000 it should be increased to 1/10,000) (Deltacommissie, 2008).

In parallel an alternative risk-based approach to update flood protection standards was initiated by the CPB economic assessment agency in 2005 (Eijgenraam et al., 2014). This approach was strongly economic in weighing (marginal) protection costs and avoided damages. Damage included direct and indirect economic damage, and loss of life expressed in monetary value through the value of statistical life concept (Bockarjova et al., 2012). With this approach optimal protection levels were determined for all dike rings in the Netherlands (Kind, 2011). It is interesting to note that the investment costs of the economically efficient flood protection standards were estimated to be € 7.8 billion: almost 70% cheaper than the investment costs of the plan of the second Delta Committee (Eijgenraam et al., 2014).

The Delta Commissioner, appointed in 2010, combined the economic assessment with the other factors that had been suggested by the second Delta committee, and, as reported in Section 4.4.1 above, new standards were presented to and adopted by Parliament in 2014. The new flood protection standards are taken from the two risk-based approaches described above. In the first place, the standards should offer a common minimum level of protection for each citizen who is protected by dikes or dunes by the year 2050. Secondly, higher standards are offered in locations where there is a risk of large numbers of victims, of high economic damage, of serious damage to vital infrastructure of national importance. The minimum protection level is a annual probability of death by flooding of less than 1:100,000 (10^{-5}). In total, six discrete protection levels in terms of flood probability are distinguished: 1:300; 1:1,000; 1:3,000; 1:10,000; 1:30,000; 1:100,000.

The higher standards in the case of high economic damage are based on the CBA that assessed economically-optimal protection levels for each dike ring, based on the equalization of marginal protection costs and avoided damage (Kind, 2011). In fact, in this study each dike ring was divided in dike ring trajectories that face different flood risks.

For the final advice on flood risk standards, the protection level in terms of return period for each dike ring trajectory was computed for local individual risk and for economic damage (CBA). The highest return period (protection level) was selected and mapped onto one of the six discrete protection levels. If a considerable group risk existed at a certain location or if vital infrastructure was threatened, the protection was raised by one step, to the higher adjacent strandard. Table 5 shows an example for a coastal dike ring trajectory in South-Holland. From the perspective of individual risk, the return period of protection should be 6,300 years, or a have an exceedance probability of less than 1/6,300 per year. From an economic perspective, the return period should be 28,100 years, which is larger. 28,100 years corresponds to a discrete protection standard of 30,000 years. If there was the danger of group risk or if vital infrastructure would be at risk, the protection standard should have been increased by one step to the next protection standard of 100,000.

Table 5 Determination of flood protection level for a dike ring trajectory

Trajectory	Return period LIR	Return period CBA	Group risk	Vital infra	Standard
14.7	**6,300**	**28,100**	**no**	**no**	**30,000**

LIR is Local Individual Risk; CBA is Cost-Benefit Analysis.

On a total of 192 dike ring trajectories, the economically optimal (according to CBA) flood protection standard is higher than the standard based on local individual risk in 117 trajectories, that is 61% of the trajectories. This does not mean in all cases that the protection level is increased, because there are only six discrete protection levels. Considering these six protection levels, we see that economic considerations increase the protection level in 44% of the trajectories. So we can conclude that CBA has played a significant role in the determination of flood protection standards in the Netherlands, although it has not excluded other considerations from playing a role.

4.4.2.2 Regional level

As we noted in Section 4.4.1 above, in 2002, the ‘Room for the River’ project was started to adapt the water defence system to the new discharge distribution after the near-floods of 1993 and 1995. As a second objective, the project was to improve spatial quality. CPB, the economic assessment agency made a first assessment of potential flood risk-reducing measures along the Dutch rivers in 2005 (Ebregt et al., 2005). At the time of analysis, 715 potential measures had been described and documented. All these measures were designed to meet the legal flood protection standards, but they had different costs and different co-benefits in terms of spatial quality. For each measure one aggregate cost estimate was documented.

CPB undertook an innovative CEA to make a distinction between relatively cheap and cost-effective, versus relatively expensive and cost-ineffective measures, as a first-cut screening of the numerous measures. The innovative part of the CEA was the way in which it weighed-in spatial quality. It did so by estimating unit costs for flood risk reduction and for four indicators of spatial quality by means of estimating a multiple regression across 593 measures, with the equation:

$$Y = C + \alpha X + \beta Z + \varepsilon$$

where Y is cost of the measure (in million Euros), X is flood risk reduction (in m^2 of decrease in high water level), Z is a vector of spatial quality indicators, α and β are parameters, and ε is an independent and identically distributed error term. The parameters α and β specify the additional costs on one unit of flood risk reduction and spatial quality, respectively. Hence, they are unit costs. Next, all the individual measures were valued by these unit costs and then compared to the actual, documented cost estimate. Measures for which the actual costs are higher than the computed (unit) costs are considered relatively expensive and measures for which actual costs are lower than the computed (unit) costs are considered relatively cheap. Measures were ranked according to the difference between actual and computed costs. Measures that are relatively expensive were not directly excluded from the selection for two reasons. Firstly, sometimes the measures were not interchangeable and only one measure could solve the flood risk problem at a certain location. Secondly, CEA cannot address all aspects that potentially play a role in decision-making (Ebregt et al., 2005).

4.4.2.3 Local level

After the determination of flood protection standards and the initial screening of flood protection measures, actual projects are designed at the local level. In the project preparation phase, CBA is obligatory for large projects for which a contribution from the State budget is requested.[4] Sometimes CBA is also used for smaller projects.[5] It is often used next to other decision-support tools such as (the obligatory) environmental impact assessment. In the CBA, a number of design alternatives should be compared. Of course, as in the case of the screening of measures above, the flood protection standards are given by the national authorities, and are therefore not re-evaluated in local level-projects (Wooning, 2007). The design alternatives all fullfill the prescribed protection standards, and are compared along their investment and maintenance costs and potentially additional costs and benefits not related to flood protection. It is therefore a somewhat constrained CBA. Below we pesent an example of such a CBA for a flood protection project along the river Waal, in the city of Nijmegen.

The river Waal is the main distributary branch of the river Rhine in the Netherlands. The river bends sharply near Nijmegen and forms a bottleneck. The dike nearly gave way in 1993 and 1995. In the Room for the River project, operations were designed that involved moving the Waal dike in Lent and constructing an ancillary channel in the flood plains, creating an island in the Waal and an urban river park in Nijmegen.

---

[4] The financial threshold for which CBA is obligatory in 225 million Euros for the large cities (Amsterdam, Rotterdam, The Hague) and 112.5 million euros for other regions (Ministry of Infrastructure and the Environment, 2012).

[5] A number of municipalities require CBAs for all spatial-physical projects.

Dike relocation was for the first time suggested in 2000 in the consultation document ‘Room for the River’. At the same moment, the city of Nijmegen was starting the implementation of a residential development plan at the same location: the ‘Waalsprong’. In order to avoid irreversible developments, the national government ordered a temporary building freeze. Dike relocation would have serious consequences for the development plan: it would make the construction of 600 houses impossible and would imply the demolition of about fifty existing houses. This spurred local opposition, that embraced an alternative ’local’ plan that focused on excavating the river bed. A project group of Rijkswaterstaat, the city of Nijmegen, the Water Board, and the Province elaborated on both alternatives, but its advice in 2004 was not unanimous. A contentious issue was whether the alternative plan was ‘robust’ against higher water levels that could result from climate change. The dike relocation alternative would be sufficient to accommodate projected maximum increases in water levels, while in case of the ‘local’ alternative additional measures should be taken in the future.

The city council embraced the ‘local’ alternative, but Province and State favoured the dike-relocation option. As from 2002, the dike relocation plan was also included in the decision-making process of the Planning Key Decision that formed the legal basis of the Room for the River project. Initially, the dike-relocation option was judged to be relatively expensive by the CEA screening of CPB (see above), but on the basis of new cost estimates of Rijkswaterstaat, CPB later adjusted its analysis. In this adjusted analysis, it was assumed that the land that should be reserved for possible future measures in the local alternative, would need to be purchased immediately; an assumption that was contested by the supporters of the ’local’ plan. The Planning Key Decision was approved by national Parliament and after public consultation, adopted in 2007. By then, the decision for the dike relocation alternative was final (Roovers, 2012).

From this phase on, decisions were made on design alternatives only. A formal CBA of four design alternatives was carried out in 2010 (Haskoning Nederland bv, 2010). The four alternatives, ‘Classical’, ‘Mosaic’, ‘Dynamic’, and ‘Preferred Alternative’ were evaluated on total investments and co-benefits on tourism and recreation (on the bases of daily expenses) and house prices. The planning horizon was fifty years and future costs and benefits were discounted at a rate of 2.5%. Sensitivity analysis was carried out by varying the planning horizon (100 years) and the discount rate (4%). From the four alternatives, the alternative ‘Mosaic’ one had the highest NPV, but in the end, the second-best alternative ‘Dynamic’ was selected (on the basis of the Environmental Impact Assessment) as the basis for the development of the final plan (City Council of Nijmegen, 2012).

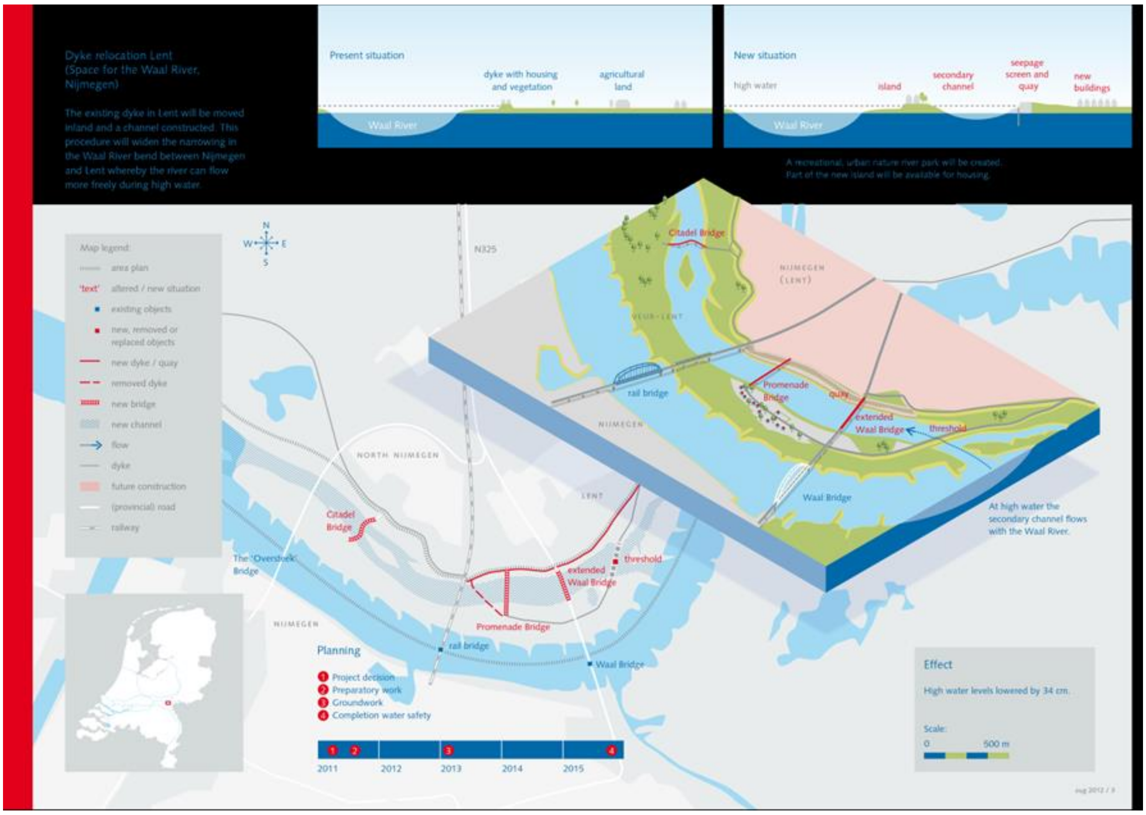


Figure 5: Dike relocation project in the city of Nijmegen.

