CONHAZ

Costs of Natural Hazards

IVM Institute for Environmental Studies

universität innsbruck

CSC Climate Service Center Germany

# Methodology report on costs of mitigation

L.M. Bouwer[1], J. Poussin[1], E. Papyrakis[1], V.E. Daniel[1], C. Pfurtscheller[2], A.H. Thieken[3], and J.C.J.H. Aerts[1]

[1] Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam; [2] Institute of Geography, University of Innsbruck; [3] Climate Service Center, Helmholtz Zentrum Geesthacht

| | |
|---|---|
| **Date** | **September 2011** |
| Report Number | **WP4 Final Report** |
| Location | **IVM** |
| Deliverable Number | **D 4.2** |
| Due date for deliverable | **September 2011** |
| Note | **Public** |

## Document information

| | |
|---|---|
| **Title** | **Methodology report on costs of mitigation** |
| **Lead Author** | L.M. Bouwer |
| **Contributors** | J. Poussin, E. Papyrakis, V.E. Daniel, C. Pfurtscheller, A.H. Thieken, and J.C.J.H. Aerts |
| **Distribution** | Public |
| **Document Reference** | WP04_2 |

## Document history

| Date | Revision | Prepared by | Organisation | Approved by | Notes |
|---|---|---|---|---|---|
| 31-08-2010 | 1 | Laurens Bouwer | VU | | First draft |
| 12-08-2011 | 2 | Laurens Bouwer | VU | | Final draft |
| 12-09-2011 | 3 | Laurens Bouwer | VU | UFZ | Final version |

## Acknowledgement

The work described in this publication was supported by the European Community's Seventh Framework Programme through the grant to the budget of the Coordination Action CONHAZ, Contract 244159.

## Disclaimer

This document reflects only the authors' views and not those of the European Community. This work may rely on data from sources external to the CONHAZ project Consortium. Members of the Consortium do not accept liability for loss or damage suffered by any third party as a result of errors or inaccuracies in such data.

## Abstract

This report provides the results from a study into the cost of mitigation measures for the reduction of natural hazard risks in European Member States. The mitigation measures considered are aimed at reducing risks from droughts, floods, storms and induced coastal hazards, and alpine hazards. A framework is proposed to classify nine types of mitigation measures, that includes: management plans, land-use planning and climate adaptation; hazard modification; infrastructure; mitigation measures (stricto sensu); communication, in advance of the events; monitoring and early warning systems; emergency response and evacuation; financial incentives; and risk transfer. Costs of mitigation that are considered are direct costs related to research and design, set-up, and operation and maintenance costs of mitigation measures, but also indirect and intangible costs (co-costs) as well as co-benefits are explored.

Through case studies an overview is provided of approaches and examples of the costing of these types of mitigation measures. It is found that costing of mitigation measures has almost exclusively focused on estimating direct costs. The major recommendation from this work is to further investigate European actions and approaches for the costing of mitigation (and adaptation). This could include a full overview of costs and actual investments of national, regional and local actions on mitigation; to further assess approaches to costing of mitigation, including indirect and intangible costs; and a stakeholder process to gain insight on which costs are important to consider in the evaluation of mitigation measures. More evidence should be made available that provide handles for government to decide on action. Also, comprehensive cost-benefit analyses of monitoring and early warning, and emergency response systems are needed to support their wider application. Finally, more holistic frameworks that address a range of costs (and benefits) would better support government motivation to undertake mitigation actions.

**Contact persons for WP4**

Laurens Bouwer (Vrije Universiteit), laurens.bouwer@ivm.vu.nl

Annegret Thieken (HZG), annegret.thieken@hzg.de

## Table of contents

# 1 Introduction

## 1.1 Mitigation of natural hazard risk

With regard to natural hazards, risk is often defined as a loss that will occur or will be exceeded with a given probability, while hazard addresses the probability and intensity of the natural processes that lead to potentially damaging situations in a given area and within a specified period of time. Changes in risk or losses over time can be caused by changes in hazard frequency or severity/intensity, for instance through climate change or changes in river basins in the case of floods, or because the numbers of people and assets at risk are increasing, i.e. an increased exposure and/or susceptibility to a hazardous situation. In this context exposure analysis answers the question "Who or what will be affected by a given hazardous situation?". Exposure can be quantified by the number or the value of elements which are at risk. Analysis of susceptibility answers the question "How will the exposed elements be affected or damaged?".

Since many natural hazards that threaten society cannot be avoided or minimised, or are becoming more frequent or damaging to the economy, it is increasingly recognised that the reduction of the consequences of these hazards requires more attention (Board on Natural Disasters, 1999; ISDR, 2005; European Commission, 2009b). This reduction of natural hazard risk is usually referred to as *mitigation* (not to be confused with mitigation of climate change; which refers to the reduction of sources or enhancement of sinks of greenhouse gasses.

The ConHaz project recognises four types of costs of natural hazards: direct, indirect and intangible costs, as well as mitigation costs. As fourth type, the costs for mitigating risk can be regarded as part of the total costs of natural hazards.

Principally, mitigation refers to damage reducing measures. The UN International Strategy for Disaster Risk Reduction (UN-ISDR) defines mitigation as[1]:

*"The lessening or limitation of the adverse impacts of hazards and related disasters".*

In some sense, mitigation is more narrowly defined than risk reduction, as the latter includes a broader range of approaches, including hazard prevention (causal factors). According to UN-ISDR, risk reduction is defined as:

*"The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events".*

In this report, we use the terms mitigation and risk reduction interchangeably. The term "mitigation measures (stricto sensu)", however, is used exclusively for measures that physically reduce

[1] See UN-ISDR Terminology of disaster risk reduction; http://www.unisdr.org/eng/terminology/terminology-2009-eng.html

the impacts. We provide a classification for different mitigation activities below, in order to indicate how they fit into different approaches to disaster risk reduction.
Disaster risk reduction and loss mitigation are parts of a risk management strategy, which is understood as a systematic process to implement policies, strategies and measures to lessen the impacts of natural hazards on a society and to improve coping capacities of affected communities. Risk management comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards (ISDR 2004). It is often seen as a cycle, as illustrated in Fig. 1, and consists of 1) disaster response during or immediately after a hazardous event, 2) recovery, and 3) disaster risk reduction, which is primarily aimed at preventing and mitigating damage. To enhance risk reduction, the disastrous event, the society's response as well as the performance of existing preventive and precautionary measures should be analysed in the aftermath of an event in the framework of a risk and an event analysis (Kienholz et al., 2004). This cycle of disaster/risk management has been increasingly used by international and national organisations and various versions have been published (e.g. PLANAT, 1998; Silver, 2001; DKKV, 2003; FEMA, 2004; Kienholz et al., 2004).

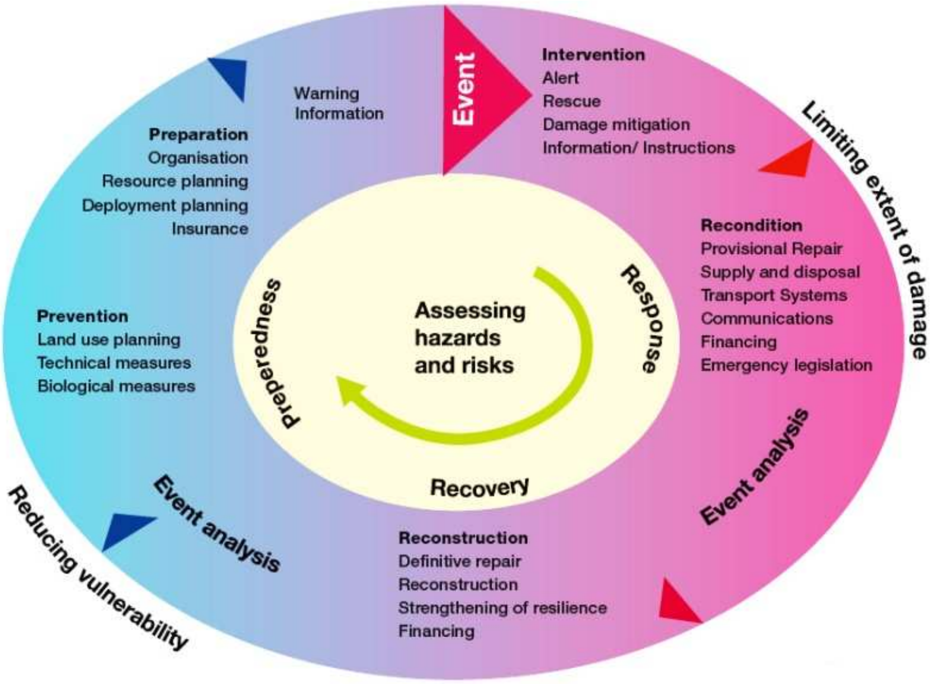



*Figure 1: The circle of integrated risk management; source: Federal Office for Civil Protection and Natural Hazards in Switzerland (PLANAT).*

Given limited resources for investments in mitigation, estimates of economic costs and benefits are needed in order to decide on the effectiveness and appropriateness of mitigation. Although many studies highlight the possibilities for studying costs and benefits (Benson and Twigg, 2004;

Brouwer and Van Ek, 2004; DFID, 2005; Mechler, 2005), there still is a lack of methods that are generally applicable for the evaluation of disaster mitigation and response strategies. Usually, particular frameworks and economic valuation methods are applied to specific types of natural disasters, for instance floods or storms.

An important aspect to consider is the role of different regulatory, legal and governance frameworks that exist in different European countries. Depending on the type of approach, communities may decide to grant different levels of government the competence over disaster risk management. This may for instance be a strong role for local government in disaster management (e.g. in Switzerland), or a strong central role (e.g. France and The Netherlands). These roles have important implications for the level at which decisions are being taken on risk mitigation, and also at which scale policies and measures are being evaluated. Using different cases explaining the costs of mitigation later in this report, we will show that the scales and levels of government vary, and the assessments of costs therefore consequently involve different approaches and scopes.

Furthermore, households can take private initiatives to reduce losses from natural hazards, and these complement government actions aimed at preventing and reducing impacts. Various methods have been developed to assess potential willingness of households to prevent losses and to comprehensively assess benefits, including contingent valuation and choice modelling (e.g., Louviere et al., 2000) and other valuation methods.

## 1.2 The role of climate change and adaptation policies

There is an increasing notion that because of climate change risks from natural hazards (extreme weather and consecutive impacts) could increase in many parts of the world. For instance, drought events are projected to increase, especially in the south of Europe and around the Mediterranean region. With increasing precipitation, the potential for flash floods and river flooding increases all around Europe. Linked to the rise of the global average temperature, the occurrence of alpine hazards could increase or decrease depending on the zones studied (OECD 2007). For windstorms, there is no clear expectation of the kind of changes in storm frequency or intensity that could occur. However, some studies point to a general increase in frequency of winter storms over Europe (Leckebusch et al., 2007; ABI, 2009; Schwierz et al., 2010). Generally, it is expected that storm tracks could shift northward, leading to a decrease in storm activity over south and middle Europe, and an increase over northern Europe. In addition, because of sea-level rise, coastal flood risk due to storm surges could increase. Therefore adaptation to increasing climate risks is needed. The European Commission issued its White Paper on Adaptation in 2009, which includes attention for increasing natural disaster risk, within Europe and other countries (European Commission, 2009b). The White Paper states that reducing risk needs to be achieved through

*"(s)trategies focused on managing and conserving water, land and biological resources to maintain and restore healthy, effectively functioning and climate change-resilient ecosystems (...)"*

The White Paper on Adaptation (EU, 2009b) further describes adaptation as a long and continuous process. Risk reduction as a continuous task has also been defined in other legislative documents, including the EU Floods Directive. This reflects the need to take a dynamic approach, rather than fixed targets for risk reduction, which accommodates concern that increasing risks are considered, such as those from climate change as well as other processes that lead to increasing exposure, including increasing population in vulnerable areas and increasing value of assets at risk.

A number of countries have already been advancing on adaptation plans, that often include plans to reduce risk from natural hazards, and these will be discussed later in the report.

## 1.3 General classification of mitigation activities

In order to structure actions on risk mitigation and their costs, we have adopted a classification of different types of mitigation measures. This classification (Table 1) is based on a clear distinction between mitigation measures that focus on hazard reduction or vulnerability reduction. In addition, measures may be discriminated on the basis of the involvement of technical or engineering solutions, legal, communication or economic instruments. Note that in principal any measure will likely involve or make use of specific technical/engineering solutions, and legal and economic instruments; but all actual measures often depend on a single category.

Table 1 shows the different categories of mitigation measures we defined for this project. The classification presented in this table is based on literature and discussions between the authors of this section based on the answers provided by the partners of the project and participants in the workshop series. Other literature has provided slightly different classifications, for instance EC (2008b) with seven classes (e.g. early warning, risk mapping, spatial planning, building codes, education and awareness, exchange of information on best practices, emergency plans and exercises) is rather close to our classification. Annex 1 includes a series of examples from different countries that have been collected throughout the ConHaz project. These are meant as further illustrations for these measures.

It is important to note that these categories in Table 1 can partially overlap. The first category contains risk management planning and adaptation plans. Climate adaptation plans is here considered as an integral part of risk mitigation planning, also because the further categories are defined from the point of view of the hazard community. For this community, climate change is only one of the possible factors that can increase or modify the hazard and impacts of disasters. Therefore, adaptation to climate change is likely to be an integral component to reduce the risks caused by disasters. Categories 2 and 3, hazard modification and infrastructure, are measures that are generally undertaken at a high level, e.g. in the case of river flood risk at the basin level. Category 4, mitigation measures stricto sensu, includes measures that are usually taken at the local, community or household level. Category 5, communication in advance of the events, e.g. by hazard and risk maps as well as information campaigns for the general public, can take place at all levels, from the national to the local level, and is linked to category 6, monitoring and early warning. Warning systems are linked to several other categories. They can influence the undertaking and effectiveness of emergency measures, they can be part of management plans, and can be part of the operation of infrastructures. These categories of measures regroup measures that are to limit the risk before the event, such as barriers and reservoirs. Category 7, emergency

*Table 1: Comprehensive categories of mitigation measures*

| | **Category** | **Main goal** | **Main approach** | **Examples** |
|---|---|---|---|---|
| 1 | Management plans, land-use planning and climate adaptation | Vulnerability reduction | Legislation, communication, economic instruments | Spatial planning; adaptation strategies |
| 2 | Hazard modification | Hazard reduction | Technical, engineering | Cloud seeding, explosives for avalanches, retention areas for floods |
| 3 | Infrastructure | Hazard reduction | Technical, engineering | Reservoirs; dams; dikes; slope stabilisation |
| 4 | Mitigation measures (stricto sensu) | Vulnerability reduction | Technical, economic instruments | Water conservation programs; hazard-proof building; reforestation |
| 5 | Communication (in advance of events) | Vulnerability reduction | Legislation, communication, | Education of public including hazard and risk maps and information about adequate behaviour in risky situations; training of experts |
| 6 | Monitoring and early warning systems (just before events) | Hazard reduction and vulnerability reduction | Technical, engineering, communication | Hydrological and meteorological monitoring; flood forecasting; extreme weather warning |
| 7 | Emergency response and evacuation | Vulnerability reduction | Technical, legislation, communication | Evacuation; emergency services and aid; response and recovery operations |
| 8 | Financial incentives | Vulnerability reduction | Legislation, communication, economic instruments | European finance institutions, subsidies, insurance |
| 9 | Risk transfer | Vulnerability reduction | Legislation, economic instruments | Insurance mechanisms; compensation |

response and evacuation, is to be developed before the event but actually undertaken during and after the event. Categories 8 and 9 are financial measures, from insurance for compensation after the event and incentive for mitigation, to risk transfer measures such as subsidies for the undertaking of prevention measures.

## 1.4 Goals, scope and approach of this report

Although many countries have been working on the economic valuation of their risk mitigation activities, there is not a generally accepted framework or method for analysing costs and benefits of mitigation. Usually, different approaches and cost categories are used for different types of hazards. While the benefits of mitigation measures usually are the avoided damage costs, there are no studies that have investigated costs of those measures across different hazards and different regions and countries. With regard to damage caused by natural hazards, the ConHaz project distinguishes between direct costs, indirect costs and intangibles (see reports D1.2, D2.2, and D3.2), and this approach will be adopted here as well (see Chapter 3). The direct costs of mitigation measures will comprise the research and development, investment, operation and maintenance costs. Comprehensive estimates that also reflect indirect costs and intangibles are available from a number of studies on mitigation measures, and these will be assessed in the current report as well.

The intention of Work Package 4 in the ConHaz project is to bring together and assess knowledge and information on the costing of natural hazard mitigation activities from different European countries. Such an assessment may help to exchange approaches between countries and between natural hazard communities, and help to identify gaps in approaches and methods, knowledge, information and data.

The goals of the current methodology report are:

- To review different types of mitigation measures, including preparedness and emergency response (evacuation and rehabilitation);
- To review the frameworks and methods for economic valuation that are used for these types of measures and for different hazards and in different European countries;
- To identify gaps in knowledge and (empirical) data; and
- To identify possible further steps and research that may overcome these gaps.

The natural hazards that will be addressed in the ConHaz project and in this study are of four types: droughts, alpine hazards, floods, as well as storms and induced coastal hazards. In addition, attention will be paid to the issue of adaptation to climate change. In this report, we classify adaptation as a special type of disaster management planning since adaptation to climate change requires planning for the more distant future. As some have suggested that there are obvious links between disaster risk management and adaptation, and risk management is a starting point for adaptation (Burton and Van Aalst, 1999; Thomalla et al., 2006; Few et al., 2006; Bouwer et al., 2007a), it potentially helps to see the two in connection and define synergies and connections. Adaptation planning, however, suffers from larger uncertainties, given the uncertain pathways of expected changes in climate and weather extremes. Therefore, we treat this category as being separate and will discuss how European countries are tackling adaptation to changing natural hazard risks due to climate change. Indicators or successful adaptation are needed in order to assess to the performance of adaptation policy (European Commission, 2009b). Information on costs and benefits of natural/weather disaster risk reduction can help to develop of such adaptation indicators.

The approach used in this report is the assessment of existing literature from various sources: academic literature, government and agency reports, private sector reports, and other publications. In addition, a series of workshops on the four hazard types has further provided information on mitigation.

## 1.5 Reading guide to this report

The following chapter presents measures and their costing for the four different natural hazard types. In Chapter 3, the methods and approaches for evaluation and economic analysis for risk mitigation are discussed. Finally, in Chapter 4, recommendations and knowledge gaps are discussed. In Annex 1, a compilation of information on mitigation measures is given. The information in this Annex was largely received from partners in the ConHaz project.

## 1.6 Acknowledgements

Much of the information on the mitigation of natural disasters contained in this report was kindly provided by colleagues in the ConHaz project and Roy Brouwer, and complemented with further analysis, literature and research results. In addition, the participants in the four hazard workshops, held between November 2010 and May 2011, provided very helpful materials and comments on mitigation approaches and measures.

# 2 Mitigation measures and costing methods

Mitigation measures for natural hazards vary depending on the hazard considered. However, several categories of measures are common to the four hazards analyzed in this project (e.g. droughts, alpine hazards, floods, and storms and induced coastal hazards) can be determined. In general, floods are the hazards for which costs have been most intensely studied. The following sections do not intend to provide a comprehensive overview of mitigation measures, but instead is meant to introduce the different categories of measures, illustrated by some examples. In addition, methods to analyse the economic costs associated with these measures are discussed.

