Ref. Ares(2018)2848373 - 31/05/2018

"NAture Insurance value: Assessment and Demonstration"

NAIAD

SC5-09-2. 16 Operationalising insurance value of ecosystems

Grant Agreement nº 730497

Deliverable 4.3

Economic water-related risk damage estimation

Due date of deliverable: 31/05/2018

Actual date of submission: 31/05/2018

Start date of project: 01-12-2016 Duration: 36 months

Should you wish to use or refer to it, please cite as follows:

Calatrava, J., Graveline, N., Moncoulon, D., Marchal, R. (2018): "*DELIVERABLE 4.3: Economic water-related risk damage estimation"*. EU Horizon 2020 NAIAD Project, Grant Agreement N°*730497*

Dissemination Level		
PU	Public	PU
CO	Confidential	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730497.

The opinions expressed in this document reflect only the author's view and in no way reflect the European Commission's opinions. The European Commission is not responsible for any use that may be made of the information it contains.

1. Edition information

Versions

VERSION	EDITION DATE	MODIFICATION	WRITTEN BY	CONTROLLED BY
1	20-03-2018	FIRST EDITION	J. CALATRAVA	
2	13-04-2018	SECOND EDITION	J. CALATRAVA N. GRAVELINE	
3	21-05-2018	FIRST COMPLETE DRAFT	J. CALATRAVA N. GRAVELINE D. MONCOULON R. MARCHAL	ALI DOUAI AMANDINE GNONLONFIN
4		FINAL	J. CALATRAVA N. GRAVELINE D. MONCOULON R. MARCHAL	ZDRAVKO KOZINC

2. Summary

1. Edition information 2
2. Summary 2
3. Introduction 3
4. Definition and types of damage costs 4
5. Approaches to assessing damage costs 7
6. Assessment of direct damage costs in flood events 8
6.1. Steps in the assessment of flood direct damage costs 8
6.2. Exposure asset assessment 9
6.3. Vulnerability assessment using damage functions 10
6.4. Transferability of flood damage functions 14
6.5. Damage cost calculation 15
6.6. Obtaining flood damage-probability curves 15
6.7. Flood damage cost assessment using insurance claim data 16
6.8. Sources of uncertainty in damage assessment 18
6.9. Spatial scale of the damage assessment 18
6.10. Existing frameworks/models for the assessment of flood direct damage costs 19
6.11. Vulnerability indicators approach 21

6.12. Assessment of direct business economic losses from flood hazards 22
7. Assessment of direct damage costs in drought events 23
8. Assessment of indirect damage costs 24
9. Assessment of intangible damage costs 26
10. NAIAD DEMOs proposed methodology 26
11. Concluding remarks 28
12. References 28
Annex 1 – Survey for companies 34

3. Introduction

The NAIAD project focuses on the contribution of ecosystems to society's resilience concerning water risks, paying particular attention to extreme-water-related disasters. It focuses on the insurance value of ecosystems, specifically on the benefits regarding water-related disaster mitigation. Against traditional grey infrastructures, NAIAD assesses Nature Based Solutions (NBS) as alternatives and/or complements for managing water-related risks. NBS are expected to reduce risks and damages losses from water-related natural hazards, while also providing additional co-benefits (economic, environmental, social).

More specifically, NAIAD focuses on flood and drought hazards, which are very different events in terms of their duration and spatial extent of both the hazard and of the associated damages (OECD, 2013). Although they are basically related, respectively, to the excess or deficit or rainfall compared to "normal" or "reference values", floods result from sudden events while droughts are cumulative events over much longer periods of time and that normally affect larger areas. Both floods and droughts may result in severe economic impacts both in rural and urban areas as a consequence of the loss of households and productive assets, loss of production, depreciation of the market value of physical assets (land, buildings, etc.), water restrictions, etc., and disruption to business. NBS can help to reduce such impacts. In France, since the creation of the Nat Cat scheme in 1982, flood and droughts represent more than 90% of the total insured damages due to Natural Disasters (excepting windstorms) – source CCR.

Within NAIAD, Work Package 4 (WP4) provides methods to assess the economic implications of NBS. In the different demonstration case studies (DEMOs), NBS will be assessed to check if they further reduce risks when compared with the current Scenarios (Business as Usual) or with

existing grey risk-reduction infrastructures. From the economic point of view, NAIAD aims to assess all the existing benefits that NBS can provide to society.