At this stage of the policy cycle, many decisions had already been taken: the flood protection standard that had to be met, and the type of project that was initially selected, i.e. the dike-relocation project was already selected instead of the 'local' river-excavation project. Moreover, CBA is a decision-supporting tool that is used alongside other tools such as environmental impact assessment and stakeholder dialogue. The result of the CBA analysis is not binding for the decision, it is explicitly meant to support decision-making, not to take over decision-making. As a result, in Nijmegen, in the end, the dike-relocation project alternative that came second-best in the CBA was chosen.

4.4.3 (How) is future climate change taken into account?

The Delta Programme that sets flood protection standards up to year 2050, takes the potential effects of climate change on sea level rise and river discharge into account. A number of climate and socioeconomic scenarios have been explored for use in the Delta Programme (PBL and Deltares, 2011). The underlying climate scenarios were developed by the Dutch Meteorological Institute KNMI (Van den Hurk et al., 2007). In the scenario with most climate change, regional sea level rise in 2050 is 35 cm, increasing to 85 cm in 2100. For future river discharge, flood protection policies in upstream countries are relevant. The maximum river discharge of the Rhine in the Netherlands is presently 'capped' at 16,500 m^3/s, because higher discharge are made impossible by flooding that would occur upstream in Germany (Kind, 2014). Due to increases in the likelyhood of extreme precipitation events, the maximum discharge is assumed to increase to 17,000 m^3/s in 2050 and 18,000 m^3/s in 2100. For the river Meuse similar calculations have been made.

The Delta Programme advocates adaptive management ('adaptive delta management') to address future uncertainties, including the impacts of climate change, in a 'transparent' manner. The Delta Commissioner summarised the challenge of adaptive management as follows: "*One* *of the biggest challenges is dealing with uncertainties in the future climate, but also in population, economy and society. This requires a new way of planning, which we call adaptive delta planning. It seeks to maximize flexibility: keeping options open and avoiding 'lock-in'"* (Kuijken, 2010 as cited in Haasnoot et al., 2013).

Different approaches towards this 'new way of planning' are being actively researched. Four points of departure are (http://deltaproof.stowa.nl):

1. Linking short-term decisions with long-term tasking. This is needed to better anticipate future events so that future measures can be accomplished in a more cost-effective manner, and to avoid adaption measures that make future solutions impossible.
2. Incorporating flexibility in possible solutions. Maintaining flexibility is needed to enable response to climatic and social changes, and to use new knowledge as it becomes available.
3. Working with multiple strategies that can be applied alternately depending on developments. Methodologies to design alternative adaption pathways have been developed.
4. Linking different investment agendas with other local authorities or private parties for the purpose of sharing costs, reducing impediments, or creating added value. This means that ambitions in other areas (e.g. agriculture, the natural environment, shipping and recreation) should be taken into account during planning. This too requires flexibility, as the option to link may require that the investments are adjusted, advanced or postponed.

These four points of departure are integrated in the proposed policy cycle of adaptive delta management (Figure 6).

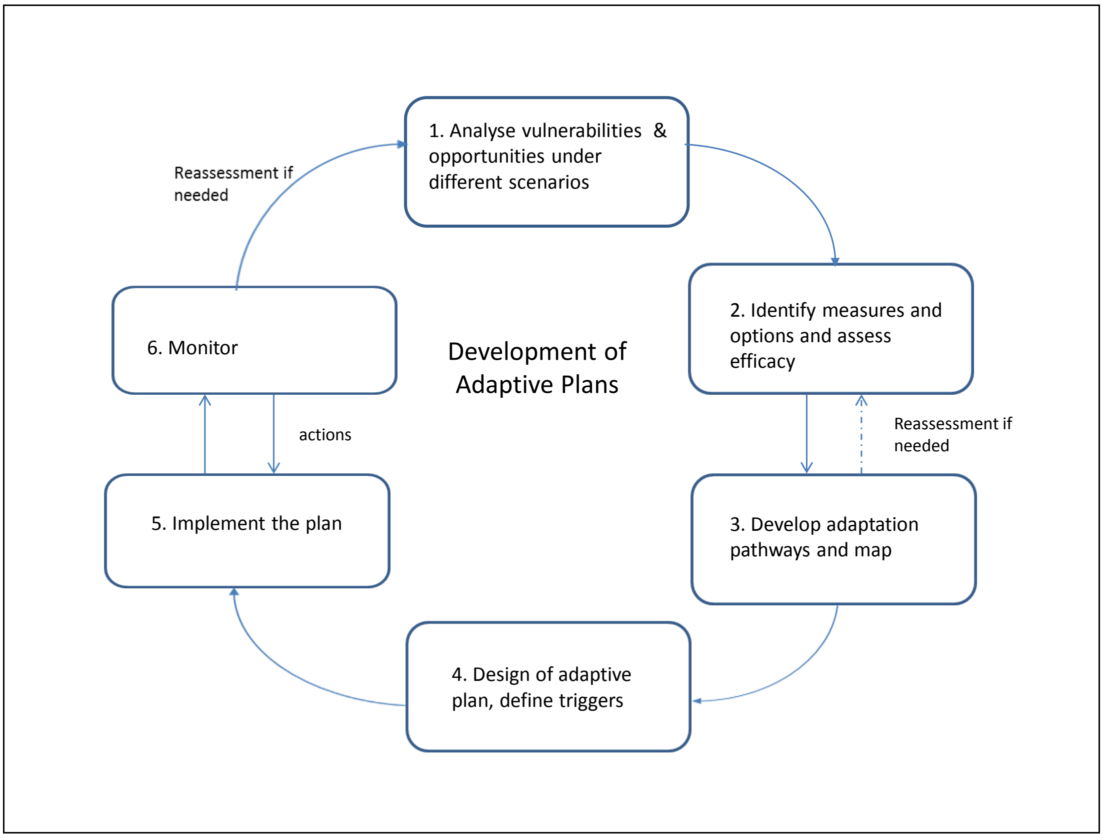


Figure 6: Policy cycle of adaptive delta management. Redrawn from Deltafact: Delta scenarios and adaptive Delta management (http://deltaproof.stowa.nl).

Haasnoot et al. (2013) developed an approach to develop adaptation pathways, or what they call ‘dynamic adaptive policy pathways’. Central to these adaptation pathways are adaption tipping points (or ‘triggers’) which are the conditions under which an action no longer meets its objectives. The timing of the adaptation point for a given action is scenario-dependent. After reaching a tipping point, additional actions are needed to keep meeting the objective. The adaptation pathways approach presents a sequence of possible actions after a tipping point in the form of adaptation trees (e.g. like a decision tree or a roadmap). Each possible route through the adaptation tree is an adaptation pathway. The graphical illustration of such an adaptation tree resembles a metro map (Figure 7).

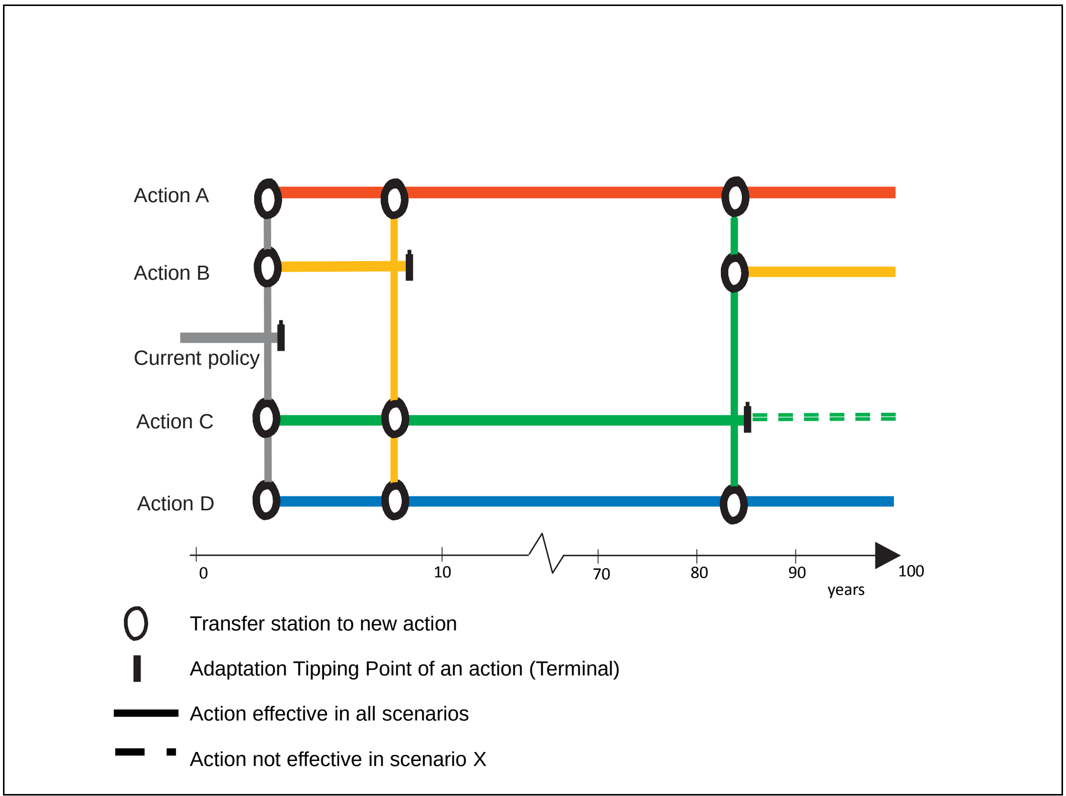


Figure 7: An adaptation pathways map. In the map, starting from the current situation, targets begin to be missed after four years. Following the grey lines of the current policy, one can see that there are four options. Actions A and D should be able to achieve the targets for the next 100 years in all climate scenarios. If Action B is chosen after the first four years, a tipping point is reached within about five years; a shift to one of the other three actions will then be needed to achieve the targets (follow the orange lines). If Action C is chosen after the first four years, a shift to Action A, B, or D will be needed in the case of Scenario X (follow the solid green lines). In all other scenarios, the targets will be achieved for the next 100 years (the dashed green line). (source: Haasnoot et al. 2013)

At first sight, the approach of the adaptation pathways and tipping points has clear similarities with the approach taken by Real Options analysis. In a recent paper, Gersonius et al. (2015) compare adaptation pathways to ROA. They observe a number of important differences in approach and method, but they also submit that the two approaches could be combined into an overarching framework or process for facilitating adaptation of flooding systems to climate change.