Of course the main benefit of each mitigation measure is the avoided damage from the respective natural hazard. We will not discuss the avoided damage which is widely covered in other work packages of the ConHaz project (in work packages WP1, 2, and 3, and for the specific hazards in WP5, 6, 7, and 8). However, we will discuss examples and methods used for assessing costs of mitigation measures and benefits beyond avoided damages.

## 2.1 Management plans, land-use planning and climate adaptation

**General description**

Management plans can be realized to decrease damage due to one or more hazards. They first thoroughly describe the nature of the hazard(s) and their potential impacts to a specific region. Next hazard management plans describe possible strategies to reduce impacts such as the enforcement of building codes, housing regulations and restrictions, the preparation of protective and hazard control infrastructures, and the planning of communication programs to raise the population awareness and preparedness. Management plans can also contain land use management or zoning plans, which can have different applications depending on the hazards considered. Zoning or land use planning in general is meant to control the construction of new buildings in hazard-prone areas, but can also regulate the use of agricultural lands, or plan land acquisitions by the state. Concerning agricultural lands, crop diversification or crop rotation are ways to limit the need for water in drought-prone areas. Land reclamation and conversion of farmlands to salt-lands are also ways to protect coastal zones and their population from coastal storm surges and erosion. Management and land-use plans can be organized at all decision levels, e.g. national, regional and local. Different examples of plans exist in Europe, such as the Planning Policy Statement 25 in the UK; organized at the national level. In France, the Risk Prevention Plans (PPR) regulate land use, guide the undertaking of risk-reducing measures by community officials and households, and limit the construction of new buildings in vulnerable areas. These PPRs are the responsibility of the federal government, but are meant to be prepared and implemented in coordination with regional and local administrations (see also Box example below).

As indicated in the previous chapter, climate change is expected to have consequences on at least three of the four hazards considered in the ConHaz project (IPCC, 2007), namely alpine hazards, floods, and droughts. Changes in storms are less certain (IPCC, 2007), although sea-level rise holds additional threats for coastal floods induced by storms.

*Table 2: European climate adaptation plans, and inclusion of disaster risk reduction (indicated by categories "Water resources management", "Coastal management", and "Emergency and rescue services"), after Swart et al. (2009).*

| **Country** | **Adaptation plan** | **Disaster risk reduction relevant sectors included** | | |
|---|---|---|---|---|
| | | Water | Coast | Emergency management |
| Denmark | Adopted 2008 | X | X | X |
| Finland | Adopted 2004 | X | | |
| France | Adopted 2006 | X | | |
| Germany | Adopted 2008 | X | X | X |
| Latvia | Expected 2009 | X | X | X |
| Netherlands | Adopted 2008 | X | X | |
| Norway | In development/preparation | | X | |
| Portugal | In development/preparation | X | X | |
| Spain | Adopted 2006 | X | X | |
| United Kingdom | Adopted 2008 | X | X | |
| Sweden | In development/preparation | X | X | |

Most European countries are concerned about these potential consequences of climate change for natural hazards. Many countries, therefore, are in the process of developing adaptation strategies in order to prepare for these changes (Swart et al., 2009; Biesbroek et al. 2010). A comprehensive overview of these European adaptation plans is given at the site http://www.eea.europa.eu/themes/climate/national-adaptation-strategies. Table 2 provides an overview of adaptation planning in European countries, and which of these plans disaster risk reduction. In order to do so, these countries often use climate and socioeconomic scenarios to assess future risks. The IPCC scenarios are commonly used for general applications, and sometimes these scenarios are adapted using downscaling (through statistical techniques or regional climate models) to the particular countries or regions, for the modelling potential future changes in natural hazards, such as floods, droughts, alpine hazards and storms. Depending on the countries and governments, these scenarios are also used for the governmental policies on natural hazards, and the preparation of the management and land use plans (Kabat et al., 2009; Biesbroek et al., 2010; EC, 2009b).

In the context of global climate change updating risk analyses and adapting risk reduction measures are continuous tasks. This has already been recognised in the EU White Paper on Adaptation (EU, 2009b), where adaptation is described as a long and continuous process. Similar approaches are proposed for the EU Floods Directive: The preliminary flood risk assessments are due in December 2011, the flood hazard and risk maps are due in December 2013 as well as the flood risk management plans due in December 2015 shall be reviewed and – if necessary – updated by December 2018, 2019 and 2021, respectively, and every six years thereafter (EU, 2007).

**Costing aspects**

Costs, for example related to the definition and enforcement of building codes, are direct tangible costs that can be subdivided into R&D, engineering and investment costs. Negative externalities related to the implementation of such measures could be aesthetical (for instance in the case of land-use planning and regulation), and valued by the means of revealed preference techniques such as Hedonic Price Models. On the other hand a potential benefit of imposing new building codes concerns technological innovation. A study has recently been carried out by the CPB Netherlands Bureau for Economic Policy Analysis (Noailly, 2010). They have investigated the influence of imposing stricter environmental regulations on the likelihood of new patents records. A positive and significant impact has been revealed using count data estimation techniques in seven European countries, between 1989 and 2004.

Furthermore, costs are made through land use planning because it can distort land market values in two ways. First, market functioning can be disturbed when authorities do not acquire land at its equilibrium market price. Second, land acquisition can affect availability of land dedicated to a specific use in a certain region, and create sudden shortages of land, potentially disturbing a well functioning land market.

In the project Flood-Era different management options were compared (see final report on http://www.flood-era.ioer.de/results.html). An investigation in England and Wales expects a 20 fold increase in the real economic flood risk by the year 2080, if present flood policies and practices are not improved significantly (Hall et al. 2005).

**Case Study 1: Risk Prevention Plans, France**

In France, risk prevention plans (Plans de Prévention des Risques, PPR) are implemented since 1995. PPRs are meant to regulate land use in order to limit the exposure of properties and people to various hazards, from floods to earthquakes or cyclones. A PPR for flood damage reduction in a certain region delimits the area that can be affected by the highest known historical flood or a flood of a 100 years return period flood, depending on which one is higher. On the basis of this information, the plan contains a map which shows the zones where it is not allowed to build and those where building is allowed under certain conditions. In the areas where construction is allowed under restrictions, the PPR can define compulsory and recommended measures. The measures can also concern already built-up areas and existing buildings. In theory, the compulsory measures have to be implemented within five years after the approval of the PPR, but this delay can be shortened. There is no deadline for the implementation of the recommended measures (Legifrance, 2011[2]). The procedure for the realization of a PPR should take approximately three years but this duration can vary (Dumas et al., 2005; Letremy and Grislain, 2009).

With regard to adaptation, many efforts are made to arrive at cost estimates for adaptation implementation. Often these adaptation measures include measures aimed at reducing natural hazard risks, and therefore these costing approaches would fall under the other mitigation measure categories, recognised in Table 1 in Chapter 1. However, the dynamic and uncertain nature of future climate change, and therefore the actual costs (and benefits) require specific approaches, to estimate the costs of mitigation projects over time. Therefore several studies have been devoted to study approaches to estimate these costs (e.g. ECA, 2009; ClimateCost project: http://www.climatecost.cc).

## 2.2 Hazard modification

### General description

This category of adaptation measures is very much hazard specific. Examples of measures to modify hazards (not pertaining to infrastructure, category no. 3 and section 2.3 of this report) include the use of chemicals (usually silver iodide and frozen carbon dioxide) to seed clouds in order to induce rainfall during droughts. For the modification of alpine hazards, techniques exist to decrease the risk of avalanches. Explosives (along a cable or by mixing gases), or special canons can be used to provoke controlled avalanches in order to decrease the weight of unstable snow and, before the situation becomes too unstable, decrease the risk of an unexpected avalanche (see also www.anena.org/index.html). Such measures are currently in application around ski resorts in the European Alps (see case study below). In addition, forests have an important protective function. In Switzerland, 17 percent of forests are managed to protect against landslides and avalanches (World Bank and the United Nations, 2010: 129). In 2008, about 20% of the forest area in Austria, i.e. 780 000 ha are protection forests (BMLFUW, 2008 http://www.forstnet.at/article/articleview/60313/1/1453).

For river floods, various modifications of river basins are possible, beyond the installation of infrastructure. The flood hazard can for instance be potentially modified by reducing surface runoff. An example in this case would be improving infiltration or soil water holding capacity. For storms and coastal hazards, wetlands and dunes potentially buffer water and protect an important part of the coast

### Costing aspects

[2] Legifrance (2011): http://www.legifrance.gouv.fr/, last accessed: 12 July 2011

Brouwer and Schaafsma (2009) provide an evaluation of intangible direct costs in the context of the implementation of designated flood disaster zones, focusing on discomfort, fear and social disruption

In this context, Brouwer and Schaafsma (2009) have carried out a choice experiment in order to measure the perceived risks of climate change and public willingness to accept compensation (WTAC) for an increase in disaster flood risk and associated welfare loss. They conduct face to face interviews, and question respondents on their opinion and perception of living in a designated flood disaster zone. In particular, they pay special attention to the estimation of the economic value of intangible welfare effects such as feelings of discomfort, fear and social disruption.

Pattanayak and Kramer (2001) report biophysical evidence of indirect benefit in terms of drought mitigation from forest and watershed conservation in Ruteng Park, Indonesia. Indeed it appears that the forest plays an important role in protecting the streams and rivers of this region. Pattanayak and Kramer (2001) measure the value of drought mitigation by carrying out a contingent valuation study targeted at farmers, located downstream the park. These agricultural households benefit from an increase in baseflow, which serves as a fixed input in agriculture production.

A report by the World Bank and the United Nations (2010) summarizes recent results of the valuation of natural systems like forests, wetlands and mangroves for natural hazard management including two examples from Europe: "In the Lužnice floodplain, one of the last floodplains in the Czech Republic with an unaltered hydrological regime, 470 hectares have monetary values per hectare of $11,788 for flood mitigation (water retention), $15,000 for biodiversity, $144 for carbon sequestration, $78 for hay production, $37 for fish production, and $21 for wood production (ProAct 2008).The economic value of forests for preventing avalanches is estimated at around $100 per hectare per year in open expanses of land in the Swiss Alps and up to more than $170,000 per hectare per year in areas with valuable assets (ProAct 2008)". During the ConHaz workshop in Innsbruck, Austria, a subalpine afforestation area in the Sellrain valley was visited. The total costs per hectare amounted to 50, 000 to 70, 000 Euro considering a lifespan of 50 years, including initial costs of 15, 000 to 20, 000 Euro per hectare for the plants and maintenance work every 5 to 10 years. In order to protect the young trees against snow pressure as well as against damage caused by domestic and game animals, mechanical support measures had to be installed additionally. As co-benefits recreational effects as well as higher water retention and interception values and higher infiltration rates were mentioned, but could not be observed e.g. during the extreme flood event in 2005.

**Case Study 2: Mitigation Measure: Hazard Modification**

**Hazard: Floods**

**Geographic Coverage: Tisza river basin (primarily Hungary and Ukraine but also Slovakia, Romania, Serbia and Montenegro)**

**Implementing Body: Several government ministries (e.g. for Hungary; Ministry for Environment and Water and Ministry for Agriculture and Rural Development)**

**Source:** NeWater project (New Approaches to Adaptive Water Management under Uncertainty): 2005-2009; funded by the 6th EU Framework Programme; www.newater.info. The project also focussed on 6 more river basins (Rhine, Elbe, Guadiana, Amudarya, Nile, Orange).

**Key Objective:** The overall objective of the 'NeWater project' is to 'develop a conceptual framework for research and adaptive management of river basins that integrates natural science, engineering and social science concepts and methodologies'. Several sub-objectives relate to identifying good practice in the case of hazard modification for floods for the Tisza river basin and elsewhere.

Main Activities for increased water retention (non-structural measures):

| | |
|---|---|
| **1. Land Use change** | 1.1 Extension of floodplains and wetlands<br>1.2 Implementation of river bypasses<br>1.3 Reforestation/Afforestation |
| **2. Change in Agricultural Practices** | Opt for agricultural practices that reduce water runoff ('catch crops') |

**Effort and Resources Required:** High (due to increasing flood intensity and frequency in recent years, largely attributed to anthropogenic factors, eg. land use changes). In the past more focus on hydro-engineering infrastructure (e.g. dykes), but recent dyke breaches and floods (2001, 2005) place more emphasis on hazard modification measures.

Implementation Level: Country, Multi-Country

**Ability to deal with risk:** Depends on several factors (cross-country collaboration, implementation of measure, climate change)

**Costs involved:** In Hungary, the 'New Vasarhélyi Plan' allocated (between 2004-2007) 15 billion HUF (6 million Euro) for clearing the river bed, and 65 billion HUF (26 million Euro) for rural development (and related infrastructure).

| Direct costs | Indirect costs | Intangible |
|---|---|---|
| **Implementation, Change in Land Use Patterns** | | |

**Case study 3: Hazard Modification**

**Hazard: Avalanches**

**Geographic coverage: European Alps (especially Austria and Switzerland)**

Besides structural mitigation measures low-cost alternatives get noticeably into practice (Stoffel 2005). Especially in the case of avalanches, artificial release measures can be highly effective in terms of damage prevention at relatively low costs. In comparison to other alpine hazards, avalanche release areas are mostly known or can be modelled reliably and only occur in areas with a certain degree of gradient, exposition and amount of windblown snow (Federal State of Tyrol 2000). Therefore, punctual measures like artificial avalanche release can be easily carried out. When blastings are performed during the whole winter season so that high snow accumulation is prevented, artificial release can help to minimise blockages of ski slopes and prevents avalanches with a high loss potential.

The principle of artificial avalanche release is quite simple. Detonations of explosives, gas-air-mixtures or military weapons trigger a collapse of the snow cover, so that the binding is lost and the snow masses flow downhill. Blasting can be done by hand or from the helicopter as mobile measures. Alternatively, they can be initialised from stationary technical facilities, like avalanche towers (with remote-controlled explosives), blasting cableways (mostly to protect skiing areas over the whole season) or gazex®. In some countries like the U.S., Canada and Switzerland, military weapons (antitank-weapons, howitzers, mortars) are used for artificial avalanche release. In most cases, temporary measures are performed by government agencies, municipalities or the police to ensure the safe execution.

Compared with technical mitigation measures (e.g. snow fences), the costs of artificial avalanche release are relatively low. On average, Switzerland requires approx. 75 tons of explosives every year (Stoffel 2005). Blasting per hand needs two kilos of pyrotechnic material and costs about 20 SFr (approx. 13 €, without wage). This amount must be doubled if helicopters are used, but does not include transportation costs. The expenses for the construction of stationary facilities are much higher: Approximately 100 000 SFr (approx. 7 000 €) are needed per installation.

The municipality of Ischgl (Federal State of Tyrol, Austria) might serve as an example on the local level. It requires about eight tons of pyrotechnics every year and carries out about 2 000 blastings.

## 2.3 Infrastructure

**General description**

The development of infrastructure for the protection against natural hazards are usually hazard specific even though some infrastructures can sometimes be used against more than one natural hazard.

For the protection against droughts, water reservoirs and dams can be built, the water can also be transferred through pipes over land, and irrigation infrastructures can be constructed. Other systems also exist which include the possibility of desalination and wastewater reclamation. Against alpine hazards, dams and nets can be built to absorb and channel avalanches, accumulate till from landslides, and stop rock flows. Another measure against landslide that requires large-scale infrastructure development is the de-watering of the hillsides. Dams, as well as dikes and barrages can also be built to stock the waters, the mud and debris flows of river floods, coastal floods as well as flash floods in mountainous areas. Against floods, additional infrastructures include constructions such as pumping facilities, and adapted urban drainage systems. Finally, for the protection against storms and coastal hazards, infrastructures can include again dams and dikes, but also breakwater systems, storm surge barriers like the ones built in the Netherlands, dune building, wetlands and adapted drainage for the waters. Salt water intrusion barriers can also protect against coastal floods as well as protecting agricultural lands from the salt.

**Costing aspects**

As it is the case with the implementation of large-scale satellite-based monitoring and early warning systems, the construction of physical infrastructures is capital intensive and involves long-term costs and benefits. In addition, some infrastructures will necessitate the conversion of large land surfaces.

In addition to R&D, implementation and maintenance costs, infrastructures can have detrimental impacts on social welfare due to their impacts on land fragmentation and aesthetics. As a counterpart they are also a potential source of benefits by bringing additional recreational activities or tourism. All these types of costs and benefits can be captured by both stated and revealed preference techniques. A comprehensive study has been carried out in the Netherlands for the program Space for the River and will be described as a separate case study (Eijgenraam, 2005).

In terms of ecological infrastructure, ecological corridors between patches of forest or wetlands can enhance environmental quality and buffer capacity against hazards in an area. Think of wetland revitalisation to enhance coastal buffer capacity against storm surges and coastal erosion. On the other hand, fragmentation can exist due to the presence of infrastructure such as roads and pipelines, but literature is not available. Yet there has been a study, of which results are not yet published (Brander, in prep.) using stated preference techniques to value the preference of individuals towards the presence of “regular” roads or railways as opposed to elevated transport infrastructures. These later would then serve as flood protection systems.

**Case Study 4: Cost-benefit analysis of flood protection in the Upper Danube (Germany)**
**Cost assessment method: investment costs and cost-benefit-analysis**
**Hazard: Floods**
**Reference:** Arnold, O., E.-M. Kiefer, H. Kugele, R. Magenreuter, K. Rempfer, M. Scheurl, R. Schmidtke (2001): Abschließendes Gesamtkonzept für den Hochwasserschutz im Donautal zwischen Ertingen-Binzwangen und Ulm/Illermündung. Gewässerdirektion Donau/Bodensee, 31 pp. (in German)
**Goal:** Aiming at an integrated flood risk management approach, flood discharges, potential inundation and damage scenarios were analyzed systematically at the Upper Danube in Baden-Württemberg, Germany. Four alternative protection schemes that were designed for a 100-year flood were developed and compared with regard to costs and benefits. The first variant consisted of the construction of four flood retention basins and local protection measures. In two other variants, only two retention basins (Wolterdingen and Riedlingen) with different retention volumes for the basin at Riedlingen were considered and combined with local protection measures. Finally, the fourth alternative only considered one retention basin (Wolterdingen) and local protection

measures. The local protection measures for all four variants were developed together with the local authorities.

In comparison to the reference state in 1990, the benefits of the variants – quantified as avoided direct losses and avoided loss of production at commercial, residential and agricultural sites and public infrastructure for four flood scenarios with return periods of 20, 50, 100 and 1000 years – were comparable, but the costs differed considerably. Therefore, the cheapest fourth alternative (one retention basin and local measures) was chosen.

**Costs involved:** The cost estimations were based on common engineering practice and expert knowledge. Costs were distinguished between investment costs (including construction costs for the retention basin and local protection measures, incidental expenses during construction, acquisition of land, costs for pumping stations and backing-up valves) and annual operational costs (for operation, maintenance, repair and monitoring). Reinvestment costs for facilities that have to be renewed during the lifetime of the infrastructure were calculated as part of the operational costs. In the cost-benefit analysis a lifetime of 80 years and an interest rate of 3% were assumed.