The present document is the third deliverable of WP4 (Economic approaches to the insurance value of ecosystems). It aims to provide DEMOs with a methodology for the assessment of the insurance value of both NBS, hybrid and grey infrastructures. The insurance value is defined as the damages costs avoided through the implementation of a given risk reduction strategy (NBS or grey infrastructure). The objective of NAIAD is to assess whether there are different insurance values (i.e. damage costs avoided) of NBS compared to grey infrastructure risk management strategies.

4. Definition and types of damage costs

Natural disasters impose large costs to societies. There is an ample literature on the assessment of the economic value of the damages caused by natural disasters, specifically concerning floods. Following Brémond et al. (2013), we can define "damage" as a negative impact of a natural hazard/disaster on a socioeconomic system and "cost" as the monetary valuation of the damage. The term "loss" would designate damages that result in the destruction or depreciation of some element of the socioeconomic system.

A first step in the assessment of the damage costs of a natural hazard is to clearly define the baseline scenario and the purpose of the assessment, e.g. for the calculation of insurance premiums, for the design of prevention and risk mitigation measures, for the assessment of compensations after the hazard, etc. (Hallegate and Przyluski, 2010). The purpose of the assessment will determine the type of damages to be measured.

The damages from natural hazards, and their costs, can be classified in tangible and intangible (Merz et al. 2010; Meyer et al., 2012). Tangible costs are those resulting from impacts from the hazard that can be easily quantified in monetary terms, while intangible costs are those that are difficult or even impossible to measure, as they comprise non-market values (Merz et al. 2010; Brémond et al., 2013; Balbi et al., 2013). The sum of all tangible and intangible costs resulting from a natural disaster is the total cost of the natural hazard for a socioeconomic system (social cost of the hazard), a concept which is symmetrical to that of total economic value, used in environmental economics to estimate the benefits provided by natural resources (Balbi et al., 2013).

At the same time, damages can also be classified in direct and indirect based on their spatial or temporal extent. Direct costs would be those resulting from damages produced in the geographical area directly affected by the natural hazard, while indirect costs would correspond to damages that take place outside the area affected by the hazard (Merz et al. 2010). However,

the distinction between direct and indirect costs is also used to represent the time scale of the damages (Merz et al. 2010; Brémond et al., 2013): direct damages would take place during the hazard event (damages to human life, infrastructures, capital or production), while indirect damages would occur later in time (production losses due to business interruptions caused by electrical shutdowns, people that cannot go to work, lost or deteriorated production capital such as trees or machines, etc.). That is, indirect damages would be induced by direct damages and would occur, either in time and/or space, outside the hazard event (Merz et al. 2010). In other words, indirect losses would be those "*spanning on a longer period of time, a larger spatial scale or in a different sector than the disaster itself*" (Hallegate and Przyluski, 2010). Both space and time dimensions are therefore of special relevance when defining the damage costs to be measured.

In sum, we can distinguish between direct tangible, direct intangible, indirect tangible and indirect intangible costs. However, such classification comes mostly from the flood damage assessment literature, but could be used for other hazards, such as droughts. Table 1 presents a typology of flood damages based on Jonkman at al. (2008) and Mao et al. (2016) and sector oriented for a practical assessment of respective damages of (i) individuals, (ii) businesses, (iii) infrastructure, and (iv) farming. A more exhaustive listing of flood damage costs in the agricultural sector can be found in Brémond et al. (2013). Regarding drought, discussion of different impacts can be found in Kallis (2008), Wilhite (1993), Wilhite (2000) and Logar and van den Bergh (2012). Table 2 shows some examples of drought impacts taken from Wilhite (1993).

A comment must be made at this point regarding the loss of production resulting from the interruption of businesses activities that some authors consider separately from direct costs. Rose (2004) distinguishes between direct effects (the physical destruction or deterioration of assets), the resulting loss of production due to business interruption, and "higher-order effects" (those impacts beyond the previous ones and induced by them). Meyer et al. (2012) also separates business interruption costs from direct costs because the methods used to estimate both are different. However, Hallegate and Przyluski (2010) consider that business interruption losses should be included in the direct costs to avoid consistency problems when dealing with drought hazards, which span over a long period of time, and that will be the criteria considered here. Another cost that is usually considered in direct costs assessment relates to evacuation and emergency services. However, we will assume that these costs are not related to the event intensity, and will not consider them in our assessment.