A recent communication on adaptive Delta management posited that the approach is still under development and that there are many knowledge gaps to be filled. To this end the approach is currently being tested in a number of regional projects (e.g., the Delta programme Rijnmond/Drechtsteden, and the water boards Delfland and Aa en Maas). The CPB Economic

Assessment Agency is currently examining various approaches to assess the costs and benefits of flexibility (Deltafact: Delta scenarios and adaptive Delta management, http://deltaproof.stowa.nl).

4.5 United Kingdom

4.5.1 Background

UK flood risk management institutions date back to the 19th century. In 1879, the UK Parliament passed the Flood Act, providing for flood walls to be constructed around London within the Thames tidal flood plain. Major floods in 1928 and 1953 led to the construction of the Thames Barrier east of the city. A series of floodgates and barriers prevent tidal flooding along the river prior to the Thames Barrier (Environment Agency, 2010).

More recently, significant flooding in 1998, 2000, 2005, 2007 and 2009 led successive UK Governments to review and improve risk management practices for flood and erosion damage around the country. Defra's 2004 **Making Space for Water** strategy laid out the national response to flood risk, signifying a paradigm shift from land drainage to reducing and managing risk from floods. Previous approaches to flood risk centred on centrally-funded drainage infrastructure and urban flood defence (Johnson and Priest, 2008). The 2004 guidance proposes a multi-level strategic analysis of flood risk management in the UK that considers environmental and social facets of flood damage, as well as adverse impacts on economic activity. It also takes a proactive approach to creating natural solutions to flood risk management, such as the expansion of existing wetland habitats and improvement of rural land management to better accommodate water levels (Department for Environment Food and Rural Affairs, 2004).

After flooding in the summer of 2007 caused the largest peacetime emergency since World War II, Sir Michael Pitt was commissioned to study the UK's flood risk management process. His review of existing procedures called for several reforms including improved flood modelling, wider capacity at the local council level for flood risk management and a general opening of attitudes around risk. This comprehensive review also cautioned that increased rainfall and extreme sea-level rise required that climate change impacts be seriously considered by the government, with its first recommendation that "the Government should give priority to both adaptation and mitigation in its programmes to help society cope with climate change." The review notes that the UK Environment Agency and Meteorological Office were world leaders in flood risk management and have highly advanced models and mapping technologies (see Figure 8) (Pitt, 2008).

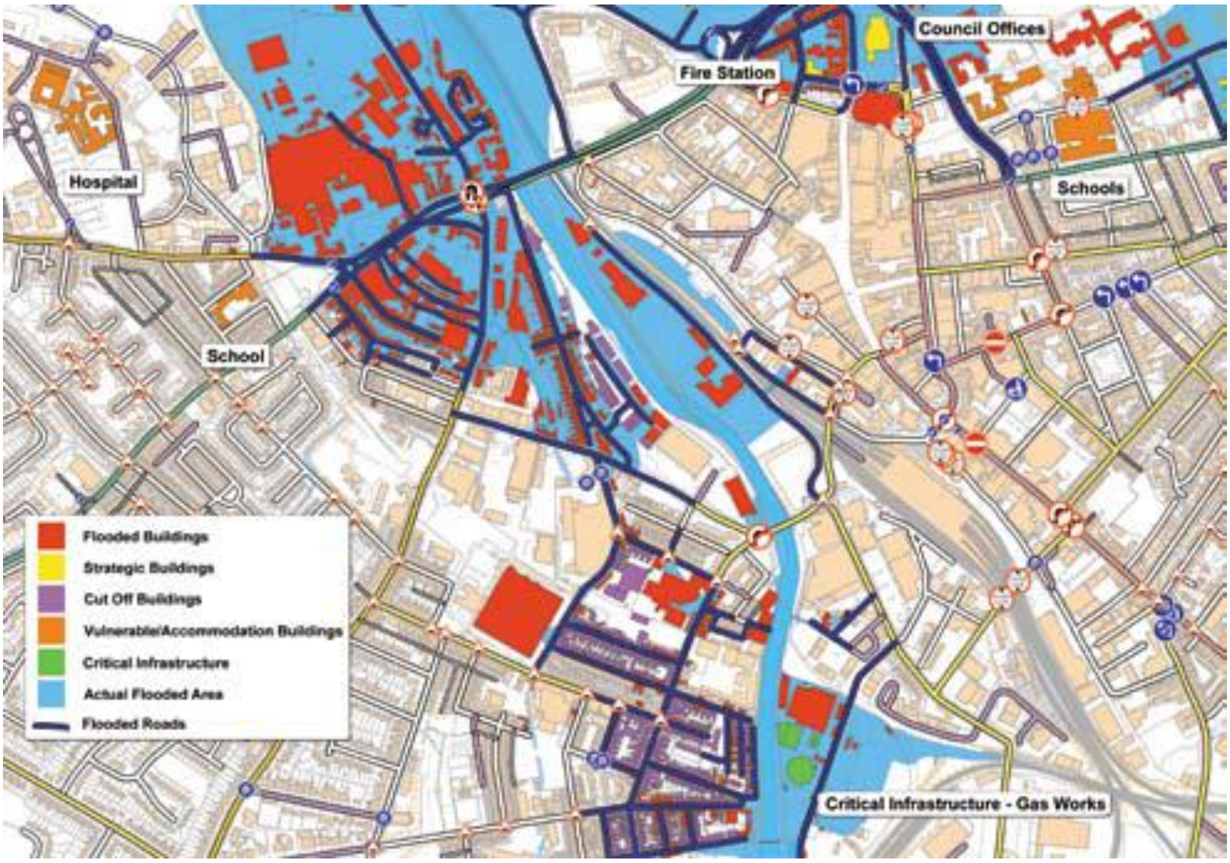


Figure 8. Example map from UK Environment Agency (Source: Ordnance Survey – Strategic Flooding Document 2007 © Environment Agency Licence A809)

The Department for Environment, Food and Rural Affairs (Defra) is responsible for flood and coastal erosion risk management and provides funding through grant in aid to the Environment Agency which also administers grant for capital projects to local authorities.

Within Defra, the Environment Agency is responsible for:

- understanding and planning for a changing climate;
- flood forecasting, warning and responding to floods;
- maintaining, renewing, improving and operating flood defences;
- overseeing the work on flood defences owned by others;

Regional/local authorities and Internal Drainage Boards are responsible for:

- planning for flood events by producing flood plans and recovery/continuity plans;
- dealing with the consequences of flooding such as humanitarian assistance, emergency housing and clear up operations;
- providing advice to local communities on what action they can take before, during and after a flood

These separate duties are not always distinct. For example, the Environment Agency operates Regional Flood Defence Committees that oversee flood defences on major waterways, while local authorities retain responsibility for managing flood risk on ordinary waterways and Internal Drainage Boards cover low-lying agricultural property.

NGOs, businesses and charities also play a role in managing flood risk. The National Flood Forum advocates on behalf of those at risk from flooding. The UK approach to flood risk management revolved around collaboration between stakeholders and implementing agencies at several levels.

Cuts in government spending in the UK have affected programmes aimed to reduce flood risk. While a special allocation was made to repair damages for floods in the winter of 2013-2014, overall funding for flood risk management in England fell by 10% from 2010-11 to 2013-2014 (House of Commons, 2015).

4.5.2 Decision-making on DRM projects and investments

UK policy on flood risk management is in line with **Directive 2007/60/EC** of the European Parliament and of the Council on the assessment and management of flood risks. This Directive requires member states to produce preliminary flood risk assessments, flood hazard and risk maps and flood risk management plans. Within the UK, these responsibilities are carried out by central Government for England and devolved to regional Governments in Scotland, Wales and Northern Ireland.

4.5.2.1 National level

National policy around flood risk management and climate variability is contained in the UK Treasury guidance for economic valuation and appraisal, known as the Green Book. The UK Government, specifically Her Majesty's Treasury (HMT), issued official guidance in 2009 for factoring in risk from climate change into project and programme appraisals in its Supplementary Green Book Guidance "Accounting for the Effects of Climate Change." These rules require consideration of risk and the effects of climate change for the following circumstances:

Where a project, programme or policy

- is affected by the weather and climate;
- has a long-term lifetime, implications or implementation periods;
- involves significant investment or high value at stake;
- provides or supports national infrastructure;
- involves significant irreversible impacts;
- has significant interdependencies with other Government activities or the wider economy; or
- addresses contingency planning or business continuity needs.

The UK Met Office offers the **UK Climate Impacts Programme** (UKCIP) climate projections in order to project impacts for 25X25 km grid areas around the UK, marine regions and river basins throughout the country. These projections are available for different scenarios of greenhouse gas emissions.

Risk assessments for Government appraisals are required to assess whether climate change will have direct, indirect or systemic impacts. The UKCIP Adaptation Wizard helps analysts assess vulnerability to climate change and suggests solutions to respond to projected impacts. In addition to direct impacts, risk assessments are directed to consider timing of a project, any threshold effects that may be triggered by an activity, international effects that may have a bearing on UK activities and flexibility in decision-making over the lifetime of a project.

According to the guidance, climate adaptation measures must be **effective** (the policy should reduce vulnerability to climate change), **efficient** (the benefits should outweigh the costs), and **equitable** (distributional consequences should be taken into account), per Government guidance. Measures to address uncertainty include incorporating decision flexibility over time, increasing resilience to climate scenarios and identifying low-cost solutions that deliver large benefits. To help value policy options under uncertainty, HMT guidance encourages the use of **Real Options Analysis** (ROA), which accounts for various decision paths and the likelihood of choosing any number of options. Appraisals are required to assess the suitability of ROA in initial risk assessments.

The **Environment Agency** has responsibility for managing risk from flooding from main rivers and the sea. This includes approving and funding flood risk management projects and studies undertaken by local authorities and drainage boards. As funding resources are limited, the Environment Agency uses economic appraisal methods to prioritise requests for grants.