For the chosen variant the investment costs amounted to approx. 45.3 Million DM and the operational costs to 1.25 Million DM per year. The investment costs of the first variant (with four retention basins) were 151% higher (approx. 80 Million DM), of the second and third variant 47% (25 Million DM) and 80% (42 Million DM), respectively. Additional operational costs of 1.5, 0.5 and 0.8 Million DM per year would have been needed for these three variants, respectively. The costs for the retention basin that is included in all four variants were estimated to 31.5 Million DM for investments and 854 000 DM per year for operations. In this case the performance of a cost-benefit analysis (with total costs of approx. 1 Million DM) saved tens of million DM. Apart from the cost savings, the chosen variant has further co-benefits, such as avoided difficulties with the acquisition of land at the planned sites of the retention basins, conflicts with nature conservation and groundwater protection.

**Case Study 5: Governmental expenditure for coastal protection in the North Sea Countries**

**Hazard: Floods**

**Source:** SAFECOAST (2008): Coastal Flood Risk and Trends for the Future in the North Sea Region. Synthesis report. Safecoast project team. The Hague, 136 pp.

**Costs involved:** Estimates have been made of governmental investments on flood protection infrastructure for different countries around the North Sea for the period 2000-2006. It is found from this study that actual government investments on flood protection is quite low, and far below 0.1% of GDP in the countries of Denmark, Germany, Netherlands, Flanders (Belgium) and England. However, the report (SAFECOAST Synthesis Report) notes that “The figures are estimates and there are information gaps, and are therefore not strictly comparable since some of the figures also include flood risk management from river flooding. Hence, the figures may be observed in terms of their order of magnitude", and "Costs related to private flood insurance (e.g. England) or private ownership (e.g. Denmark) are not included in the table".

For comparison: Switzerland invests 0.6% of its GDP for the protection against natural hazards (including 37% for insurance) (Wegmann et al., 2007). Further expenses for the mitigation of alpine hazards are presented in the Conhaz-Report D8.1.

| | | Denmark | Germany | Netherlands | Flanders | England |
|---|---|---|---|---|---|---|
| **Annual spending on coastal protection** 2000-2006 averaged | [Mln € / yr] | 11 [a] (coast) | 110 [b] (coast) | 550 [c] (coast / rivers) | 20 [d] (coast) | 620 [e] (coast / rivers) |
| **GDP (nominal)** Current prices | [Bln €] national | 188 | 2156 | 468 | 274 | 1672 |
| 2000-2005 averaged | [Bln €] subnational | | 353 [b2] | | 157 [d2] | 1434 [e2] |
| Sources: National and regional policy documents and master plans, National treasuries, Eurostat | | | | | | |

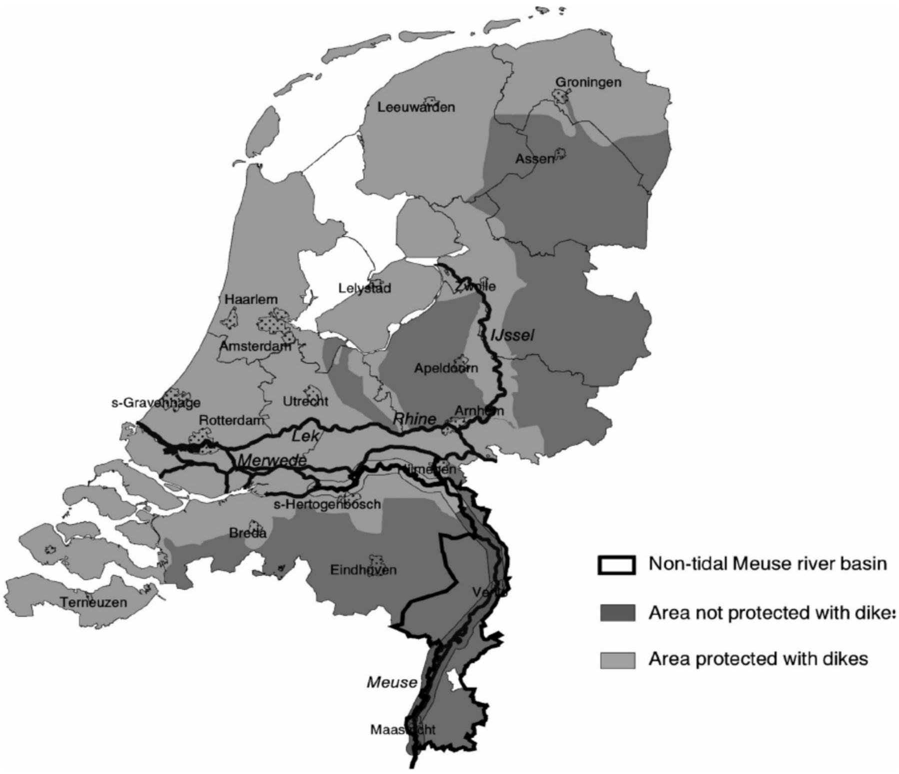
a) DCA (2008) – Annual coastal protection spending on 110 km of Danish west coast in 2004-2008 are 86 mln Krone – Euro conversion fixed at 0,134. Dikes at Danish Wadden coast funded locally (no data, but expected to be below € 5 million).
b) Estimate total of average coastal protection spending in the 4 coastal states that border the North Sea.
b2) Cumulative (regional) GDP of 4 North Sea coastal states (sum of the figures as presented in table 2.1)
c) This amount includes total flood defence (rivers and coasts) spending from both national government and the water boards. The part of this amount that is allocated annually for coastal protection alone is estimated at 10-20% (among which annual nourishments of 45 million). Water in beeld, 2007 and Dutch National treasury (2008)
d) Figures by MOW MDK Flanders coastal division (~50% nourishments). Excluding spending related to the Sigma plan ( 880 million until 2030)
d2) GDP of Flanders region only (Vlaams Gewest).
e) Includes central and local government spending. Pound – Euro conversion fixed at 1,45 (Defra, 2006c)
e2) GDP England (excluding Scotland, Wales and Northern Ireland)

*Table 2.5: Estimates of current governmental expenditure and GDP in the North Sea countries*

**Case Study 6: Infrastructure (Strengthening of dikes for the Meuse river basin)**
**Hazard: floods**
**Geographic Coverage: The Netherlands**
**Type of Study: Cost-benefit analysis (CBA) of different flood control strategies**

**Source:** Brouwer, R., Kind, J.M. (2005), 'Cost-benefit analysis and flood control policy in the Netherlands'. In: Brouwer, R. and Pearce, D.W. (eds.) *Cost-Benefit Analysis and Water Resources Management*. Edward Elgar Publishing, Cheltenham, UK, 93-123.

**Goal:** There is a necessity to provide additional protection against flood risk as a consequence of anticipated increases in water discharge along the Meuse river (e.g. an increase from 3800 $m^3$/s to 4600 $m^3$/s as a result of climate change and land subsidence). The study evaluates the role of traditional dike-strengthening (along other long-term managed realignment strategies) as safeguard mechanisms against flood risk. The current level of protection by the existing dikes allows major flooding in downstream areas to occur once every 1250 years. As a result of climate change precipitation can increase up to 40% over the next 100 years allowing flooding to occur every 300 years by 2050 and every 50 years by 2100. An increase in water discharge along the Meuse could result in a financial loss of approximately €9.5 billion, the majority of which corresponds to damage to houses (42%), trade and recreation (22%) and the service sector (15%). The study evaluates the relative costs and benefits of dike strengthening (amongst other management strategies) as a means to maintain current safety levels.




The Meuse river basin: Protected and unprotected areas. Source: Brouwer and Kind (2005)

**Effort and Resources Required:** Moderate to high, but dike-strengthening appears to be by far the most cost-efficient strategy for maintaining safety levels. It has the highest benefit to cost (B/C) ratio at 6.8. While the investment cost of dike-strengthening amounts to $428 million, the benefits from risk reduction correspond to $2.927 billion (i.e. net benefits are equal to $2.499).

Compared to alternative management strategies (that include the realignment of rivers, estuaries, widening and restoring floodplains), dike-strengthening requires modest land-use changes.

**Implementation Level:** Country, Regional

**Ability to deal with risk:** Substantial, but net benefits and level of protection depend on:

1. Area flooded in case of an increase in river discharge
2. Probability of flooding
3. Economic growth scenarios
4. Use of discount rate (and corresponding valuation of future flood damage)
5. Climate change scenarios

| Direct costs | Indirect costs | Intangible |
|---|---|---|
| Infrastructure (Dike-strengthening) - $428 million | | |

## 2.4 Mitigation measures (stricto sensu)

**General description**

Mitigation measures (stricto sensu) are meant to reduce the physical impacts and costs of the natural hazards. They can be very diverse and have different scales of implementation (e.g. from measures at the scale of a river basin to measures at the scale of a house). Therefore, different measures can be decided and implemented at different levels such as the state, the regions, the local communities or the private households. However, usually what is meant are relatively small scale measures that can be implemented over wider areas, to limit effects once a hazard occurs. These measures are meant to limit the damage and life losses caused by natural hazards without needing the construction of large-scale infrastructures.

Mitigation measures for droughts include measures such as water demand management or conservation programs, rationing, the use of lower quality water, the increase of the water price, and the provision of water to vulnerable people.

State or regional scale mitigation measures against alpine hazards, for instance, are land restoration, plantations, water retention and reforestation.

Against floods, mitigation measures can be taken by the state or the regions such as with measures at the scale of river basins. However, most flood damage mitigation measures concern communities and households, and these are considered in this section. Communities, for instance, can work on bridges and roads to decrease the risk damage of the transport ways and other infrastructure. Households can take different kinds of measures to flood-proof or wet-proof their houses, and protect their possessions and their lives. Those measures include ones such as the construction of refuge zones in case the evacuation is not possible, the use of one-way valves on wastewater pipes, and the possibility to put washing machines, dryers, fridges as well as personal documents safe in heightened places of the house.

Concerning storms and coastal hazards, mitigation measures (stricto sensu) are also mainly local measures. Measures that can be taken are the cutting/cleaning of trees close to houses and roads, the protection of electrical and phone lines by, for instance, putting them underground, and the creation of refuge zones under buildings for the protection of people. Against other coastal hazards such as salt water floods on agricultural lands or erosion, it is possible to grow flood or salt resistant crops, or to grow plants meant to stabilize beaches and dikes. Certain of the measures described here need constant or yearly maintenance.

**Costing aspects**

The use of temporary local flood protection systems may have extra costs compared to permanent measures: cost of deployment (material, human resource, time), which is likely to be affected by adverse weather conditions; costs of storage when not in use (Crichton, 2003). The author does not provide valuation methodologies for these two types of costs, but these are market prices, except for time spent for deployment (and maybe discomfort of deploying the system under adverse weather conditions).

Hensher et al. (2006), apart from presenting results from a choice experiment, also provide a short overview of studies on the social costs of drought prevention measures. Two types of measures are illustrated: mitigation measures such as water use restriction, and infrastructures such as water storage facilities. Individuals' welfare can be negatively impacted in different ways, and each of these impacts can be valued by the means of different methods: Assessment of direct costs (market price; drought related expenditures by commercial and industrial customers and emergency expenditures by public authorities), contingent valuation method (welfare losses due to the implementation restrictions in water use) or choice experiment modelling (welfare losses due to the implementation of a given infrastructure).

Some semi-quantitative information on the effectiveness of different flood-proofing measures was published by the ICPR (International Commission for the Protection of the Rhine; (2002). Some figures about avoided damage were published by Kreibich et al. (2005): From six different building precautionary measures under study, flood adapted use and adapted interior fitting were the most effective ones. They reduced the damage ratio for buildings by 46% and 53%, respectively. The damage ratio for contents was reduced by 48% due to flood adapted use and by 53% due to flood adapted interior fitting. In a consecutive study, Kreibich et al. (2011) investigated the cost-benefit ratios of different precaution measures (see box below).

**Case Study 7: Mitigation Measure: Precautionary measures for the protection of buildings against floods**
**Hazard: floods**
**Geographic Coverage: Germany (Elbe and Danube catchments)**
**Type of Study: Cost-benefit analysis (CBA) of different precautionary measures**
**Source:** Kreibich, H., Christenberger, S., Schwarze, R. (2011), 'Economic motivation of households to undertake private precautionary measures against floods', Natural Hazards and Earth Systems Science 11: 309-321.
**Key Objective:** Measures to self-insure and self-protect at the household level can be very important in mitigating against flood damage. The main objective of the study is to quantify the corresponding costs and benefits of such precautionary measures. The estimates for the corresponding costs and benefits are based on: a. 759 interviews of private home owners in the Elbe and Danube catchments (following the floods of 2002, 2005 and 2006), b. expert interviews, and c. a literature review including catalogues and price lists for building materials and housing appliances. The study assesses the following precautionary measures (relating to building protection against flood risk):

1. Building without a cellar (building without a cellar reduces building costs and renders buildings less prone to flooding; on the other hand it reduces storage space)
2. Adapting the building structure (e.g. making use of a specially stabilised foundation, water-proofing the cellar, opting for steel frame and brick buildings, utilising waterproof drywalls)
3. Using water barriers (e.g. use of sandbags can protect against inundation)
4. Ensuring secure storage of oil and other hazardous material (e.g. storage in flood-proof fuel oil tanks). Damage from oil contamination can also extend to neighbouring properties.

The study only assesses the direct benefits and costs of these measures, and not any indirect and intangible ones.

**Effort and Resources Required:** Low to moderate depending on the precautionary measure (e.g. low for water barriers, moderate for adapting the building structure). Implementation can be facilitated by a supporting legal framework (e.g. in Germany federal law stipulates that all oil tanks need to be flood-proofed in flood-prone areas). Generally speaking, though, most precautionary measures are still voluntary. As can be seen by the table below, benefits from most precautionary measures exceed costs when the flood frequency is relatively high (1-10ys).

**Implementation Level:** Local (Household level)

Ability to deal with risk: Some measures (e.g. the use of water barriers) may require complementary infrastructure (e.g. prior flood warning system). Adoption of precautionary measures is dependent on other external factors:

1. Prior experience of flooding
2. Awareness of living in flood-prone areas
3. Provision of financial incentives (e.g. insurance contracts, government finance schemes)

| Direct costs | | | | | Indirect costs | Intangible costs |
|---|---|---|---|---|---|---|
| Type of Mitigation Measure | Frequency of Flood (in years) | Mitigation Cost p.a. (€) | Mitigation Benefit p.a. (€) | Benefit -Cost Ratio | | |
| Construction without cel ar | 1 | 3120 | 2832 | 9.08 | | |
| Construction without cellar | 10 | 3120 | 2832 | 0.91 | | |
| Adapting building struc ture (waterpr oof skin) | 1 | 2268 | 20473 | 9.03 | | |
| Adapting building structure (waterproof skin | 10 | 2268 | 2047 | 0.90 | | |
| Mobile water barriers | 1 | 668 | 23491 | 42.63 | | |
| Mobile water barriers | 10 | 668 | 2349 | 4.26 | | |
| Securing oil tanks | 1 | 82 | 15466 | 188.61 | | |
| Securing oil tanks | 10 | 82 | 1547 | 18.87 | | |

Note: All damages/benefits assume that both cellar and ground floor are affected.

## 2.5 Communication, in advance of the events

**General description**

Different forms of communication are used by the EU member States and the regions in order to increase the awareness and preparedness of the populations at risk of natural hazards. These include legislation enforcements, such as the information obligation for houses and apartments' sales and rents in France, as well as mass media campaigns, assistance programs, pamphlets presenting the risk and the measures that can be undertaken by communities, households and businesses, and education and training programs. Websites providing information risks to the population and industries are also widely in use. Apart from providing information well in advance of the event, communication means are also used to inform the public that an extreme natural event is about to take place.

The internet is obviously an important means to communicate information on natural hazard risk. The websites of the Environment Agency in the UK (www.environment-agency.gov.uk) and the French government (www.prim.net; www.meteofrance.com) provide information on floods, droughts and other hazards, as well as advices to protect businesses, communities and households against the risk. In Austria and The Netherlands, flood hazards and other natural hazards are communicated to the general public through websites (http://www.risicokaart.nl/). The German project MEDIS established an interactive web-service for communities to develop a locally adapted brochure about flood hazards, damage mitigation and insurance options (http://nadine.helmholtz-eos.de/webbroschuere/start). Further information is provided by the ICPR (International Commission for the Protection of the Rhine; 2002) as well as national institutions, e.g. http://www.bbk.bund.de/ (Germany) or http://publikationen.lebensministerium.at/publication/publication/view/3051/28607 (Austria). Thorough information for different natural hazards is available in Switzerland (http://www.kgvonline.ch) in German and French.

For droughts, the information campaigns to the general public usually concern water conservation. Communication on alpine hazards informs and warns people about avalanche risks, however, there are no separate warnings for debris flows.

Finally, communication campaigns on storms and coastal hazards are rare. They mainly provide advice to the population to protect/not harm the sand dunes, in order to stop erosion and floods, as well as people's possessions and lives in case of floods or storms. They may also give information to coastal farmers to protect their crops and their lands. Obviously, there is overlap for coastal floods with the communication on flood risks emanating from rivers, for example in the case of the Dutch flood risk maps (http://www.risicokaart.nl/).

**Costing aspects**

Costing of communication campaigns usually involves the operational costs for programmes that include information campaigns that make use of websites, media (television, radio), pamphlets and other means of communication.

Estimates of these costs however are not always available. In The Netherlands an extensive campaign was held to inform the general public on flood risks and motivate awareness and self-preparedness, called "Nederland leeft met water" (The Netherlands lives with water; http://www.nederlandleeftmetwater.nl), the cost of which is some 10 million Euros for three years[3]. The boxes below give some further detail of costs of communication activities. It was estimated that 25 to 30 Million Euro will be spent between 2003 and 2010 for flood hazard mapping in the German Federal State of Baden-Wurttemberg (Moser 2003).

