CONHAZ
Costs of Natural Hazards

Natural Hazards: direct costs and losses due to the disruption of production processes

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Abstract

In recent decades, Europe has witnessed a significant increase in direct damages from natural hazards. A further damage increase is expected due to the on-going accumulation of people and economic assets in risk-prone areas and the effects of climate change, for instance, on the severity and frequency of drought events in the Mediterranean basin. In order to mitigate the impact of natural hazards on European economies and societies, an improved risk assessment and management needs to be achieved. While natural hazard analysis and modelling has made considerable progress over the last decades, there is still much research effort needed to improve assessments of the costs of natural hazards. Particularly in comparison with hazard modelling, simple approaches still dominate loss assessments, mainly due to limitations in available data and knowledge on damage processes and influencing factors. Moreover, the significant diversity in methodological approaches makes it difficult to establish comprehensive, robust and reliable cost figures that are comparable across different hazards and countries. This is also, because state-of-the-art approaches for the assessment of direct costs as well as of losses caused by the disruption of production processes are not only natural hazard specific, but also specific for different sectors or elements at risk in defined regions or countries. These methods as well as data sources and terminology are compiled, systemized and analysed in the present report. Similarities and differences between the cost assessment methods of different natural hazards are identified, so that most can be learned from the various approaches applied in different European countries. In addition, knowledge gaps and research needs are highlighted and recommendations for best practices of cost assessments are provided.

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Content

1 Introduction

In recent decades, Europe has witnessed a significant increase in direct damages from natural hazards (Munich Re, 2007). A further increase in damage is expected due to the combined effect of on-going accumulation of people and economic assets in risk-prone areas and the effects of climate change, for instance, on the severity and frequency of drought events in the Mediterranean basin (Meehl and Tebaldi, 2004; Gao and Giorgi, 2008). Also coastal and flood hazards are projected to increase in many places due to an expected rise in sea level (Nicholls et al., 2008; IPCC, 2007) and river discharges (te Linde et al., 2010). At the same time, risk-prone areas such as deltas or flood plains continue to attract human developments, thereby increasing the vulnerability of these places (Kummu et al., 2011).

Traditional approaches for the protection against natural hazards were generally characterized by a safety mentality. Protection was aimed at design criteria without a detailed analysis and debate about the complete spectrum of possible events, failure scenarios and protection objectives. This traditional safety mentality (or 'promise of protection'), is increasingly being replaced by what is referred to as 'risk management'. Risk management is based on a comprehensive analysis of not only the hazard side, but also of the possible consequences and an appraisal of potential risk reducing measures. In this context, risk is commonly defined as damage that occurs or will be exceeded with a certain probability in a certain time period (e.g. Merz et al., 2010). Within this evolving context of decision-making in risk management, damage assessments have gained growing importance. Knowledge of potential direct damages from natural hazards is important, amongst others, to identify economic assets at risk, to examine the effectiveness of hazard mitigation strategies, or, to calculate insurance premiums (Messner et al., 2007).

Since definitions of different cost categories still vary between hazard communities, and concepts are a matter of continuous research, we need to define the terms as used in the framework of the Conhaz project and thus also in the present report. *Direct damages* refer to losses that occur due to a direct physical impact of a hazard on humans, economic assets or any other object. Examples for direct damages are the loss of life e.g. due to drowning, the destruction of buildings, contents and infrastructures e.g. due to landslides, or the loss of crops and life stock due to droughts. *Indirect damages*, instead, occur outside of the hazard area, due to a loss in turnover of businesses, for instance, when supplies are disrupted. Examples for indirect damages are negative feedbacks to the wider economy, for instance resulting from production losses of suppliers, the costs of traffic disruption or the costs of emergency services (e.g. Parker et al., 1987; Smith and Ward, 1998; Messner et al., 2007). Both, direct and indirect damages can be further classified into *tangible* and *intangible* damages, depending on whether they are traded in a market and thus can be easily expressed in monetary terms. *Tangible damage* refers to damage for which a market price exists, such as destroyed economic assets or damage to resource flows. Damage that is difficult to quantify in monetary terms because no 'market price' exists, such as adverse health effects, loss of life, damages to environmental goods or services are referred to as *intangible damages* (Merz et al., 2010). An overview on the typology described above, including several examples, is provided in Table 1.

Table 1: Typology of damages from natural hazards with examples (Adapted from: Penning-Rowsell et al. 2003; Smith & Ward 1998)

	Tangible	Intangible
Direct	Physical damage to assets: - buildings - contents - infrastructure	- Loss of life - health effects - Loss of ecological goods
Indirect	- Loss of industrial production - Traffic disruption - emergency costs	- Inconvenience of post-flood recovery - Increased vulnerability of survivors

The present report focuses on direct tangible damages to economic assets, which occur due to the direct impact of natural hazards on properties of all economic sectors. Since impacts of different natural hazards on economic properties vary substantially, and since they occur in varying spatial and temporal resolutions, damage assessments require hazard specific methods and parameters (Blong 2003; Grünthal et al. 2006). While flood damage results from hazard characteristics such as water depth, flow velocities, buoyancy or waves (Kelman & Spence, 2004), avalanche damage is mainly caused by snow pressure (BUWAL, 1999a). In the present report, we will examine direct cost assessment methods for floods, droughts, coastal hazards, and Alpine hazards. Even though damaging processes are different for the four hazard types addressed, a standard approach for the assessment of direct damage is the use of susceptibility functions (alias damage functions). All of these functions that are applied for the different hazard types have in common that they describe the relation between a single or several hazard parameters, such as avalanche pressure, water depth or drought-induced soil subsidence, and resulting monetary damage for a certain type or use of object at risk (Smith, 1981; Wind et al. 1999, BUWAL et al. 1999b; Keiler et al. 2006; Totschnig et al. 2010; Fuchs et al. 2007). In addition to these hazard parameters, some damage functions exist that also take vulnerability (resistance) parameters into account, such as differences in building structures or the level of undertaken mitigation measures (e.g. BUWAL, 1999a; Keiler et al., 2006, BAFU, 2010).

In addition to direct damages, the present report also covers losses due to the disruption of production processes. These types of losses occur in industry, commerce and agriculture in areas that are directly affected by a hazard event. In the literature, these losses are sometimes referred to as direct damage, as they occur due to the immediate impact of a hazard. On the other hand, they are often also referred to as indirect damage, because these losses do not necessarily result from a physical contact between the hazard and assets, but from the interruption of economic processes, which often last much longer than the direct impact of the hazard. Various approaches are applied to estimate losses due the disruption of production processes. These range from detailed input-output analyses of economic processes in risk-prone areas (FEMA, 2011), comparisons of average production out-put during non-hazard years with output during hazard years (SLF, 2000), to simpler approaches. The latter approaches estimate losses due to the disruption of production processes as a certain percentage of the potential direct damages (NRE, 2000).

Even though considerable research efforts have been made in recent years to estimate direct damage as well as losses due to the disruption of production processes from natural hazards, there is still much research effort needed to arrive at European-wide and robust approaches. Particularly in comparison with hazard modelling, simple approaches still dominate loss assessments, mainly due to limitations in available data and knowledge on damage mechanisms. Moreover, the significant diversity in methodological approaches makes it difficult to establish comprehensive, robust and reliable costs figures that are comparable across different hazards and countries. Against the background of this significant diversity in methodological approaches used, this report compiles and systemises terminology, available approaches as well as data sources. Similarities and differences between the different natural hazards are identified. Knowledge gaps and respective research needs identified and recommendations for best practices of cost assessments are provided.

The remainder of the report proceeds as follows. Section 2 provides an overview of cost assessment approaches applied to evaluate direct damages from floods (2.1), droughts (2.2), coastal hazards (2.3) and Alpine hazards (2.4). In addition, data sources that could be useful for cost assessments are discussed in section 2.5. Section 3 provides a cross hazard comparison. Knowledge gaps, research needs and recommendations for best practices are discussed in section 4.

Objective

The objective of this report is the compilation and analysis of approaches, data availability and quality and terminology for the assessment of direct costs as well as of losses caused by the disruption of production processes. Methods used in different hazard communities will be systemised and similarities as well as differences identified, so that most can be learned from each hazard type. Recommendations for best practice of cost assessments are given and knowledge gaps and respective research needs identified.

2 Compilation of approaches and data sources

2.1 Floods

Terminology

Flood events can have a wide range of detrimental effects for affected individuals and societies. According to the European Commission, approximately 700 people died and about half a million people were displaced due to floods in the European Union since 1998. Moreover, floods also caused the loss of at least € 25 billion in insured economic assets.[1]

According to the EU Flood Directive, the term flood refers to "*the temporary covering by water of land not normally covered by water* (European Parliament and the Council of the European Union, 2007)." Floods can originate from the sea (coastal floods), rivers (fluvial floods), from heave rain events (pluvial floods), or from below the surface (groundwater floods) (de Bruijn et al., 2009). The current chapter will discuss cost assessment methods for fluvial floods. These usually develop over longer time periods following prolonged periods of (strong) precipitation and can have a large spatial extent. Cost assessments of coastal floods are discussed in section 2.3.

In line with the terminology adopted within the framework of the CONHAZ project (see Table 1), flood damages are most commonly categorized in direct and indirect, as well as tangible and intangible damages. Although the differentiation between direct and indirect as well as tangible and intangible damage is widely used, interpretations and delineations still vary (Jonkman et al., 2008). Rose (2004), for instance, discusses the difficulty to clearly distinguish between direct and indirect costs and refers to the resulting challenge to undertake comprehensive flood damage assessments, while avoiding double-counting. In addition to this most common categorization, few others are discussed in the literature on flood damages. Smith and Ward (1998), for instance, distinguish between primary and secondary damages. While primary damages result from the event itself, secondary damages are at least one causal step away from the flood event. Following this categorization, the loss of production of a firm which is flooded and therefore unable to produce would refer to as primary indirect loss. The induced losses of production of customers or suppliers in- and outside the affected area due to backward and forward linkages would be indicated as secondary indirect damages.

Important glossaries on 'Terms and definitions of risk sciences' and the 'Language of risk' are provided by the Centre for Disaster Management and Risk Reduction Technology (CEDIM) [2] and the FLOODSite project, respectively.[3]

[1] http://ec.europa.eu/environment/water/flood_risk/index.htm
[2] http://www.cedim.de/download/glossar-gesamt-20050624.pdf
[3] http://www.floodsite.net/html/partner_area/project_docs/T32_04_01_FLOODsite_Language_of_Risk_D32_2_v5_2_P1.pdf

Approaches for the estimation of direct damage

A standard approach to assess direct flood damages consists of the following three steps (Merz et al., 2010; Messner et al., 2007):

(1) Classification of elements at risk by pooling them into homogeneous classes.
(2) Exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their asset value.
(3) Susceptibility analysis by relating the relative damage of the elements at risk to the flood impact.

This three-step procedure holds true for relative damage functions that express damages as a ratio of the total asset value (0=no damage / 1= total destruction). Alternatively, absolute damage functions exist that directly provide an absolute monetary value for the element or object at risk. In this case, step 2 and 3 are combined within a single damage function. The three steps are discussed in greater detail in the following paragraphs.

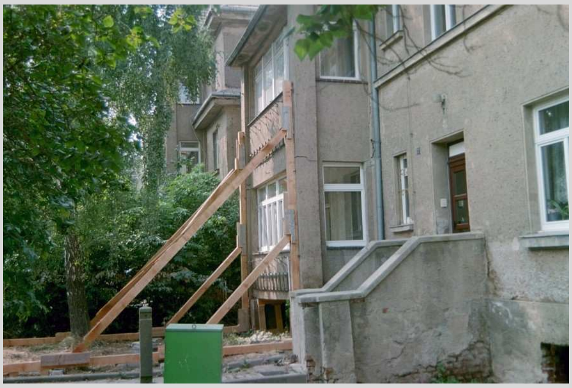
(1) Classification of elements at risk

Flood damage assessments can show varying degrees of detail, depending on the spatial and temporal scale of the analysis. While micro-scale assessments usually consider very detailed and object-based information on houses, infrastructural elements or cars, meso- and macro-scale assessments usually consider aggregated asset categories such as land-use units (Merz et al., 2010). Since it is generally not possible to assess damages on the basis of individual objects due to a lack of available data and resources, similar units or elements at risk are usually pooled together and classified as a single group. Most often, classifications of elements at risk reflect economic sectors such as private households, agriculture, commerce or industry (ICPR, 2001). This classification approach reflects the assumption that elements within an economic sector show comparable susceptibility characteristics and can thus be grouped together. As far as the residential sector is concerned, for instance, flood damage predominantly occurs at building structures and content and inundation depth and flow velocities have been identified as an important damage-influencing parameter (Thieken et al. 2005). In contrast, agricultural areas are predominantly affected by a loss of crops. Here, the season when the flood occurs and the duration of the flood are the decisive damage-influencing parameters (Förster et al., 2007). Another advantage of classifying elements at risk along economic sectors is the fact that economic data, which are needed for damage assessments, are often readily available on aggregated levels from national or regional statistical offices.

Even though a classification of similar elements at risk is usually necessary for reasons of practicality in flood damage assessments, it should be noted that a large variability can exist even within single asset categories (Merz et al., 2004). To address this issue and to reflect this variability within an economic sector at least partly, a number of damage assessment methods have introduced further differentiations within single categories. The so-called FLEMOps and FLEMOcs models, which provide further differentiations within the private and commercial sector in Germany, are examples for this (Thieken et al., 2008a, b; Kreibich et al., 2010a). Since flood impacts to private households vary considerably, the FLEMOps model distinguishes between three different building types (one-family homes, (semi-) detached houses, multi-family houses) and two classes indicating the quality of the building (low/medium quality and high quality).[4] Because the variability of objects within one class is large even with such a finer classification of sub-classes, it can be expected that the estimated asset values and the respective damage functions only partially reflect the variance that is observed in damage data.

Textbox 1: Integrating building susceptibility in the classification of elements

Empirical data of flood damages to individual buildings show a large dispersion, resulting in considerable uncertainty of depth-damage functions derived from such data (Merz et al., 2004). One reason for the large dispersion is that different building types show varying susceptibility to flood impacts. Flow velocity, for instance, has a very different impact for a clay building compared with a building made of reinforced concrete. An interesting classification approach, which allows to take differences in the susceptibility of various building types into account, has been developed by Maiwald and Schwarz (2010). Based on empirical observations and engineering judgment, a typology of five different damage grades to buildings were derived, ranging from water penetration (D1), to a collapse of the building or major parts of it (D5). Moreover, the building stock was grouped into five main building types, based on similarities in terms of structural characteristics and consequently flood susceptibility. The main five building types are clay, prefabricated, framework, masonry, reinforced concrete and flood resistant designed buildings. Subsequently, the five building types are classified into so-called susceptibility classes on the basis of the observed damage grades (D1-D5). The advantage of this approach, compared to applying standard classification approahces is that the varying susceptibility of different construction types at the building level can be considered in flood damage modelling. This is done by constructing vulnerability functions for each vulnerability class that are used to derive monetary flood damages (Maiwald and Schwarz, 2010). However, it should be noted that the proposed approach is rather suited for micro-scale damage assessments because such detailed data are usually not available for larger areas or can only be collected with considerable effort.


D3: Subsidence, cracks


D5: Collapse

(2) Exposure analysis and asset assessment

Following a classification of elements at risk, it needs to be established which of these elements are actually at risk from flooding. Identifying assets at risk is usually done with the help of geo-

[4] The FLEMOcs model for the commercial sector introduces a differentation on the basis of the size of the company and four sub-sectors of the economy

graphical information systems (GIS), by overlaying object or land-use data with flood extent maps. Moreover, the respective values of the exposed elements need to be identified, to derive quantitative damage estimates of the exposed assets. Even though a number of approaches have been applied to estimate asset values for exposed elements, only few risk assessment studies provide detailed information on the procedure followed to estimate respective asset values. A good overview on different methodological approaches to estimate assets value as well as a case study for Tyrol (Austria) is provided by Huttenlau and Stötter (2008). In addition, also Merz et al. (2010) provide an overview on different estimation approaches, which shows that the level of detail considered, is influenced by the spatial scale of the analysis, the availability of input data and the required accuracy of the damage assessment. While micro-scale assessments, for instance, base their estimations on the construction costs of different building types (Blong, 2003), studies on the macro-scale use the gross capital stock of fixed assets in the exposed area (MURL, 2000). Even though asset values are mainly defined by the type of the element at risk, they can still vary in space and time. Variations in time occur, for instance, due to inflation, new investments or innovations. To take variations in time into account, asset values can be adjusted using price indices or by regularly updating the underlying data base. Spatial variations can occur due to regional differences in asset values of the same object type, for example due to differences in material or labor costs. These variations can be taken into account by using regional or local data instead of information on a national level, or, by applying economic adjustment factors such as purchasing power parities (ICPR, 2001).