Flood and erosion risk management projects in the UK must utilize **Flood and Coastal Erosion Risk Management** (FCERM) appraisal procedures developed by the Environment Agency. These procedures start with a risk-based approach considering the probability of a set of given outcomes. The following simple formula demonstrates the logic employed in this assessment:

risk = probability X consequence

The probability of property loss for a given town or community is calculated using a time- and frequency-based approach, where the likelihood of damage to a specific area grows over time or as the frequency of threatening events grows. Events that increase the source of risk, such as sea-level rise, or higher levels of rainfall, can be incorporated into this model.

The portfolio of flood management planning is comprised of a hierarchy of strategies. Figure 9 shows how these build on each other to form a risk management programme. This structure shows how high-level catchment and coastal plans must collaborate with a range of other environmental considerations. By requiring engagement with local stakeholders, the FCERM process balances strategic and local interests in project planning (HM Treasury, 2009).

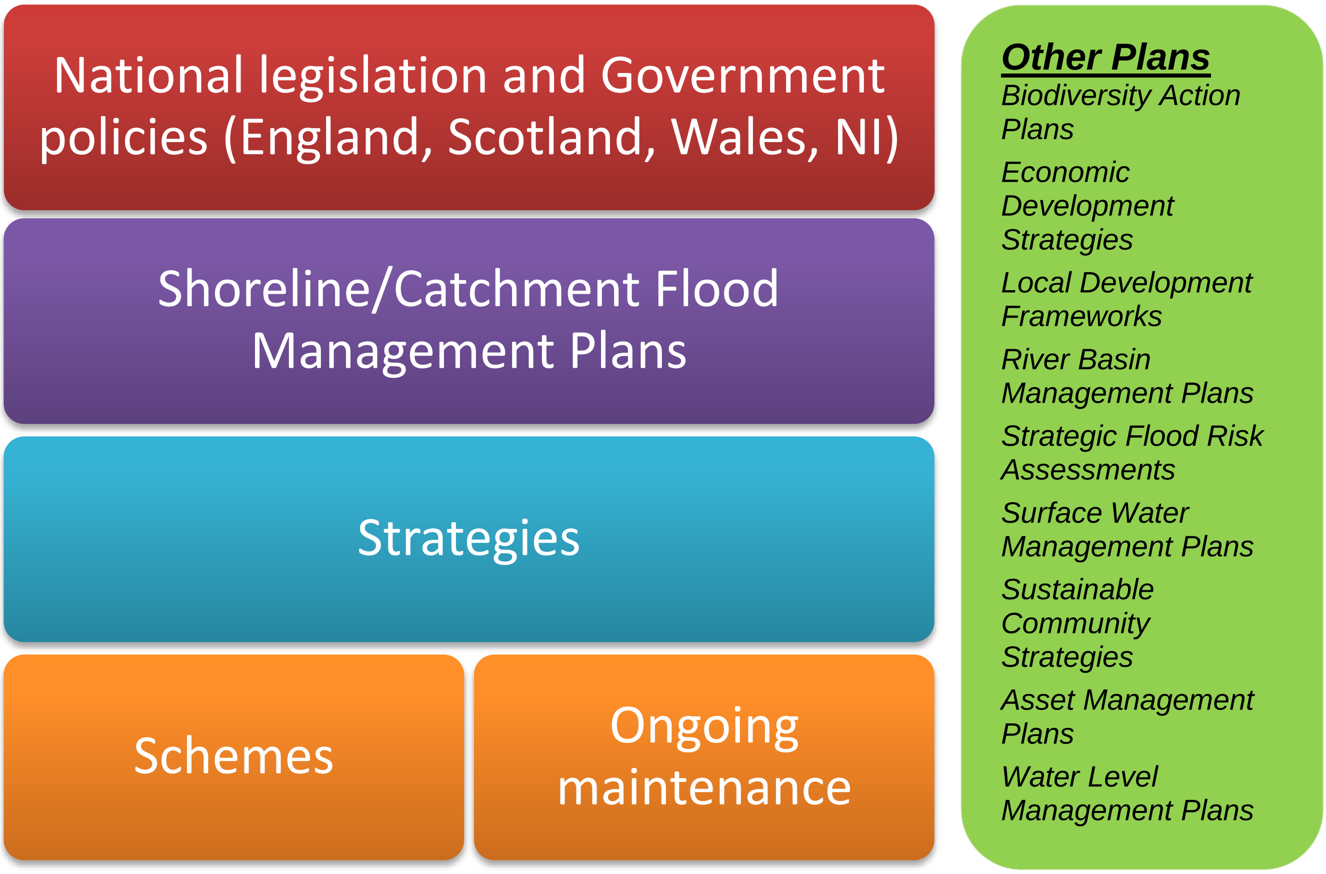
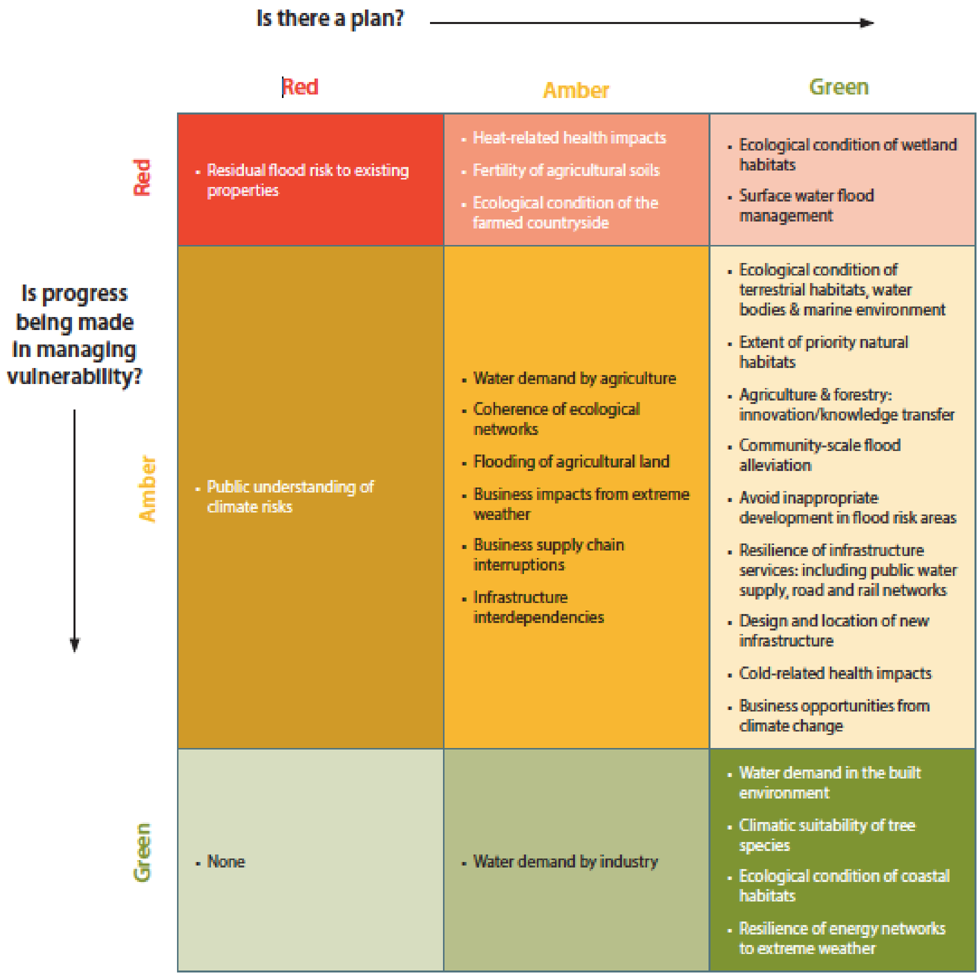


Figure 9. Portfolio of flood risk management planning (Source: Environment Agency, 2010)

Project appraisals are generally conducted via Cost Benefit Analysis (CBA), with Cost Effectiveness Analysis used when a legal requirement is present, if the project aims to sustain the present standard of service, or after CBA to establish the best option to accomplish a desired outcome.

In addition to incorporating climate risk into planning and project evaluation, continual review of progress against plans and milestones are essential for measuring progress of any risk management programme. The United Kingdom set up an independent technocratic committee to provide reliable guidance on climate policy. This **Committee on Climate Change** (CCC) produces regular reports on climate risk in the United Kingdom that serve to evaluate progress on policies and goals.

In 2015, the Adaptation Sub-Committee of the CCC reviewed the National Adaptation Programme, noting satisfactory progress but calling for greater ambition in the country's response to climate change. Within this review, the CCC developed an evaluation framework to measure progress on adaptation goals, evaluating **planning**, **implementation** and **vulnerability reduction** across sectors. The progress report calls for prioritisation in adaptation planning for the areas of water scarcity, flood risk, heat stress and natural capital.



Source: ASC assessment of policies and plans, and progress, in each area identified as an adaptation priority.
Notes: Adaptation priorities have been categorised as follows:
- Red: plans and policies do not exist or do not account for climate change, indicators of vulnerability are increasing.
- Amber: plans and policies partially address climate change risks, indicators of vulnerability show mixed progress.
- Green: plans and polices are in place that account for climate change, indicators of vulnerability are falling.

Figure 10. CCC evaluation of adaptation priorities (Source: Committee on Climate Change, 2015)

In an earlier review, the CCC found several shortfalls in the implementation of UK climate risk management efforts:

- After a major flood in 2012, the committee found that three quarters of existing flood defences were insufficiently maintained. Flood defence maintenance plans have been put on hold due to spending cuts on the local and national level;
- The risk assessment finds that water, transport and ICT infrastructure are all falling behind in planning for climate resiliency. Major projects include climate risk measures, but consideration of new transport routes is needed because research into climate impacts has not been conducted;
- While large companies are beginning to adopt climate-smart business practices, trends show narrow action without participation from small businesses;
- The UK's Heatwave Plan addresses public health risks from heatwaves, but essential building such as hospitals and care homes carry risk from overheating;
- Suffering from a paucity of evidence, the UK's emergency response planning seems to have yet to incorporate climate risk in planning for the future. This is a crucial area to build resilience in as climate impacts will require a nimble and ready emergency response system.

The Climate Change Committee will continue to produce annual progress reports on climate risk assessments and measures taken to manage this risk (Committee on Climate Change, 2014; 2015).

4.5.2.2 Regional level

Scotland passed the Flood Risk Management Act in 2009, which establishes the Scottish Environmental Protection Agency (SEPA) as the responsible party, under the direction of Government ministers, for managing flood risk. Flood risk management districts are set up around river basins to manage watershed-specific risks, for which SEPA prepares risk assessments. The legislation requires SEPA to include long-term developments, including any impact of climate change on the occurrence of floods within risk assessments. Each risk assessment must be reviewed every six years. SEPA is also required to develop management plans for those districts that are deemed to have risk of flooding (Parliament of Scotland, 2009).