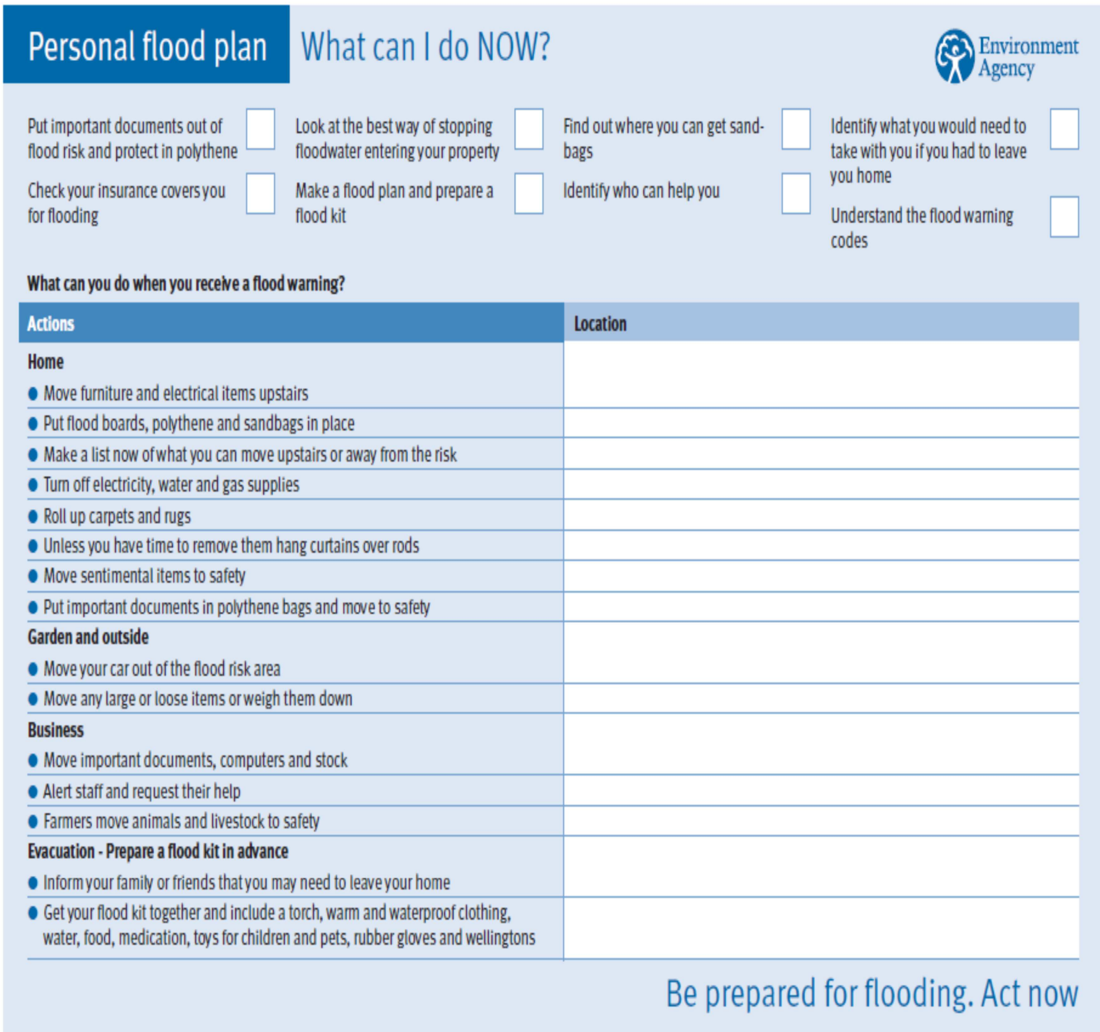
[3] http://www.communicatieonline.nl/nieuws/bericht/nieuwe-campagne-nederland-leeft-met-water/

**Case Study 8: Mitigation Measure: Communication**
**Hazard: Floods**
**Geographic Coverage: Wales, UK**
**Implementing Body: Flood Awareness Campaign (Environment Agency)**
**Source:** Environment Agency (www.environment-agency.gov.uk/113810.aspx); and Burningham, K., Fielding, J., Thrush, D. (2008), 'It'll never happen to me': Understanding public awareness of local flood risk, Disasters 32(2): 216-238.
**Key Objective:** Promotion of flood awareness across priority communities in Wales
**Main Activities Involved:**

| | |
|---|---|
| 1. Sign-up for Flood Warnings | Free service informing of imminent flooding via telephone, email, sms text message or fax |
| 2. Flood Plan | Checklist of personalised practical steps in case of flood. List of relevant contact details for assistance. Online submission and feedback available from the Environment Agency. Flood plan also available at a community level. |
| 3. Visit by Flood Awareness Officers | Visit of households in vulnerable communities. Meetings with community representatives. Dissemination of materials related to flood prevention. |
| 4. National Flooding Exercise | Emergency flooding exercise to test preparedness to flooding (4-11 March 2011) |
| 5. Further Information on Flood Preparation | Brochures as well as direct telephone line for information (Floodline). Information on purchase of flood protection products and services. |

**Effort and Resources Required:** Moderate
**Implementation Level:** Regional
**Ability to deal with risk:** Sufficient for moderate risks. Flood awareness associated with flood experience, age and social class of respondents (Burningham et al. 2008)
Costs involved: 10/11: £580,565 (only labour costs)

| Direct costs | Indirect costs | Intangible |
|---|---|---|
| Implementation, printing of materials, | None | Minor time costs for participants |



Personal flood plan

What can I do NOW?

Environment Agency

- Put important documents out of flood risk and protect in polythene ☐
- Check your insurance covers you for flooding ☐
- Look at the best way of stopping floodwater entering your property ☐
- Make a flood plan and prepare a flood kit ☐
- Find out where you can get sand-bags ☐
- Identify who can help you ☐
- Identify what you would need to take with you if you had to leave you home ☐
- Understand the flood warning codes ☐

**What can you do when you receive a flood warning?**

| Actions | Location |
|---|---|
| **Home** | |
| • Move furniture and electrical items upstairs | |
| • Put flood boards, polythene and sandbags in place | |
| • Make a list now of what you can move upstairs or away from the risk | |
| • Turn off electricity, water and gas supplies | |
| • Roll up carpets and rugs | |
| • Unless you have time to remove them hang curtains over rods | |
| • Move sentimental items to safety | |
| • Put important documents in polythene bags and move to safety | |
| **Garden and outside** | |
| • Move your car out of the flood risk area | |
| • Move any large or loose items or weigh them down | |
| **Business** | |
| • Move important documents, computers and stock | |
| • Alert staff and request their help | |
| • Farmers move animals and livestock to safety | |
| **Evacuation - Prepare a flood kit in advance** | |
| • Inform your family or friends that you may need to leave your home | |
| • Get your flood kit together and include a torch, warm and waterproof clothing, water, food, medication, toys for children and pets, rubber gloves and wellingtons | |

Be prepared for flooding. Act now

Example of ‘Personal Flood Plan’ by the Environment Agency.

**Case Study 9: Mitigation Measure: Communication (Web Mapping Services)**
**Hazard: Floods**
**Geographic Coverage: Bavaria, Germany**
**Implementing Body: Bavarian Environment Agency (Bayerisches Landesamt für Umwelt)**

**Source:** Bavarian Environment Agency (http://www.lfu.bayern.de/wasser/hw_ue_gebiete/informationsdienst/index.htm); Hagemeier-Klose, M., Wagner, K.. (2009), Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication, Natural Hazards and Earth System Sciences 9: 563-574.

**Key Objective:** Provision of user-friendly information on flood-related risks (past, present and future) + Use for spatial planning

**Main Services Provided:** Maps provide the following information

| | |
|---|---|
| 1. Expected frequency of floods | (frequent -10yr flood, medium -100yr flood, seldom/extreme – 1000 yr flood) |
| 2. Legal status of flood plains | Information on areas legally designated as flood plains with legal consequences for construction and/or restrictions on use |
| 3. Water depth | Water depth designated with different shades of blue |
| 4. Historical data | Information on prior flooding |
| 5. Actual data on water level | Real-time information (gauge levels). Information on closest gauge stations and measurements. |

**Effort and Resources Required:** High initials set-up costs, then moderate
**Implementation Level:** Regional
**Ability to deal with risk:** Sufficient for moderate risks and those familiar with the internet. Application allows user to 'zoom in' and receive personalised information.
**Costs involved:**

| **Direct costs** | **Indirect costs** | **Intangible** |
|---|---|---|
| **Implementation** | **None** | **Minor time costs for participants** |


Flood risk web map. Source: Bavarian Environment Agency.

## 2.6 Monitoring and early warning systems

**General description**

Various meteorological and hydrological observations (including coastal water, river and groundwater) have been set up to monitor and forecast droughts, floods, storms and induced coastal hazards, and alpine hazards. This is done in order to better understand the occurrence of these hazards and construct effective warning systems meant to increase the potential undertaking of preparedness and emergency measures.

When a hazardous situation is occurring, real-time information about the upcoming event is used to make decisions concerning emergency response (e.g. evacuation) and loss mitigation. The ultimate goal of (flood) warnings is to prevent fatalities, and in the second place to limit (ecomonic) losses. As shown in the graph below, an early warning system can work very effectively: for example, data from floods caused by dam failures show that fatalities are almost prevented if the warning time amounts to at least 1.5 hours (Von Thun, 1984 cited in WBGU, 1997).

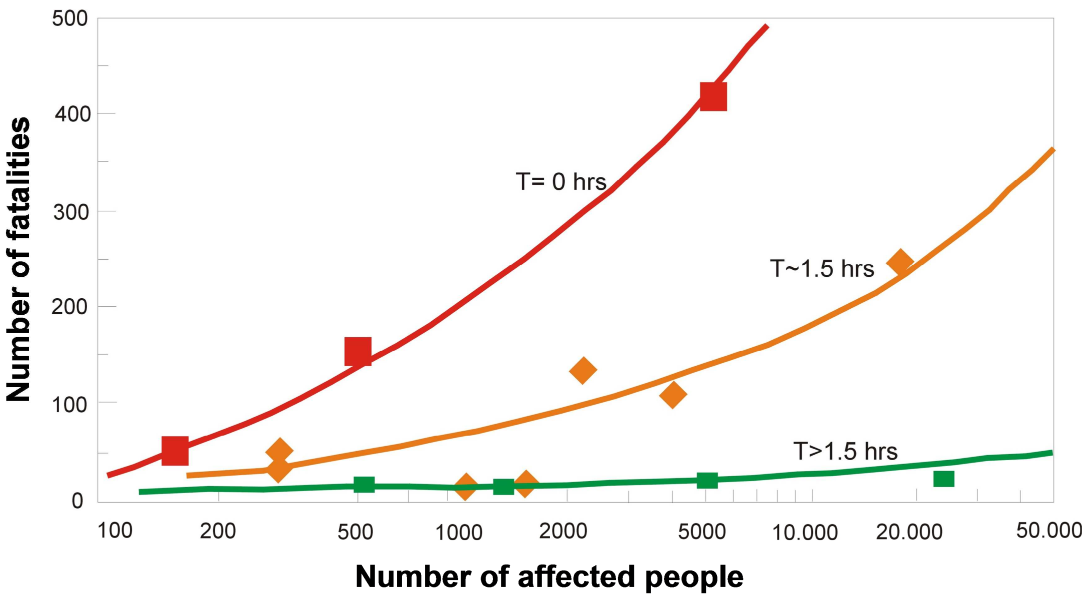



*Figure 2: Effectiveness of early warning in event of dam failure and flash floods (Data: Von Thun, 1984, as cited in WBGU, 1997).*

A successful early warning system consists of five basic components: detecting the situation, developing forecasts, warning civil protection and affected people, taking the correct actions and behaving adapted to the situation (Table 3). However, the entire system is more than a series of components. Although each component should conform to the state of the art, the decisive factor is the interaction between the technical system, the operator, and the organisation (Bayrak, 2011), as well the interaction with the public. For example, Penning-Rowsell and Green (2000) illustrate that the impacts of flood warnings on flood damage reduction depend on the reliability of flood warnings, the proportion of residents available to respond to a warning, the proportion of residents able to respond to a warning, and the proportion of residents who respond effectively.

They conclude that benefits of early warning systems can only be realised when the total system of forecasting, warning and responding is operating effectively. Unfortunately, this is frequently not the case. This is supported by data from severe flooding in Central Europe (e.g. Thieken et al., 2007). However, investments in early warning systems are often slanted towards the development of monitoring and flood forecasting systems, while distribution and implementation of forecasts and warnings are neglected (Grünewald et al., 2001).

*Table 3: Elements of an early warning system (modified from Parker et al., 1994).*

| | Activities | Participants, Stakeholder | Factors for success |
|---|---|---|---|
| **Collecting data** | Collection of meteorological data and forecasts<br>Collection of hydrological and hydrometrical data | Meteorological Services<br>Central and regional water management authorities | Automatic data collection and remote data transfer<br>Weather radar<br>Dense monitoring networks |
| **Forecasting** | Data collection and interpretation<br>Flood modelling and forecasting<br>Release of warnings | Flood forecasting centres<br>Central and regional water management authorities | Operational flood forecasting system including a rainfall-runoff model and a hydraulic river model<br>Good transfer of information within countries and across borders |
| **Warning** | Receive of forecasts and warnings<br>Interpretation and decision-making<br>Forwarding warnings<br>Providing (public) information<br>Coordination of and cooperation with all participants and the media | Regional and local decision-makers<br>Flood committees<br>Civil protection (rescue service, police, fire brigades etc.)<br>Media | Clear responsibilities<br>24-hour standby<br>Rapid and efficient communication<br>Long forecasting periods, few false warnings, targeted forecast data<br>Good transfer of information within countries and across borders |
| **Reacting** | Coordination of measures and participants<br>Informing the public (alerting) | Flood committees<br>Local authorities<br>Civil protection | Good information systems for the public with feedback |
| **Behaving** | Evacuation<br>Flood defense<br>Reducing flood damage by emergency measures | Users of water and water ways (navigation, shipping, wastewater treatment)<br>Companies and industry at risk<br>People at risk<br>Power authorities | Appropriate reaction to information and warnings<br>Availability of help<br>Risk awareness<br>Flood experience |

A European-wide effort for the early warning for weather related natural hazards is made jointly by the national meteorological offices, through the Meteoalarm website (http://www.meteoalarm.eu). This website provides national and sub-national information from the meteorological offices, on the occurrence of wind, snow/ice, thunderstorms (rain, wind and lightning), fog, extreme high and low temperatures, coastal events (surge), forest fire, avalanches, and heavy rain. This European based system uses four risk levels which correspond to four awareness levels and corresponding awareness levels: (1) no particular awareness is required; (2) the weather is potentially dangerous, and people need to be attentive of the meteorological conditions; (3) the weather is dangerous, and people have to be very vigilant and stay informed about the meteorological conditions; (4) the weather is very dangerous, and people must keep themselves informed and be prepared for a life and limb threatening meteorological phenomena.

For droughts, an example of a warning system is available in Spain, where rainfall levels are collected and compared to water usage, in order to control the reservoir levels. Four alert stages exist depending on the reservoir levels, and for each stage, different restrictions in water usage are implemented (Martin-Ortega and Markandya, 2009). Depending on the countries in Europe, monitoring and warning systems for droughts are generally dealt with at the national or regional levels. At the European level a European Drought Observatory is being developed by the Joint Research Centre's DESERT Action http://edo.jrc.ec.europa.eu/php/index.php, with the aim of drought forecasting, assessment and monitoring

Alpine hazards result from movements of water, snow, ice and rocks and include snow avalanches, floods, debris flows and landslides (UNDRO, 1991). The monitoring and warning of e.g. avalanches is done at the European scale with the European Avalanche Warning Services (http://wwww.avlanches.org) as an association of avalanche warning centres in Europe. In the case of flood events in alpine countries, there are warnings in TV and Radio, but also online through the Central Institute for Meteorology and Geodynamics in Austria, if high intensities of precipitation or floods could occur (http://www.zamg.ac.at/weather/warnings/index.php?ts=1285139701).

The monitoring of and warning for floods (both large scale river floods and small scale flash-floods in mountainous areas) are a national and regional competence in Europe. Some efforts are made at the European level to coordinate information, forecasting and early warning, for instance through the Joint Research Centre of the European Commission (http://floods.jrc.ec.europa.eu) and the EFAS flood alert system. National monitoring and warning systems for floods exists in most European countries. The monitoring system is generally coupled with a website meant for the information of the population (see for example these countries; France: www.vigicrues.gouv.fr; United Kingdom: www.environment-agency.gov.uk/homeandleisure/floods/31618.aspx, Germany: http://www.hochwasserzentralen.de/). In France, the national and daily weather emission also warns the population according to observed satellite, rainfall and river flow information. In large, international river basins catchments flood warnings have to be communicated to the nations downstream. In Europe, transboundary flood warning is organized by the international river commissions, e.g. the ICPR, the International Commission for the Protection of the river Rhine (see http://www.iksr.org/index.php?id=140&L=3). Another project example for transboundary flood management including flood warning is TIMISFlood at the River Mosel (http://www.timisflood.net/en/index.php).

Storm surges and coastal hazards' monitoring and warning systems are developed at the national and regional levels, depending on the European countries. Different techniques are being used, which include the monitoring of ground movements for landslides and coastal erosion, the monitoring of sea water levels, and the use of satellite data for the monitoring of depressions and high wind fields and land surface movements in mountainous regions.

**Costing aspects**

Costs related to monitoring and early warning systems are basically implementation costs, such as R&D, engineering, investments and operation and maintenance costs. These types of (direct and tangible) costs have market prices, typically not associated with negative externalities.

Monitoring and early warning measures can have non negligible costs. The EC (2008a) mentions the example of GMES (Global Monitoring for Environment and Security), supported by Inspire (Infrastructure for Spatial Information in Europe), as an illustration of standardized data collection. GMES (http://www.gmes.info/) was launched in 1998 and provides land, marine and atmosphere information, climate change information and emergency and security information. The INSPIRE Directive (2007/2/EC) is complementary to the GMES initiative and has been elaborated to ensure that the spatial data infrastructures of the Member States are compatible and usable across borders and in a Community context (EC, 2008a). The European communication COM(2009)589 (EC, 2009c) indicates that € 4 billion would be needed for operating GMES during the period of 2014-2020. This total amounts splits up into estimated annual costs of € 430 million for the operational activities and €170 million for R&D. See also the Box on GMES below.

Early warning systems avoid costs in other categories of risk mitigation, by increasing preparation time, by allowing better targeted actions, unnecessary preparation and evacuation of people in hazard areas (see e.g. Parker et al. 2009; Rogers & Tsirkunov 2010). Besides investment and operation costs of early warning systems, there also exist societal and economic losses due to false alarms, e.g. lost production or loss of trust in the system and misbehaviour in consecutive warnings, might occur. Rogers & Tsirkunov (2010) state that there is a trade-off between timeliness, warning reliability, costs of false alerts and damage avoided. An example, how this trade-off can be assessed and used to develop optimal flood alerts is given by Schröter et al. (2008). Costs and benefits of a landslides early warning system were assessed by Huggel et al. (2010).

In addition, early warning systems are a potential source of extra-revenue, equal to the value of information they bring. For example, according to Williamson et al. (2002), the provision of weather information can help reducing uncertainties for actors in no relations with disasters. They mention the examples of the agricultural sector that could benefit from better prediction on future yields, or the energy sector that could make a more efficient use of power generating resources. Other sectors could also benefit from improved weather forecasts such as: construction works, transportation and the organization of large-scale events... These co-benefits can be marketed and be a source of extra revenues. Bouma et al. (2009) propose a valuation framework for informational investments in satellite observations systems. The framework was applied in the context of the use of a satellite observation system for monitoring Dutch water quality in the North Sea. They also addressed the role of users and stakeholders and describe the benefits of such a monitoring system for decision making under conditions of uncertainty. In this case study, benefits of investing in informational systems were values at 74,000 Euros per week while the costs of satellite investment were valued at 50,000 Euros per week. Interestingly, the method used in the paper allowed relating the value of information to its level of accuracy, showing that probabilities of false-alarms would reduce the economic value of information.

**Case Study 10: Mitigation Measure: Monitoring and Early Warning (Global Monitoring for Environment and Security – GMES – programme)**

**Hazard: Multiple Types**

**Geographic Coverage: EU**

**Implementing Body: European Commission (EC) and European Space Agency (ESA)**

**Source:** PricewaterhouseCoopers (2006), 'Executive summary: Socio-economic benefits analysis of GMES', October 2006.

**Key Objective:** The programme is dedicated "to the monitoring and forecasting of the Earth's subsystems. It also contributes directly to the monitoring of climate change". GMES services also address emergency response (e.g. in case of natural disaster, technological accidents or humanitarian crises) and security-related issues (e.g. maritime surveillance, border control).