The relevance of each type of damage is case-specific. For instance, the non-market effects of hazards depend on the level of impact on the environment, on the cultural or historical heritage, on public health and on human life. Indirect effects are directly related to the duration of the

reconstruction pace after the hazard, but also to the spatial extent of the assessment (Hallegate and Przyluski, 2010; Molinari et al., 2014).

Table 1. Types of flood damages and examples, adapted from Jonkman at *al.* (2008) and Mao et *al.* (2016)

	Tangible	Intangible
Direct	INDIVIDUALS: housing, vehicles BUSINESSES: Capital assets (buildings, machinery, vehicles), inventory stocks, business interruption inside the area affected by the flood hazard. AGRICULTURE: Crops, capital assets (farmland, machinery, buildings, cattle, plantations). INFRASTRUCTURES: Transportation (roads, railways, harbours and airports) and utilities (power, communication, water supply, sewage). PUBLIC BUILDINGS: hospitals, education and administrative buildings. OTHER: Evacuation and rescue operations, reconstruction of flood defences, clean up.	- Loss of life, fatalities. - Health impacts: Injuries, inconvenience and moral damages. - Inconveniences caused by the interruption of utilities and communications. - Historical and cultural losses. - Damages to environmental assets.
Indirect in time	INDIVIDUALS: temporary housing of evacuees, loss of house value, loss of income due to lost capital. BUSINESSES: cost of relocation (temporary or permanent), loss of property value, loss of income due to lost capital assets; loss of markets. AGRICULTURE: loss of property values, reduced productivity, loss of markets. PUBLIC BUILDINGS: temporary or permanent relocation.	- Long-term impacts on ecosystems - Interruption of service in public buildings
Indirect in space	BUSINESSES: loss in production by suppliers and consumers of businesses directly affected by the flood.	
Indirect both in time and space	BUSINESSES/AGRICULTURE: loss of markets. MACROECONOMIC; Adjustments in production and consumption patterns outside the flooded area, reduced tax proceeds, etc.	- Societal disruption - Psychological traumas - Undermined trust in public authorities

Both space and time dimensions are of special relevance when defining the impacts to be considered, and thus the damage costs to be measured. Moreover, the time will differ significantly depending on the hazard in question. For instance, the time scale of a drought is not comparable to that of a flash flood or an earthquake. The spatial and time extent of the

assessment will have a direct impact on the magnitude of indirect impacts and must thus be clearly defined. Merz et al. (2010) recommends choosing the time and spatial boundaries of the assessment in accordance with those of the public policy project to be evaluated, and indicating potential impacts beyond such boundaries, at least qualitatively. The issue of the spatial and time extent to be considered in each DEMO case study is discussed in sections 7.1 and 7.2 of NAIAD Deliverable 4.1 (Graveline et al., 2017), respectively.

Table 2. Type of drought damages (adapted from Wilhite, 1993)

Economic	Social	Environmental
Reduced crop production. Reduced dairy and livestock production. Reduced timber production. Loss of trees. Mortality of livestock. Increased prices of food and timber. Increased cost of feeding livestock. Increased cost of providing water resources. Increased cost of energy production. Increased cost of transportation from impaired navigability. Losses in recreation sector. Restrictions of credit to agricultural and forestry businesses. Lost jobs. Decreased tax revenue.	Food shortages. Health problems. Fatalities. Conflicts among water users. Increased poverty. Reduced quality of life. Social unrest. Rural to urban migration.	Increased fire risk. Reduced water levels. Increased soil erosion. Landscape degradation. Reduced water and air quality. Damages to wildlife and fish habitats. Wildlife mortality.

5. Approaches to assessing damage costs

There are two different perspectives and aims that justify the assessment of damage costs: (i) the assessment of a significant observed past hazard event (e.g. the 2014 flood in Montpellier, France), (ii) the estimation of damages in different scenarios to illustrate the avoided costs or extra costs of a scenario compared to a reference or baseline scenario. The NAIAD perspective adopts the second objective in order to assess the avoided damages of NBS scenarios. The first aim (assessment of real past events) is, for instance, realized by governments and local communities to explore the total damages of an event and produce return on experience (REX) dedicated to improve risk reduction policies, or realized by insurance market in order to be able

to mobilise the necessary Insurance expert force, for their asset/liability management and ensure the financial feasibility of the compensation payments. The second aim is generally used for exposure assessments to non-necessarily occurred events.