Wales established its own national strategy for flood and coastal erosion risk management in 2011. This framework aims to reduce the consequences of flooding for communities and the environment, raise awareness of flood and coastal erosion risk, provide an effective and sustained response to floods and erosion events, and prioritise investment in the most at-risk communities. This strategy takes a similar shift as the central UK Government's Making Space for Water, shifting attention and resources to account for environmental damages and involving community members in raising awareness. Welsh Government guidance requires that responsible local and regional authorities maximise opportunities to adopt to climate change in flood risk management investments. This National Strategy is due for review and update in 2016 (Welsh Government, 2011).

Northern Ireland's 2009 Water Environment Regulations implement the floods directive in the country. The Northern Irish Department of Agriculture and Rural Affairs coordinate risk assessments and management plans for local authorities in Northern Ireland. Preliminary risk assessments are required to consider the likely impact of climate change on the occurrence of floods. Review of existing management plans is required by 2021 (Northern Irish Government, 2009).

4.5.2.3 Local level

Local authorities are permitted to undertake works on flood, sea and coastal defences where they are not the responsibility of the Environment Agency or internal drainage boards. The latter is responsible for action to reduce inland flooding in specific districts with special drainage needs. All projects receiving Environment Agency funding must follow FCERM appraisal guidelines as outlined above.

The National Planning Policy Framework, issued in 2012, requires that local planning authorities take full account of flood risk, coastal change and water supply and demand in their Local Plans. Development in areas of high flood risk is discouraged, with a sequential, risk-based approach applied to manage flood risk of any new development. Local flood risk management efforts must include:

- applying a Sequential Test which guides new developments to areas with the lowest probability of flooding;
- applying the Exception Test which requires that development in a zone with high flood risk have wider sustainability benefits to the community that outweigh flood risk and that the development will be safe for its lifetime, taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, will reduce flood risk overall;
- safeguarding land from development that is required for current and future flood management;

- using opportunities offered by new development to reduce the causes and impacts of flooding; and
- where climate change is expected to increase flood risk so that some existing development may not be sustainable in the long-term, seeking opportunities to facilitate the relocation of development, including housing, to more sustainable locations (Department for Communities and Local Government, 2012).

In Scotland, local authorities must submit flood risk management plans to SEPA for review and approval.

4.5.3 How is future climate change taken into account?

The Thames Estuary 2100 (TE2100) project serves as an example of how climate change plays a central role in flood risk management. TE2100 is a major review of options for managing flood risk in the Thames Estuary, which includes London and the south east of England. It is the first major flood risk project in the UK to put climate change adaptation at its core. The Environment Agency worked with the Met Office Hadley Centre to apply the latest science of climate change impacts to projects of impacts on the Thames estuary area.

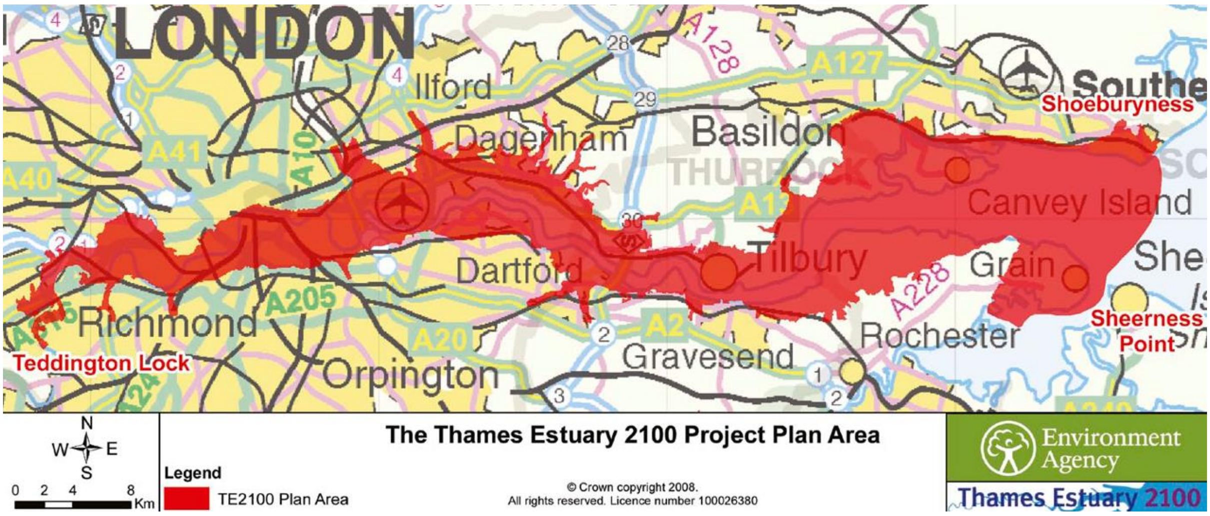


Figure 11. Study area for TE2100 project (Source: Environment Agency, 2012)

Climate change impacts are considered in TE2100 in impacts from sea level rise, uncertainty in systemic impacts, and increased winter rainfall. Impacts from climate change on the Thames estuary are expected to include a 20-90 cm sea level rise and increased rainfall of up to 40% by 2080. Flood risk is also evaluated with an eye towards aging infrastructure, environmental impacts from flooding and socio-economic impacts from flood events.

TE2100 commenced in 2002 and identified 23 geographic ‘policy areas’ to be assessed for flood risk through 2170. Using **Real Options Analysis**, the Environment Agency considered several different action options, from doing minimum maintenance on existing flood defence structures to constructing major new barriers and locks in the Thames to change the hydrology of the estuary.

Of note, **Multi-Criteria Analysis** was employed to quantify the impacts of various options that evaded monetary valuation. This approach quantified impacts of flooding and mitigation efforts on non-monetary measures such as water quality, damages to critical infrastructure, sense of community, etc. Once the impact of each option was determined on the 23 individual policy units, the Environment Agency was able to recommend the preferred course of action for a given geographic area. Estuary-level actions were considered in part on their efficiency for a group of policy units. This nuanced approach allowed the Government to chart a path of strengthening existing infrastructure through to 2034, in part because sea-level rise projects have been improved to show less of an increase in pressure on the Thames Barrier.

The ROA approach identified alternative infrastructure projects to be activated after a review of climate projections and existing circumstances in 2050. A regular 5-year review of the TE2100 plan will also allow for flexibility in decision making and informed management of flood risk in the area, even under great uncertainty.

To test the integrity of the options analysis under different **climate change scenarios**, costs and benefits were calculated over four different scenarios of possible sea level rise, from 0.5 metres to 2.7 metres of sea level rise by 2100. Sensitivity testing showed that higher levels of sea rise would move damages forward in time and increase the costs from flood damages. If sea levels rose to the highest scenario tested, total property damages from pursuing the top ranked action would be expected to rise as high as £3.5 billion, compared to £1.3 billion under the current models relied on by Defra (Environment Agency, 2009).

As climate change is expected to exert upward pressure on costs from flood damages in the Thames Estuary, sensitivity testing builds a stronger case for reducing the risk of damages and of updating appraisal values on options at regular time intervals. Significant feedback events such as ice sheet melts could lead to higher sea level rise than is projected in current models. Applying scenario testing shows the value of including model uncertainty in decisions around long-term flood risk management. With regular updates and reviews of models and appraisal data, the UK Government can ensure that the most efficient, effective and fair adaptation options are pursued over time.

5 Conclusions

This report examined DRM strategies of European countries with the aims of understanding how decisions are taken in the selection and design of DRM options at different scales, to examine how climate change, and its associated uncertainty, is or could be integrated into DRM strategies, and to draw lessons for decisions related to adaptation to climate change in Europe in general. The focus of choice is on disasters caused by floods.

A database of DRM investments for floods in Europe was constructed, containing 110 observations on investments/projects from 32 studies and databases, covering 16 European countries. In addition, detailed case studies of DRM policies were carried out in Austria, Czech Republic, The Netherlands and the United Kingdom.

The first conclusion is that for the assessment of long-term investments in flood protection infrastructures, most countries employ some form of cost-benefit analysis (CBA). However, other decision-making tools such as CEA, multi-criteria decision-making analysis (MCA), and Real Options Analysis (ROA) are also used, sometimes as substitutes, but in most cases, as complements. The Netherlands provide an interesting example where CBA - together with other tools – is used at the highest level of decision-making on flood protection standards, and where much more participatory and multi-criteria approaches are employed for local-level decisions on the actual design of flood control infrastructures. The use of CBA and participatory decision-making is supported by the EU Floods Directive. In practice, CBA tends to focus primarily on tangible costs and benefits such as avoided direct damage to buildings and infrastructure. In order to include intangible damages in the equation (human casualties, health, environmental damages, etc.), decision-makers often take recourse to some sort of MCA. MCA approaches can range from very simple (setting protection standards on the most stringent of four criteria such as in The Netherlands) to rather advanced (such as MCA optimisation methods used in the United Kingdom). ROA is not a substitute for CBA, but rather an extension. It has not yet entered the standard toolbox of project appraisal, but it offers interesting possibilities for the appraisal of complex, long-term investments in flood protection. As yet, there is no single superior decision-making tool to fit all circumstances. We found that there is growing recognition across Europe, also promoted by the EU Floods Directive, that participatory approaches to decision-making should be employed, whenever this is feasible.

The second conclusion is that DRM offers good value for money. Across European countries and across a wide variety of DRM investments, we observed a mean and median benefit-to-cost ratio of 5.9 and 3.0, respectively. So the return on DRM investments is high, even though intangible benefits are often not accounted for. These returns are high for investments in flood control, flood damage mitigation, as well as preparedness.

The third conclusion that we like to draw from the results of the research is that DRM provides a good entry point to examine the state of affairs with decision making on adaptation to climate change. Almost three-quarters of the assessments of DRM investments that we collected in our database pay attention to climate-change aspects (sea level rise, rising riverine flood risk, changing precipitation patterns, etc.). This attention starts around 2004 and the majority of studies after 2004 (80%) take climate-change impacts into account in one way or another. The way that climate change is taken into account differs across and within countries, depending on the specific context and decision-making level. The sophistication of the approaches ranges from simple updates of protection design standards based on one 'most-likely' scenario of future (climate) changes, to complex applications of 'Dynamic Adaptive Policy Pathways' (The Netherlands) and 'Real Options Analysis' (United Kingdom). The evidence suggests that the approaches have by no way settled yet: governments, government agencies and academic researchers are experimenting with approaches and are actively evaluating and developing the options. In this context, the European Commission has rightly argued that in investment projects, climate change-related risk management should be integrated into existing project lifecycle appraisal approaches to manage the additional risk from climate change. These existing approaches can vary between countries and sectors. From a practical perspective it is important that risk management approaches complement existing project appraisal processes but not replace them (European Commission, n.d.).

Because the research in this report focussed on flood risk management, we should be careful in generalizing the conclusions to investments in adaptation to climate change in general. The most obvious generalization would be to adaptation of long-lived infrastructures in general (for example also with respect to mitigating public health risks from heatwaves). In addition, the high returns of investments in preparedness seem to offer some evidence that investments in preparedness to other climate-related extreme events (heatwaves, storms, droughts) might also offer comparable returns. Decision-making approaches on adaptation investments in general can benefit from the methods and tools that we found are currently being used and that are currently being developed in existing DRM domains. Further work in this work package will build on the insights on DRM and adaptation decision-making identified in this report and help to inform the pan-European analysis of fiscal disaster risk and related DRM decisions as a response to future flood and drought risk.