Some of the exposed elements are usually comprised of several asset categories. As far as buildings are concerned, values of fixed assets such as structural elements and moveable items such as interior, are often estimated separately (ICPR, 2001), since they show a different susceptibility to flood impacts. Treating these categories separately is especially useful, when precautionary behavior of the population at risk shall be incorporated in flood damage modelling. For instance, while structural elements cannot be removed from the flood zone, it is possible to remove mobile assets during a flood to avoid damages.

(3) Susceptibility analysis

After elements at risk have been classified and those assets that are exposed to flooding have been identified and assigned a respective value, the final step is to define their susceptibility. A standard approach to define the susceptibility of elements at risk and to estimate direct flood damages, is the use of damage (susceptibility) functions (Smith, 1994). These functions define for the respective elements at risk the relationship between hazard and exposure characteristics and the damage that can be expected under the given circumstances. Numerous damage influencing parameters can be taken into account to define the susceptibility of elements at risk. These can be differentiated into impact and resistance parameters (Thieken et al., 2005). Impact parameters reflect specific flood and thus hazard characteristics such as inundation depth, flow velocity or contamination of flood water. In contrast, resistance parameters refer to the capacity of exposed elements to resist flood impacts like size, type and structure of a building. Moreover, also flood mitigation measures, such as water proofing of buildings or adapted use, flood experience and early warning are important resistance parameters (ICPR, 2002; ABI, 2003; Kreibich et al., 2005, 2007; Parker et al., 2007; Olfert and Schanze, 2008). A comprehensive overview on damage influencing factors that have been considered in flood damage assessments is provided by Merz et al. (2010).

Even though flood damage results from a complex interplay between flood impact and resistance parameters, the effect of many parameters on damage are largely unknown and therefore widely neglected in damage modelling. A reason for the fact that there is only limited quantitative information available on the effects of single damage influencing parameters (see e.g. Smith, 1994; Wind et al., 1999; Penning-Rowsell and Green, 2000; Kreibich et el., 2005; 2009; Thieken et al., 2005; Parker et al., 2007), is that they are very heterogeneous in space and time and therefore difficult to predict. For instance, whether an oil tank is destroyed by a flood can make the difference between severe damages due to heavy contamination of flood waters or marginal damages due to water contact only. As a result, the majority of modelling approaches estimate flood damage with susceptibility functions (alias damage functions) that are solely based on the type or use of an element at risk and inundation depth. These depth-damage functions are considered as the standard approach to assess urban flood damages (Smith, 1994). However, some multiparameter models have been developed for example for Japan by Zhai et al. (2005) and for Germany (Thieken et al., 2008a; Elmer et al., 2010; Kreibich et al., 2010a). Studies have shown that the application of multiparameter models that take several damage influencing parameters into account, can improve the reliability of flood damage modelling (Apel et al., 2009; Elmer et al., 2010). Studies that consider other damage influencing parameters than inundation depth usually assessed their effect on observed damages independently from each other. However, the susceptibility to flooding and the resulting damage depends on many factors which are often interrelated. While flood mitigation measures might have a significant damage reducing effect in areas with low flow velocities, the same measures can be ineffective at locations with high flow velocities. To gain insights into the complex interplay of damage influencing parameters, more multivariate analyses are necessary (see e.g. McBean et al. 1988).

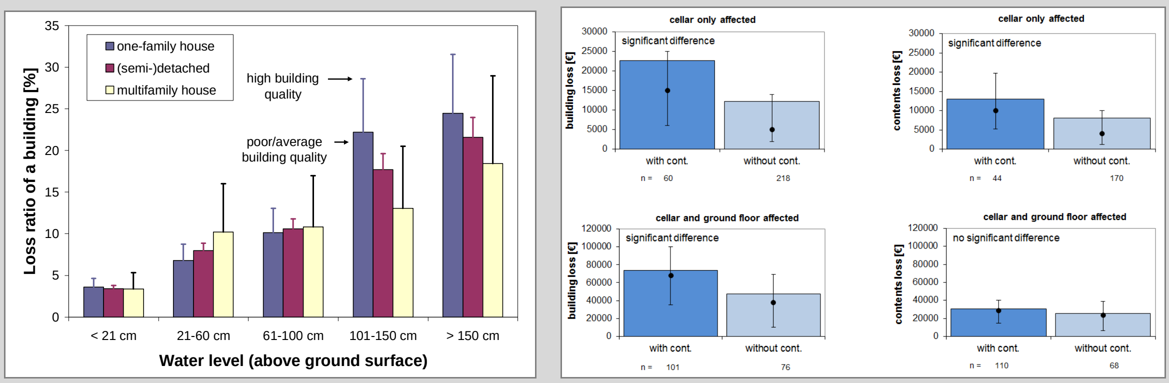
Given the observed changes to more integrated flood risk management concepts in Europe and against the background of projected increases in flood risk due to ongoing socio-economic development in risk-prone areas and the effects of climate change on river discharges, flood mitigation measures such as water proofing of houses or flood adapted use have received renewed attention in recent years (ICPR, 2002; Parker et al., 2007; Kreibich et al., 2005, 2011). Still, only few attempts have been made to integrate such damage reducing measures in flood damage modelling. Exceptions are the flood loss estimation models FLEMOps and FLEMOcs, which take private precaution into account as one of five damage determining parameters (Thieken et al., 2008a; Kreibich et al., 2010a). Thus, it is necessary to gain more insights into damage reducing effects and the costs efficiency of various flood mitigation measures. To integrate such resistance factors in flood damage modelling is especially needed to identify and develop effective risk mitigation strategies to address the projected increase in flood risks.

Textbox 2: Multiparameter flood damage modelling taking precautionary behavior into account: Flood Loss Estimation Model for the private sector (FLEMOps)

Several studies have outlined the large uncertainties associated with flood damage assessments. The uncertainties stem from the fact that very complex damaging processes are usually described using simple depth-damage functions. An example of a multi-parameter flood damage model that takes several damage influencing parameters into account is the FLEMOps series (e.g. Apel et al., 2009; Elmer et al., 2010; Thieken et al., 2008a).

The FLEMOps model has been developed based on comprehensive empirical data of up to 2158 private households that were affected by flood events in 2002, 2005 and 2006 in Germany. In addition to details on suffered damages, this data set also provides information on several damage influencing parameters at the object level, such as contamination of flood water, building quality or the level of precautionary measures. Using detailed statistical analysis (Kreibich et al., 2005; Thieken et al., 2005), this information was integrated in a multi-parameter flood loss model. FLEMOps calculates the damage ratio for private households using five different classes of inundation depth, three individual building types and two classes of building quality. Further model enhancements were made to integrate other damage influencing parameters. In a first additional modelling step referred to as FLEMOps+, the influence of private precaution and the contamination of flood water can be taken into account, using scaling factors (Büchele et al., 2006). In a second additional modelling step, the influence of flood frequency was included, because average damages were found to be higher for less probable events, independent from water level (Elmer et al., 2010).

Validations of the original model and its enhancements showed that such multi-parameter models outperform standard flood damage models that only relate damage to water depth (e.g. Apel et al., 2009; Elmer et al., 2010).



Source: Büchele et al., 2006 and Kreibich et al., 2011

There are mainly two approaches to develop damage functions that are needed for flood risk assessment. First, damage functions can be empirically derived using observed flood damage data. An example for such an empirical data base is the HOWAS data base (Merz et al., 2004) and its successor, the HOWAS 21 data base in Germany,[5] which currently comprises almost 6000 individual damage cases from different economic sectors, such as private households, industries and infrastructures. This database was e.g. used to derive the FLEMO (Thieken et al., 2008a; Kreibich et al., 2010), MURL (MURL, 2000) and Hydrotec (Emschergenossenschaft and Hydrotec, 2004) damage functions. Second, damage functions can be derived using a synthetic approach. Following this approach, experts e.g. from the insurance industry or engineers estimate the amount of damages that would occur at a specific element at risk under certain flood conditions. The Multi-coloured Manual in the UK as well as the HISS-SSM, which is the standard software in the Netherlands to evaluate flood damages, are examples of this approach (Kok et al., 2005; Penning-Rowsell et al., 2005). Both approaches can also be combined, as it was done in the case of the so-called Rhine Atlas provided by the International Commission for the protection of the Rhine (ICPR, 2001) or in Australia (NRE, 2000; NR&M, 2002). Advantages and disadvantages of the empirical and synthetic approach are discussed in Merz et al. (2010).

Besides, a choice needs to be made between relative and absolute damage functions. While relative damage functions define the expected damage as a proportion of the maximum asset value, absolute damage functions estimate the expected damages directly in monetary terms. Relative damage functions are e.g. applied for damage assessments along the river Rhine (ICPR, 2001; MURL, 2000). In the UK or in Australia, absolute damage functions are used (Penning-Rowsell et al., 2005; NR&M, 2002 and NRE, 2000).

An overview on various approaches applied to estimate direct flood damages that were referred to in the previous section is provided in Table 2.

Table 2: Approaches for the estimation of direct flood damage

	Country	Relative/absolute approach	Empirical/synthetic data	Economic sectors covered	Loss determining parameters	Validation	Data needs
Model of Multi-coloured Manual (Penning-Rowsell et al. 2005)	UK	absolute	synthetic	Residential, and commercial properties, leisure and sport facilities, public buildings, infrastructure	water depth, flood duration, building/object type, building age, social class of the occupants, warning time	Yes (Penning-Rowsell and Green, 2000)	Values of exposed assets, socio-economic information, hazard characteristic,

[5] (http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start)

FLEMO models of GFZ (Büchele et al. 2006; Thieken et al. 2008a; Kreibich et al. 2010a; Seifert et al. 2010; Elmer et al. 2010)	Germany	relative	empirical	residential buildings, public and private services, producing industry, corporate services, trade	water depth, contamination, building type, quality of building, precaution, business sector, number of employees	Yes (at micro and meso-scale) Thieken et al. 2008a; Seifert et al. 2010; Elmer et al. 2010	values of exposed assets, residential building and company characteristic, hazard characteristics
Model of ICPR (ICPR 2001)	Germany	relative	empirical - synthetic	Residential, commercial, forestry, agriculture infrastructure	water depth, economic sector	n.a.*	land use data, values of exposed assets, water depth
Anuflood (NR&M, 2002)	Australia	absolute	empirical	Residential and commercial properties, infrastructure	water depth, object size, economic sector, object susceptibility	n.a.	Property characteristics , water depth
RAM (NRE 2000)	Australia	absolute	empirical-synthetic	Buildings, agricultural areas, infrastructure	object size, object value, lead time, flood experience	n.a.	Object characteristic, land use, warning times, flood experiences, season
Model of MURL (MURL 2000)	Germany	relative	empirical	Residential and commercial properties, infrastructure, agriculture forestry	water depth, economic sector	n.a.	land use data, values of exposed assets, water depth
Model of Hydrotec (Emschergenossenschaft and Hydrotec 2004)	Germany	relative	empirical	Residential buildings, commerce, vehicles, agriculture, forestry, infrastructure	water depth, business sector	n.a.	land use data, values of exposed assets, water depth
HAZUS-MH (FEMA 2011; Scawthorn et al. 2006)	USA	relative	empirical - synthetic	Residential buildings, commerce, infrastructure, agriculture, vehicles	water depth, flow velocity, wave action object type, riverine or coastal flooding	n.a.	object type, land use data, hazard characteristics
MEDIS Model (Förster et al. 2007; Tapia-Silva et al. 2011)	Germany	relative	empirical - synthetic	Agriculture (e.g. wheat, rye, barley, corn, oilseed plants, root crops, sugar beets and grass)	Flood duration, crop types, season,	Yes at meso-scale (Förster et.al. 2007)	market prices of agricultural goods, planted crop types, flood characteristics

HIS-SSM (Kok et al., 2005)	The Netherlands	relative	synthetic	Residential and commercial properties, agriculture Infrastructure Nature Recreation Vehicles	Flood depth Flow velocity Economic sector	n.a.	values of exposed assets, socio-economic data, land use, hazard characteristics
Schwarz and Maiwald (Maiwald and Schwarz, 2010)	Germany	relative	empirical	Residential properties	Water depth, flow velocity structural characteristics,	Yes (Maiwald and Schwarz, 2010)	information on building structure, land use data, hazard characteristics

* n.a. stands for not available

Approaches for the estimation of losses caused by the disruption of production processes

As mentioned earlier, losses due to the disruption of production processes occur in industry, commerce or agriculture in areas that are directly affected by a flood event, for example when people are unable to carry out their work due to a destruction of their workplace or because it cannot be reached. Losses due to the interruption of production processes that occur outside of the flood area, e.g., because suppliers are no longer able to deliver their products, are defined as indirect damages in the CONHAZ project and thus not addressed in the present report. There are several studies that estimated flood losses due to the disruption of production processes (Parker et al., 1987; Booysen et al., 1999; MURL, 2000; NRE, 2000; NR&M, 2002; Emschergenossenschaft & Hydrotech, 2004; FEMA, 2011). However, definitions of disruption of production processes are different from model to model, so that concepts and outputs vary considerable.

(1) Classification of elements at risk

Methods to estimate losses due to the disruption of production process can show varying degrees of detail, mainly depending on the spatial but also temporal scale of the analysis. On the micro-scale, the business interruption loss can be assessed on the level of single companies from the value added lost or from costs that occur when additional facilities need to be temporarily rented. For such micro-scale assessments, detailed cost figures can be obtained using site surveys or labor and economic statistics (Parker et al., 1987; FEMA, 2011). On the meso-scale, losses due to the disruption of production processes are specified on an aggregated level, representing economic sectors or branches. Here, sectors that show similar characteristics with respect to production process and value added are grouped together, such as e.g. retail trade, wholesale trade, heavy industry, light industry, high technology, construction or agriculture (FEMA, 2011).

(2) Exposure analysis and asset assessment

Information on areas, where losses due to the disruption of production processes (potentially) occur, can again be derived by overlaying object or land-use data with flood extent maps, what is usually done within Geographical Information Systems (GIS). Different from the assessment of direct economic damages, the time period chosen plays a much more important role when estimating losses due to the disruption of production processes, as it defines the length of the interruption and thus the amount of the losses that accrue. This time period can last considerably longer than the presence of actual flood water in the flood zone, because buildings and machinery need to be cleaned and repaired before production can start again. In order to set the temporal model boundaries to estimate losses due to the disruption of production processes, the repair, reconstruction or the clean-up time can be used (e.g. FEMA, 2011).

Moreover, the production processes at risk from flooding need to be quantified in monetary terms. In most models, monetary business interruption losses are modeled as losses of flows for a certain time period (Parker et al., 1987; Booysen et al., 1999). Flows are defined as the outputs or services of stocks over time (Rose and Lim, 2002). Often, the value added is used as measure for the sum of flows in a company (Parker et al., 1987; Penning-Rowsell et al., 2005). Thus, in order to estimate losses due to the disruption of production processes, the flows that can be potentially affected by a flood need to be established. On the micro-level, the value added lost can either be calculated using the total turnover of a company per day, which must be determined in a survey (e.g. Parker et al., 1987), or, when no survey can be accomplished, by using data from statistical offices (e.g. FEMA, 2011). On the meso-scale, losses can be derived using information aggregated on the level of economic sectors. The US model Hazus-MH MR5 (See Textbox 3) provides information on output per square foot per day for 33 occupancy classes, such as retail trade, hospitals, high technology, agriculture or schools and libraries (FEMA, 2011). Data are derived from statistical offices such as the US Bureau of Labor Statistics.