The GMES services have six main thematic areas:

1. Land Monitoring: land monitoring service to provide accurate and cross-border harmonised geo-information at global to local scales
2. Marine Environment Monitoring: marine environment monitoring service for regular and systematic reference information on the state of the oceans and regional seas
3. Atmosphere Monitoring: atmosphere monitoring service for records on atmospheric composition for recent years, current data for monitoring present conditions and forecasting the distribution of key constituents for a few days ahead
4. Emergency Management: emergency management service with a worldwide coverage, and a wide range of emergency situations resulting from natural or man-made disasters
5. Security: services for security applications for supporting related European Union policies in the following priority areas: border surveillance, maritime surveillance, support to EU external action
6. Climate Change: monitoring of the Earth's subsystems and help to better monitor and understand climate change"

**Effort and Resources Required:** High due to focus on multiple services as well as costly equipment and maintenance. Below are estimates of the scheme funding:

| 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total (€M) | Funding |
|---|---|---|---|---|---|---|---|---|
| 100 | 100 | 100 | 100 | 100 | 100 | 100 | **700** | ESA |
| 110 | 150 | 190 | 225 | 260 | 300 | 340 | **1575** | additional public expenditure |

The Net Present value of benefits from the scheme are estimated at 34 billion Euros over 2006-2030 (e.g. €145 million per annum from flood protection, €25 from protection against landslides and earthquakes).

**Implementation Level:** Multi-Country

**Ability to deal with risk:** Depends on the natural hazard. E.g. there are estimates that GMES contributes to a 1.5% reduction in flood costs, 0.75% reductions in damage and injury due to landslides and 1% reduction in the impact of earthquakes.

| Direct costs | Indirect costs | Intangible |
|---|---|---|
| **Set-up (e.g. satellites) Implementation** | | |

**Case Study 11: Monitoring and early warning: SAIH – Sistema Automático Información Hidrológica, Spain**

**Hazard: floods**

**Reference:** Presentation “Flood risk, prevention and control in the Mediterranean: the case of Spain” given by Marta Moren at the CRUE Midterm Seminar, Madrid 20 October 2009

**Goals:** The Automatic Hydrological Information System (SAIH) is one pillar of the Spanish strategy for flood risk prevention. It has three main objectives:

- Automatic provision of information in real time,
- Short term forecasts of water levels and flow discharges,
- Management of the optimal use of reservoirs and canals.

SAIH covers all catchments in Spain. The state of implementation is illustrated in the figure below. The system includes all elements of an early warning system: data acquisition, data processing and modeling, including modules for decision making as well as communication and provision of warning information including inundation maps. Altogether, 1775 control points, e.g. reservoirs, flow gauges in rivers, flow gauges in channels, rainfall gauges, booster stations, have been set up and integrated in the system by 2008. In addition, radar data have been used to predict rainfall and hydrographs for flash floods in catchments with a concentration time of less than 6 hours. For the protection and management of international river catchment, a cooperation between Spain and Portugal was agreed upon (Albufeira 11/30/98) and secures continuous data exchange in case of a flood event. The investment costs of SAIH amount to 374 M€ (figure updated in 2006). The annual operational costs are estimated to be 18 M€.


## 2.7 Emergency response and evacuation

**General description**

Emergency responses can include providing information, medical care, food, water, and shelters to the population, evacuating vulnerable people, searching for and rescuing endangered people (e.g. in the case of avalanches), and maintaining water and power supplies during and after an event. Most of these responses are common to all four hazards concerned by this study. However, each hazard also has specific consequences that require specific responses. These responses need preparedness and can be planned with emergency management plans. These emergency plans can be prepared by the state, but their effectiveness increases when they are tailored to regional and local constraints and specificities. Since droughts occur at national or regional scales, and over long time periods, the emergency response will mostly concern the rationing of water for certain usage and the provision of water to vulnerable people. Local plans can also be prepared in order to deal with the droughts consequences such as forest fires. For floods, alpine hazards and storms, plans can be built at all levels of decisions. For instance, in France and in the UK, households and businesses are advised to prepare their own emergency plan which includes important details such as the building specific damage-reducing and evacuation procedure; the location of an emergency kit containing electrical lights, radio, batteries and drinkable water; copies of important documents, emergency phone numbers, etc. (http://www.prim.net; http://www.environment-agency.gov.uk). The efficiency of the state, region or local emergency response highly depend on the monitoring and warning systems since the earlier the alert is given, the earlier people can react, protect their possessions and lives, and of necessary, be evacuated.

**Costing aspects**

Based on data from the flood in 2000, Penning-Rowsell & Wilson (2006) suggest using a fixed percentage of 10.7% of the direct economic property losses as estimate for the variables costs of emergence response in the UK. This method has also been included in the Multi-Colored Manual (Penning-Rowsell et al., 2005). Fuchs et al. (2007) estimate the cost of evacuation as a function of direct evacuation costs, weighted by the interval of recurrence of the evacuation, making use of the following equation:

$$C = \frac{(W \cdot T \cdot N_w \cdot N_b) + (N_p \cdot C_{acc} \cdot N_d)}{n},$$

where $C$ on the left hand side is the total cost of evacuation per year; the first term in parenthesis on the right hand side corresponds to the labour cost of the staff conducting the evacuation, while the second term in parenthesis reflects the actual costs of board and lodging – i.e. $W$ is the hourly wage of persons conducting the evacuation; $T$ is the average time per person needed for evacuation of one building; $N_w$ is the number of persons of the avalanche safety service conducting the evacuation of one building; $N_b$ is the number of buildings to be evacuated; $N_p$ is the number of persons to be evacuated; $C_{acc}$ are the costs for board and lodging of evacuated people per day; $N_d$ is the average number of days of evacuation per person; and $n$ is the recurrence interval (in years) of evacuation.

Zhai and Ikeda (2006) proposed a complementary type of valuation framework, using CVM. They proposed an estimate of the WTP for avoiding the inconvenience of an evacuation. It is interesting noting that the greatest inconvenience reported by respondents was the lack in information and food supply.

**Case Study 12: Mitigation Measure: Emergency and Evacuation Response (1995 Evacuation)**

**Hazard: Floods**

**Geographic Coverage: the Netherlands (primarily Gelderland)**

**Implementing Body: Local authorities**

**Source:** Bezuyen, M.J., van Duin, M.J. and Leenders P.H.J.A. (1998), Flood management in the Netherlands, Australian Journal of Emergency Management 13: 43-49.

**Key Objective:** Precautionary evacuation measures (rise in water levels for several major rivers: Meuse, Rhine, Waal; threat of dike breach)

**Main Activities Involved:**

| | |
|---|---|
| 1. Rijkswaterstaat (Dept of Public Works and Water Management) | Alarming prognosis of imminent flood risks (25 January 1995) |

| | | |
|---|---|---|
| 2. | Mobilisation of local authorities (mayors, polder boards) | Dissemination of information and subsequent evacuation (humans, cattle) |
| 3. | Police / Fire brigades | Enforcement of no-entry zone after initial evacuation |

**Effort and Resources Required:** Large. 250,000 evacuated but most voluntarily (only 3% made use of public means, as well as temporary accommodation) and without assistance. Minor problems with farmers and firm owners.

Implementation Level: Regional but large-scale

**Ability to deal with risk:** Sufficient

**Factors that Facilitated Success of Operation:** a. Preparation and earlier floods in 1993, b. Communication on the severity of risk (local authorities, media), c. Gradual development of threat, d. Self-regulating behaviour (limited need to use public assistance for evacuation).

**Costs involved:**

| **Direct costs** | **Indirect costs** | **Intangible** |
|---|---|---|
| Initial Evacuation Cost (appx. € 250 million for individuals), Economic Damage (e.g. suspension of production), Compensation (€ 225 per household) | Losses to Supply Companies and Customers | Minor time costs for as a result of increased traffic in regions outside the endangered area |

**Case Study 13: Mitigation Measure: Emergency and Evacuation Response (2008 Storm Surge and Lake Flood Simulation Exercise – Exercise 'Waterproef')**

**Hazard: Floods**

**Geographic Coverage: the Netherlands, Dutch coast and lake Ijssel**

**Implementing Body: Taskforce Management Overstromingen (Dutch Ministry of Interior and Ministry of Public Works and Water Management)**

**Source:** De Jong, M. and Helsloot, I. (2010), The effects of information and evacuation plans on civilian response during the Dutch national flooding exercise 'Waterproef', Procedia Engineering 3: 153-162.

**Key Objective:** Simulation Exercise. Evaluation of preparedness according to 3 different flood scenarios

**Main Activities Involved:**

| | |
|---|---|
| Decision-Making Processes for Evacuation | Practice relevant processes and assess preparedness |
| Involvement of Civilians | Assess responsiveness of the public. Allow the public to provide feedback |
| Special Exercise Environment | Create TV news bulletins, Internet information, Telephone emergency telephone lines |

**Effort and Resources Required:** Medium to large. 10,000 people participated in the exercise.

**Implementation Level:** Regional.

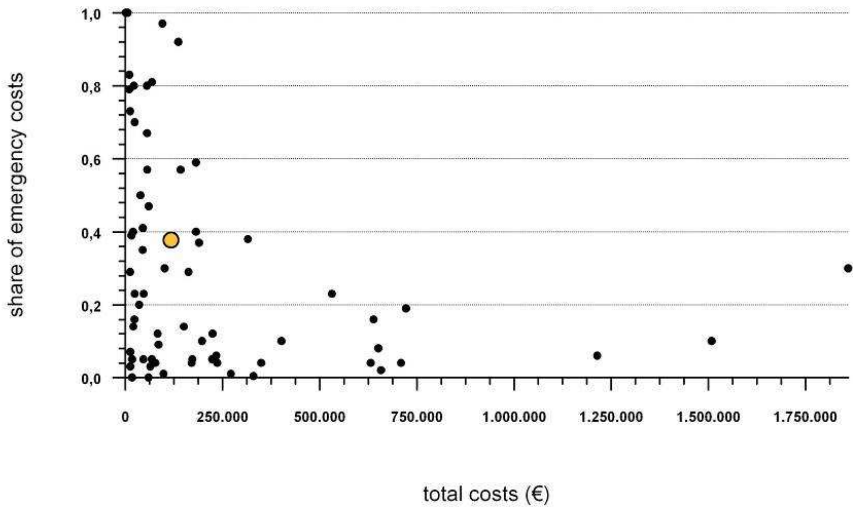
**Ability to deal with risk:** Sufficient.
**Costs involved:** approximately € 3 million.

**Case Study 14: Mitigation Measure: Emergency services in western Austria, 2005**

The following case study relies on results of a survey carried out by Pfurtscheller and Schwarze (2010). The main focus was to identify triggers of economic vulnerability and resilience, but also to evaluate the costs of emergency. The costs of emergency services are often borne by both, statutory and voluntary organizations, such as civil protection, the national military, voluntary local fire brigades, the Red Cross, etc. Pfurtscheller & Schwarze (2010) mainly concentrated on the costs of municipal fire brigades, omitting the costs of national and voluntary private emergency services.

The catastrophic flood event in Tyrol in August 2005 caused an estimated total economic loss of 410 million € (Tiroler Landesregierung 2006a). That represents 2.1% of the gross regional product (2002 basis, total GRP 19.2 billion €; Tiroler Landesregierung, 2006b). The main characteristic of flood events in Alpine regions is the very high exposure of private households and structures and the partly or fully destruction of infrastructure, like railways and roads. This leads to the assumption of an 'alpine damage structure' or 'special vulnerabilities' to natural hazards in these regions. This extreme event affected in total 61 of 279 municipalities of the province of Tyrol, but the main damage region consisted of 20 municipalities. In sum 1.200 structures and buildings were partly or totally affected.

The large-scale floods caused the high number of activated members of fire brigades and other local volunteers (up to 13 400 per day). Additionally approximately 1 500 members of the armed forces, police and Red Cross devoted in total 320 000 mission hours for emergency, clean-up and evacuation. 15 private and army helicopters evacuated approximately 450 people. For several days airborne supply was the only way to get in contact with the local inhabitants, because of the breakdown of communication and road networks (information orally provided by the regional fire department). The study relies primarily on a questionnaire among local fire brigades ($n_{total}$=325, $perc_{returned}$ 51%). This data is spatially matched with municipality areas due to different classification, e.g. in some cases one municipality consist of several fire departments. It is complemented by regional socio-economic data, data on disaster relief spending for private, industry and trade losses by the Austrian Catastrophe Fund and losses from public authorities at the scale of municipalities from the Tyrolean government. Besides of other results, the return period of the flood event, the permanent settlement area, the duration of the emergency situation and "special settings" such as multiple events have a strong impact on the activities of the local crisis management. Generally, the main finding here is that the flood duration and the occurrence of multiple hazards have both a strong significant impact on the total hours spent on and, thus, the costs of emergency services. The share of clean up costs is driven by the flood intensity (measured by inundation area) and the coincidence of multiple hazards. The duration of the emergency period shows a strong impact with great error margin however, so that its effect is not statistically significant. Unobserved characteristics of the location (such as the structure of housing, share of frame houses versus stone houses, etc.) also seem to have a great effect on the cost of clean up, since the set of variables only explains for less than half of the variance observed in our data. The loss in material (damage to cars, machines, safe-guarding material, etc.) is driven in our sample overridingly by the days of the event and to a lesser extent by the flood intensity (measured by the area of inundation). It is also significantly affected by the number of vehicles used in the emergency operation but, surprisingly, not significantly by number of personal in action. Pfurtscheller & Schwarze (2010) compute the total costs of emergency services by summing up the money equivalent of service hours, i.e. services hours multiplied with an average hourly wage of 38 €. This rate will be typically charged by a local fire brigade in Germany, similar economic conditions to mirror the Austrian situation. It seems fair to be used as an average value for hourly wages to be paid for special services in Austria as well. Comparing the total cost of emergency services with the total cost per municipality, consisting of the damages to private buildings and public infrastructure (as recorded by Austrian funds for catastrophes), they arrive at a share of services costs at around 40 per cent on average (37% in our sample, marked by the high-lighted yellow dot). The median value is much higher (76 %) because emergency costs are often the only costs incurred in most municipalities.




Share of emergency costs over the total cost per municipality (sum of emergency costs, damages to private buildings and public infrastructure), Source: Pfurtscheller & Schwarze 2010.

Obviously the share of emergency costs is relatively high in cases of low and moderate damages (beta, low 125 000 €) and decreases as the amount of damages increases. Yet, even at very high total costs (> 0.5 Mill. €), the shares of emergency spending can be valued about 20%. Given this high variance and functional relationship, they find that average values are misleading as a rule of thumb to establish the costs of emergency services.

## 2.8 Financial incentives

**General description**

Financial incentives may be given in various forms that lead to risk reducing behaviour or measures. A well-known approach comes from the insurance sector, where discounts of premiums or lower deductibles are offered when the policy holder implements certain measures or behaviour that leads to a lower risk. Also, governments may set up funds to stimulate measures from lower levels of government, citizens or businesses.

An example of a mitigation fund is the French “Fond de Prévention des Risques Naturels Majeurs” which provides grants for the prevention of alpine hazards, floods, cyclones, as well as other hazards not considered in the present report. This fund also finances the acquisition of lands and buildings endangered by the hazards (FPRNM, 2006). At a larger scale, European finance institutions, such as the European Investment Bank (EIB), may also stimulate national governments to undertake actions. An example includes the programme in the Czech Republic to reduce flood risks worth over 500 million Euros, as part of the implementation of the national Strategy for Protection against Floods. This programme is supported for 59% by the EIB (http://www.eib.org/projects/loans/2006/20060249.htm) Some authors have argued that the European Union Solidarity Fund (EUSF), that finances government disaster relief after large events, should be reformed to support disaster risk reduction, and not only relief (Hochrainer et al., 2010).

**Costing aspects**

Costs of financial incentives involve the direct costs of programmes that stimulate measures undertaken by (other) governments, households and private businesses. Few comprehensive studies are available that have detailed the investments in risk reduction through financial investments. A number of studies have looked at the potential to stimulate measures at household levels by leveraging insurance conditions (e.g. Botzen et al., 2009; Kreibich et al., 2011). Although single studies highlight the use of programmes to stimulate investments for risk reduction measures through e.g. government programmes, no comprehensive estimates of national or European efforts are available.

**Case Study 15: Mitigation measure: Financial Incentives: Fund for the Prevention of Major Natural Risks (France)**

For instance, in France, a national subsidy system, the Barnier Fund or Fund for the Prevention of Major Natural Risks can subsidise studies on assessments of natural disaster risk and prevention measures. The fund can also finance the costs of mitigation measures made compulsory by a PPR, as well as the relocation of homeowners and the destruction of houses exposed to natural hazards that pose a considerable threat to human lives or were severely damaged by a natural disaster. Until the end of the year 2012, and with a maximum of €55 million per year, this fund will pay up to 50 per cent of the expenses for the studies before the implementation of prevention measures, 40 per cent of the costs of prevention measures, and 25 per cent of the costs of protection measures (FPRNM, 2006). Prevention and protection measures are respectively defined as measures such as ones meant to manage water flows and rivers, and ones that are to protect human lives and inhabited buildings.

The Barnier fund is financed by collecting a fixed percentage on the natural disaster coverage premium that is paid by every French household. This percentage was 2 per cent in 2005 and increased to 4 per cent in 2006, to 8 per cent in 2008 and to 12 per cent in 2009 (Letremy and Grislain, 2009). In 2006, €52.8 million was collected for the fund. An increase in use of the fund led to a very low balance by the end of 2007. The increases in 2008 and 2009 of the percentage collected were to improve this balance. In 2009, €105.6 million were collected.

## 2.9 Risk transfer

### General description

To financially protect countries, businesses and households, different systems exist across Europe. Risk transfer mechanisms are aimed at spreading losses between people and/or over time. Insurance is a widely used risk transfer mechanism, but many other forms exist (see e.g. Warner et al., 2009). Entirely private or mixed public/private insurance systems have been created in most European countries, including in the UK, in Germany and in France (Botzen and Van den Bergh, 2008; Bouwer et al., 2007b).

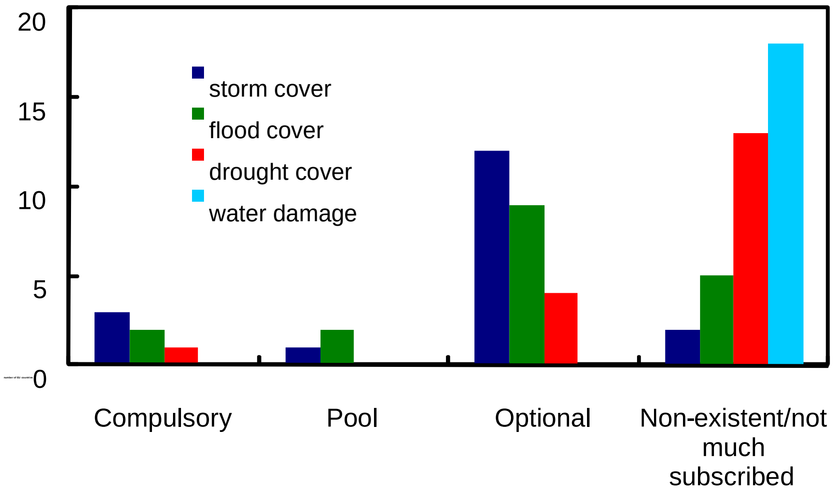



*Figure 3: Private sector insurance availability in 18 European countries (from Bouwer et al., 2007b; data from CEA, 2005).*

Figure 3 provides an overview of private sector insurance availability in Europe, for cover against different types of weather-related losses. Insurance systems in Europe do not always include all of the four hazards concerned by the ConHaz project. For instance, drought insurance is rarely provided because it is often regarded as not commercially viable, while floods, storms, and alpine hazards, are more commonly covered. Especially storm insurance has a good availability, and take-up in households across Europe is high. Comparisons and overviews of different natural hazard insurance systems in Europe are given by a number of authors (Swiss Re, 1998; Vetters and Prettenthaler, 2003; Von Ungern Sternberg, 2004; Bouwer et al., 2007b; Botzen et al., 2010).