6 References

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D. and Schütz,. H. (1997). Resource flows: The material basis of industrial economies. Washington DC: World Resources Institute.

Andersen, I.E. and B. Jaeger (1999). Scenario workshops and consensus conferences: Towards more democratic decision-making, *Science and Public Policy* 26(5): 331–340. DOI: 10.3152/147154399781782301.

Annema, J. A., Koopmans C., and van Wee, B. (2007). Evaluating transport infrastructure investments: The Dutch experience with a standardized approach. *Transport Reviews* 27 (2):125-50. DOI:10.1080/01441640600843237.

Ariyabandu, M.M. (2001). Bringing together disaster and development - concepts and practice, some experience from South Asia. Helsinki (28 August - 1 August September): Paper presented at the 5th European Sociological Association Conference.

Beros, M. (2013). EIB financing for flood protection. JASPERS Flood Management Best Practices Workshop. Brussels, September 17, 2013.

BMF (2014) Katastrophenfondsgesetz 1996. 10. Bericht des Bundesministeriums für Finanzen. Federal Ministry of Finance.

BMLFUW (2015) Flood control and individual precautions. Available at http://www.bmlfuw.gv.at/en/fields/water/Protection-against-natural-hazards/Floodcontrol.html. Accessed September 24, 2015.

BMLFUW (2015b) Richtlinie für Kosten-Nutzen-Untersuchungen im Schutzwasserbau. Available at: http://www.bmlfuw.gv.at/wasser/wasser-oesterreich/foerderungen/foerd_hochwasserschutz/knu_sw.html. Accessed September 24, 2015.

Bockarjova, M., Rietveld, P., and Verhoef, E. T. (2012). Composite valuation of immaterial damage in flooding: Value of stastical life, value of statistical evaluation and value of statistical injury. Amsterdam: Tinbergen Institute. TI Discussion Paper.

Bötger, E. and te Linde, A. (2014). Verschillende perspectieven op de nieuwe waterveiligheidsnormen (Different perspectives on the new water safety standards, In Dutch). Amersfoort: Twynstra Gudde/Kennis voor Klimaat.

Brans, J.P. and Vincke, P. (1985). A preference ranking organization method: The PROMETHEE method. *Management Science* 31: 647–656.

Bunderskanzleramt (2009) Administration in Austria. Available at: https://www.bka.gv.at/DocView.axd?CobId=41629. Accessed September 24, 2015.

Ceframe (2013). 531 Concept for national / regional implementation Central European Flood Risk Assessment and Management in CENTROPE. Available at: http://www.ceframe.eu/index.php?option=com_docman&task=doc_download&gid=316&Itemid=90. Accessed September 24, 2015.

City Council of Nijmegen (2012). Bestemmingsplan Nijmegen Ruimte voor de Waal (Development Plan Nijmegen Room for the Waal, in Dutch). Nijmegen.

Committee on Climate Change. (2014). Managing climate risks to well-being and the economy. Adaptation Sub-Committee Progress Report 2014. UK Government, Committee on Climate Change, London.

Committee on Climate Change. (2015). Progress in preparing for climate change. 2015 Report to Parliament. UK Government, Committee on Climate Change, London.

Czech Hydrometeorological Institute (2013): Vyhodnocení povodní v červnu 2013 - závěrečná souhrnná zpráva (Evaluation of flood in June 2013 - Final report). On-line. URL: http://voda.chmi.cz/pov13/SouhrnnaZprava.pdf.

Clar,C. and Steurer, R. (2014). Mainstreaming adaptation to climate change in a federal state setting: Policy changes in flood protection and tourism promotion in Austria? *Österreichische Zeitschrift für Politikwissenschaft*, 43 (1): 23-47.

de Jong, W. M. and Geerlings, H. (2003). Exposing weaknesses in interactive planning: The remarkable return of comprehensive policy analysis in The Netherlands. *Impact Assessment and Project Appraisal* 21 (4): 281-91. DOI: 10.3152/147154603781766149.

de Ridder, W., Turnpenny, J.,Nilsson, M., von Raggamby, A. (2007) A Framework for tool selection and use in integrated assessment for sustainable development. *Journal of Environmental Assessment Policy and Management* 9 (4): 423–441. DOI: 10.1142/S1464333207002883.

Deltacommissie (2008). Working together with water. A living land builds for its future. Delta Committee.

Delta Commissioner (2010). The 2011 Delta Programme. Working on the Delta. Investing in a safe and attractive Netherlands, now and in the future. The Hague: Ministry of Transport, Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality, Ministry of Housing, Spatial Planning and the Environment.

Delta Commissioner (2014). Deltaprogramma 2015. Werk aan de delta. De beslissingen om Nederland veilig en leefbaar te houden (Delta Programme 2015. Working on the delta. The decisions to keep the Netherlands safe and liveable, In Dutch). The Hague: Ministry of Infrastructure and Environment, Ministry of Economic Affairs.

Department for Communities and Local Governments. (2012). National planning policy framework. UK Government, Department for Communities and Local Government, London.

Department for Environment, Food and Rural Affairs. (2004). Making space for water: developing a new Government strategy for flood and coastal erosion risk management in England. UK Government, Department for Environment, Food and Rural Affairs, London.

Ebregt, J., Eijgenraam, C. J. J., and Stolwijk, H. J. J. (2005). Kosteneffectiviteitsanalyse van maatregelen en paketten: Kosten-batenanalyse voor Ruimte voor de Rivier, deel 2 (Cost-effectiveness analysis of measures and packages: Cost-benefit analysis of the Room for Rivers project, part 2, in Dutch). CPB Document 83. The Hague: CPB Economic Assessment Agency.

EFDRR (European Forum for Disaster Risk Reduction) (2013). How does Europe link DRR and CCA? Working paper by the Working Group on Climate Change Adaptation and Disaster Risk Reduction.

EIB (European Investment Bank) (2006). EIB Accelerated Flood Prevention. http://www.eib.org/projects/pipeline/2006/200602489 (accessed 9/23/2015).

Eijgenraam, C. J. J., Koopmans, C., Tang, P. J. G., and Vester A.C.P. (2000). Evaluation of infrastructural projects: Guide for cost-benefit analysis, Sections I and II. The Hague/Rotterdam: CPB/NEI (Ecorys).

Eijgenraam, C., Kind, J., Bak, C., Brekelmans, R., den Hertog, D., Duits, M., Roos, K., Vermeer, P. and Kuijken, W. (2014). Economically efficient standards to protect the Netherlands against flooding. *Interfaces* 44 (1): 7-21. doi.org/10.1287/inte.2013.0721.

ELLA (n.d.) Preventive flood management measures by spatial planning for the Elbe River basin. Results and proposed actions. ELBE-LABE .Availble at: http://www.landesentwicklung.sachsen.de/download/Landesentwicklung/ELLA_EN.pdf Accessed September 24, 2015.

Environment Agency (2009). TE2100 plan technical report appendix H: Appraisal in TE2100. UK Government, Environment Agency, Bristol.

Environment Agency (2010). Flood and coastal erosion risk management appraisal guidance. UK Government, Environment Agency, Bristol.

Environment Agency (2012). TE2100 plan. Managing flood risk through London and the Thames Estuary. UK Government, Environment Agency, Bristol.

European Commission (n.d.). Non-paper. Guidelines for project managers: Making vulnerable investments climate resilient. European Commission, DG Climate Action, Brussels.

European Commission (2004). Flood risk management. Flood prevention, protection and mitigation. COM(2004)472 Final. Brussels.

Finnveden, G, Nilsson, M., Johansson, J., Persson, Å., Moberg, Å. and Carlsson. T. (2003). Strategic environmental assessment methodologies—Applications within the energy sector. *Environmental Impact Assessment Review* 23(1): 91–123. DOI: 10.1016/S0195-9255(02)00089-6.

Fošumpaur, P. and Satrapa, L. (2011) Risk based evaluation of economical efficiency of flood control measures (p. 53-60). In: Fošumpaur, P. (ed.) Natural Hazards (Optunusatuib If Protection, Interaction with Structures). Prague: Czech Technical University in Prague, Faculty of Civil Engineering.

Genovese, E. (2006) A methodological approach to land use-based flood damage assessment in urban areas: Prague case study. European Commission Joint Research Centre. Luxembourg: Office for Official Publications of the European Communities.

Gersonius, B., Ashley, R., Pathinara, A., and Zevenbergen, C. (2013). Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change* 116 (2):411–423. DOI 10.1007/s10584-012-0494-5.

Gersonius, B., Ashley, R., Jeuken, A., Pathinara, A., and Zevenbergen, C. (2015). Accounting for uncertainty and flexibility in flood risk management: comparing Real-In-Options optimization and Adaptation Tipping Points. *Journal of Flood Risk Management* 8(2): 135-144. DOI:10.1111/jfr3.12083.

Haasnoot M., Middelkoop H., Van Beek E. and Van Deursen W. (2011). A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development*, 19 (6): 369–381. DOI: 10.1002/sd.438.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., and ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change* 23 (2), 485-498. DOI:10.1016/j.gloenvcha.2012.12.006.

Hahn, C. (2009) Austria: New start-up for flood control. Flood Prevention. Available at: http://www.aquamedia.at/fileadmin/user_upload/downloads/download_4753.pdf. Accessed September 24, 2015.

Hallegatte, S. and Przyluski, V. (2010). The economics of natural disasters: Concepts and methods. Policy Research Working Paper (No. 5507). Washington, D.C.: The World Bank.

Hawley, K., Moench, M. and Sabbag, L. (2012). Understanding the economics of flood risk reduction. A preliminary analysis. Boulder, CO.: Institute for Social and Environmental Transition – International.

Haskoning Nederland bv. (2010). Projectnota MER Dijkteruglegging Lent. Maatschappelijke Kosten/Baten Analyse (Project report EIA dike relocation Lent. Socail Cost/Benefit analysis, In Dutch). de Bel, Mark and Apon, Daisy. Nijmegen: Municipality of Nijmegen.

Hegger, D.L.T., Driessen, P.P.J., Dieperink, C., Wiering, M., Raadgever, G.T.T., and van Rijswick, H.F.M.W. (2014). Assessing stability and dynamics in flood risk management. *Water Resources Management* 28 (12): 4127:4142. DOI: 10.1007/s11296-014-0732-x.

Hembeleton-Hamann, C. (2007). Geomorphological hazards in Austria. In: Kellerer-Pirklbauer, A. (ed.)Geomorphology for the future. Innsbruck University pp.33-56.

Helmer, O. (1977). Problems in futures research. Delphi and casual cross-impact analysis. *Futures* 9(1), 17–31. DOI:10.1016/0016-3287(77)90049-0.