Additional losses due to the disruption of production processes that are considered by existing models are relocation expenses that include the cost of shifting and transferring, and the rental of temporary space. These losses are quantified sector specific, as well, and are again derived from statistical offices (FEMA, 2011).

(3) Susceptibility analysis

Several damage influencing parameters have been taken into account by existing models to define the susceptibility of production processes to flood impacts and thus to define the time period of interrupted business operations (Kreibich et al., 2010b). Flood hazard parameters considered are water-depth (e.g. FEMA, 2011; Parker et al., 1987; Emschergenossenschaft & Hydrotech, 2004), flood duration (e.g. Parker et al., 1987; FEMA, 2011), and the return period (MURL, 2000; Booysen et al., 1999). Vulnerability parameters taken into account are differences in economic sectors (FEMA, 2011; MURL, 2000; Parker et al., 1987) and the value added. The model by Parker et al. (1987), e.g. distinguishes five classes of water depth, while Booysen et al. (1999) assume that floods with a return period of 50 years lead to a period of business interruption of two months. A similar approach is applied by the MURL model for flood loss estimation in Germany on the meso-scale (MURL, 2000). However, in comparison to Booysen et al. (1999), the deduced business interruption durations are considerably lower. Unfortunately, both studies do not reveal, on which data they based their assumptions, but MURL (2000) comments that its estimates are very conservative.

An empirical analysis of damage-influencing parameters in terms of losses due to the disruption of production process is provided by Kreibich et al. (2010b). In order to identify both hazard and resistance parameters that influence the disruption of production processes, empirical data from telephone surveys were analyzed, which were conducted among businesses in the Elbe and Danube catchments in 2003, 2004 and 2006. It was found that all hazard parameters taken into account, namely inundation depth, flood duration and flow velocity, were significantly correlated to both the duration of interruption as well as the amount of losses. It was shown that a water level of 20cm leads to a mean business interruption of 16 days. If water levels rise, also the duration of the interruption increases and an inundation depth of 150cm leads to a mean business interruption of 59 days (Kreibich et al., 2010b). In terms of resistance parameters, it was found that both precautionary measures and the size of the business were correlated to the duration of the business interruption. In terms of monetary damage, the economic sector, the number of employees and the size of the company were significantly related. Small companies with up to ten employees experienced mean damages of 28.000€, while losses in companies with more than 100 employees accrued to a mean of €1.29 Million (Kreibich et al., 2010b).

As mentioned above, also relocation costs are considered by existing methods. In order to define when relocation costs occur, the damage threshold of the respective building is considered. The US model HAZUS-MH assumes that relocation losses only occur if the damage ratio of a building reaches a threshold of 10%. As long as this threshold is not reached, it is assumed that the occupants will not need to relocate (FEMA, 2011).

A simpler approach to estimate losses due to business interruption is chosen by the Australian flood loss models Anuflood (NR&M, 2002) and RAM (NRE, 2000). They define business interruption losses as indirect losses, which also include costs for emergency response, costs for non-provision of public services and clean-up costs. These indirect losses were calculated as a fixed ratio of direct damage. Whereas Anuflood uses in general a fixed ratio of 55%, RAM recommends an average ratio of 30%, which should be decreased to 20% in rural areas with sparse population and increased to 45% in densely populated urban centers. In the case of RAM, these ratios have been derived from reported damage data and are thus empirical in nature. Other empirical findings principally support the approach to use direct damage to estimate losses due to the disruption of production processes, because they show that direct damage is strongly correlated with production losses (Kreibich et al., 2010b). However, there is hardly any quantitative information on the ratio that best describes the relation between direct damage and production losses. Moreover, the ratio between direct damage and production losses will vary substantially per economic sector and region. In addition, it should be noted, that uncertainties related to direct costs assessments, are then also incorporated in estimations of losses due to disrupted business processes. Due to the great variability of production losses among different economic sectors and regions, more detailed approaches based on an assessment of forgone added value are, therefore, to be preferred for sound cost estimates.

Textbox 3: Estimation of flood losses due to the disruption of production processes in the US

The US model Hazus-MH MR5, which is provided by the US Federal Emergency Management Agency (FEMA, 2011), estimates losses due to the disruption of production processes on the basis of relocation expenses, capital related income losses, wage losses and rental income losses. Relocation expenses include the cost of shifting and transferring, and the rental of temporary space. These costs are assumed to be incurred once the building reaches a damage threshold of 10%. Cost per day and area factors are specified for various economic sectors in order to derive monetary losses. Capital related income losses, wage losses and rental income losses are estimated depending on the building recovery time. Building recovery time is calculated by summing up the time needed for physical restoration of the building, as well as time for clean-up, time required for inspections, permits and the approval process, as well as delays due to contractor availability. All these components are estimated in dependency of water depth and business branch. The thus derived flood and sector specific building recovery time is used to estimate monetary costs per day and area, which are defined for various economic sectors (e.g. wage per square foot per day for the financial sector).

No.	Label	Occupancy Class	Rental Cost (2006)		Disruption Costs (2006)
			($/ft^2/month)	($/ft^2/day)	($/ft^2)
Residential					
1	RES1	Single-family Dwelling	0.68	0.02	0.82
2	RES2	Mobile Home	0.48	0.02	0.82
3	RES3A	Multi-family Dwelling; Duplex	0.61	0.02	0.82
4	RES3B	Multi-family Dwelling;	0.61	0.02	0.82
5	RES3C	Multi-family Dwelling; 5 - 9 units	0.61	0.02	0.82
6	RES3D	Multi-family Dwelling; 10 - 19 units	0.61	0.02	0.82
7	RES3E	Multi-family Dwelling; 20 - 49 units	0.61	0.02	0.82
8	RES3F	Multi-family Dwelling; 50+ units	0.61	0.02	0.82
9	RES4	Temporary Lodging	2.04	0.07	0.82
10	RES5	Institutional Dormitory	0.41	0.01	0.82
11	RES6	Nursing Home	0.75	0.03	0.82

Source: FEMA, 2011

Models for the estimation of business interruption losses due to flood events on the micro- and meso-scale are listed in Table 3.

Table 3: Approaches for the estimation of flood losses caused by the disruption of production processes (dpp)

	Country	Loss estimated as	Loss type	Loss determining parameters	Validation	Data needs
Parker et al. (1987)	UK	monetary dpp-loss [€]	losses to flow	water depth, flood duration, business branch, value added	n.a.	Empirical data on losses, ground floor area, hazard characteristics

Booysen et al. (1999)	South Africa	dpp-duration [days] monetary dpp-loss [€]	losses to flow	annuality of the flood dpp-duration, value added	n.a.	Turnover, added value, return period
MURL (2000)	Germany	dpp-duration [days] monetary dpp-loss [€]	losses to flow	annuality of the flood dpp-duration, business branch,	n.a.	Added value per economic sector, return period
RAM (NRE, 2000)	Australia	monetary dpp-loss [€]	losses to stock	direct losses	n.a.	Direct flood damages
Anuflood (NR&M, 2002)	Australia	monetary dpp-loss [€]	losses to stock	direct losses	n.a.	Direct flood damages
HAZUS-MH (FEMA, 2011)	USA	dpp-duration [days] monetary dpp-loss [€]	losses to flow	water depth, business branch dpp-duration,	n.a.	Economic figures (e.g. rental costs per economic sector; wages per sq.ft / day / per industry), hazard characteristics
Hydrotec (Emschergenossen-schaft and Hydrotec, 2004)	Germany	dpp-duration [days] monetary dpp-loss [€]	losses to flow	water depth dpp-duration,	n.a.	Added value per economic sector, inundation depth

Uncertainty of damage assessments

Even though considerable research efforts have been made in recent years to estimate direct flood damages, several studies have documented the large uncertainties still associated with such assessments (Merz et al., 2004; Apel et al., 2008; Apel et al., 2009; Freni et al., 2010; de Moel and Aerts, 2010; Merz and Thieken, 2009). Merz et al. (2004) for example show on the basis of post-flood surveys that depth-damage relations derived from empirical data exhibit considerable uncertainty. The uncertainty of damage functions is also reflected by significantly different shapes of damage curves that are applied to estimate direct flood damage to residential buildings in Europe (Figure 1).

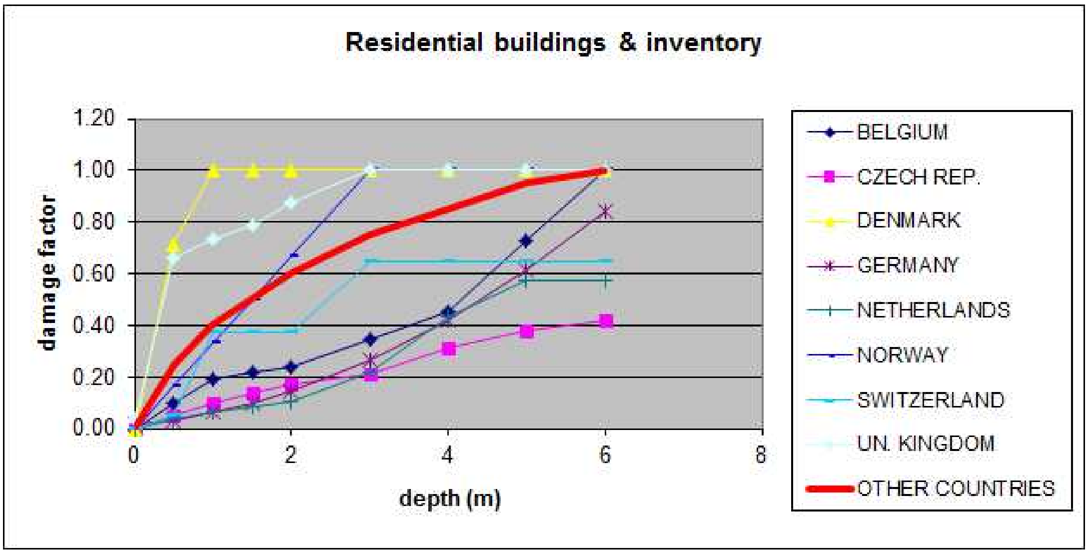


Figure 1: Damage functions used Europe for residential buildings and inventory[6]

There are several reasons for the uncertainties associated with direct flood damage assessments. One issue that has been repeatedly mentioned is the lack of reliable, consistent, comparable and publicly available damage data (Mileti, 1999; NRC, 1999; Dilley et al., 2005; Greenberg et al., 2007). This has been identified as a major obstacle to develop reliable damage models (Merz et al., 2010). Many of the publicly accessible data bases, such as EM-DAT (Centre for Research on the Epidemiology of disasters – CRED, Brussels), provide aggregated damage data on regional or national levels. However, for damage model development, object oriented information is needed that provides insights into the quantitative effect of various flood impact and resistance parameters on flood damages. Such data bases, like the HOWAS 21 data base maintained in Germany,[7] are hardly available or restricted in use. Besides, regarding the few data sets available, little is known on the way these data have been collected and on their quality.

Additional uncertainties in flood damage assessments arise from the need to transfer existing damage models (a) between elements at risk, (b) in time and (c) in space (Merz et al., 2010). The transfer between elements at risk (a) refers to the enormous variability in observed damage for similar elements at risk. Two buildings with the same structural characteristics that are located next to each other can experience largely different damage amounts during the same flood event. This has to do with the fact that both, flood impact (flow velocity, contamination of flood water, water depth) but also flood resistance parameters (e.g. precautionary measures), can significantly vary within short spatial distances. Even with a large effort, it is possible only to a very limited extent to integrate these variations in flood damage modelling (Merz et al., 2010). Transfer in time (b) refers to the fact that the susceptibility of elements at risk can change within short time frames. For instance, flood experience and related behavioral changes of the affected population can have a large effect on observed damages (Kron and Thumerer, 2002; Wind et al., 1999). Examples are the two flood events in the lower Rhine valley in 1993 and 1995, which showed very similar flood hazard characteristics. Still, damages during the flood in 1995 were

[6] Presented by José I. Barredo (2010): Flood risk in Europe using Corine land cover datasets, in CONHAZ project workshop - Flood loss assessment, London, 26th of November 2010. Source of the chart: Huizinga H.J. (2007): Flood damage functions for EU member states. Technical report, HKV Consultants. Implemented in the framework of the contract #382441 F1SC awarded by the European Commission - Joint Research Centre.

[7] (http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start)

only half of the amount experienced during the flood 15 months earlier. The significant reduction in observed damages was mainly attributed to the improved preparedness of the population at risk (Kron and Thumerer, 2002). Finally, transfer in space (c) relates to the uncertainties that are introduced when damage models, which have been developed for a certain area, need to be transferred to other regions. Such a transfer implicitly assumes that the relation between damage influencing parameters and the resulting economic damage are similar in different regions. That this is not necessarily the case has been shown by Thieken et al. (2008a), who validated the FLEMOps model in five Saxon municipalities that were affected by the Elbe flood in 2002 and five municipalities in Baden-Wuerttemberg that experienced a flood in December 1993. While the model delivered very good estimates of the event in 2002 in Saxony, deviations were found to be large for the municipalities in Baden-Württemberg, demonstrating the limited transferability of damage models in space and time (Thieken et al., 2008a).

The quality of existing damage models can be evaluated by performing model validations (e.g. Seifert et al., 2010; Penning-Rowsell and Green, 2000). Model validations usually assess, whether a model produces similar results compared to observed flood damages in a given area for a certain flood event and whether it is suitable to predict unobserved situations (Merz et al., 2010). Model validations can also be used to assess, whether model performance can be improved by considering additional parameters, such as e.g. flood frequency, which might then be integrated in the respective model (e.g. Elmer et al., 2010). A major shortcoming of modelling direct flood damages is that model validations are hardly performed. A main reason for this can again be found in limited or missing data availability to perform such analyses (Merz et al., 2010).

2.2 Droughts

Terminology

Droughts had far-reaching impacts in recent decades in the European Union and have caused damages as high as 100 billion Euros in the last three decades (European Commission, 2007). Between 2000 and 2006, about 15% of the total area of the EU and about 17% of the population were affected by droughts (European Commission, 2007). The Committee of European Agricultural Organizations in the European Union estimates that the drought and the associated heatwave in Europe in 2003 caused damages as high as 13.1 billion Euros (COPA-COGECA, 2003). In the future, drought damages are expected to increase in Europe and especially in the Mediterranean basin, given the projected effects of climate change (e.g. Gao and Giorgi, 2008; IPCC, 2007; Schär et al., 2004; Meehl and Tebaldi, 2004).

Compared to other natural hazards, such as storms or floods, droughts show several distinct characteristics: first, it is difficult to define the start and the end of a drought, because the effects of a drought event usually accrue slowly over time. As a result, drought is also referred to as a creeping phenomenon (Wilhite, 2005). Second, drought damages are spread over large geographical areas and have so far been mainly associated with non-structural damages and not so much with structural damages, as compared to other natural hazards. Third, there is up to date no commonly used definition of the term drought, because whether or not a drought exists, highly depends on regional and application-specific characteristics. Region specific definitions are needed, due to variations in hydro-meteorological characteristics in different regions around the world (Mishra and Singh, 2010). Application-specific definitions are developed, because the agricultural sector might have a very different understanding of a drought than the tourism industry or environmental organizations. In their classification study, Whilhite and Glanz (1985) collected 150 different definitions of the term drought.

According to the definition adopted by the European Commission, which also applies for the present report, "[...] droughts are the expression of a temporary decrease in average water availability (European Commission, 2007)." Usually, droughts are caused by a deficiency in rainfall, while their acuteness and duration can be aggravated by high air temperatures, heat-waves and high rates of evapotranspiration. Droughts often have a strong seasonal component and mainly occur during spring and summer. Thus, drought events are first of all a natural phenomenon. However, the intensity and duration of droughts is often influenced by anthropogenic activities, in particular *water scarcity* situations. Water scarcity, which needs to be distinguished from drought, refers to a long-term imbalance between water demand and supply of available water resources, owing to high volumes of water being used for agriculture, industries or private consumption (European Commission, 2007). Drought events can be accompanied by heat-waves, as it was the case in Europe in 2003 (Fink et al., 2004). While there is no universal definition for a heat-wave, any prolonged period of high temperatures usually lasting at least 3 consecutive days, especially accompanied by high night-time temperatures, maybe deemed a heat-wave (Ostro et al., 2009). Droughts and heat waves can also lead to so-called low-flows. While no common definition could established, low-flows refer to situations when water levels drop considerably below their normal conditions. If water levels become too low, this can lead to interferences with navigation or the cooling of power plants.