Risk transfer mechanisms commonly used are relief funds. Relief funds are usually nationally provided, but a European Union Solidarity Fund (EUSF) also exists which supports governments in countries that suffered from a "major" natural disaster (EUSF, 2010). More information on the EUSF is provided in the Case Study below. In the UK, relief funds provided by the State are not available whereas it is not supposed to be available in Germany, but usually is. In France, no relief fund is available, but even though the insurance system is privately provided, the natural disaster declaration needed for the compensations is controlled by the State. Therefore, the incentive for households to undertake mitigation measures is low since they can expect to be compensated by, or via the intervention of, the federal government in case of a disaster. This is true for the compensation of alpine hazards, floods' damage, and cyclones – not for all storm surges' damage.

One interest of natural hazard insurance is the possibility to provide financial incentives to households to take mitigation measures, for example through risk based premiums or deductibles. This is done for floods, in the UK (ABI and EA, 2009) and in France through a link between the PPRs and deductibles. Incentives for mitigation through insurance appear to be non-existent for droughts, alpine hazards and storms. Some research has highlighted the opportunity to link insurance systems with more incentives to reduce risks (see e.g. Thieken et al., 2006; Botzen et al., 2009; Warner et al., 2009). For example, Swiss monopoly insurers invest approx. 15% of the premium incomes in prevention (Ungern-Sternberg 2002).

**Costing aspects**

Risk transfer and in particular insurance comes at a cost, which includes risk premiums, as well as transaction costs and taxes. Secondly, depending on whether the system is set-up ex ante or ex post, costs differ. Different forms of risk transfer have different costs, largely related to the size of the system and the cover provided (see e.g. Warner et al., 2007). In general, expensive ex ante commercial systems have high cover (but also relatively high transaction costs), while government ex post systems (relief funds set up after a disaster, for instance) may have relatively low direct costs, but high opportunity costs. Raschky et al. (2009) and Schwarze et al. (2011) compared the costs and benefits of the risk transfer mechanisms of three provinces in Austria, Germany and Switzerland, respectively, that were affected by flooding in August 2005 and also assessed the willingness of people to pay for insurance (see below).

**Case Study 16: Mitigation Measure: Weather Risk Transfer Instruments**
**Hazard: Droughts but also other types**
**Geographic Coverage: EU**
**Implementing Body: Private Companies, EU member states**

**Sources: 1**. Roth, M., Ulardic, C., Trueb, J. (2008), "Critical success factors for weather risk transfer solutions in the agricultural sector: A reinsurer's view', Agricultural Finance Review 68(1): 1-7. **2**. European Commission (2007). Agricultural Insurance Schemes. Report N° AGRI-2007-0343, Brussels.

**Key Objective:** Agricultural yields and commodity prices are sensitive to weather patterns such as drought incidences (e.g. 47% of crop losses in the US between 1981-2003 are attributed to droughts). Stakeholders are hence increasingly interested in weather risk transfer products. The key innovation of such schemes is that they explicitly link insurance to an underlying systemic risk (e.g. low rainfall). Farmers, input providers and food processors demand such risk transfer solutions. For instance, seed companies are increasingly bundling weather risk transfer products with seed bags, so that their clients buy a joint product that covers expenses for the seeds in case of droughts.

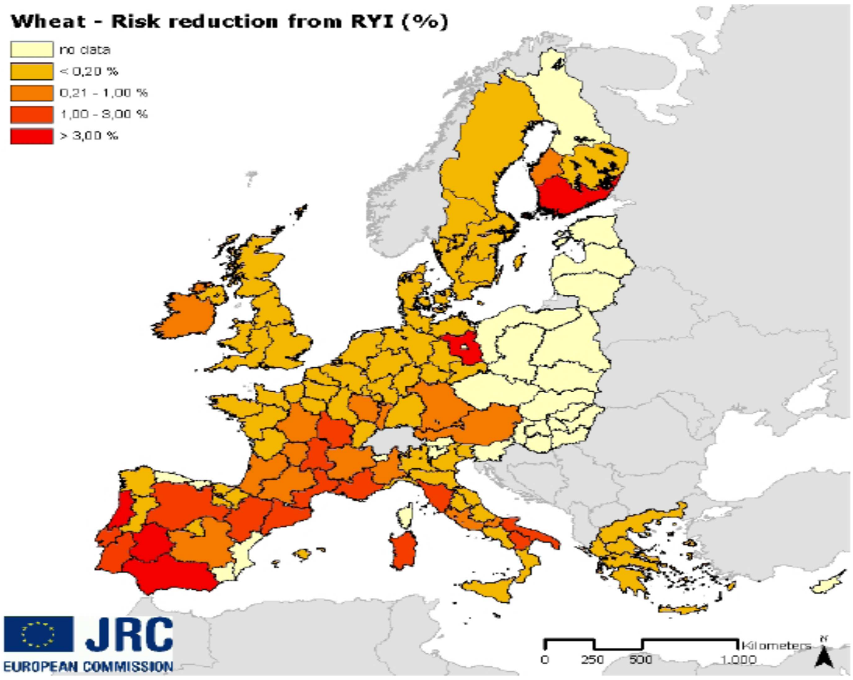
Effort and Resources Required: Moderate but still several difficulties that inhibit a widespread adoption of such risk transfer instruments:

1. High regulation of agricultural markets
2. Inadequate information for stakeholders
3. Uncertainty regarding the link between weather (e.g. drought) indices and agricultural yields

PricewaterhouseCoopers claims there has been a healthy growth of the weather risk transfer sector (rising from $2.5-9.7 billion in 2001 to 19.2 billion for 2007). The Net Present value of benefits from the scheme are estimated at 34 billion Euros over 2006-2030 (e.g. €145 million per annum from flood protection, €25 from protection against landslides and earthquakes).

Implementation Level: Country

**Ability to deal with risk:** Has been substantial in certain geographical regions (e.g. Southern Spain, Southern France, Portugal)




Wheat production risk reduction from area yield insurance:
Source: European Commission (2007)

| Direct costs | Indirect costs | Intangible costs |
|---|---|---|
| Insurance Payments:<br>Cost per hectare varies according to crops:<br>Barley 9.0 – 19.5 €/ha<br>Maize 5.5 – 35.3 €/ha<br>Potato 43.6 – 130.4 €/ha<br>Rice 8.7 – 26.8 €/ha | | |

**Case Study 17: Mitigation Measure: Risk Transfer (European Union Solidarity Fund)**
**Hazard: Multiple (floods, fire, storms etc)**
**Geographic Coverage: EU + candidate countries**
**Implementing Body: EU Commission**

**Source:** Hochrainer, S., Linnerooth-Bayer, J., Mechler, R. (2010), ‘The European Union Solidarity Fund: Its legitimacy, viability and efficiency’, Mitigation and Adaptation Strategies to Global Change 15: 797-810..

**Key Objective:** The European Union Solidarity Fund (EUSF) was created in 2002 following major floodings in central and eastern Europe. Its key objective is to “show practical solidarity with member States and candidate countries by granting exceptional financial aid if these were the victims of disasters of such unusual proportions that their own capacity to face up to them reaches to their limits". Countries can request aid for emergency measures if the satisfy one of the following conditions (*major disaster thresholds*):

1. a natural disaster causes direct damages exceeding €3 billion (at 2002 prices)
2. damages amount to 0.6% of the gross national income of the country concerned.

Payments are confined to 'finance operations undertaken by the public authorities alleviating *non-insurable* damages". The EUSF can cover public expenses that deal with:

1. restoration of public infrastructure
2. provision of services for relief and clean-up
3. protection of cultural heritage

The majority of EUSF financial assistance has been allocated for flood events (45%), fire (27%), storms (16%) and earthquakes (4%). National authorities need to submit an application to the European Commission within 10 weeks following the natural disaster.

**Effort and Resources Required:** High. The fund has an annual budget of €1 billion and the Commission decides how to allocate this according to applications by affected countries. To ensure that the fund has sufficient capital to cover damages occurring late in the year, at least a quarter of its budget needs to be available during the last four months.

**Implementation Level**: Country, Multi-country

**Ability to deal with risk:** So far, this has been sufficient. Since its inception annual payouts from the fund have been in the range of €20 to €700 million (i.e. within the annual budget). Nevertheless, the time delay between grant applications and payments has been substantial (averaging 8-10 months), and this has been notably high for poorer member states (where financial assistance is likely to be more urgent). Contrary to its envisaged function of promoting 'cohesion in the face of disparate coping capacity', Eastern European countries receive on average less financial assistance. This may be due to the fact that Western richer member states have a higher capital stock exposed to natural hazards. Hochrainer et al. (2010) estimate that there is "an annual probability of 8% that payments will exceed the Fund's capacity of €1 billion, meaning that the EUSF has an expected shortfall every 12 years on average". Climate change is likely to increase the frequency and intensity of weather-related disasters and hence require an augmented budget in the medium term.

Hochrainer et al. (2010) claim that an "EU responsibility for disaster losses may create disincentives for taking preventive actions". They suggest the following measures that could help reform EUSF (and place more emphasis on pre-disaster support rather than post-disaster relief):

1. Transfer part of the fund's risk through commercial reinsurance or directly to the capital markets (e.g. catastrophe bonds). The Fund can provide assistance to national insurance pools and make available any needed additional capital.
2. Link eligibility to country-level risk-management measures as a way of reducing moral hazard (e.g. payments conditional to land-use planning and building regulations).

| Direct costs | Indirect costs | Intangible costs |
|---|---|---|
| €1 billion per annum | | |

**Case Study 18**: **Comparison of risk transfer systems in Austria, Switzerland and Germany**

**References**: Raschky, P., R. Schwarze, M. Schwindt, H. Weck-Hannemann (2009): Alternative Finanzierungs- und Versicherungslösungen – Vergleich unterschiedlicher Risikotransfersysteme dreier vom Augusthochwasser 2005 betroffener Länder: Deutschland, Österreich und Schweiz. Report of the KGV Prevention Foundation, Berne, Switzerland, 28 pp. (in German).

Schwarze, R., M. Schwindt, H. Weck-Hannemann, P. Raschky, F. Zahn & G.G. Wagner (2011): Natural Hazard Insurance in Europe: Tailored Responses to Climate Change are Needed. - Env. Pol. Gov. 21: 14–30.

Cost assessment methods: Comparison of insurance premiums and survey data on willingness to pay, Hazard: Flood, Sector: residential/private households

In the project of Raschky et al. (2009) and Schwarze et al. (2011) the risk transfer mechanisms of three provinces that were affected by flooding in August 2005 were compared. These provinces and mechanisms in place were: i) Bavaria (Germany) with a pure market-based insurance system and public relief in case of very severe events, ii) Grisons (Switzerland) with a compulsory insurance against natural hazards and alpine risks provided by a public (monopoly) cantonal property insurer (KGV) and iii) Tyrol (Austria) with a tax-based disaster fund that is supplemented by market insurance. In Austria and Germany insurance against losses due to natural hazards can be contracted as addition to a building fire insurance. Accordingly, insurance density varies significantly: While in Grisons/Switzerland 100% of the homes are insured against natural hazards, this holds for less than 15% in Tyrol/Austria and for only 10% in Bavaria/Germany.

In addition, the costs for the insurance, i.e. the premiums, differ in the three systems. People in Tyrol would pay an annual net premium of approximately 420 Euros for a fixed sum insurance assuming a house worth 335,000 Euros, i.e. approximately 1‰. Considering information of two German insurers a relative premium of more than 1‰ was calculated for Bavaria. Assuming a house with a value of 300,000 Euros and an excess of 1% of the sum insured, the yearly net premium for an insurance against damage due to fire and natural hazards would amount to 313 Euros at the first insurer (Bruderhilfe). The premium of the second insurer (Gerling) is based on an excess of 10% of damage and results in an annual net premium of 376 Euros. In contrast, the monopoly insurer in Grisons can provide insurance coverage for a house worth 500,000 CHF (about 335,000 Euros), for a yearly premium of 150 CHF (about 100 Euros). This corresponds to a relative premium of 0.3‰, i.e. less than one third of premiums in Austria or Germany.

The lower costs of public monopoly insurance was already realized within Switzerland, where in seven of 26 cantons (the so called GUSTAVO cantons), insurance is offered by private companies, which charge significantly higher premiums. Ungern-Sternberg (2002) and Fischer (2008) identified different reasons for the higher efficiency of public monopoly insurers: low advertising and other competition costs, larger reserves of the monopoly insurers and their right to participate in the processes of the Building Codes and Land Use Planning as well as the financing of the Fire Service and Cantonal Civil Defence Services. In fact, Swiss monopoly insurers invest 15% of the premium incomes in prevention (Ungern-Sternberg 2002).

For comparison: In Spain, where a comprehensive legal compulsory insurance against damage caused by geo-atmospheric hazards and other ‘extraordinary events’ (terrorist attacks, political unrest) was put in place, the annual contribution amounts to 0.092‰ of the insurance sum for buildings.

Raschky et al. (2008) also present data on the willingness to pay (WTP) for insurance against losses due to natural hazards. Data result from a survey among flood-affected households in Bavaria and Tyrol. Unfortunately, only a comparatively small share of the surveyed households was willing to answer these questions, i.e. 29.3% (of 218 households) in Tyrol and 44.9% (of 305 households) in Bavaria. Among those with a positive WTP for insurance the average monthly WTP amounted to 24.76 € per month (i.e. 297 € per year) in Tyrol and to 54.05 € per month (i.e. 649 € per year) in Bavaria. These figures were reduced to 17.33 € and 47.65 € per month (or 208 € and 572 € per year) when cases with a WTP = 0 were included. The big difference between the numbers in Tyrol and Bavaria might be due to the fact that it cannot be excluded that some people in Bavaria referred their answer to a yearly WTP. Nevertheless, the WTP is approximately in the same order of magnitude of the current insurance premiums.

# 3 Analysis and assessment of measures and economic valuation methods

## 3.1 Economic valuation methods and frameworks

The costs of mitigation of natural hazard risks can be classified according to the three cost categories that were adopted in the ConHaz project (see Work Packages WP1, 2 and 3). These costs types are indicated in Table 4, and include the following categories:

a. Direct costs;
b. Indirect costs;
c. Intangible costs

The direct costs refer to any costs attributed to research and design, the set-up, and operation and maintenance of infrastructure/other measures for the purposes of mitigating (or adapting to) natural hazards. The indirect costs relate to any secondary costs (externalities), occurring to economic activities/sectors (or localities) that are not directly linked to such infrastructure investment. Both direct and indirect costs are costs that are measurable in monetary terms. The intangible costs refer to any additional impacts, for which no market price exists; such costs often come in the form of health or environmental impacts, for which monetary values are generated with the use of appropriate statistical techniques.

For all types of mitigation measures, the direct costs are most often easily quantifiable based on the market price of the relevant investment (set-up and maintenance; see Fuchs et al. 2007). For example, for the purposes of land-use planning or set-up of early-warning systems (e.g. for protection against floods and avalanches) the direct costs can relate to the purchase of land in risk-prone areas or the cost of satellite systems. Evacuation as a preventive measure against natural hazard risks can, for instance, involves the cost of physically evacuating individuals as well as any economic damage that can be attributed to suspension of production.

There is often less emphasis given on the indirect costs of mitigation against natural hazards, which usually receive secondary attention in the literature. For instance, while evacuation can directly disrupt production in the vicinity of the hazard-affected area, this may also have indirect consequences for consumers located far away or distant firms that use the produce of the affected area as an intermediate input for their own production.

Intangible costs require the use of specific methods in order to translate respective impacts in monetary terms (Garrod and Willis 2000). Given the complexity of generating such monetary estimates, intangible costs are often ignored (or underrepresented) in studies that focus on the cost assessment of mitigation measures. Such costs can obviously be important and their exclusion can naturally lead to incomplete and biased estimates of the overall mitigation costs. In the case of evacuation measures, for instance, there may be substantial intangible time costs as a result of traffic congestion both in the risk-affected as well as surrounding areas. In the case of infrastructure building, changes in landscape or the natural environment may reduce the aesthetic value attached to the affected area. Economists have traditionally employed a range of techniques in order to provide monetary estimates for such intangible costs. *Hedonic*

*Pricing Models* (HPM; see Table 4) for instance estimate values for environmental services (e.g. aesthetic values/proximity to recreational sites) by correlating market prices of marketed goods (e.g. houses) with the extent of environmental amenities in their vicinity. The *Revealed Preferences* (RP) method attaches monetary values to intangible services by indirectly deriving their implicit demand from the directly observed consumer behaviour (and purchasing habits) of associated services (e.g. indirectly deriving the value of fisheries by observing the direct demand for fishing licenses). The *Contingent Valuation* (CV) method, often commonly referred to as *Stated Preference* method, asks individuals to directly state their preferences (and values) rather than indirectly infer those from actual choices.

*Table 4. Types of mitigation and valuation methods.*

| Categories | Direct costs | Indirect costs | Intangible costs |
|---|---|---|---|
| Management plans, land-use planning, climate adaptation | Implementation. Market price | Distortion on land market values. Deviation from market equilibrium price<br>Shortage in land availability. Market price | Aesthetics. Revealed Preferences (RP), Hedonic Price Modelling (HPM) |
| Hazard modification | | | |
| Infrastructure | | | Fragmentation. Stated Preferences (SP) |
| Mitigation measures (stricto sensu) | | | Inconvenience and discomfort. SP |
| Communication | | | |
| Monitoring, early warning systems | | | |
| Emergency response, evacuation | | | Controlled disaster: discomfort and fear. SP<br>Evacuation, inconvenience. SP |
| Financial incentives | | | |
| Risk transfer | | | |

One can naturally also frame any mitigation measure in terms of implied opportunity costs. Investment in any of the aforementioned mitigation measures may for instance restrict spending on other types of mitigation or expenditure. For example, increased spending on monitoring and early warning systems for floods may reduce spending on actual hazard modification measures either for the case of floods or other types of natural hazards. Similarly, an increase in spending in natural hazard mitigation may restrict public spending in non-natural hazard specific investment (e.g. education, health etc).

Issues related to data availability and quality are particularly important in determining the accuracy of cost estimates of mitigation measures (either direct, indirect or indirect). While market prices often provide relatively accurate estimates for direct costs (although maintenance/decommissioning costs that take place in the far future can often be underestimated) this is not the case for intangible costs. The very fact that there are no universally-agreed criteria for categorising costs implies that there is naturally confusion with respect to what studies treat as direct, indirect and intangible expenditures. The use of alternative methods to indirectly assess costs can also hamper the comparability of cost estimates across studies (for instance, in contingent valuation studies, the *willingness to accept* compensation for the loss of any environmental service is often found to exceed the *willingness to pay* estimate to preserve the same environmental good; Horowitz and McConnell, 2002).