Hisschemöller, M. and Hoppe, R. (1995). Coping with intractable controversies: The case of problem structuring in policy design and analysis. *Knowledge and Policy* 8 (4): 40-60. DOI: 10.1007/BF02832229.

HM Treasury. (2009). Accounting for the effects of climate change: supplementary green book guidance. UK Government, HM Treasury, London.

Hornich, R. (2013). Actual status of the transportation of the Flood Directive in Austria. 6th Bulgarian-Austrian Seminar. Available at: http://uacg.bg/filebank/att_5907.pdf . Accessed September 24, 2015.

Hoss, F. (2010). A comprehensive assessment of Multilayered Safety (Meerlaagsveiligheid) in flood risk management. MSc thesis for the Technical University of Delft. Delft: Technical University of Delft.

Husby, T. G., de Groot, H.L.F., Hofkes, M.W. and Droës, M.I. (2014). Do floods have permanent effects? Evidence from the Netherlands. Journal of Regional Science 54 (3): 355-77. DOI: 10.1111/jors.12112.

ICPDR [International Commission for the Protection of the Danube River] (2014). Flood risk management plan for the Danube river basin district. Available at: http://wisa.bmlfuw.gv.at/dms/at-gv-bmlfuw-wisa/fachinformation/hochwasserrisiko/hochwasserrisikoplan/Entwurf_RMP/icpdr_frmp_2015.pdf?1=1. Accessed on 24 September 2015.

IPCC (Intergovernmental Panel on Climate Change) (2012). Managing the risks of extreme events and disasters to advance climate change adaptation (the SREX report). Cambridge and New York: Cambridge University Press.

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Science* 9(3): 251–273.

Johnson, C. L. and Priest, S. J. (2008). Flood risk management in England: a changing landscape of risk responsibility? *International Journal of Water Resources Development* 24 (4): 513-525. DOI: 10.1080/07900620801923146.

Jones, R.N. and Preston B.L. (2011). Adaptation and risk management. *Wiley Interdisciplinary Reviews: Climate Change* 2 (2): 296-308. DOI: 10.1002/wcc.97.

Keeney, R. and Raiffa, H. (1976). Decisions with Multiple Objectives: Preferences and Value Trade-Offs. New York: Wiley.

Kendík, T. and Březina, K. (2014). Průchod povodněv červnu 2013 vltavskou kaskádou (Vltava river cascade during the flood in June 2013). XXXIV. Priehradné dni 2014.

Kind, J.M. (2011). Maatschappelijke kosten-batenanalyse waterveiligheid 21e eeuw (Social cost-benefit analysis water safety 21th century, in Dutch). 1204144-006. Delft: Deltares.

Kind, J.M. (2014). Economically efficient flood protection standards for the Netherlands. *Journal of Flood Risk Management* 7 (2): 103-117. DOI: 10.1111/jfr3.12026

Kron, W. (2005), Flood Risk = Hazard • Values • Vulnerability, Water International, 30(1), 58-68.

Kørnøv, L. and Thisen W. A. H. (2000). Rationality in decision- and policy-making: Implications for strategic environmental assessment. Impact Assessment and Project Appraisal 18 (3): 191-200.

Kundzewicz, Z., Ulbrich, U., Brücher, T., Graczyk, D., Krüger, A., Leckebusch, G.C., Menzel, L., Pińskwar, I., Radziejewski, M. and Szwed, M.   (2005) Summer floods in Central Europe - Climate change track? *Natural Hazards* 36 (1): 165 - 189. DOI: 10.1007/s11069-004-4547-6

Kundzewicz, Z. W., Hirabayashi, Y. and Kanae, S. (2010) River floods in the changing climate - Observation and projection. *Water Resources Management* 24 (11): 2633-2646. DOI: 10.1007/s11269-009-9571-6.

Lebensministeirum (2006) Flood protection in Austria. Availble at: http://www.bmlfuw.gv.at/en/fields/water/Protection-against-natural-hazards/Floodcontrolaustria.html. Accessed September 24, 2015

Lebensministeirum (2013) The Austrian strategy for adaptation to climate change. Available at: http://www.bmlfuw.gv.at/umwelt/klimaschutz/klimapolitik_national/anpassungsstrategie/strategie-kontext.html. Accessed September 24, 2015.

Lindblom, C. E. (1990). Inquiry and Change. The Troubled Attempt to Understand and Shape Society. New Haven: Yale University Press.

Ministerstvo Životního Prostředí (2015) Voda, Available at: http://www.mzp.cz/cz/voda (Accessed: 20 May 2015).

Ministry of Infrastructure and the Environment (2012). KBA bij MIRT verkennningen (CBA for MIRT surveys). The Hague: DG Ruimte en Water.

Mouter, Niek. Cost-benefit analysis in practice: A study of the way Cost-Benefit Analysis is perceived by key individuals in the Dutch CBA practice for spatial-infrastructure projects. T2014/2. 2014. Delft, Delft University. TRAIL Thesis Series.

Mechler, R., & The Risk to Resilience Study Team. (2008). *The cost-benefit analysis methodology* (Risk to Resilience Working Paper No. 1). M. Moench, E. Caspari, & A. Pokhrel (Eds.). Kathmandu, Nepal: Institute for Social and Environmental Transition-Boulder, Institute for Social and Environmental Transition-Nepal, & Provention Consortium.

Mechler, R., Czajkowski, J., Kunreuther, H., Erwann, M.-K., Botzen, W., Keating, A., McQuistan, C., Cooper, N., O'Donnell, I. (2014). Making communities more flood resilient: The role of cost benefit analysis and other decision-support tools in disaster risk reduction. Zurich Flood Resilience Alliance. Available at opim.wharton.upenn.edu/risk/library/ZAlliance-decisiontools-WP.pdf.

Mechler, R. (2016). Reviewing estimates of the economic efficiency of disaster risk management: Opportunities and limitations of using risk-based Cost-Benefit Analysis. *Natural Hazards*, DOI: 10.1007/s11069-016-2170-y

MMC (2005). Natural hazard mitigation saves-: an independent study to assess the future savings from mitigation activities. Vol. 1 – Findings, conclusions, and recommendations. Vol. 2 – Study documentation, appendices. Multihazard Mitigation Council. Washington, D.C.: National Institute of Building Sciences.

Nachtnebel, H.P. (n.d.) Flood forecasting in Austria. Available at: https://iwhw.boku.ac.at/integratedflood/Nachtnebel_Module3_Floodforecasting_Austria.pdf. Accessed September 24, 2015.

Northern Irish Government. (2009). The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009. Northern Irish Government, Department of Agriculture and Rural Affairs, Belfast.

Okuyama, Y. and Sahin, S. (2009). Impact estimation of disasters: A global aggregate for 1960 to 2007. Policy Research Working Paper (No. 4963). Washington, D.C.: The World Bank.

Parliament of Scotland. (2009). Flood Risk Management (Scotland) Act 2009. Scottish Government, Edinburgh.

PBL and Deltares (2011). Deltascenario's. Verkenning van mogelijke fysieke en sociaaleconomische ontwikkelingen in de 21ste eeuw op basis van KNMI'06 en WLO scenario's voor gebruik in het Deltaprogramma 2011-2012. (Delta scenarios. Exploration of possible physical and socio-economic developments in the 21st century on the basis of KNMI'06 and WLO scenarios for use in the Delta Programme 2011-2012, in Dutch). Report 1205747-000, Delft: Deltares.

Pearce, D, Atkinson, G. and Mourato, S. (2006). Cost-benefit analysis and the environment — Recent developments. Paris: Organisation for Economic Co-Operation and Development (OECD).

Pitt, M. (2008). The Pitt review: learning lessons from the 2007 floods. UK Government, Cabinet Office, London.

Rayner, T. and Kuik, O. (2010). Draft appraisal methods inventory. D2.2. of the RESPONSES project – European responses to climate change (contract number 244092).

Romijn, G. and Rennes, G. (2013). Algemene leidraad voor maatschappeijke kosten-batenanalyse (General guidelines for social cost-benefit analysis, in Dutch). The Hague: CPB/PBL.

Roovers, G..(2012). De systeembenadering van professionals als drager van de besluitvorming in het rivierbeheer. Dissertation. Delft: Technische Universiteit Delft.

Schröter, K., Ostrowski, M., Quintero, F., Corral, C., Velasco-Forero, C., Sepere-Torres, D., Nachtnebel, H.P., Kahl, B., Beyene, M., Rubin, C. and Gocht, M. (2008). Effectiveness and efficiency of early warning systems for flash-floods (EWASE). CRUE Research Report 1-5. www.crue-eranet.net.

Scussolini, P., Kaprová, K., Melichar, J., Sainz de Murieta, E. and Galarraga, I. (2015). Economics of adaptation to climate-change: Policy and decision context of case studies. Deliverable 6.1 of the EU FP7 ECONADAPT study. Bath: University of Bath.

Smith, K. (1996). Environmental Hazards: Assessing Risk and Reducing Disaster. Second Edition. Routledge, London, UK.

Shreve, C.M. and Kelman, I. (2014). Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction. *International Journal of Disaster Risk Reduction* 10 (x): 213-235. doi.org/10.1016/j.ijdrr.2014.08.004.

Sklenář, P., Zeman , E., Špatka, J. and Tachecí P. (2006). Flood modelling concept and reality - August 2002 flood in the Czech Republic (pp. 155-170). In: Marsalek J. et al. (eds.). Transboundary floods: Reducing risks through flood management. Dordrecht: Springer.

Srinivas, N. and Deb, K. (1994) Multi-Objective function optimization using non-dominatedsorting genetic algorithms, *Evolutionary Computation*, 2(3):221–248. DOI: 10.1162/evco.1994.2.3.221.

Stagl, S. (2007) SDRN Rapid Research and Evidence Review on Emerging Methods for Sustainability Valuation and Appraisal: A report to the Sustainable Development Research Network, Final Report.

Stiefelmeyer, H. and Hlatky, T. (2008). HORA-An Austrian platform for natural hazards as a new way in risk communication. Interpraevent 2008 Conference Proceedings Vol 1. Pp. 229-236. Available at: http://www.interpraevent.at/palm-cms/upload_files/Publikationen/Tagungsbeitraege/2008_1_229.pdf. Accessed September 24, 2015.

Thieken, A.H., Cammerre, H., Dobler, C., Lammel, J. and Schöberl, F. (2014). Estimating changes in flood risks and benefits of non-structural adaptation strategies- a case study from Tyrol, Austria. *Mitigation and Adaptation Strategies for Global Change* (published online 31 October 2014): DOI 10.1007/s11027-014-9602-3.

Timonina, A., Mechler, R., Williges, K. and Hochrainer-Stigler, S. (2013). Deliverable 2.1: Catalogue and toolbox of risk assessment and management tools. ENHANCE (Enhancing Risk Management Partnerships for Catastrophic Natural Disasters in Europe).