Droughts can cause direct damages to a variety of economic sectors, with far reaching indirect (or secondary) effects to the wider economy (Mysiak and Markandya, 2009; Mishra and Singh, 2010). As stated earlier, direct damages in the framework of the CONHAZ project are defined as those damages that occur due to a physical contact between the hazard and exposed economic assets. In the case of droughts, this direct contact is less obvious than for other natural hazards, making drought-related damages more difficult to delineate in space and time. This might also be the reason, why the literature on consequences of droughts mainly refers to drought impacts instead of (monetary) damages. Direct drought damages, as defined in the current report, refer to losses that occur in water-use sectors directly affected by a drought event, such as agriculture, hydropower production or livestock production (Mysiak and Markandya, 2009). Examples of direct drought damage are reduced or lost crop yield, losses in livestock production or reduced hydropower production. In addition, droughts and related soil subsidence can cause considerable structural damage, even though this aspect has received little attention in the literature, so far (e.g. Corti et al., 2009; Dlugolecki, 2007).

Approaches for the estimation of direct damage

The distinct characteristics of droughts and drought-induced damage implicated that simulation frameworks that were developed to quantify direct damages from other natural hazards (e.g. Apel et al., 2009), were hardly applied to estimate direct damages from droughts. A large part of the literature that addresses direct drought damages focus on past events (Corti et al., 2009;

Martin-Ortega and Markandya, 2009; Benson and Clay, 1998; Horridge et al., 2005). Except for the agricultural sector (e.g. Gobin, 2010), no ex ante models seem to be available to assess potential direct drought damages. This also implies, that comprehensive modelling approaches that take potential direct drought damages of various sector into account, are not available, according to our knowledge. As a result, the standard approach to assess direct damages from natural hazards, which usually comprises (1) classification of elements at risk, (2) exposure analysis and (3) susceptibility analysis holds true for the assessment of direct drought damage only to a limited extent. In reverse, this also means that there is no standard approach to assess direct drought damage. Generally, it can be stated that there is a lack of concepts and modelling frameworks to quantitatively estimate the monetary costs associated with droughts (Corti et al., 2009).

(1) Classification of elements at risk

As discussed above, a large part of existing literature addressing direct drought damages focus on past events (Corti et al., 2009; Martin-Ortega and Markandya, 2009; Benson and Clay, 1998; Horridge et al., 2005). For studies that evaluate direct drought damages *ex post,* no classification of elements at risk along similar susceptibility characteristics or asset values is required. Cost figures are usually evaluated using self- or media reports or are derived by comparing production outputs of a drought year to the average production during non-drought years (e.g. Martin-Ortega and Markandya, 2009). These studies can show varying degrees of detail and provide damage estimates for various economic sectors and subsectors (e.g. Martin-Ortega and Markandya, 2009; Horridge et al., 2005) or provide aggregated cost estimates for the agricultural GDP as a whole (Benson and Clay, 1998). Especially when estimating direct drought damages *ex post,* by comparing production outputs between drought and non-drought years, it should be noted that direct and indirect damages cannot be separated from each other. Benson and Clay (1998), for instance, compare agricultural GDP in a drought period to the years preceding the drought. However, whether the reduction in agricultural GDP is caused by direct production losses or indirect damages spreading throughout the economy cannot be established.

Predictive models that would require a classification of elements at risk along similar susceptibility characteristics or asset values are hardly available. An exception is the agricultural sector, for which ex ante crop yield models like CropSyst (Stöckle et al., 2003) or AQUACROP (Steduto et al., 2009) exist. These can be used to simulate crop yield under various conditions, including droughts, and are applied to specific crop types or cultivars like winter wheat or potatoes (Gobin, 2010; Song et al., 2010). Crops are classified based on a set of parameters such as crop phenology, morphology or growth (Stöckle et al., 2003). Such crop yield models can also be linked to climate change scenarios to estimate the effect of climate change and increased drought risk on crop production (e.g. Gobin, 2010; Moriondo et al., 2011). While the output of these models initially provides no cost estimate as such in monetary terms, their output can be used in agro-economic models to estimate direct drought damages such as drought-related income losses.

An aspect that received little attention in the literature, so far, is drought-related damages to buildings due to soil subsidence. Since existing studies suggest that not all building types are affected the same way by soil subsidence (Crilly et al., 2001), these findings could be used to classify buildings at risk in dependency of similar susceptibility characteristics. However, this has not been done so far, according tour knowledge.

(2) Exposure analysis

Delineating droughts and their impacts in space and time is difficult due to its distinct characteristics described above. For studies that evaluate direct drought damages *ex-post*, no exposure analysis based on drought parameters is required. In this case, exposed assets are not identified by overlaying maps showing drought parameters with economic assets but by comparing the output of a certain sector in a drought year with the average output in a non-drought year (Benson and Clay, 1998) or (self-) reported cost estimates (Martin-Ortega and Markandya, 2009).

To identify areas or assets exposed to droughts, several different drought indices are available, which can be used to define the spatial extent, severity, intensity and duration of droughts (Mishra and Singh, 2010). They include the Palmer drought severity index (Palmer, 1965), rainfall anomaly index (van Rooy, 1965), crop moisture index (Palmer, 1968), soil moisture drought index (Hollinger et al., 1993) and others (see Mishra and Singh, 2010). Practically, all these drought indices are based on precipitation alone, or, additionally also take other meteorological parameters into account, such as temperature and soil moisture (Mishra and Singh, 2010). Probably, the most widely used regional index for monitoring droughts is the Palmer drought severity index, which uses precipitation and temperature to estimate moisture demand and supply within a two-layer soil model (Palmer, 1965). Amongst others, it has been applied in studies to define the spatial extent and severity of different drought events (Karl and Quayle, 1981) or to predict crop production and drought forecasting (Heddinghaus and Sabol, 1991). The Palmer Drought Severity Index was also applied in a study that examines the relation between past drought events and recorded damages to buildings due to soil subsidence (Corti et al., 2009). A comprehensive review of drought indices and their strengths and weaknesses is provided in Mishra et al. (2010).

(3) Susceptibility analysis

As discussed above, many studies evaluate damages of past drought events *ex post*. In these studies, susceptibility to droughts is not determined by predefined relations between certain drought hazard and resistance parameters and expected damages, but by self- or media reports or comparisons between drought and non-drought years. Martin-Ortega and Markandya (2009) e.g. provide direct damage estimates for various sectors due to a drought event that occurred in Catalonia (Spain) in 2007 and 2008. The economic sectors included are e.g. agricultural production, gardening and flower companies, swimming pool providers and hydropower production. While production losses in the agricultural sector are, for instance, estimated using (self-) reports of farmer unions or the media, damage to hydropower providers are based on a comparison between power production in the drought period and average power production in the years preceding the drought event. The thus derived drought-related decrease in hydropower production is multiplied with an average market price for electricity (Martin-Ortega and Markandya, 2009).

With respect to the agricultural sector and crop yield models, susceptibility is defined on the basis of crop types and plant phenology or types of life stock (Stöckle et al., 2003). Horridge et al.

(2005), for instance, estimate the productivity losses to various agricultural sectors caused by a severe drought in Australia in 2002 and 2003 by developing several formulae that relate productivity losses to rainfall deficits for various types of crops and livestock. Crop yield models can also be coupled with agro-economic models to arrive at cost estimates. Holden and Shiferaw (2004) use a bio-physical crop yield model in combination with an agro- economic model to study the effects of an increased drought risk on household production and consequently on production losses and income losses per capita for a case study area in Ethiopia (Holden and Shiferaw, 2004).

The only damage function available for drought-induced subsidence damage is provided by Corti et al. (2009). The function relates annual soil moisture deficits to subsidence damages and was constructed based on empirical observations and provides damage in absolute terms. Thus, following the classification introduced in the previous chapter, it can be referred to as an empirical, absolute damage function. The function provided by Corti et al. (2009) is based on a single parameter, namely 'annual soil moisture deficit'. While this function was constructed from and validated for observed data, it could possible also be used for an ex-ante analysis of drought-induced building damage due to soil subsidence. Other susceptibility functions (alias damage functions) reflecting additional damage influencing parameters such as soil type, structural characteristics of the building or the level of mitigation measures are not available. Given the enormous cost associated with structural damage due to soil subsidence already today (See Textbox No. 4), and the expected increase in damages due to the effects of climate change, ex ante models should be developed that can be used to assess such impacts for observed or hypothetical drought events (Corti et al., 2009). No models on drought-related soil subsidence damage are currently available that take different aspects of susceptibility into account. In order to develop such models, again damage data would be required on the level of individual objects that provide insights into the damaging processes. An example for such a data base is provided by Crilly et al. (2001). They show that not all building types are affected the same way from soil subsidence. Crilly (2001) analysed a data base containing information on 484 individual subsidence claims. It provides information on the property (e.g. location, year of construction), the damage (e.g. crack widths and locations, timescale, cause), foundation and ground conditions (e.g. soil type, foundation type) and vegetation as well as monitoring and mitigation measures (e.g. types of monitoring, structural repair). The analysis indicates that detached houses show a greater susceptibility to soil-subsidence than other properties. Also, the age of the building, the time period in which it was built and the soil type were found to influence damage to buildings. These insights could be used to develop multiparameter models that take droughts resistance paramenter into account.

An overview on approaches to assess direct drought damages that were referred to in the present report is presented in Table 4.

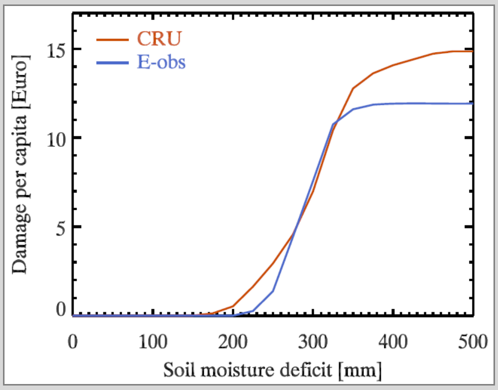
Table 4: Approaches for the assessment of direct drought damages.

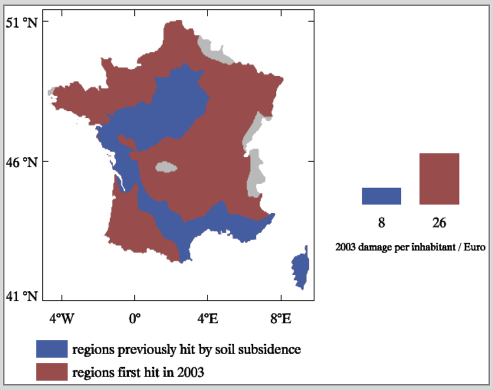
	Country	ex ante / Ex-post	economic sectors covered	Loss determining parameters	Validation	Data needs
Martin-Ortega and Markandya (2009)	Spain	Ex post	Irrigators, Swimming pool providers and related sector, gardening and flowers, Hydroelectric production	Comparison drought to non-drought years Reported cost figures	Reported damage figures partly compared with other cost estimates	Primary studies (reported cost figures)
Benson and Clay (1998)	Africa	Ex post	Agriculture GDP	Comparison drought to non-drought years	n.a.	Sector specific and national GDP
Horridge et al. (2005)	Australia	Ex post / ex ante	Agriculture, livestock, trade, transport, construction	Input-output tables, changes in stock price elasticity	n.a.	Input-output tables, trade matrices, matrix of commodity tax revenues, input factors values, stock changes of domestic output and imports.
Holden and Shiferaw (2004)	Ethiopia	Ex post / ex ante	Agriculture Livestock	Crop yield, soil erosion, production characteristics Commodity prices, labour and capital prices	n.a.	Biophysical data, socio-economic data, market prices for agricultural products
Corti et al. (2009)	France	Ex post / ex ante	Residential buildings	Soil moisture deficit index	Yes (Corti et al., 2009	Soil moisture data, population density
COPA-COGECA (2003)	Europe	Ex post	Agriculture Forestry Livestock production	Reported cost figures	n.a.	Primary studies (reported cost figures)

Textbox 4: Droughts and associated building damage in France

One of the few studies that explicitly addresses the estimation of direct drought damages to buildings comes from Corti et al. (2009), who examine the link between past drought events and annual variations in damages to buildings due to soil subsidence in France. Soil subsidence can be understood as the interplay between meteorology, soil hydrology and soil mechanics and leads to a swelling or shrinking of soil due to changes between dry and wet conditions (Bronswijk, 1989). The amount of vertical soil-movement depends on the combined soil properties and can have damaging effects on infrastructure and buildings. Corti at al. (2009) use a model driven by meteorological input data, to investigate the link between soil moisture extremes and recorded building damages. Information on damages to buildings due to soil subsidence between 1989 and 2002 were derived from insurance data and disaggregated based on population distribution. Information on the drought-related hazard, namely soil subsidence, is derived from an indicator based on the Palmer Drought Severity Index (PDSI), which provides information on the ‘annual soil moisture deficit’. Susceptibility is defined by applying a single vulnerability curve, which was empirically constructed on the basis of the recorded damage data. This absolute vulnerability curve provides for each grid cell in France on a 0.05 degrees spatial resolution a damage value per capita in dependency of the respective annual soil moisture deficit at this location. A strong link is found between soil moisture extremes and related building damages. Moreover, it is found that there has already been a strong shift in soil moisture conditions in France since the early 1990s, with much drier conditions as compared to the thirty preceding years. This is mainly attributed to an increase in temperatures for this period years (Corti et al., 2009).

The authors also applied the model to specifically analyse the severe 2003 European heat wave, which led to widespread drought (Schär et al., 2004). For this event, extraordinary drought-induced subsidence damages of 1060 Mio Euro were reported in France (CCR, 2007; Gao and Giorgi, 2008). During this event, many regions were affected by a drought and related soil-subsidence for the first time. The findings show that regions without prior drought experience showed a much higher vulnerability due to a lack of preparedness and adaptation. This has important implications given the projected effects of climate change, because previous humid regions could soon be affected by droughts (Seneviratne et al., 2006), resulting in high levels of subsidence-related damages (Corti et al., 2009).





Source: Adapted from Corti et al. (2009)

Approaches for the estimation of losses caused by the disruption of production processes

Studies that explicitly address drought losses due to the disruption of production processes are scarce. As discussed above, studies that assess drought damages by comparing production output of drought years with non-drought years often implicitly also consider losses caused by the disruption of production processes (e.g. Benson and Clay, 1998; Horridge et al., 2005). However, in these studies, it is not possible to distinguish between the different types of damages. In line with studies that assess direct drought damages, also assessments of losses caused by the disruption of production process evaluate these either ex post or by comparing production output or prices between drought and non-drought years (Rijkswaterstaat, 2004; Fink et al., 2004; COPA-COGECA, 2003; Martin-Ortega and Markandya, 2009).

One of the few reports that explicitly takes losses due to the disruption of production process into account examines potential damages caused to the shipping sector in the Netherlands as a result of low-flows (Rijkswaterstaat, 2004). When river water levels become too low during drought periods, ships can no longer load their full cargo or need to stop their service completely. In addition, also waiting times at sluices increase if water levels fall below a critical level. As a result, shipping costs increase, because more passages are necessary to carry the same amount of cargo. At which level low-flows lead to losses in the shipping industry is location specific. For the Rhine in the Netherlands, which is one of the most heavily navigated rivers in the world (ICPR, 2008), large ships can no longer load the full cargo as soon as discharge falls below 1250 m^3/s at Lobith (Rijkswaterstaat, 2004). To quantify damages to the navigation sector due to low flows, the study compares the total amount of cargo shipped during an average year to the total amount of cargo shipped during a drought year. The total amount of cargo that is shipped during a year is estimated based on the amount of cargo that can be transported per ship and the waiting times of ships at sluices (Rijkswaterstaat, 2004). Possible changes in demand or the shipping fleet are not considered. This modelling approach is also used to estimate the effects of climate change on river discharges and consequently losses due to the disruption of production processes in the shipping industry. It is found that the yearly increase in shipping costs due to the effects of a moderate climate change is small compared to expected changes in the shipping sector that are not related to low-flows. However, for a climate scenario assuming extremely dry summers, losses to the shipping sector would be large because shipping in its current form would no longer be possible (Rijkswaterstaat, 2004).