## 3.2 Whole Life Cycle Costing (WLCC)

The costs (direct, indirect, intangible) of any mitigation measure naturally need to be contrasted against the implicit accruing benefits (which can again be either direct, indirect or intangible: i.e in effect the avoided costs of natural hazards - the focus of Work Packages 1-3). Any reliable cost-benefit analysis of infrastructure investment (for mitigation or adaptation of natural hazards) requires an accurate estimation of all costs associated with the inception and implementation of the project (i.e. during the entire life cycle of the asset). The Whole Life Cycle Costing (WLCC) approach attempts to provide such a systematic consideration of all present and future costs linked to mitigation investment (and assets more broadly). In the UK for instance, the WLCC approach is often advocated as the best practice for appraisal of public investment projects (Langdon 2007). First, the spatial and time scales of any mitigation/adaptation project (i.e. the project ‘boundaries’) need to be defined before proceeding with such estimations (Viavattene and Faulkner, 2009). Second, since there is an implicit time dimension of costs, all costs need to be converted in present value terms with the use of appropriate discounting.

Costs can be defined according to the stage of the life-cycle at which they materialise (Lampe et al., 2005). Although there are no universally adopted definitions, costs are often divided according to the following categories (Viavattene and Faulkner, 2009):

- Concept, Design (e.g. planning costs, consultancy fees)
- Construction (e.g. building costs)
- Operation (e.g. use and maintenance costs)
- End of Life (e.g. decommissioning and disposal costs)

Initial set-up costs that are only incurred once are often referred to as capital costs (these often include costs related to the concept, design, land acquisition and initial infrastructure/construction for the project). The following additional cost types are sometimes included in WLCC analyses, when there is an interest of incorporating costs beyond the direct set-up and maintenance of infrastructure:

- Monitoring and Environmental Costs (e.g. external social/environmental impacts)
- Disruption Costs (e.g. extra costs due to disruption as a result of maintenance operations)
- Performance Loss Costs (e.g. expected costs as a result of potential risk of damage)

This categorisation allows for the application of different discount rates for different costs and stages of the life-cycle of the project. Lower discount rates usually apply for longer term costs in order to reduce the sensitivity of cost estimates to the period they materialise. Costing elements are also often divided into a. fixed (i.e. constant over the life cycle of project), b. variable, c. semi-variable (i.e. costs with both a fixed and variable component) and d. step costs (i.e. constant for a certain period, and then scaled-up for consecutive years), depending on the variability of cost levels over time. It is often advised that WLCC analyses incorporate a sensitivity analysis, that takes into account probabilities of error in cost estimates as well as occurrence of events that may influence cost magnitudes. Any WLCC analysis should extend beyond providing cost estimates, but also contrasting these with available costs from alternative proposals. More recently, the application of the WLCC has been extended to non-structural measures (e.g. flood warnings systems). Viavattene and Faulkner (2009) advocate for a qualitative assessment preceding any quantitative appraisal of costs, particularly for the case of non-structural measures (where there is still less information available on cost estimates). This would include composing an 'uncertainty index' of individual cost elements, by combining information on data availability with the expected variability of costs over time (with higher uncertainty scores attached to variable compared to fixed costs).

Table 5, based on Langdon (2007) gives an overview on how the Whole Life Cycle Costing approach has been implemented across some EU member states.

*Table 5. Implementation of Whole Life Cycle Costing approaches in some EU countries.*

| Country | Implementation |
|---|---|
| 1. UK | WLCC is seen by the UK government as the most reliable method for determining the cost effectiveness of Private-Public Partnership (PPP) projects. The Building Cost Information Service (BCIS) – the trading division of the Royal Institution of Chartered Surveyors – has issued definitions/guidance/templates for costing of constructed assets. There is also an initiative to develop a generic WLCC IT tool for the UK (for the local authorities) |
| 2. Ireland | Large Quantity Surveying (QS) firms often use the WLCC approach. This is also the case for some major property developers and financial institutions. |
| 3. Netherlands | Main focus of WLCC in the Netherlands is in the housing sector. Housing associations often procure based on WLCC methods, but often making only limited use of WLCC modelling techniques. The Dutch Government Building Agency offers a standard method for WLCC in Excel form. |
| 4. France | CSTB, a state-owned industrial and commercial research and evaluation centre, has considerable expertise in WLCC analysis. There is a lack of a common approach to WLCC in public procurement. |
| 5. Germany | There is no governmental support or endorsement of any standard methodology of WLCC. As a result different organisations develop (and apply) their own WLCC approaches. |
| 6. Finland | WLCC is still used in a limited manner. An internet-based tool for public procurement has been developed in order to simplify WLCC calculations for municipalities and the local government. |

# 4 Knowledge gaps and recommendations

## 4.1 Knowledge gaps

A general knowledge gap is the lack of attention of studies for costs other than direct costs (that include research and design, set-up, and operation and maintenance costs). In most examples of mitigation measures (see the Case Studies throughout this report) indirect costs and intangible costs are often ignored or considered only to a limited extent. Moreover, there is a lack of a systematic collection of costs for mitigation.

**Droughts**

There is a need to better understand costs for adapted land use and long term planning perspectives. Also, there seems to be a need for increasing efforts to estimate costs of mitigation measure (stricto sensu) use, public awareness campaigns and education, monitoring and improve warning systems, development of emergency preparedness, response and evacuation plans. Drought insurance has only limited availability in Europe, and financial incentives for mitigation measures are infrequently applied.

**Alpine hazards**

Knowledge gaps for alpine hazards include the assessment of the mitigation of intermixtures of different hazards (multi-hazards and cascade effects) and multipurpose use of mitigation measures. Furthermore, dynamics of risks based on climate change effects, regionalising meso-scaled methods to model climate change impacts, assessment of costs of emergency, evacuation and clean-up, and implementation into CBA and related economic methods are missing. In addition, increased international cooperation in the case of cross-national catastrophes (e.g. with early warning and communication) would enable coordination in emergency cases, and help decrease damage costs.

There is a need for improved holistic risk management, land-use and emergency plans. Similarly as for droughts, there is also a need for private use of mitigation measures (stricto sensu), improvement of the communication programs regarding floods and geologic mass movements, and coherent financial incentives, bettering risk transfer systems (e.g. Austria).

**Floods**

Mitigation measures (stricto sensu) are well known but not broadly implemented, possibly also because good cost-benefit studies are lacking. Some literature is now emerging that underpins the usefulness of these approaches (e.g. Botzen et al., 2009; Kreibich et al., 2011). Increased knowledge of the key factors influencing the efficiency of these measures, as well as of the high uncertainties of the costs of these measures, and of the operation and maintenance costs, which are usually neglected in economic valuation, could help increase the interest for and the undertaking of mitigation measures (stricto sensu) by businesses and households. Implementing financial incentives, such as insurance incentives, could also help to increase the implementation of these measures.

**Storms and induced coastal hazards**

There appears to be a need for further development of costs estimates for management, land-use and emergency plans. These plans, combined with the development and improvement of communication and public awareness campaigns could help to increase the public awareness on the hazards. Such plans and campaigns could also be combined with financial incentives, such as hazard insurance with risk-based premiums, in order to provide incentives for the undertaking of mitigation measures (stricto sensu).

Finally, evaluating the costs of all the categories of mitigation measures could help government, willing businesses and households to choose the measures they will implement, and further increase their undertaking.

## 4.2 Best practice approaches for estimating costs of mitigation

Best practice approaches for mitigation measures of natural hazard risk are discussed in the different hazard reports, for droughts, floods, storms and induced coastal hazards, and alpine hazards (reports D5.2, D6.2, D7.2 and D8.2 respectively). Work Package 4 and the current report discuss the cost of these mitigation measures, and ways to assess and report on these.

Best practice approaches for assessing these costs include the following:

- When considering costs of mitigation of natural hazard risk, focus is most often on direct costs. These costs are relatively straightforward to calculate. However, comprehensive and comparable overviews for national level total efforts and costs are rarely available.
- Efforts to collect information on unit costs for different types of mitigation could serve as a first step.
- More attention should be spent in economic valuation on indirect and intangible costs (see Table 4, in Chapter 3) related to mitigation measures. Different approaches and examples exist however, to account for these costs as well, and are discussed through this report under the different headings of the mitigation measures distinguished in this report.
- In the assessment of the costs of mitigation to natural hazards the focus is on the direct investments in 'hard' mitigation measures, i.e. the categories infrastructure and mitigation measures (strict sensu) (see Table 1 in Chapter 1). A good practice is to also consider other options, especially communication, emergency response and evacuation, and financial instruments (including financial incentives for risk reduction and risk transfer). Also, the costs of management planning are relatively under-reported.

## 4.3 Potential for knowledge transfer between the different hazard communities

- While costing of some mitigation measures, for example monitoring and early warning, have received considerable attention in the areas of alpine hazards, there could be an exchange of knowledge and approaches on costing of these measures in other hazard areas, in particular droughts.
- Likewise, costs of emergency response (and evacuation) have also been assessed (sometimes only to a limited extent) for floods and alpine hazards, but less so for storms and induced coastal hazards and droughts.

## 4.4 Recommendations and research needs

- Costing of mitigation measures has almost exclusively focused on estimating direct costs, including research and design, set-up, and operation and maintenance costs. Approaches to comprehensively assess all costs and benefits of measures over the lifetime of the mitigation project, including Whole Life Cycle Costing (WLCC) (see Section 3.2), could be explored further. Some experience has been in gained in European countries, but more holistic frameworks that address a range of costs (and benefits) would better support motivation to undertake mitigation actions.
- Traditionally, analysis of the costs and benefits of measures for the mitigation of natural hazard risk have focused on structural and technical measures that include the categories of infrastructure and mitigation (stricto sensu). However, the latter has been employed less often, and therefore more evidence at large scales should be made available that provide handles for government to decide on action.
- Some aspects of mitigation have received less attention than others. While intuitively, actions on monitoring and early warning, emergency response have benefits for societies confronted with natural hazards, comprehensive cost-benefit analyses of these types are needed to support their wider application.

Further research could be undertaken that investigates actions and approaches for the costing of mitigation of natural hazard risks. Aspects that could be studied are:

- Development of a database of unit costs of mitigation measures, based on information from measures taken across European countries. This could lead to the establishment of European standards for construction costs of mitigation measures.
- To provide a full overview of national, regional and local actions in EU member states on mitigation, focussing on their costs and actual investments made by different actors (public, private, and European).
- To further assess different approaches for costing of mitigation, including categories of direct, indirect and intangible costs. Actors that could be included are European finance institutions, banks, insurance companies, and national and local governments.

- Through a stakeholder process, better insights could be gained on which direct, indirect and intangible costs are important to consider in the evaluation of costs and benefits of mitigation measures.

## Annex 1. Inventory of examples of mitigation measures

| Hazards | Profiles / countries | Measures | | Decision and implementation level: National, regional, local | Remarks |
|---|---|---|---|---|---|
| | | Categories | Examples of measures | | |
| Droughts | Spain, US + France, Germany | Management plans | Developing contingency plans: management and mitigation plan | National, regional | |
| | | Land-use planning | Improve land-use: crop diversification, crop rotation | Regional, local | |
| | | Hazard modification | Weather control: seeding clouds with chemicals to induce rainfall | National, regional | |
| | | Infrastructure | Augment water supply and develop new water supply infrastructures: for irrigation, rehabilitating reservoirs, dams and transfers, desalination, improve supply efficiency: leakage control, wastewater reclamation | National, regional, local and water providing companies | |
| | | Mitigation measures (stricto sensu) | Water demand reduction/conservation programs: establish stage triggers and define measures to be implemented for each stage, e.g. rationing, use lower-quality water, water transfers;<br>Put right price tag on water + provision of water to elder people, sick people, etc, vulnerable people (drought 2003 in France) | National, regional, local and water providing companies | |
| | | Communication | Raising public awareness with mass media campaigns, pamphlets to individuals, businesses and municipalities on water conservation techniques by individuals and companies, education programs - website: http://www.environment-agency.gov.uk/default.aspx | National, regional | |
| | | Monitoring and early warning systems | Monitoring of rainfall levels and comparison with usage levels;<br>Improving data collection and availability | National, regional | |
| | | Emergency response and evacuation | Define alert procedures, drought relief, water rationing and provision, technical assistance programs, funds for recovery programs | National, regional | |
| | | Financial incentive, subsidies and risk transfer | Insurance rare for all European countries, some exceptions of countries with insurance coverage rarely followed by mitigation incentives (France, UK + US, Africa, India) + drought relief funds | National | |

| Hazards | Profiles / countries | Measures | | Decision and implementation level: National, regional, local | Remarks |
|---|---|---|---|---|---|
| | | Categories | Examples of measures | | |
| **Alpine Hazards: avalanches, floods, landslides and rocks (debris)** | Austria, Switzerland (+France, UK, Germany, Italy) | Management plans | Soft: Laws on land-use and spatial planning + in Austria: regional and local development plan | All levels | Holub and Fuchs (2009) |
| | | Land-use planning | Soft: spatial planning in Austria contains the depiction of hazard zones based on modelling results and hence, determine the level of land-use (permanent use, building bans, building requirements, areas for technical mitigation, etc.), in Switzerland are similar measures | All levels | Holub and Fuchs (2009) for Austria |
| | | Hazard modification | For avalanches: provoking avalanches with calculated amounts of explosives by cables or by using gas, or with a canon. In Switzerland, use of military weapons (wikipedia.fr); high importance of protection forests | All levels | http://www.anena.org/index.html |
| | | Infrastructure | Hard, technical: dams, dikes, bed load barrages for floods, dams for landslides and rocks, dams and nets to block the snow for avalanches, nets and de-watering hillsides for landslides, nets for rocks | All levels | |
| | | Mitigation measures (stricto sensu) | Hard, biological: land restoration, plantations, increase of water retention, reforestation | All levels | |
| | | Communication | Use of hazard maps for awareness raising (if publicly accessed), but not much on map design for communication in Austria at the moment; in France: www.prim.net + legislation on sales and rents | All levels | Holub and Fuchs (2009) |
| | | Monitoring and early warning systems | Soft: identifying hazard zones, warning systems at the European level (see cooperation), in France (Cemagref (unité Erosion torrentielle, neige et avalanches à Grenoble), ONF (agences et services de restauration de terrain en montagne), and Meteo France for warning) | All levels | |
| | | Emergency response and evacuation | Soft: Emergency plans for communities and crisis management - Austria: regional and local responsibilities choose their actions according to the scale of the hazard impact + fire departments on voluntary basis | All levels | |
| | | Financial incentive, subsidies and risk transfer | Soft: relief funding and private insurance (different between countries) - but no public financial incentive for mitigation, sometimes in special conditions related to insurance, subsidies: FPRNM in France (http://catalogue.prim.net/index.php?init=1&catid=&motcle=subvention) | All levels | For Austria (Holub and Fuchs, 2009) |

| Hazards | Profiles / countries | Measures | | Decision and implementation level: National, regional, local | Remarks |
|---|---|---|---|---|---|
| | | Categories | Examples of measures | | |
| Floods | UK from partners, France | Management plans | Risk Prevention Plans in France; in UK: Catchment Flood and Shoreline Management Plans (www.environment-agency.gov.uk/default.aspx), plans and guidelines for risk assessment and preparedness (www.cabinetoffice.gov.uk/ukresilience/response/recovery_guidance/economic_issues/financial_aid.aspx) | National, Regional, Local | |
| | | Land-use planning | Land Use planning policy in the UK (PPS25 - www.environment-agency.gov.uk/default.aspx): regulation, planning, land acquisition (WP6_036), Risk Prevention Plans in France | National, regional, local | |
| | | Hazard modification | Modification of the rivers, retention zones | National, Regional (Catchment scale) | |
| | | Infrastructure | Adapted urban drainage system, dikes in the Netherlands, France, UK, etc., pumping facilities, dams | Local in UK, Regional or Basin scale for dikes + National in Romania (see Storms questionnaire p30) | |
| | | Mitigation measures (stricto sensu) | Road maintenance for emergencies, flood defences, modification of houses: flood proofing of buildings (ref-uge zone, heightening objects/machines, one-way valves, PVC instead of wood, etc. (ICPR,2002)), preparation and mitigation with measures (www.cabinetoffice.gov.uk) | Local | |
| | | Communication | Education, legislation on sales and rents (France), websites for before and after: in the UK, www.floodforum.org.uk, maps.environment-agency.gov.uk, www.environment-agency.gov.uk/default.aspx and guidances ; www.prim.net (France) with hazard information, guidance, and explanation of national poli-cies | National | |
| | | Monitoring and early warning systems | See cooperation; monitoring (www.environment-agency.gov.uk/default.aspx), modeling, Flood warning by Environmental Agency in UK (four levels of alert); prevention, monitoring and warning in France: www.vigicrues.fr + Meteo France | National, ex: Environment Agency EA in UK | |
| | | Emergency re-sponse and evacua-tion | Flood plans by local authorities, businesses, households advised in France and UK (www.environment-agency.gov.uk/default.aspx, www.prim.net) + emergency response and recovery (http://www.cabinetoffice.gov.uk/ukresilience/response/recovery_guidance/economic_issues/financial_aid.aspx) and Civil Contingencies Act 2005 (National), info during and after event, maintain power and water supplies during and after event | National, Local | |
| | | Financial incentive, subsidies and risk transfer | Relief funds in Germany, Private insurance in UK, no compensation from the government (Pitt review, 2008 p79) and insurance does not cover everything, depends on the risk / Public-private partnership in other countries or nothing (France) + for incentives: planning obligations S106 in UK for protection incentive by developers, possible incentive by insurance in UK for mitigation by households (or no coverage), incentive in theory in France with risk prevention plans + Subsidies in France: FPRNM (include land acquisition) | National, Local households | |

| Hazards | Profiles / countries | Measures | | Decision and implementation level: National, regional, local | Remarks |
|---|---|---|---|---|---|
| | | Categories | Examples of measures | | |
| **Storm surges and induced coastal hazards: erosion, dike breach, floods** | Belgium, Denmark, Bulgaria, Germany, Estonia, Greece, Spain, France, Ireland, Italy, Cyprus, Latvia, Lithuania, Malta, The Netherlands, Poland, Portugal, Romania, Slovenia, Finland, Sweden, UK | Management plans | Building codes and zoning, regulation, flood risk mapping | National (Belgium, Bulgaria, Denmark, Estonia: authorization, Spain, Ireland, Cyprus, Lithuania, Malta, The Netherlands, Poland, Portugal, Romania, Sweden: guidelines), Region (Denmark, Spain, France, Italy, The Netherlands?, Portugal islands, Finland), Local (Denmark, Ireland, Italy, Cyprus, The Netherlands?, Sweden) | |
| | | Land-use planning | Land-use restriction, set-back zones, land reclamation and conversion of farmland to salt, relocation of threatened buildings | National (Bulgaria, Spain, Latvia, Malta, Portugal, Finland: guidelines, Sweden: guidelines), Region (France, Italy, Finland), Local (Italy, Finland, Sweden) | |
| | | Hazard modification | - | - | |
| | | Infrastructure | Physical infrastructure to protect the coast (dikes, dams, seawall, breakwaters, groyne, revetment, storm surge barriers, salt water intrusion barriers), dune building, building on pilings, adapting drainage | EU (financing), National (Bulgaria, Denmark, Germany: co-financing, Estonia: authorization and financing, Greece, Spain, Ireland: financing, Italy: guidance and finance, Cyprus, Lithuania, Malta, The Netherlands, Poland, Portugal, Romania, Slovenia, Finland: authorization and guidance, Sweden: evaluation), Region (Belgium: Flanders, Denmark, Germany, Estonia: financing, France, Italy, Lithuania, The Netherlands, UK: England, Scotland, Wales, N.Ireland), Local (Denmark, Estonia, Greece, France, Ireland, Italy, Cyprus, Latvia, Lithuania, The Netherlands, Finland, Sweden) | |
| | | Mitigation measures (stricto sensu) | Growing flood or salt tolerant crops, beach nourishment, maintenance, cutting and cleaning trees, adapted electric and phone lines (underground), refuge zones under buildings | National (Denmark - for authorization, Greece, Italy: guidance and finance, Lithuania, The Netherlands, Poland, Portugal, Slovenia), Region (France, Italy, The Netherlands, Finland: guidance, UK: N.Ireland), Local (Denmark, Greece, France, Italy, Latvia, Lithuania, Malta, The Netherlands, Finland, UK: England, Scotland, Wales, N.Ireland) | |
| | | Communication | Providing advices. France: www.prim.net and legislation for house sales and rents | National (Spain, France) | |
| | | Monitoring and early warning systems | Monitoring evolution of the foreshore/coastline, satellite monitoring of wind fields and land surface movements in mountains, storm tide monitoring system, early warning systems | International(GLOSS, Global Sea Level Observing System), National (Denmark, France, Lithuania, Poland), Region (Belgium: Flanders, Spain)National (Spain, France) | |
| | | Emergency response and evacuation | Emergency flood shelters, evacuation systems, plans | National (Belgium, Bulgaria, Italy, The Netherlands, Portugal, Spain, UK), Regional (Belgium, Bulgaria, France, Italy, Spain), Local (Belgium, Bulgaria, France, Spain, UK) | |
| | | Financial incentive. Risk transfer | Risk-based hazard insurance. Public private partnership in France. Relief funds and subsidies in France, relief fund in the Netherlands | National (France: Storms), Local (France, households: wind) | |

## References


ABI and EA (2009). Flooding Information Sheet – Your questions answered. Association of British Insurers, Environment Agency. Last retrieved on 12 August 2010 from http://www.environment-agency.gov.uk/homeandleisure/floods/31654.aspx

Alexander, D. E. 2002: Principles of emergency planning and management, Oxford, New York.

Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (2008): Richtlinien für die Wirtschaftlichkeitsuntersuchung und Priorisierung von Maßnahmen der Wildbach- und Lawinenverbauung, Abs. 2 Z 3 Wasserbautenförderungsgesetz 1985, Vienna.

Bayrak, T. (2011). Performance evaluation of disaster monitoring systems. Natural Hazards, 58, 1193-1208.

Biesbroek, G.R., R.J. Swart, T.R. Carter, C. Cowan, T. Henrichs, H. Mela, M.D. Morecroft, D. Rey (2010). Europe adapts to climate change: comparing national adaptation strategies. Global Environmental Change, 20, 440-450.

Benson, C., Twigg, J. (2004). Measuring mitigation: methodologies for assessing natural hazard risks and the net benefits of mitigation. Provention Consortium, Geneva.

Board on Natural Disasters (1999). Mitigation emerges as major strategy for reducing losses caused by natural disasters. Science, 284, 1943-1947.

Botzen, W.J.W., J.C.J.M. van den Bergh (2008). Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries. Risk Analysis, 28, 413-426.

Botzen, W.J.W., J.C.J.H. Aerts, J.C.J.M van den Bergh (2009). Willingness of homeowners to mitigate climate risk through insurance. Ecological Economics, 68, 2265-2277.

Botzen, W.J.W., Van den Bergh, J.C.J.M. & Bouwer, L.M. (2010). Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands. Natural Hazards, 52(3), 577-598.

Bouma, J.A., H.J. van der Woerd, O.J. Kuik (2009). Assessing the value of information for water quality management in the North Sea. Journal of Environmental Management 90 (2009) 1280–1288.

Bouwer, L.M., R.P. Crompton, E. Faust, P. Höppe, R.A. Pielke Jr. (2007a). Confronting disaster losses. Science, 318, 753.

Bouwer, L.M., D. Huitema and J.C.J.H. Aerts (2007b). Adaptive flood management: the role of insurance and compensation in Europe. Deliverable D 1.2.4 of the NeWater project, Institute for Environmental Studies, Vrije Universiteit Amsterdam.

Brander, L.M. (2011) Economic Valuation of Landscape Fragmentation, PhD thesis, Faculty of Economics and Business Administration, Vrije Universiteit Amsterdam.

Brouwer, R. and Schaafsma, M. (2009). The Economics of Flood Disaster Management in the Netherlands. In. Guha Sapir, P., Santos, I. & Borde, A. (eds.), Natural disasters: do they cost the earth? Earthscan Publications.

Brouwer, R. and van Ek, R. (2004). Integrated ecological, economic and social impact assessment of alternative flood protection measures in the Netherlands. Ecological Economics, 50, 1–21.

Buckle, P., G. Marsh & S. Smale 2000: New Approaches to Assessing Vulnerability and Resilience. Australian Journal of Emergency Management, Available at: www.radixonline.org/resources/buckle-marsh.pdf, 28.7.2010.

Burton, I. and Van Aalst, M. (1999). Come hell or high water: integrating climate change adaptation into bank work. Environment Department Paper 72, World Bank, Washington.

CEA (2005). The Insurance of Natural Events on European Markets. Document AB 5050 (06/05), Comité Européen des Assurances, Paris.

Crichton, D., (2003). Temporary local flood protection in the United Kingdom – An independent assessment. Working Paper.

DFID (2005). Natural disaster and disaster risk reduction measures: a desk review of costs and benefits. Department for International Development, UK.

Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks

Dumas, P., Chavarot, A., Legrand, H., Macaire, A., Dimitrov, C., Martin, X., Quefelec, C. (2005). Mission d‟enquête sur le régime d‟indemnisation des victimes de catastrophes naturelles. Mission interministérielle de l‟Inspection générale de Finances, du Conseil général des Ponts et Chaussées et de l‟Inspection générale de l‟Environnement, Paris.

ECA(2009). Shaping climate resilient development: a framework for decision making. Economics of climate adaptations working group.

Eijgenraam, C.J.J. (2005). Kosten-batenanalyse voor Ruimte voor de Rivier. CPB No 82-83 April 2005

Emergency Management Australia 2004: Emergency management in Australia - concepts and principles, available at http://www.ema.gov.au/www/emaweb/emaweb.nsf/Page/Publications_AustralianEmergencyManualSeries_AustralianEmergencyManualSeries-A-Z, 21.7.2010.

Englehardt, J.D., and C. Peng (1996). A Bayesian benefit-risk model applied to the South Florida building code. Risk Analysis, 16, 81-91.

European Commission (EC) (2008a). Assessing the Potential for a Comprehensive Community Strategy for the prevention of Natural and Manmade Disasters. Final Report. March 2008

European Commission (EC) (2008b). Member States' Approaches towards Prevention Policy – a Critical analysis. Final Report. March 2008

European Commission (2009a). A Community approach on the prevention of natural and man-made disasters. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. COM(2009)82

European Commission (2009b). White Paper: Adapting to climate change: Towards a European framework for action. COM(2009)147.

European Commission (2009b). Global Monitoring for Environment and Security (GMES): Challenges and Next Steps for the Space Component. COM(2009)589 final.

EUSF (2010). Last retrieved on 12 August 2010 from http://europa.eu/legislation_summaries/regional_policy/provisions_and_instruments/g24217_en.htm

Federal Emergency Management Agency (FEMA) 2010: Fundamentals of Emergency Management, Independent Study 230. Available at http://training.fema.gov/EMIWeb/IS/is230a.asp, 21.7.2010.

Federal Office for Civil Protection and National hazards in Switzerland (2010). The circle of integrated risk management. Available at http://www.planat.ch/index.php?userhash=35176411&l=e&navID=5, 20.7. 2010.

Federal State of Tyrol (2000). Lawinenhandbuch. Innsbruck.

Few, R. H. Osbahr, L.M. Bouwer, D. Viner, F. Sperling (2006). Linking climate change adaptation and disaster risk management for sustainable poverty reduction: synthesis report. European Commission and Vulnerability and Adaptation Resource Group.

Fischer M. (2008). Der lange Weg zur integralen Elementarschadenversicherung und -vorbeugung in der Schweiz. Vierteljahrshefte zur Wirtschaftsforschung 77(4): 98–103

FPRNM (2006). Le fonds de prévention des risques naturels majeurs (FPRNM). Last retrieved on 12 August 2010 from http://catalogue.prim.net/index.php?init=1&catid=&motcle=subvention

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: 113-129.

Garrod, G. & Willis, K.G. (2000). Economic Valuation of the Environment: Methods and Case Studies, London: Edward Elgar.

Hall JW, Sayers PB, Dawson RJ (2005) National-scale Assessment of Current and Future Flood Risk in England and Wales. Natural Hazards 36: 147-164

Hensher, D., Shore, N., Train, K. (2006). Water Supply Security and Willingness to Pay to Avoid Drought Restrictions. The Economic Record, 82, 56-66.

Hochrainer, S., J. Linnerooth-Bayer, R. Mechler (2010). The European Union Solidarity Fund: Its legitimacy, viability and efficiency. Mitigation and Adaptation Strategies for Global Change, 15, 797-810.

Horowitz, J.K. & McConnell, K.E. (2002). A review of WTA/WTP studies, Journal of Environmental Economics and Management, 44, p. 426–447.

Holub, M., Fuchs, S. (2009). Mitigating mountain hazards in Austria – legislation, risk transfer, and awareness building. Natural Hazards and Earth System Sciences 9, 523-537.

Huggel, C, N. Khabarov, M. Obersteiner, J.M. Ramirez (2010). Implementation and integrated numerical modeling of a landslide early warning system: a pilot study in Colombia. – Natural Hazards 52: 501-518.

ISDR - International Strategy for Disaster Reduction (2005). Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan; www.unisdr.org

Joy, C.S. 1993: The cost of flood damage in Nyngan, Climatic Change, 25, p. 335-331.

Kabat, P., L.O. Fresco, M.J.F. Stive, C.P. Veerman, J.S.L.J. van Alphen, B.W.A.H. Parmet, W. Hazeleger, C.A. Katsman (2009). Dutch coasts in transition. Nature Geoscience, 2, 450-452.

Kreibich, H., A.H. Thieken, Th. Petrow, M. Müller, B. Merz (2005): Flood loss reduction of private households due to building retrofitting – Lessons learned from the Elbe floods in August 2002. – Natural Hazards and Earth System Sciences 5: 117-126.

Kreibich, H., R. Schwarze & S. Christenberger (2010): Nutzen und Kosten privater Hochwasservorsorge. In: „Hochwasserschäden – Erfassung, Abschätzung und Vermeidung“ (Thieken, A., Seifert, I., Merz, B.; Hrsg.). Oekom-Verlag, München, Kapitel 13.2, S. 263-270.Kreibich, H., Christenberger, S., Schwarze, R. (2011). Economic motivation of households to undertake private precautionary measures against floods. Natural Hazards and Earth Systems Science, 11, 309-321.

Lampe, L., Martin, P., Barrett, M., Jefferies, C., Woods-Ballard, B., Kellagher, R., & M. Hollon (2005). Post-project monitoring of BMPs/SUDS to determine performance and whole-life cycles. London, UK: IWA Publishing.

Langdon, D. (2007). Life cycle costing (LCC) as a contribution to sustainable construction: A common methodology. Literature Review. Davis Langdon Management Consulting.

Letremy, C., Grislain, N. (2009). Assurances des risques naturels en France : Sous quelles conditions les assureurs peuvent-ils inciter à la prévention des catastrophes naturelles ? Etudes et documents, Risques et assurance, Service de l‟Economie, de l‟Evaluation et de l‟Intégration du Développement Durable (SEEIDD), Commissariat Général au Développement Durable (CGDD), Ministère de l‟Ecologie, de l‟Energie, du Développement Durable et de l‟Aménagement du Territoire (MEEDDAT), 1, 1-129.

Lindell, M.K., C.S. Prater, R.W. Perry & W.C. Nicholson 2006: Fundamentals of Emergency Management, FEMA. available at http://training.fema.gov/EMIWeb/edu/fem.asp, 20.7.2010.

Martin-Ortega, J., Markandya, A. (2009). *The cost of drought: the exceptional 2007-2008 case of Barcelona*. Basque Centre for Climate Change Working Paper Series. www.bc3research.org/working_papers/downpubli_9.html

Mechler R. (2005). Cost-benefit analysis of natural disaster risk Management in developing and emerging countries. GTZ, Eschborn.

MICORE 2008. Report on risk definition for each study site"; Edited by O. Ferreira (UALG), P. Ciavola (UniFe) and C. Armaroli (UniFe).

Morselt, T., Engelsman, G. J., Lobbes, E 2007: Estimating cost functions for evacuation, emergency services and cleanup in case of floods, Rebel group, Rotterdam.

Noailly, J. (2010). Improving the energy efficiency of buildings: The impact of environmental policy on technological innovation CPB No 137. January 2010.

OECD (2007). Climate change in the European Alps: Adapting winter tourism and natural hazards management; http://www.oecd.org/document/43/0,3746,en_2649_34361_37819437_1_1_1_1,00&&en-USS_01DBC.html)

Parker, D., S. Priest, S. Tapsell, J. Handmer, A. Schildt (2009): Developing models to estimate the benefits from flood warnings (Executive Summary). FloodSite Report Number T10-08-11

Penning-Rowsell, E., C. Johnson, S. Tunstall, S. Tapsell, J. Morris, J. Chatterton, C. Green (2005): The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques. Flood Hazard Research Centre, Middlesex University Press.Penning-Rowsell, E. & T. Wilson 2006: Gauging the impact of natural hazards: the pattern and cost of emergency response during flood events, Trans Inst Br Geogr., NS 31, 99 -115.

Pfurtscheller, C. & R. Schwarze 2010: Kosten des Katastrophenschutzes. - In: A. Thieken, I. Seifert & B. Merz (eds.): Hochwasserschäden - Erfassung, Abschätzung und Vermeidung, München, p. 253 - 262.

PricewaterwouseCoopers (2006). Executive summary – Socio-economic benefits analysis of GMES. ESA contract 18868/05, July 2006.

ProAct Network (2008). The Role of Environmental Management and Eco-Engineering in Disaster Risk Reduction and Climate Change Adaptation. Nyon, Switzerland.

Rogers, D. & V. Tsirkunov (2010): Costs and benefits of early warning systems. Global Assessment Report on Disaster Risk Reduction (GAR 2011), UN-ISDR and the World Bank. 17 pp.

Rose, A.: Defining and measuring economic resilience to disasters, in: Disaster Prevention and Management, 13, 307 - 314, 2004.

Rudolf-Miklau, F. 2009: Naturgefahren-Management in Österreich - Vorsorge-Bewältigung - Information. - Vienna.

Sachsen-Anhalt 2002: Bericht Hochwasserkatastrophe 2002. Available at: http://www.sachsen-anhalt.de/LPSA/fileadmin/Files/Bericht_Hochwasserkatastrophe_2002.pdf, 28.7. 2010.

Stewart, M.G. (2003). Cyclone damage and temporal changes to building vulnerability and economic risks for residential construction. Journal of Wind Engineering and Industrial Aerodynamics, 91, 671-691.

Pattanayak, S.K. , Kramer R.A. (2001). Pricing ecological services: Willingness to pay for drought mitigation from watershed protection in eastern Indonesia. Water Resources Research, Vol. 37, NO. 3, PAGES 771–778, March 2001.

Schröter, K., M. Ostrowski, C. Velasco, H.-P- Nachtnebel, B. Kahl, M. Beyene, C, Rubin, M. Gicht (2008): Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE). CRUE Research Report No I-5. www.crue-eranet.net

Stoffel, L. (2005). Künstliche Lawinenauslösung. In: Tec 21, 131, 9:4-7.

Swart, R., R. Biesbroek, S. Binnerup, T. R. Carter, C. Cowan, T. Henrichs, S. Loguen, H. Mela, M. Morecroft, M. Reese, D. Rey (2009). Europe adapts to climate change: comparing national adaptation strategies. Partnership for European Environmental Research (PEER), Report No. 1.

Swiss Re (1998). Überschwemmung – ein versicherbares Risiko? Marktübersicht. Zurich: Swiss Re. 36 pp. (in German).

Thieken, A.H., Petrow, T., Kreibich, H.,Merz, B. (2006). Insurability and mitigation of flood losses in private households in Germany. Risk Analysis 26, 383-395.

Thomalla, F., T. Downing, E. Spanger-Siegfried, G. Han, J. Rockström (2006). Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. Disasters, 30, 39-48.

Thywissen, K. 2006: Components of Risk - A Comparative Glossary. UNU-EHS, SOURCE No. 2/2006.

Ungern-Sternberg T. (2002). Gebäudeversicherung in Europa. Die Grenzen des Wettbewerbs. Berne: Haupt

Vetters, N. & Prettenthaler, F. (2003). Extreme Wetterereignisse: Nationale Risikotransfersysteme im Vergleich. Institute of National Economy, University of Graz. 25 pp. (in German).

Viavattene, C., & and Faulkner H. (2009). Assessing the feasibility of undertaking a ‘whole life’ approach to the costing of non-structural measures in urban flood management projects. FRMRC Research Report SWP3.3, November 2009.

Von Ungern-Sternberg, T. (2004). Efficient Monopolies - The Limits of Competition in the European Property Insurance Market. Oxford: Oxford University Press. 176 pp.

Warner, K., Ranger, N., Surminski, S., Arnold, M., Linnnerooth-Bayer, J., Michel-Kerjan, E., Kovacs, P., Herweijer. C., Bals, C., Bouwer, L.M., Burton, I., Cutter, S., Osman Elasha, B., Höppe, P., Loster, T., Mahul, O., Mearns, R., Sokona, Y. & Ward, B. (2009). Adaptation to climate change: linking disaster risk reduction and insurance. United Nations International Strategy for Disaster Reduction, Geneva.

Warner, K., Bouwer, L.M. & Ammann, W. (2007). Financial services and disaster risk finance: examples from the community level. Environmental Hazards, 7(1), 32-39.

Wegmann, M., Merz, H. & K. Meierhans Steiner (2007). Jährliche Aufwendungen für den Schutz vor Naturgefahren in der Schweiz - Strategie Naturgefahren Schweiz, Umsetzung des Aktionsplans PLANAT 2005 - 2008. Bern

Williamson, R.A., Hertzfeld, H.R., Cordes, J., Logsdon, J.M., (2002). The socioeconomic benefits of earth science and applications research: reducing the risks and costs of natural disasters in the USA. Space Policy 18, 57–65.

World Bank and United Nations (2010). Natural Hazards, UnNatural Disasters – The Economics of Effective Prevention.

Zhai, G., Ikeda, S. (2006). Flood risk acceptability and economic value of evacuation. Risk Analysis, 26, 683-694.