Tinbergen, J. (1961). De economische balans van het Deltaplan (Balance sheet of the Delta Plan, in Dutch). Report of the Delta Committee, pages 63-74.

Welsh Government. (2011). National strategy for flood and coastal erosion risk management in Wales. Welsh Government, Cardiff.

Wooning, A. (2007). OEI bij SNIP. Lelystad: RWS RIZA.

Tol, R.S.J. and Langen, A. (2000). A concise history of Dutch river floods. *Climatic Change* 46 (3): 357-369. DOI:10.1023/A:1005655412478.

Toothill, J. (2002) Central European flooding. An EQECAT Technical Report. Houston TX.: ABS Consulting.

UK Government (2012). Foresight reducing risks of future disasters: Priorities for decision makers. Final Project Report. The Government Office for Science, London, UK.

van Asselt, M.B.A. and Rijkens-Klomp, N. (2002). A look in the mirror: Reflection on participation in Integrated Assessment from a methodological perspective. *Global Environmental Change* 12(3): 176–184. DOI:10.1016/S0959-3780(02)00012-2.

van Dantzig, D. (1956) Economic decision problems for flood prevention. *Econometrica* 24: 276-87.

Van den Hurk B.J.J.M., Tank A.M.G.K., Lenderink G., van Ulden A., van Oldenborgh G.J., Katsman C., van den Brink H., Keller F., Bessembinder J., Burgers G., Komen G., Hazeleger W. and Drijfhout S. (2007) New climate change scenarios for the Netherlands. Water Science & Technology 56, (4), 27–33. DOI:10.2166/wst.2007.533.

van der Heijden, K. (2005). Scenarios: The Art of Strategic Conversation. New York: John Wiley.

van Rijswick, M., van Doorn-Hoekveld, W., Gilissen, H.K., Keessen, A. and Wiering, M. (2015). Shifts in floods policies in the Netherlands. *H2O magazine*, May 2015, http://www.h2o.net/magazine/catastrophes-catastrophes-naturelles/shifts-in-floods-policies-in-netherlands.htm.

Williges, K., Mechler, R., van Slobbe, E., Werners, S., Migliavacca, M., and others (2013). Improved methods and metrics for assessing impacts vulnerability, and risk management, IIASA, Technical report D 2.4.

Database

Ballesteros-Cánovas, J.A., Sanchez-Silva, M., Bodoque, J.M. and Díez-Herrero, A. (2013). An integrated approach to flood risk management: A case study of Navaluenga (Central Spain). *Water Resources Management* 27 (8): 3051-3069. DOI: 10.1107/s11269-013-0332-1.

Boettle, M., Rybski, D. and Kropp, J.P. (2013). Adaptation to sea level rise: Calculating costs and benefits for the case study Kalundborg, Denmark. In: Schmidt-Thomé, P. and Klein, J.

(eds.). *Climate change adaptation in practice: From strategy development to implementation* (pp. 25-34). Hoboken NJ: John Wiley & Sons Ltd.

Förster, S., Kneis, D., Gocht, M., Bronstert, A. (2005). Flood risk reduction by the use of retention areas at the Elbe River. *International Journal of River Basin Management* 3 (1): 21-29. DOI: 10.1080/15715124.2005.9635242.

Fošumpaur, P. and Satrapa, L. (2011). Risk based evaluation of economical efficiency of flood control measures (p. 53-60). In: Fošumpaur, P. (ed.) Natural Hazards (Optunusatuib If Protection, Interaction with Structures). Prague: Czech Technical University in Prague, Faculty of Civil Engineering.

Fuchs, S., Thöni, M., McAlpin, M.C., Gruber, U., Bründl, M. (2007). Avalanche hazard mitigation strategies assessed by cost effectiveness analyses and cost benefit analyses – Evidence from Davos, Switzerland. *Natural Hazards* 41 (1): 113-129. DOI 10.1007/s11069-006-9031-z.

Gersonius, B., Ashly, R., Pathirana, A. and Zevenbergen, C. (2013). Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change* 116 (2): 411-423.

Gersonius, B., Morselt, T.,van Nieuwenhuijzen,, L., Ashley, R. and Zevenbergen, C. (2012). How the failure to account for flexibility in the economic analysis of flood risk and coastal management strategies can result in maladaptive decisions. *Journal of Waterway, Port, Coastal, and Ocean Engineering* 138: 386-393.

Gocht, M. (2004). Nutzen-Kosten-Analyse. In: Bronstert, A. (ed.). Möglichkeiten zur Minderung des Hochwasserrisikos durch Nutzung von Flutpoldern an Havel und Oder (pp. 173-181). Brandenburgische Umwelt Berichte 15. Potsdam: Mathematisch-Naturwissenschaftlichen Fakultät der Universität Potsdam.

Grontmij Nederland bv (2007). MER Gebiedsontwikkeling Perkpolder. Middelburg/Eindhoven.

Holub, M. and Fuchs, S. (2008). Benefits of local structural protection to mitigate torrent-related hazards. *WIT Transactions on Information and Communication Technologies* 39: 401- 411. DOI: 10.2495/RISK080391.

House of Commons. (2015). Forty-eigth report of session 2014-15 of House of Commons Committee of Public Accounts: strategic flood risk management. UK Parliament, House of Commons, Westminster.

Jha, A.K., Bloch, R. and Lamond, J. (2012). Cities and flooding. A guide to integrated urban flood risk management for the 21st Century. Washington D.C.: The World Bank.

Kontogianni, A., Tourkolias, C.H., Damigos, D. and Skourtos, M. (2014). Assessing sea level rise costs and adaptation benefits under uncertainty in Greece. *Environmental Science & Policy* 37: 61-78. DOI: 10.1016/j.envsci.2013.08.006.

Larsson, J. (2012). Assessment of flood mitigation measures. Further development of a proactive methodology applied in a suburban area in Gothenburg. Master of Science Thesis in Master's Programme Geo and Water Engineering. Gothenburg: Chalmers University of Technology.

OPW, Cork City Council and Cork County Council (2010). Lee catchment flood risk assessment and management study. Draft catchment flood risk management plan. Cork: Office of Public Works (OPW), Cork City Council and Cork County Council.

PBL and Deltares (2011). Deltascenario's. Verkenning van mogelijke fysieke en sociaaleconomische ontwikkelingen in de 21e eeuw op basis van KNMI'06 en WLO scenario's voor gebruik in het Deltaprogramma 2011-2012 (Delta scenarios. Exploration of possible physical and socio-economic development in the 21th century on the basis of KNMI'06 and WLO scenarios for use in the Delta programme 2011-2012). Deltares

Porthin, M., Rosqvist, T., Perrels, A. and Molarius, R. (2013). Multi-criteria decision analysis in adaptation decision-making: A flood case study in Finland. *Regional Environmental Change* 13 (6): 1171-1180. DOI: 10.1007/s10113-013-0423-9.

Poussin, J.K., Botzen, W.J.W. and Aerts, J.C.J.H. (2015). Effectiveness of flood damage mitigation measures: Empirical evidence from French flood disasters. *Global Environmental Change* 31: 74-84. DOI: 10.1016/j.gloenvcha.2014.12.007.

Projectconsortium MKBA Sigmaplan (2005). Sigmaplan: Maatschappelijke Kosten-Batenanalyse. Syntheserapport 4024-060. Antwerpen: Projectconsortium MKBA Sigmaplan p/a Resource Analysis.

Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A. and Ruta, G. (2010). Adaptation in the UK: a decision-making process. London, UK: Grantham Research Institute on Climate Change and Environment and Centre for Climate Change Economics and Policy.

Saint-Geours, N., Grelot, F., Bailly, J.-S. and Lavergne, C. (2015). Ranking sources of uncertainty in flood damage modelling: a case study on the cost-benefit analysis of a flood mitigation project inthe Orb Delta, France. Journal of Flood Risk Management 8 (2): 161-176. DOI: 10.1111/jfr3.12068.

Schröter, K., Ostrowski, M., Quintero, F., Corral, C., Velasco-Forero, C., Sepere-Torres, D., Nachtnebel, H.P., Kahl, B., Beyene, M., Rubin, C. and Gocht, M. (2008). Effectiveness and efficiency of early warning systems for flash-floods (EWASE). CRUE Research Report 1-5. www.crue-eranet.net.

Thompson, P.M., Wigg, A.H. and Parker, D.J. (1991). Urban flood protection post-project appraisal in England and Wales. *Project Appraisal* 6 (2): 84-92.

Woodward, M., Kapelan, Z. and Gouldby, B. (2014). Adaptive flood risk management under climate change uncertainty using Real Options and optimization. *Risk Analysis* 34 (1): 75-92. DOI: 10.1111/risa.12088.

Zhou, Q., Panduro, T.E., Thorsen, B.J. and Arnbjerg-Nielsen, K. (2013). Adaptation to extreme rainfall with open drainage system: An integrated hydrological cost-benefit analysis. *Environmental Management* 51 (3): 586-601. DOI 10.1007/s00267-012-0010-8.

Annex A. Some alternative classifications of DRM measures in flood risk management.

	EU Floods Directive	Dutch Multilayered Safety (Hoss 2010)	Hegger 2014	Hawley et al. 2012
Flood defense/structural and non-structural flood control			Infrastructural works, such as dikes, dams, embankments and weirs, upstream retention or giving more space to the river within its current embankments ("keeping water away from people")	Dams, dikes, flood diversion, levee, drainage, embankment, restoration of flood plain
Prevention	Preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas	Preventing river or seawater from inundating areas that are usually dry. When talking about a dike ring, this refers to preventing water from entering the dike ring.	Proactive spatial planning or land use policies ("keeping people away from water"), aimed at building only outside areas that are prone to flooding.	
Protection	Structural and non-structural measures to reduce the likelihood of floods and/or the impact of floods in a specific location			
Exposure reduction and property modification				Flood-proofing, zoning, building regulations, voluntary purchase
Mitigation			Smart design of the flood-prone area. Measures include spatial orders, constructing flood compartments, or	

	EU Floods Directive	Dutch Multilayered Safety (Hoss 2010)	Hegger 2014	Hawley et al. 2012
Spatial solutions		Spatial planning and adaption of buildings that proactively counter floods	(regulations for) flood-proof building	
Preparation/preparedness/ behavioral response modification	Informing the population about flood risks and what to do in the event of a flood		Measures include developing flood warning systems, preparing disaster management and evacuation plans and managing a flood when it occurs	Forecast and early warning system, preparedness
Emergency response/Crisis management	Developing emergency response plans in the case of a flood		Disaster plans, risk maps, early-warning systems, evacuation, temporary physical measures such as sand bags, medical help and so on	
Recovery	Returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population		Measures include reconstruction or rebuilding plans as well as compensation or insurance systems	

Sources: European Commission, 2004; Hoss, 2010; Hegger et al. 2014; Hawley et al. 2012.