Losses due to the disruption of production processes resulting from droughts have also been assessed ex post for the energy sector. During times of droughts and heat waves, water levels can become so low, or temperatures so high that power plants can no longer divert enough cooling water from rivers due to physical or legal reasons (Fink et al., 2004). Isar 1, for example, a nuclear power plant in Germany had to reduce its power generation by 40% during the heat wave in 2003. Even though the reduced production of power plants did not lead to energy shortages in Europe, electricity prices increased at the Amsterdam Power Exchange Spot market (APX). The average base price increased to about 84 Euros per MWh in August 2003, compared to the previous year price when it was about 41 Euro per MWh (Fink et al., 2004). During the peak of the heat wave, also the average daily base price reached its peak with 660 per MWh Euro on August 11th 2003. An overview on studies that estimate drought losses caused by the disruption of production processes that were discussed in the previous paragraphs is provided in Table 5

Table 5. Approaches for the assessment of drought losses due to the disruption of production processes.

	Country	ex ante / Ex-post	economic sectors covered	Loss determining parameters	Valida-tion	Data needs
Martin-Ortega and Markandya (2009)	Spain	Ex post	Hydroelectric production	Comparison of production output between drought with non-drought years	n.a.	Primary studies (reported cost figures)
Fink et al. (2004)	Europe	Ex post	Power production	Comparison of prices between drought and non-drought years	n.a.	Stock prices, drought periods
Rijkswaterstaat (2004)	Netherlands	Ex post / ex ante	Navigation	water levels, Waiting times, loading capacities, overall carriage capacity of the existing fleet,	n.a.	River water levels, waiting times at sluices, load capacity, climate change projections

Uncertainties of damage assessments

Uncertainties encountered in drought damage assessments differ from damage modelling approaches used for other natural hazards due to the fact that there are hardly predictive models available. Many studies are ex post assessments which rely on self- or media reports or a comparison between production output in drought and non-drought years. In this context, uncertainties do not stem from uncertainties in the susceptibility function or uncertainties related to correctly delineate a drought in space and time, but from self-reports or the comparison between production outputs. To base costs estimates on self-reports or comparison between drought and non-drought years has several disadvantages that should be considered when using such costs estimates. First, self-and media reports can hardly be checked in terms of quality and reliability and especially self-reported damage figures might be severely biased, as they are e.g. needed to claim aid or compensation (CONHAZ workshop). Often, such costs estimates are provided by associations such as e.g. agricultural organisations that might pursue own interests (e.g. COPA-COGECA, 2003). Martin-Ortega and Markandya (2009), for example, discuss that gardening and flower companies reported losses of about 700 – 1.050 Million Euros in the aftermath of the severe drought in Barcelona in 2007 and 2008. According to estimates of public authorities, damages amounted to about 300 million Euros (Martin-Ortega and Markandya, 2009). Second, comparing the output of a drought year to a non-drought year is problematic, as changes in production can also be caused by non-drought related effects, such as mismanagement. Besides, different cost types such as direct and indirect costs cannot be separated from each other. To what extent agricultural GDP is reduced during a drought year due to direct damages to crops and life stock or indirect effects spreading through the economy cannot be established. Such a distinction might be useful, however, with respect to the formulation of mitigation or adaptation strategies.

For the agricultural sector, ex ante models exist in form of crop yield models, which can be used to estimate e.g. income losses due to increased drought risk (Holden and Shiferaw, 2004). A validation of the CropSyst model showed that the models can accurately predict crop production for various types of plants (Tingem et al., 2009). Tingem et al. (2009) used the CropSyst model to simulate crop-productivity in Cameroon to compare simulated with observed yields of maize, sorghum, groundnut and soybean from eight sites. Results showed that the model was capable of simulating yield production well with a percentage difference of only -2.8%, ranging from -0.6% to -4.5%. Larger uncertainties are probably introduced when translating changes in yield to monetary values based on average market prices (e.g. Holden and Shiferaw, 2004), as commodity prices showed considerable variability in recent years.

For the susceptibility function developed to relate annual soil moisture deficit to structural building damages, the same aspects of uncertainty discussed in section 2.1 apply. These relate to the need to transfer existing damage models between elements at risk as well as in time and space.

2.3 Coastal hazards

Terminology

Over the past decades, damages from coastal hazards to human lives, infrastructure, ecosystems and social networks increased tremendously (Costanza and Farley, 2007; World Resources Institute, 2005). Several reasons can be mentioned for the observed increase in losses. First, the frequency and severity of coastal storms increased, what has been attributed to cyclical trends aggravated by global warming (Webster et al., 2005; Emanuel, 2005). Second, vulnerability to coastal hazards increased strongly due to an accumulation of people and economic assets in risk prone coastal areas, often accompanied by poor spatial planning polices (Dircke et al., 2010; Costanza and Farley, 2007). A third factor is sea-level rise due to global climate change, which leads to a further increase in risk of coastal flooding. This trend can be further aggravated or even outweighed by soil subsidence that occurs especially in deltaic areas (e.g. Ward et al., 2011; Aerts et al., 2009).

Coastal hazards in general can be defined as “a natural phenomenon that exposes the littoral zone to risk of damage or other adverse effects” (Gornitz, 1991). Except for tsunamis or soil subsidence, coastal hazards are usually triggered by storms, such as high waves, high flow velocities or storm surges. Coastal storms are characterized by strong winds and heavy rainfall, and the resulting hazards reported in literatures can be classified mainly in two forms: wind storm (Schwierz et al, 2007; Heneka, and Ruck, 2008), and storm surge flood (Benavente et al., 2006; Danard et al., 2003; Friedland, 2009). Since storm events that occur in Europe are no hazards that are typical for coastal areas, as it is the case for tropical typhoons, the costal hazard discussed in the present report is storm surge floods. These also possesses the most destructive power (Danard et al., 2003). Hurricanes, inland winter storms, tropical typhoons but also tsunamis are not addressed in this report. Storm surges are generated by cyclonic wind piled-up water, which makes sea level rise above the ordinary tide level. A storm surge flood can thus be defined as an abnormal and sudden rise of sea level, induced by a storm event (Danard et al., 2003). They are usually associated with high flow velocities and wave activities in addition to coastal inundations and have caused substantial losses in Europe. In 1953, a major storm surge hit the south-western coast of the Netherlands, destroying 50.000 buildings, making 300.000 people homeless and leaving about 1800 victims behind (Aerts et al., 2009). In February 2010, the depression Xynthia caused a storm surge in southern France, leaving about 50 victims behind when flood defenses broke and sea water filled houses up to their roofs.[8] Direct economic losses from coastal hazards mainly concern built capital such as residential buildings, industrial facilities, building contents, infrastructures or coastal engineering structures but also agricultural crops, livestock or fisheries.

Approaches for the estimation of direct damage

Approaches to estimate the direct costs of coastal hazards generally follow the same methodological procedure described in chapter 2.1 and thus comprise the three steps: (1) classification of elements at risk (2) exposure analysis and asset assessment and (3) susceptibility Analysis.

Currently, methods to assess direct economic losses due to coastal flooding in Europe are generally the same as applied for riverine flooding (e.g. Kok et al., 2005; Penning-Rowsell et al., 2005; Vanneuville et al., 2006). In the Netherlands e.g., with its long shoreline and large parts of the country being located below sea level, potential damages from riverine and coastal flooding are assessed using the same method, namely the HIS-SSM (Kok et al., 2005). Also for Belgium, the UK and France, three other European countries at risk from coastal floods, we could not identify different costing methodologies for riverine and coastal flooding (e.g. Mrs.Tina Mertens, Belgium Coastal Divison, Conhaz Workshop on ‘Coastal Hazards’).

However, in contrast to riverine flooding, storm surges show several distinct characteristics that distinguish them from riverine flooding, such as higher waves and flow velocities (Kelman, 2002). These different hazard characteristics can cause considerably higher damages. According to FEMA (2000), “only highly engineered, massive structural elements are capable of withstanding breaking wave forces (Nadal et al., 2010).” In addition, it can also be expected that salt water will lead to different damaging processes compared to sweet water. Therefore, it could be expected that different hazard and vulnerability factors are taken into account when estimating the direct costs due to coastal flooding, for example by applying different susceptibility functions (alias damage functions). However, even though coastal floods show these different characteristics, there are, according to our knowledge, no cost assessment methods in Europe that take these variations into account.

Few approaches actually exist that take the special characteristics of coastal flooding into account. Even though these models were not developed for the European context, they are presented below to demonstrate possible approaches that take the distinct characteristics of coastal floods into account. Damages and losses of built capital due to coastal flooding are very much related to the location of the objects, such as the distance to shore lines. Therefore, zone-based damage estimation was developed by FEMA (2005) that differs from the generic depth-damage functions that were developed for riverine flooding. The FEMA model classifies the coastal areas

[8] http://www.guycarp.com/portalapp/publicsite/catdocument.pdf?instratreportid=1921

into two different zones: (1) V-zones along the water's edge, which are subject to damage from both inundation and three-foot wave action associated with 100-year flood events (FEMA, 2011); and (2) A-zones further inland, where flood forces such as flow velocities are lower. In considera-tion of the higher flood forces occurring in the V-zone, the respective damage functions reflects a much faster increase in damage compared with the curves for the A-zones. Recent damage as-sessments in coastal areas even showed that also in coastal A-zones (non-velocity zones), damages to buildings were much higher than in non-coastal zones, leading to the conclusion that the V-zone function should be applied also to A-zone coastal areas. This was also supported by laboratory tests that showed that typical wood frame panels fail under wave conditions that are much less severe than the 3-foot wave, which was used, so far, to differentiate between coastal V- and A-zones. Also Nadal et al., (2010) show that high flow velocities and wave ac-tions associated with costal floods generate much higher damage than inundations alone. They find that storm surges can increase the damage to buildings by up to 140 per cent compared with still water, as it is reflected in the standard depth-damage function. These findings exemplify the need to derive and develop separate damage functions and assessment methods for storm surges also in the European context, given the different damage causing process of riverine and coastal flooding and the expected rise in sea-levels. An overview on approaches that take the special characteristics of coastal flooding into account is presented in Table 6.

Table 6: Approaches for the estimation of direct costs of coastal hazards

	Country	Relative/absolute approach	Empirical/synthetic data	Economic sectors covered	Loss determining parameters	Validation	Data needs
Nadal et al. (2010)	USA	Relative	Synthetic	Buildings	Building type, Flow velocity, wave action, inundation depth	n.a.	Building characteristic, hazard characteristics
FEMA (2011)	USA	relative	empirical - synthetic	Residential buildings, commerce, infrastructure, agriculture, vehicles	water depth, flow velocity, wave action object type,	n.a.	object characteristic, land use data, hazard characteristics

Approaches for the estimation of losses caused by the disruption of production processes

As far as losses due to the disruption of production processes due to coastal hazards are con-cerned, we are not aware of any specific method others from the ones discussed in section 2.1. The only difference that is introduced by Parker et al 1987 is that the duration of a business dis-ruption is assumed to be longer for salt water intrusion. While motors that are affected by fresh water merely need to dry out, those affected by salt water need to be repaired or even replaced. Since time spans for the delivery of new machines can range from days to months, salt water intrusion can lead to considerably longer disruption processes.

Uncertainty of damage assessments

As the same cost assessment methods are applied for coastal and riverine floods in Europe, the same uncertainties and aspects of validations apply as discussed in section 2.1. An important uncertainty stems when assessing coastal floods from the fact that the specific damage influencing parameters of coastal floods are not taken into account by current cost assessment methods. There is little known to what extent damage functions are interchangeable between riverine and coastal floods. Results from the US suggest that this should not be done, because wave activities and high flow velocities will lead to significant different damage patterns (FEMA, 2011; Nadal et al., 2010). Recorded damage data as well as laboratory tests undertaken by FEMA in the US showed that wave action and higher flow velocities in coastal areas lead to different and higher damage patterns compared to river flooding (FEMA, 2011). The FEMA therefore concludes that the use of standard depth-damage functions should be avoided, "whenever high velocity flows, ice or debris induced damage, erosion and soil/foundation failure, or unusually long-duration flooding are likely" (Nadal et al., 2010). Given the observed and projected increase of sea-levels (IPCC, 2007), and the associated increase in the risk of coastal flooding, it is important to gain further insights into these aspects also in the European context.

2.4 Alpine hazards

Terminology

Due to their steep topography, Alpine areas face a number of distinct natural hazards that mainly result from high relief energy. Examples for these are landslides, avalanches, rock fall and also floods. Moreover, the distinct topographical features of Alpine areas often also lead to a high exposure of people and capital, resulting in a high vulnerability. Because land that can be used for human settlements if often scarce in Alpine regions, urban developments have frequently been extended into areas that are prone to alpine hazards to meet the growing demand for land (Totschnig et al., 2010). According to Tappeiner (2008), only 17% of the total area of the European Alps is suitable for permanent settlements. As a result, the value at risk of alpine hazards increased in recent years (Keiler et al., 2006; Fuchs and McAlpin, 2005; Totschnig et al., 2010). In Switzerland, for instance, the number of buildings in mountain areas with an altitude of 1000m above sea level and higher quadrupled between 1900 and 1998 (SLF, 2000). Moreover, hazard prone areas often face the risk of multiple and potentially coinciding extreme events, because several Alpine hazards are triggered by the same natural drivers. Heavy rainfall, for instance, can not only trigger floods but also landslides or debris flows.

As indicated above, relief energy can be regarded as the unifying characteristic of Alpine hazards. Following from this, Alpine hazard are defined in the present report as the "occurrence of potentially damaging processes resulting from movement of water, snow, ice, debris and rocks on the surface of the earth, which includes floods, debris and mud flows, landslides, and snow avalanches." These hazards are inherent in the nature of mountainous regions and may occur with a specific magnitude and frequency in a given region (UNDRO, 1991), and are thus addressed in the present report. Even though Alpine hazards are usually confined to a local or regional level, they have caused substantial economic and human losses in recent decades. As different definitions are used for Alpine hazards, we will provide a short explanation of each Alpine hazard addressed in this report in the following paragraphs.

In the Alpine context, mainly two types of floods can be distinguished. *Flash floods*, which result from heavy rain events, can lead to flood waves in steep valleys and are characterized by a high speed of onset and a high energy. Due to their sudden onset, flash floods are difficult to forecast and warning times are usually short, posing a serious threat to people and economic assets. *River floods*, in contrast, result from enduring rainfall events and usually affect larger catchment areas. As they develop over longer time periods, better forecasts are available and warning times are longer (see also Conhaz report WP8).

Many different definitions exist for the terms debris and mud flows and the delineation to floods on the one hand and landslides on the other is not always clear. An overview on the discussion and attempts to arrive at a uniform terminology is provided in Hungr et al. (2002). Following their definition, debris and mud flows refer to a very rapid flow of saturated, non-plastic debris in a steep channel. A key characteristic of debris flows is the presence of an established channel or regular confined path (Hungr et al., 2002). Debris and mud flows, in turn, differ by the transported sediment, namely debris and mud. As debris flows can reach peak discharges that are up to 40 times greater compared with extreme floods, they can unfold high destructive power and can cause substantial damages in Alpine regions. Based on empirical data, Totschnig (2010) estimates that debris flows caused annual losses of about 25 million between 1972 and 2004 in Austria injured 29 people and caused 49 fatalities.

A landslide, as defined in the present report, is a mass of soil, debris and/or rock, which moves downslope by gravitational forces (Glade, 2003). A landslide develops as a result of complex processes, which make it difficult to predict such events in advance. This is especially true for landslides that occur for the first time, while it has been possible to predict re-activated landslides based on continuous observations and monitoring. Landslide velocity differs widely and can range from millimetres per year to meters per second. Landslide movement can be sudden and constraint to short time periods but can also last for decades or even centuries (Glade, 2003). According to the OFDA / CRED International Disaster Database, 75 landslide events between 1903 and 2004 resulted in the loss of more than 16.000 lives and in damages exceeding USD 1.7 billion.[9]

Avalanches can be defined as “rapid, gravity-driven masses of snow moving down mountain slopes” (Ancey 2001). Mainly two types of avalanches can be distinguished, namely what are called slab-avalanches and loose-snow avalanches (Hanausek 2000). The term slab avalanche refers to a situation when a large amount of snow simultaneously moves downhill. These often develop when different layers of snow are on top of each other. Loose snow avalanches mostly occur on steep and rocky slopes when the snow has a low cohesion. They are triggered by single snow particles that start to move downhill and push other snow particles downwards. Avalanches occur frequently in Alpine region and can cause severe economic and human losses due to their kinetic energy and high pressure. During the very snow-rich winter 1998/99 in Switzerland, avalanches caused direct damages as high as 439 Million Swiss Francs and left 71 victims in the whole Alpine regions behind (Nöthiger et al., 2002). According to Mr. Andreas Pichler

[9] http://www.ehs.unu.edu/file/get/3672

from the ‘Austrian Service for Torrent and Control’ (Conhaz workshop Alpine hazards), about 1 million people in Austria live in areas at risk from avalanches.

Approaches for the estimation of direct damage

Approaches to estimate the direct damage of alpine hazards generally follow the same methodological procedure described in the previous chapters and thus comprise the three steps: (1) classification of elements at risk (2) exposure analysis and asset assessment and (3) susceptibility Analysis.

(1) Classification of elements at risk

Elements at risk of Alpine hazards are classified on the basis of similar vulnerability characteristics and / or similar asset values (e.g. Glade, 2003; BUWAL, 1999b). While micro scale assessments estimate potential direct damages due to alpine hazards on the level of individual buildings (e.g. BUWAL, 1999a: p.88), studies on the meso- and macro scale usually distinguish between different types of land-use categories. In line with the discussion in chapter two, the level of detail mainly depends on the scope and purpose of the analysis and the availability of appropriate data. Since many Alpine hazards are usually events that are constrained to the local or regional level, micro-scale damage assessments appear to be more common, compared with cost assessments of other (large-scale) hazards (e.g. Bell and Glade, 2004; BUWAL, 1999b). The majority of studies that investigate direct damages from landslides, debris flows and avalanches focus on residential buildings or areas (Totschnig et al., 2010; Fuchs et al., 2007; BUWAL, 1999b, a; Huttenlau et al., 2010b).

In terms of railway infrastructure, the Austrian Federal Railway (ÖBB) provides a classification of all their financial assets that are of operational importance, namely railway cross sections (base section, track super structure, contact line), interlocking blocks, (station) buildings, bridges and transformer substations (Moran et al., 2010).

(2) Exposure analysis and asset assessment

To identify areas at risk from Alpine hazards, the same procedure is followed as described in section 2.1. Following this approach, economic assets at risk are identified by combining the information of hazard maps with information on land-use categories or single objects at risk. This is commonly done with the help of a GIS. Glade (2003) for example overlays potential debris flow maps and rock fall run out maps with information on building structures. Examples of maps showing the risk of avalanches, mudslides, floods and rock fall are provided in BUWAL (1999a).

Since the value of economic assets does not depend on the type of hazard, the same approach, which is discussed in section 2.1, is also applied by current studies to estimate economic values at risk from Alpine hazards. Glade (2003), for instance, who examines potential damages from landslides in Rheinhessen (Germany), directly adopts the asset values that were established for flood damage assessments (e.g. MURL, 2000). Thus, economic assets are commonly defined on the basis of statistical data, such as gross capital stocks or based on values that are derived from the analysis of insurance data. In contrast to studies that examine hazard or vulnerability parameters, there are only few studies that describe the methods to estimate values of economic assets at risk from natural hazards. Overviews on different approaches to estimate values of economic assets exposed to natural hazards are provided by Huttenlau and Stötter (2008) as well as Merz et al. (2010). A detailed example of the method to derive the value of exposed assets for the Austrian province of Tyrol (Austria), which faces several alpine hazards, is provided by Huttenlau and Stötter (2008). In their case, the stock of elements and asset values were obtained from anonymised insurance contracts of a regional insurance company.

As mentioned above, Alpine hazards are often relatively small-scale events. This also means that exposed asset values need to be available with a high level of detail. An example for this is the Swiss evaluation tool Economie2.0, which provides very detailed information on average values of various types of assets, ranging from different types of buildings, infrastructural elements to agricultural production (BAFU, 2011).

(3) Susceptibility Analysis

In line with the assessment of direct costs of floods and coastal hazards, the susceptibility of economic assets to alpine hazards is commonly quantified with the help of damage functions. Many of these functions are relative damage functions and thus describe the potential damage as a ratio of the total asset value (See Table 7). As far as floods are concerned, there are, according to our knowledge, hardly any damage approaches available that consider special characteristics of Alpine floods, such as e.g. high flow velocities or shorter warning times. Huttenlau (2010b), for example, transferred standard riverine depth-damage functions to calculate potential damages in the Austrian province of Tyrol. The transfer of depth-damage functions for Alpine floods seems problematic for the same reason discussed in the section on coastal hazards. It can be expected that damaging processes are different for Alpine floods associated with high flow velocities compared with slow rising river floods and that damages might be considerably higher (Nadal et al., 2010). A cost assessment method that considers the differences in damaging processes is the Swiss tool ECONOME2.0, which is the standard software in Switzerland to evaluate the efficiency of hazard mitigation measures (BAFU, 2010). Within the model, three different damage functions are integrated that reflect two different types of floods and respective damaging processes. A distinction is made between static floods and dynamic floods. The differentiation between static and dynamic floods is based on the downward slope of the respective area or, if available, information on flow velocities (Kimmerle, 2002; Romang, 2004; BAFU, 2010).

Specific damage functions have been developed for debris flows, landslides and avalanches. In contrast to the predominant depth-damage functions applied in flood damage assessments, the main hazard parameter taken into account when assessing potential damages from landslides and avalanches is the intensity of the event. The intensity of an event is for instance expressed in terms of kilojoule (kJ) for landslides (BUWAL, 1999b), kilo newton per square meter (kN/m^2) or kilopascal (kPa) for avalanches (Keiler et al., 2006; BUWAL, 1999b), and deposit-depth in the case of debris flows (Fuchs et al., 2007).

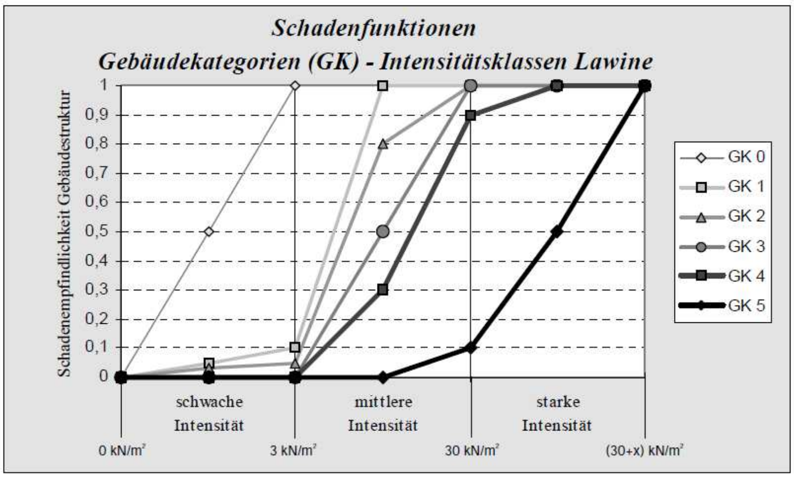
In addition to these hazard impact parameters, a number of susceptibility functions (alias damage functions) exist that also consider resistance parameters. In terms of resistance parameters to Alpine hazards, consideration is given to different building categories and the existence of avalanche mitigation measures. BUWAL (1999a) provides a set of empirical, relative damage functions for avalanches and landslides that take differences in the susceptibility of various building categories into account (See Textbox). Buildings are grouped into five different classes ranging from ‘no resistance’ to ‘very high resistance’ to avalanches and landslides. In addition to the differentiation into five susceptibility classes of buildings, Keiler et al. (2006) also take into account the effect of avalanche mitigation measures in damage modelling, such as avalanche deflectors and reinforced construction on the avalanche-exposed side of the building. The effectiveness of such a mitigation measure is reflected by grouping the respective building into a different building category class, if a mitigation measure is present. For instance, in case a building was reinforced, the damage function for the building category 5 (very high resistance) is applied instead of building category 4 (high resistance). Which buildings have implemented an avalanche mitigation measure is assessed during field visits or through the identification of areas where a building code has been enforced. Simpler approaches exist for rock falls and partly also for landslides: the vulnerability of elements at risk is assumed to be equal to total damage (Glade, 2003;Huttenlau et al., 2010). It is thus assumed that an economic asset at risk will be totally destroyed, once it is affected by a rock fall.

As far as the susceptibility of infrastructure is concerned, the Austrian Federal Railway (ÖBB) defined 5 different damage classes that can occur at their railroad system (Moran et al., 2010). While class one refers to flood events that only reach the base section without any noticeable damage, damage class 5 describes a situation, in which a complete reconstruction of the railroad track is necessary and the overhead is damaged due to a flooding of track super structure. This classification shall be further used to collect standardized damage data which can be used to construct flood damage functions specifically for railway infrastructure by combining it with information on observed flood hazard parameters (e.g. depth, flow velocity, duration). Better insights into damage to infrastructure seem to be an important, since Alpine hazards can cause substantial losses to Railway networks. According to Mr. Christian Rachoy from the Austrian Federal Railways (Conhaz workshop ‘Alpine Hazards’), the replacement of 100m railroad track cost about € 0.05 Million while the destruction of a passenger train results in losses as high as €11 Million. Also the Swiss tool Econome2.0 provides susceptibility factors for various parts of the railway infrastructure.

Estimatig the direct costs of avalanches and landslides in the Swiss Alps

An interesting case study on how to assess the direct cost of alpine hazards is provided by BUWAL (1999a). It estimates potential direct damages from a number of alpine hazards, such as avalanches and debris flows, for the alpine community of St. Niklaus. St Niklaus is situated in the steep Mattern valley and consists of several villages. This case study is of interest, as it considers several alpine hazards, namely landslides and avalanches. Areas at risk are identified by overlaying respective hazard maps with information on exposed assets with the help of a Geographical Information System (GIS). The values of the exposed assets are provided per surface area (e.g. residential buildings), per meter of line elements (e.g. road or cable) and per point elements (e.g. single objects and poles). The values linked to these geographical elements are derived from observed damage cases and expert judgment (BUWAL, 1999a). Potential damages are quantified with a set of hazard-specific damage functions, which are based on empirical damage data. These functions not only take hazard parameters into account but also consider differences in the susceptibility of buildings. From the hazard side, consideration is given to the intensity of the event, which is expressed in kilo newton per square meter (kN/m^2) for avalanches and kilojoule (kJ) for landslides. In addition, also differences in the susceptibility of buildings are considered by providing individual damage functions for five different building categories. These are: very light constructions (no resistance), light constructions (very low resistance), mixed buildings (low resistance), mural constructions (medium resistance), concrete constructions (high resistance) and enforced walls (very high resistance). An overview of the avalanche damage functions is provided in the Figure below.

	Schadenempfindlichkeit Gebäudestruktur bei LAWINEN						
Gebäude-kategorien	0 kN/m²	schwache Intensität	3 kN/m²	mittlere Intensität	30 kN/m²	starke Intensität	(30+x) kN/m²
GK 0	0.0	0.5	1.0	1.0	1.0	1.0	1.0
GK 1	0.0	0.05	0.1	1.0	1.0	1.0	1.0
GK 2	0.0	0.03	0.05	0.8	1.0	1.0	1.0
GK 3	0.0	0.0	0.0	0.5	1.0	1.0	1.0
GK 4	0.0	0.0	0.0	0.3	0.9	1.0	1.0
GK 5	0.0	0.0	0.0	0.0	0.1	0.5	1.0



Source: BUWAL, 1999b

An overview of studies that assess direct costs of Alpine hazards that are mentioned in the present report is given in Table 7. A review on the assessment of physical vulnerability for alpine hazards is provided by Papathoma-Köhle et al. (2011).

Table 7: Approaches for the assessment of direct damages from Alpine hazards

	Country	Relative/absolute approach	Empirical/synthetic data	Economic sectors covered	Loss determining parameters	Validation	Data needs
Floods							
Huttenlau, (2010b)	Austria	Relative / absolute	empirical	Residential buildings	Water depth	n.a.	Values of exposed assets, inundation depths
Economie 2.0	Switzerland	Relative	n.a.	Residential buildings, infrastructure, agriculture, forestry, recreation	Flood intensity, flood type (static / dynamic), object susceptibility	n.a.	Flood intensity maps, slope, flow velocity, object data, mitigation measures
Debris flows							
Econome 2.1	Switzerland	Relative	n.a.	Residential buildings, infrastructure, agriculture, forestry, recreation	Debris flow intensity, object susceptibility	n.a.	Debris flow intensity maps, slope, object data, mitigation measures
Fuchs et al. (2007)	Austria	Relative	empirical	Residential buildings	Debris flow-depth	n.a.	Values of exposed assets, debris flow depth
BUWAL (1999b)	Switzerland	Relative	Empirical	Urban areas	Intensity (kJ), building characteristics	n.a.	Values of exposed assets, hazard characteristics
Totsching et al. (2010)	Austria	Relative	Empirical	Dwelling houses	Intensity (deposition height)	n.a.	Values of exposed assets, hazard characteristics
Avalanches							
BUWAL (1999b)	Switzerland	Relative	Empirical	Urban areas	Intensity (kN/m^2), building characteristics	n.a.	Values of exposed assets, hazard characteristics
Keiler et al. (2006)	Austria	Relative	Empirical	Buildings	Hazard intensity (kPa), building characteristics, avalanche mitigation measures	n.a.	Hazard characteristic, volume and average price of buildings, building characteristics

Economie2.0	Switzerland	Relative	Empirical	Residential buildings, infrastructure, agriculture, forestry, recreation	Avalanche intensity, object susceptibility	n.a.	Avalanche intensity maps, object data, mitigation measures
Rock fall							
Huttenlau et al. (2010)	Austria	n.a.	n.a.	Residential buildings, industry and commerce, vehicles	0 = no damage 1 = total damage	n.a.	Hazard map, Values of exposed assets
Economie2.0	Switzerland	Relative	n.a.	Residential buildings, infrastructure, agriculture, forestry, recreation	Rock fall intensity map. Object susceptibility	n.a.	Rock fall intensity maps, object data, mitigation measures
BUWAL (1999b)	Switzerland	Relative	Empirical	Urban areas	Intensity (kJ), building characteristics	n.a.	Values of exposed assets, hazard characteristics

Approaches for the estimation of losses caused by the disruption of production processes

Studies that explicitly address losses due to the disruption of production processes in the context of Alpine hazards are scarce. A reason for this could be that Alpine hazards are often rather confined to the local level. Thus, following the CONHAZ definition of 'production losses' (as compared to 'indirect losses'), also the hazard areas in which losses of production processes occur, are spatially rather restricted.

Similar to studies discussed in the section of drought damages, also losses due to the disruption of production processes due to avalanches were derived by comparing figures of average years with the year of the event. Losses that occurred in the tourism industry in Switzerland were estimated at about 19 Million Swiss Francs. This figure was derived by comparing the average number of overnight stays between 1993 to 1998, with the number of overnight stays in the avalanche winter of 1999. During the winter months before the avalanche events happened, a significant increase in overnight stays of about 11 per cent had still been observed. In February and March, however, communities that were affected by avalanches, such as Lötschental, Evolene, and Andermatt saw a steep decline in overnight stays of about 40%. Monetary losses were derived by multiplying the number of forgone overnight stays with an expected average expenditure of 200 Swiss Francs per day (SLF, 2000).

In addition, also ex-post assessments are used to provide an indication of losses due to the disruption of production processes. In the Swiss community Elms, the cable car company experienced losses due to the disruption of production processes of about 800.000 Swiss Franc. The cable car had to be shut down in February, when touristic activities came to a halt in the aftermath of the avalanche. Also the cable car in the community of Engelberg had to be closed for security reasons and experienced losses of about 2 Million Swiss Francs (SLF, 2000).

Another study that address losses due to the disruption of production processes (and indirect losses) due to Alpine hazards comes from Nöthiger (2000), who also investigate losses in the tourism sector in the two communities Davos and Elm (Switzerland). Both communities were inaccessible for three and ten days, respectively, in the aftermath of major avalanche events. In order to assess the losses of the tourism industry in these two communities, 437 questionnaires were sent out to hotels, restaurants, cable cars and industrial facilities.

Few studies or cost estimates exist for indirect damages due to Alpine hazards that comprise losses due to the disruption of production processes implicitly. The Austrian Federal Railway System (ÖBB) provides cost estimates in case the railway system is disrupted due to an Alpine hazard event. According to Rachoy (Conhaz workshop), a disruption of the network, for instance in the aftermath of a landslide, causes costs as high as €322.000 per day. These costs comprise about € 200.000 because freight trains need to be detoured via Germany, € 107.000 due to rail replacement bus service and € 15.000 due to forgone infrastructure usage fees. However, as these costs predominantly accrue outside of the hazard zone, they rather refer to indirect damages according to the ConHaz classification. Moreover, the Austrian Environmental Ministry investigated the disruption losses in tourism sector in terms of missed cash per day in the framework of CBA analysis for evaluating mitigation measures and policies (BMLFUW, 2008a; BMLFUW, 2008b)

Uncertainties of damage assessments

As discussed above, the assessment of direct costs of Alpine hazards are in line with the approaches discussed in the previous sections on floods and costal hazards. For a discussion of the uncertainties inherent in this approach, we therefore refer to the discussion in section 2.1. As far as floods are concerned, a main uncertainty stems from the fact that only few methods (e.g. Econome2.0) take the different hazard characteristics of Alpine floods into account, such as higher flow velocities. Often, standard depth-damage functions are applied (e.g. Huttenlau, 2010b). However, significantly different damaging processes can be expected, as it has been shown by Nadal et al. (2010).

2.5 Data sources

Data needs for the application of various cost assessment methods have been described in the previous chapters (see Tables 2-5). The focus of the present chapter will be on data and data bases that are needed for model development. For the development and validation of damage models, predominantly object specific damage data are needed, since these can provide insights into the damaging processes. However, there are few general databases that contain damage data due to natural hazards, which are useful for the development or validation of cost methods. As the overview below exemplifies, most data bases are event-specific data bases while object-specific data bases are rare.

Object-specific data bases

Probably the best known example for a synthetically generated database of flood damage is the one of the Flood Hazard Research Centre (FHRC) from Middlesex University, UK. The developed absolute damage functions are published in the Multi Coloured Manual (Penning-Rowsell et al. 2005 and updated for 2010), as well as in its predecessors (Penning-Rowsell & Chatterton 1977; Parker et al. 1987).

HOWAS 21, the flood damage data base for Germany (http://nadine.helmholtz-eos.de/HOWAS21.html) contains object specific flood damage data of private households, commerce and industry, traffic areas and roads, watercourses and hydraulic structures (Thieken et al. 2010). The data sets contain at least the following information: affected economic sector, direct loss in monetary terms, water depth, flood event, spatial localization and the method of data acquisition. Many datasets additionally contain further information on the flood impact, e.g. flow velocity, duration, contamination, the affected object and mitigation measures. HOWAS 21 is designed to contain empirical and synthetic loss data. However, until now only empirical data is contained, including all data of the "old" German HOWAS flood damage database (Buck and Merkel 1999; Merz et al. 2004). Up till now, HOWAS 21 contains about 5900 datasets of flood damage cases from flood events between 1978 and 2006.

An object specific flood damage database for railway infrastructure has been recently initiated by the Austrian Federal Railway (ÖBB) (Moran et al., 2010). Damages to five different asset types are collected by a standardized documentation system. The database collects information on the damaged object (e.g. identifier, value), on the damage (e.g. type of destruction, recovery costs), on the flood event (e.g. depth, flow velocity, duration) and on possible mitigation measures (e.g. structural or non-structural measures).

Event-specific data bases

Most of the existing damage data bases are event-specific and contain aggregated damage figures. As damage are accessible only at an aggregated level, these data bases provide no insights into damaging processes and can thus not be used for model development. Therefore, the overview here is kept short. A broader overview of data bases for alpine countries is presented in the CONHAZ Report on "Costs of Alpine hazards" by C. Pfurtscheller, B. Lochner and A. H. Thieken (pages 28-30).

Probably the most well-known examples are the NatCatSERVICE data base from Munich Re (www.munichre.com) and the EM-DAT International Disaster Database (www.emdat.be). The NatCatSERVICE database from Munich Re contains overall and insured loss figures and fatalities of natural catastrophes. The natural events are classified in geophysical (e.g. earthquake), meteorological (storm), hydrological (flood, mass movement wet) and climatological events (extreme temperature, drought, wildfire). A complete dataset for natural catastrophes worldwide is available since 1980. It allows trend analyses and statistics at global, continent and country levels. For some countries, e.g. for Germany, for the United States, the records are complete since 1970. The best basis for long-term analyses is provided by data on the "great natural catastrophes" since 1950. The EM-DAT International Disaster Database contains worldwide data on the occurrence and impact of natural disasters (floods, droughts, storms, mass movements, etc.)

technological disasters and complex emergencies from 1900 to the present. The database is free and fully searchable through the website, also allowing users to download available data. The database is compiled from various sources, including United Nations agencies, non-governmental organizations, insurance companies, research institutes and press agencies. For a disaster to be included in the database, at least one of the following criteria has to be fulfilled: 10 or more people reported killed, 100 or more people reported affected, a call for international assistance, or the declaration of a state of emergency. In addition to the main focus, i.e. providing information on the human impact of disasters, EM-DAT provides disaster-related economic damage estimates. The estimated damages are given in US$ ('000) for the year of the event. The economic impact of a disaster usually consists of direct (e.g. damage to infrastructure, crops, housing) and indirect (e.g. loss of revenues, unemployment, market destabilization) consequences on the local economy. However, there is no standard procedure to determine a global figure for the economic impact.

Several other event specific global data bases exist that address losses from various natural hazards and economic sectors. Examples are CATDAT for earthquakes and volcanoes (http://earthquake-report.com/2011/03/11/catdat-dataset-hide-program/), the SIGMA database of SWISS RE covering natural and man-made disasters (http://www.swissre.com/sigma/) or the 'Global Active Archive of Large Flood Events' maintained by the Dartmouth Flood Observatory (http://www.dartmouth.edu/~floods/). In addition, national data bases exist such as the Swiss flood and landslide damage database maintained by the Swiss Federal Institute for Forest, Snow and Landscape (http://www.wsl.ch). An overview on several event specific databases for natural disasters on global, regional or national scale is provided by Tschoegl et al. (2006).

3 Assessment of approaches – Cross hazard comparison

The presented approaches for the assessment of direct damage and production losses are compiled and qualitatively analyzed (Tables 8 and 9) using the following criteria.

1. Scope and purpose: This criterion regards the comprehensiveness of the method in the decision making system and examines if the method deals with certain types of costs or if it provides a comprehensive approach (gradation: sectoral, comprehensive)
2. Spatial scale: The spatial implementation dimension of the methods is analyzed under this criterion (gradation: local, regional, national, global)
3. Time scale: The time scale is analyzed concerning the time period that each method is covering when applied (gradation: short-term (on the spot up to several months), mid-term (approximately one year), long term (more than one year))
4. Data availability: This criterion concerns the availability of the data necessary for the application of each cost-assessment method (gradation: low, moderate, high).
5. Data quality: This criterion concerns the quality assurance of the data necessary for the application of each cost-assessment method (gradation: low, moderate, high).
6. Effort required: The financial and the human resources that are demanded for the application of each method are compared under this criterion (gradation: low, moderate, high).
7. Expected precision: It describes the precision of the results produced (gradation: low, moderate, high).
8. Scientific or practice approach: This criterion illustrates the development and application context of the approaches by classifying them into the scientific or the practical fields (gradation: scientific, scientific and practical, practical).
9. Skills required: This criterion refers to the knowledge skills required for the application of the methods (gradation: desk research, econometrics/statistics, modelling)
10. Ability to deal with the dynamics of risk. This criterion refers to the ability of the methods to deal with the dynamics of risks and to be implemented in future risk scenarios, mainly linked to climate change (gradation: low, moderate, high).
11. Implemented ex-ante or ex-post: It deals with the ability of the methods to be applied ex ante in a hypothetical or laboratory setting or ex-post based on market observations (gradation: ex-ante, ex post, ex-ante and ex-post).
12. Application. Describes, to what extent the respective method is applied by the four hazard communities (gradation: + = frequently applied, o = partially applied, - = rarely / not applied)
13. Example: Provides a reference to a study that applied the respective approach

Table 8: Cross hazard comparison – Direct Damages

	Scope	Spatial scale	Time scale	Data availability (AV)	Data quality (QU)	Effort required	Expected precision	Scientific or practice approach	Skills required	Ability to deal with the dynamics of risk	Implemented ex-ante or ex-post	Application: Floods	Application: Droughts	Application: Coastal	Application: Alpine	Example
Susceptibility Function (based on a single hazard parameter)																
Empirical (absolute / relative)	Sectoral / compre-hensive	Local to national	Short term	Low /Moderate	Low / Moderate	Low / Medium	Low / Moderate	Scientific / Practical	Statistics / Modelling	High	Ex-post / Ex ante	+	o	o	+	ICPR, 2001
Synthetic (absolute / relative)	Sectoral / compre-hensive	Local to global	Short term	Low /Moderate	Low /Moderate	Low /Medium	Low / Moderate	Scientific / Practical	Statistics / Modelling	High	Ex-post / Ex ante	+	-	o	-	Klijn et al., 2007
Multiparameter models (based on several hazard impact and /or resistance parameters)																
Empirical (absolute / relative)	Sectoral	Local / region-al	Short Term	Low	Low / Moderate	Medium / High	Moderate / High	Scientific	Statistics / Modelling	High	Ex-post / Ex-ante	o	-	-	o	Elmer et al., 2010
Synthetic (absolute / relative)	Sectoral	Local / region-al	Short Term	Low	Low / Moderate	Medium / High	Moderate / High	Scientific	Statistics / Modelling	High	Ex-post / Ex-ante	o	-	o	-	Penning-Rowsell et al. (2005)
Reported cost figures																

Self- / Media reports	Sectoral / Comprehensive	Local to Global	Short term / Long Term	Moderate	Low / Moderate	Low	Moderate	Practical	Desk research	n.a.	Ex post	o	+	o	o	Martin-Ortega et al. (2009)
Comparison hazard and non-hazard time periods																
	Sectoral	Local / national	Short term /Mid term	Moderate	Low / Moderate	Low / Moderate	Moderate	Practical / Scientific	Desk research	n.a.	Ex post	-	o	-	o	Benson and Clay (1998)
Integrated assessment models																
Agro-economic models	Sectoral	Local / Regional	Short term / Long Term	Low / moderate	Low / Moderate	High	Moderate	Scientific	Modelling / Statistics	High	Ex-Post / Ex ante	-	o	-	-	Holden and Shiferaw (2004)

Several conclusions can be drawn from the cross hazard comparison provided in Table 8. In comparison with other natural hazards, there is an extensive literature on assessing direct damage of flooding. Numerous studies apply a broad bandwidth of different methods, ranging from basic susceptibility functions (based on a single hazard parameter) to complex multiparameter models (based on several hazard impact and / or resistance parameters). Detailed practice guides are also available, such as the report resulting from the FLOODsite project (www.floodsite.net/html/innovaton_outcomes.asp). Nevertheless, given the large (economic) impact of floods in Europe, the challenges of scarce public resources, and an increasing vulnerability, the available damage estimation methods are far from being satisfying. Complex damaging processes are still commonly described by simple models, model validations are scarce, associated uncertainties are hardly known and thus not communicated. Resistance factors, such as the level of precautionary measures, are rarely taken into account by current cost assessment methods, hampering the evaluation and development of effective risk mitigation strategies. A more balanced viewpoint between hazard and damage assessments seems warranted, because the availability of reliable damage assessment methods is a prerequisite for the assessment of flood susceptibility and risk and consequently for the optimization of flood mitigation and control measures.

Still, the advances in flood damage assessment could trigger subsequent methodological improvements in other natural hazard areas with comparable time-space properties such as coastal storms or certain Alpine hazards. It has been demonstrated in recent years that multiparamter flood damage models outperform models based on single parameter damage functions. Besides, these models enable the consideration of precautionary measures as an important damage influencing variable. Also in the context of Alpine hazards and especially avalanches, multiparameter models have been developed. Given these promising results, it should be striven to integrate more hazards specific impact and resistance parameters in damage modelling, also with regard to other hazard types. Examples, for which model improvements can be expected from distinct multiparameter models are e.g. coastal hazards, Alpine floods but also droughts. Even though studies e.g. showed that drought-induced soil subsidence can cause large amount of damages to buildings and infrastructure, no models exist that take drought resistance parameters into account. Since existing studies suggest that building characteristics have a significant influence on damages due to drought induced soil subsidence, future models should explore ways to evaluate respective drought mitigation measures.

Table 8 also shows that synthetic damage functions based on ‘what if analysis’, which are carried out by engineers or experts from the insurance industry, have been primarily developed for flood damage assessments. As the empirical basis of object specific damage data, which are needed for the development of empirical damage models, remains scarce, the application of synthetic damage functions or combined empirical-synthetic approaches could be a promising option also for other hazard types. As far as Alpine hazards are concerned, Table 8 shows that mainly empirical damage functions and multiparameter models are applied. This is somewhat surprising, because object specific damage data are scarce for many local-scale Alpine hazards, such as landslides or avalanches. Given the thin empirical data basis, the development of empirical-synthetic susceptibility functions and multiparameters damage models could possibly lead to advances in these fields. The development of empirical-synthetic damage functions could also significantly improve the assessment of coastal floods. Even though it has been demonstrated that coastal floods lead to different damaging patterns, standard depth-damage functions are commonly applied in Europe. Given the lack of object specific damage data of coastal flooding, the development of synthetic or empirical-synthetic damage functions, which account for the distinct damaging processes of storm surges, could help to close this gap.

Drought damage assessments differ significantly from the other three risk types and are mainly assessed ex-post using cost figures reported by media or self-reports from interest groups and governmental authorities, or by comparisons between drought and non-drought periods. This difference in the methodological approach can partly be explained by the different nature of the phenomenon ‘drought’. In contrast to the other hazard types, ex ante drought damage models are still lacking. This lack of ex-ante models should be overcome to enable drought risk assessments and the evaluation of drought damage mitigation strategies. Data base exist (and should be continuously expanded) that, in principal, could be used to develop multi-parameter models that integrate additional hazard and resistance parameters, when modelling drought related subsidence damage (Crilly, 2003).

Moreover, Table 8 shows that most of the available damage models focus on certain sectors. Comprehensive damage models that provide a complete picture of damages from natural hazards are rare. To arrive at more comprehensive damage assessments, the way forward should be to integrate several sector and hazard specific damage models under a common modelling framework, such as the HAZUS model family of FEMA in the US. While such a common framework would provide more complete and comparable results, it would still be possible to give consideration to different susceptibility characteristics of various sectors, as well as to different damaging processes of various hazards.

Table 9: Cross hazard comparison – Losses due to the disruption of production processes

	Scope	Spatial scale	Time scale	Data availability (AV)	Data quality (QU)	Effort required	Expected precision	Scientific or practice approach	Skills required	Ability to deal with the dynamics of risk	Implemented ex-ante or ex-post	Application				Example
												Floods	Droughts	Coastal	Alpine	
Assessment of losses to economic flows																
Based on: Damage data	Sectoral	Local / region-al	Short term	Low	Low / Moderate	Moderate	Low / Moderate	Scientific / Practical	Statistics / Modelling	High	Ex post / Ex ante	o	-	o	-	Parker et al. (1987)
Based on: Statistical data	Sectoral	Local / region-al	Short term	Moderate / High	Moderate / High	Moderate	Moderate	Scientific / Practical	Desk re-search	High	Ex post / Ex ante	o	-	o	-	FEMA (2011)
Percentage of direct damages																
Empirical	Sectoral	Re-gional	Short Term	Moderate	Low / Moderate	Low	Low / Moderate	Practical	Desk re-search	High	Ex ante / Ex post	o	-	-	-	NRE (2000)
Synthetic	Sectoral	Re-gional	Short Term	Moderate	Low / Moderate	Low	Low / Moderate	Practical	Desk re-search	High	Ex ante / Ex post	o	-	-	-	NR&M. (2007)
Comparison hazard / non-hazard																
	Sectoral	Local / Re-gional	Short term / Mid term	Moderate / High	Low / Moderate	Low / Moderate	Low / Moderate	Low / Moderate	Desk re-search	Moder-ate	Ex post	-	o	-	o	SLF (2000)
Reported cost figures																

	Sectoral / Compre-hensive	Local to Global	Short term / Long Term	Moderate	Low / Moderate	Low	Low / Moderate	Practical	Desk re-search	n.a.	Ex post	-	+	-	-	Martin-Ortega et al. (2009)

Table 9 shows that also in terms of production losses, floods received most attention in the literature compared with other studies. Comparatively many studies are available for production losses due to floods, ranging from simple approaches, which use a fixed share of direct damages, to sophisticated assessments of losses to economic flows, which are e.g. based on losses of sector specific added value, wage losses or relocation expenses. While the former can be useful for a rapid appraisal of production losses, we consider the latter as more appropriate to arrive at sound cost estimates. Overall, it can be concluded that also production losses are mostly assessed using simple models that are commonly not validated. In addition, the uncertainties associated with these models are hardly known and thus not communicated.

Detailed assessment approaches of production losses are so far mostly lacking for other natural hazard types. Especially for other large-scale events like e.g. droughts, deploying such approaches could provide more accurate cost figures. This should be useful, because the ex-post approaches that are currently applied for production losses due to droughts, such as comparisons between drought and non-drought years, do not allow to distinguish between direct damage, production losses, or indirect damages. Such a distinction could be useful, though, when developing drought mitigation and adaptation policies. It would e.g. provide hints, whether damages occur mostly at the farmer's level (direct) or through multiplier effects through the economy (indirect damages). Moreover, the ex-post models are unable to deal with the dynamics of risk. Therefore, more advanced and ex-ante models are needed to investigate the development of future drought damages and to evaluate different drought mitigation strategies.

4 Knowledge gaps and recommendations

In section 4.1, we will discuss knowledge gaps and subsequently recommendations that apply to all hazard types addressed in the present report, namely floods, droughts, coastal hazards and alpine hazards. In section 4.2, we will additionally discuss aspects specifically per hazard type. The knowledge gaps and recommendations have been identified based on the literature review provided in the previous chapters as well as on feedback collected from stakeholders during a series of workshops. These workshops were held as part of the Conhaz project to collect additional information from stakeholders that develop, apply or use cost assessment methods.

4.1 Overarching knowledge gaps and recommendations

4.1.1 Terminology and comparability of direct cost assessments

Aim of the present report was to collect, systemize and to analyze existing cost assessment methods. We found that no common terminology is currently used for different damage categories (e.g. direct vs. indirect) across the various hazards. Moreover, numerous different approaches exist for the assessment of direct costs for the four different hazard types under investigation. In addition, we found that also the state of development of direct cost assessment methods differs widely across the different hazard types. Flood damage modelling has received greater attention in comparison with damage assessments of droughts or coastal storm surges. Generally, it can be stated that current terminology and methods to assess direct damages from natural hazards are characterized by a considerable heterogeneity. This significantly hampers the comparability of cost estimations.

Given the observed methodological and terminological differences between the approaches, we conclude that a robust comparison of the direct costs of different natural hazards is challenging on the basis of the existing approaches. A valid comparison between the different hazards in terms of their direct costs seems only possible if these costs are assessed in a common framework.

<u>Recommendation:</u> *A consistent terminology should be adopted, which can be uniformly used to collect, analyze, model and compare costs of various natural hazards in the European Union. We believe that the current terminology adopted for the CONHAZ project, which is outlined in the introduction of the present report, could provide a good framework for the classification of cost categories.*

4.1.2 Data availability and quality

The lack of reliable, consistent and publicly available damage data is being identified as a major obstacle to understand the damaging processes and thus to develop, improve and validate methods for direct cost assessment across all hazard types. While natural hazards are often analysed in the aftermath in terms of the hazard characteristics, detailed evaluations with respect to associated damages and damaging processes are rather scarce. There are a number of event databases, which contain aggregated damage figures. However, there is a particular lack of detailed, object specific damage data which are necessary for process understanding, and to develop, to validate and to improve damage models. In addition, most of the available damage data are heterogeneous, collected by different organizations and standards, are of low quality and are often not validated. Exposure data, such as economic assets at risk, are mostly only available at an aggregated level. This often leads to a spatial mismatch between hazard and exposure data.

Recommendation: *Greater attention should be paid to damage data collection and availability. Much larger efforts are required in terms of empirical and synthetic object-specific damage data collection to provide homogenous and reliable data on damages and damage influencing factors to scientist and practitioners. In addition to existing event data bases, more object-specific data including a broad range of potentially damage influencing parameters need to be collected in order to improve existing and to develop new cost assessment methods through more knowledge of damaging processes. In order to improve the homogeneity of damage data, a minimum standard of object specific damage data collection should be established that applies to European data bases.*

4.1.3 Uncertainty and validation of direct cost assessments

The predominant approach to estimate the direct costs of natural hazard is the use of susceptibility functions. The majority of these cost assessment methods describe complex damaging processes with rather simple functions, which are often based on a single hazard parameter, such as depth-damage functions in the case of floods. Many damage influencing hazard but also resistance parameters, such as mitigation measures, are hardly reflected by current models. Amongst others, this results in the considerable uncertainties commonly observed in cost assessments. With respect to flood damage assessment, it has been shown that the development of multi-factor models, which take multiple hazard and resistance factors into account, can improve the validity of cost estimations.

Recommendation: *More efforts should be made to develop multi-factor damage models that better capture the variety of damage influencing factors. Special attention should be paid to integrate resistance parameters, because information on their effectiveness provides key insights for risk management, as it allows evaluating and compare various structural and non-structural risk mitigation strategies.*

Currently, existing damage models are hardly validated. However, such validations are needed, because they allow to determine the accuracy of cost assessments. While such analyses have been partly carried out with respect to flood damage modelling, similar exercises for droughts, coastal flooding or Alpine hazards are lacking. In addition, many damage models are currently transferred in space and time, e.g. from region to region or from one flood event to the other. However, it is still an open question, to what extent and under which conditions this is possible, at all. Model validations in different regions and at different time steps could provide insights into this aspect.

Recommendation: V*alidating the result of existing damage assessment methods should be intensified and more uncertainty analysis have to be undertaken before we arrive at a set of sound and useful models within Europe. Additionally, model-intercomparisons are a helpful strategie for evaluating the results of different methods.*

4.1.4 Completeness of direct cost assessments

Many of the existing approaches to assess direct damage from natural disasters are sector specific. The main focus of existing methods has been especially on residential areas, what can be explained by the large contribution of this economic sector to overall losses. Besides, data from other important sectors such as infrastructure or businesses are even scarcer and even more inhomogeneous than data from the residential sector. The fact that many models are still sector specific also means that they can only provide an incomplete picture of potential direct damages from natural hazards. The need to arrive at comprehensive damage models is emphasized by recorded damage data, which show that all economic sectors contribute significantly to overall losses. This is especially the case for industry and commerce as well as for infrastructural elements. However, only relatively few damage models exist that examine damage of these sectors.

Recommendation: *New or existing cost assessment methods could strive to reflect a greater spectrum of the direct losses caused by natural hazards by considering a broader range of economic sectors that are affected by natural hazards. Particularly, more data and studies for industry, commerce and infrastructure are needed. Since damaging processes differ by sector and hazard, developing single integrated assessment models seems challenging. The way forward should be to integrate several sector and hazard specific damage models under a common modelling framework, such as the HAZUS model family of FEMA in the US. While such a common framework would provide more complete and comparable results, it would still be possible to give consideration to the aforementioned differences.*

Losses due to the disruption of production processes received relatively little attention, even though they can also significantly contribute to overall damages, especially for large-scale events. Currently, mainly three approaches are applied to derive damage figures on this cost type, detailed analyses of economic processes, comparisons of production output between hazard and non-hazard years, or simple approaches that derive production losses using a fixed share of direct damage estimates.

Recommendation: Especially for large-scale natural hazards, more attention should be paid to the assessment of losses caused by the disruption of production processes. While comparisons between hazard and non-hazard years and approaches that use a fixed share of direct damages might be sufficient for a rapid appraisal of production losses, they involve considerable uncertainty. Changes in production output between hazard and non-hazard years can be influenced by third factors, independent from the respective disaster. The relation between direct damages and production losses can vary substantially and there is hardly any empirical data that would allow to draw conclusions how high the respective share should be. Therefore, it is recommended to base cost estimates of production losses on more detailed assessments of losses to economic flows within the hazard zone.

Currently, there are hardly any integrated damage-assessment methods that are able to take the effect of coupled and coinciding natural hazards into account. This seems to be especially important in the case of Alpine hazards (see background paper WP8 on Alpine Hazards), because various Alpine hazards are driven by the same natural processes and thus potentially coincide.

Recommendation: *Work towards the development of integrated damage-assessment methods that strive to reflect the interplay of possible coinciding natural hazards.*

4.2 Hazard specific knowledge gaps and recommendations

4.2.1 Floods

The methods used for the quantification of the asset values exposed to floods vary considerably in terms of detail, the stratification in economic classes and the spatial disaggregation of asset values. Compared to the resolution and level of detail of flood hazard modelling, even the most detailed asset assessments can be regarded as coarse, often leading to a spatial mismatch between flood hazard and exposure data.

Recommendation: *In order to overcome this mismatch, classification and disaggregation of asset values need to receive greater attention. Studies are necessary, which investigate the variability among elements at risk, from which recommendations can be drawn on the adequate approach and detail of classification. Field surveys may be used to assess the variety of exposed objects, e.g. building types and company characteristics.*

Given the current shift to integrated flood risk management in Europe, it would be especially important to further investigate the potential of flood mitigation measures. While it is increasingly acknowledged that technical flood protection needs to be accompanied by protection measures on the level of individual buildings and businesses, the damage-reducing effect of such measures is still largely unknown. Insights into these aspects are important, because they allow to evaluate and to choose between various risk mitigation strategies. This seems to be especially important against the background of the projected increase in flood risk in many places due to climate change and increased vulnerability.

Recommendation: *More sophisticated methods, e.g. multivariate analyses and exercises in data-mining, should be applied for identifying patterns in damage data and for correctly attributing damage-influencing factors to observed damage. The main emphasis should be put on examining the damage-reducing effects of flood mitigation measures for different flood types.*

A number of studies in recent years examined the development of future flood damages. These studies usually use climate as well as socio-economic scenarios to examine the range of possible developments. As far as the socio-economic scenarios are concerned, these are predominantly restricted to changes in land-use change, GDP and population. However, in order to provide more realistic assessments of flood risk over time, information on additional socio-economic variables would be important, such as changes in the number of dwellings, changes in building price indices or changes in the number of households and household size.

Recommendation: *Socio-economic scenarios that are developed in the future should be expanded and should include additional socio-economic variables that are needed to arrive at more realistic assessments of changes in the development of future flood damage.*

4.2.2 Droughts

The compilation of methods that assess the direct cost of droughts revealed that most of the available studies are ex-post analyses that are based on self- and media reports. Since these are prone to biases, current drought damage estimations show a large uncertainty. At the same time, hardly any methods are available for the ex-ante analysis of drought damages. However, the few studies that is available show that droughts can cause substantial damages not only to agricultural production but also to infrastructure and buildings, navigation, or power production. Even though drought-induced soil subsidence causes substantial structural damage to buildings and infrastructure, this aspect has been hardly addressed by the current literature. Most of the studies examining drought damages focus on the agricultural sector, so far.

<u>Recommendation:</u> Given the projected increase in frequency and intensity of droughts, e.g. in the Mediterranean basin, the development of such ex-ante evaluation approaches is therefore important. The development of ex-ante models is also needed to examine the development of drought damages over time and to evaluate various drought damage mitigation strategies. Given the large damage associated with drought-induced soil subsidence, future research should especially focus on structural drought damages assessments.

Other studies assess drought damages by comparing production output during drought years with production output during non-drought years. Also this approach implies considerable uncertainties, because a decline in production can have other reasons that are external to drought events. In addition, following this approach, no differentiation can be made between direct and indirect damages. It cannot be established whether production output is reduced during a drought year due to direct damages to crops and life stock or due to indirect effects spreading through the economy. Such a distinction might be useful, though, with respect to the prioritization of mitigation and adaptation strategies. In addition, the methods currently applied are unable to take the dynamics of drought damages over time into account.

<u>Recommendation:</u> More sophisticated drought damage models that are based on assessments of losses to economic flows should be developed. These could significantly improve current cost assessments.

So far, there are no drought damage models, according to our knowledge, that take drought mitigation measures into account. As a result, the damage reducing effect of drought mitigation measures is largely unknown. This significantly hampers the evaluation and choice among different adaptation strategies. This is e.g. the case in terms of drought damages to buildings due to drought-related soil subsidence. Against the background that existing studies suggest that damage amounts caused by this phenomenon are comparable with other large scale natural disasters, such as floods, this should be further investigated.

<u>Recommendation:</u> Future model development should strive to capture the effect of drought mitigation measures. Existing data bases on drought-induced soil subsidence to different types of building could provide a basis for this future work.

4.2.3 Coastal Hazards

A major drawback of current methods to assess directs costs of coastal hazards are the lack of specific damage functions. Across Europe, damage functions that were derived and constructed for the assessment of riverine flooding are commonly applied to assess potential damages from coastal flooding. This is problematic, given the different damaging processes that can be observed for riverine and coastal flooding. It can be expected that flood forces and thus resulting damages are considerably higher for coastal flooding, as it has been demonstrated by studies from the US.

These findings exemplify the need to derive and develop separate damage functions and assessment methods for storm surges also in the European context, given the different damage causing process of riverine and coastal flooding and the expected rise in sea-levels.

<u>Recommendation:</u> *Given the expected effects of global warming on sea-levels and the associated increase in the risk of coastal flooding, specific damage functions should be derived and applied for the assessment of coastal flooding. Alternatively, future research could address the question to what extent damage functions for riverine flooding can be transferred to coastal areas in order to derive adjustment factors. In line with the recommendation provided by FEMA for the US, standard depth damage functions should not be applied if high flow velocities and wave forces can be expected (Nadal et al., 2010).*

4.2.4 Alpine Hazards

Especially in the context of Alpine hazards, there is a risk of cascading and coinciding natural hazards that can show very different damaging processes. However, no methods are currently available that take this into account.

Often, standard depth damage functions are applied also for flood events in Alpine areas. This is problematic, because floods in mountainous regions can show very different hazard characteristics, e.g. in terms of flow velocities. Following from this, different and more severe damaging processes can be expected that are not captured by applying standard depth-damage functions.

<u>Recommendation:</u> *Especially in the context of Alpine hazards, it seems important to work towards integrative damage assessments methods that are able to capture potentially coinciding events. In line with the recommendation provided by FEMA for the US, standard depth damage functions should not be applied if high flow velocities, ice or debris induced damage or erosion can be expected (Nadal et al., 2010).*

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