The assessment of damages from hazards can be performed in different spatial scales Merz et al. 2010): micro-scale (based on single elements at risk, such as buildings, infrastructures, etc.), meso-scale (considering spatial aggregation units, such as residential areas, industrial areas, administrative units, etc.), and macro-scale (based on large spatial units such as municipalities, regions, etc.). The choice of method will mostly depend on the availability and quality of data and on the objective of the assessment. In NAIAD, we will work with individual elements at risk from the project's GIS database, which can be latter spatially aggregated to provide a meso-scale assessment of the relative impact of NBS.

The next section will focus on the assessment of direct damage cots from flood events, while the following section will comment on the specificities for the case of drought events. Later, we will discuss on the assessment of indirect costs.

6. Assessment of direct damage costs in flood events

6.1. Steps in the assessment of flood direct damage costs

A common feature of most studies assessing the direct damages of floods is the use of damage models/functions. The assessment of direct damages using damage modelling and estimation aims to establish the costs of a hazard based on its magnitude (event intensity) and the vulnerability/sensitivity of the elements at risk (Naulin et al., 2016). Merz et al. (2010) provide a comprehensive description of the use of damage models to assess the direct costs of flood events. This includes the following steps (Merz et al., 2010; Faudi et al., 2015) that are depicted in Figure 1:

1. The characterisation of the flood hazard event (flood maps);
2. The assessment of the exposure of the elements at risk;
3. The susceptibility/vulnerability analysis to define the damage functions/models.
4. Calculation of the value of the damage cost.

The characterisation of the flood hazard event can be done either using maps of past flood events, flood risk maps or simulations of floods from hydrological models (hazard models). In

NAIAD, these will be developed for each DEMO in Task 6.2 (Processes representation / Risk modelling).

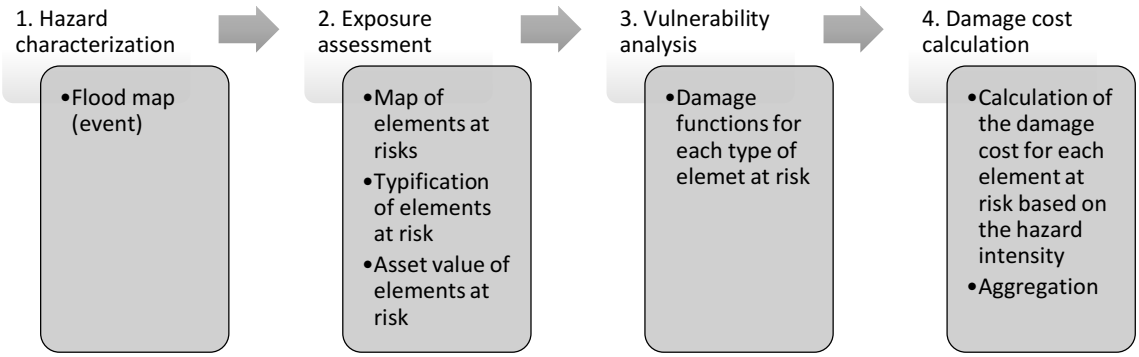


Figure 1. Steps in flood damage modelling

6.2. Exposure asset assessment

The exposure assessment first requires the definition and classification of the elements at risk, which are usually pooled into homogeneous classes of assets (residential, commercial, industrial, agricultural, infrastructures, etc.) for which the assessment is done (Moncoulon et al., 2014). The detail of the classification depends on the heterogeneity of buildings and income within the area of study. In NAIAD, based on Merz et al. (2010)[1] we recommend the following typology of elements at risk or refine it:

(i) Residential buildings
(ii) Commercial and industrial buildings
(iii) Agricultural land and buildings
(iv) Infrastructures and public building
(v) Networks (electricity, roads, gas, …)

However, **the choice of the classification of elements at risk to be used will depend on the damage functions available** in the assessment and/or the **sources of data** for the development of these functions.

[1] Their exact typology is: Private households, Industry and manufacturing, Services sector, Public sector, Lifelines and infrastructure, Agriculture and others (flood defence structures; emergency services, clean-up services). We do not account for the last category in the damage cost assessment.

In the case of NAIAD, we will investigate the inclusion of green infrastructures in the classes of assets. The economic viability of NBS as an alternative to mitigate hazard risks depends on the potential of NBS for both reducing damages and providing additional ecosystem services (including co-benefits), both of which mostly depend on the preservation in good condition of NBS/ecosystems. Consequently, natural capital should be considered as a relevant "element at risk", that can be damaged, thus reducing the provision of ecosystem services (intangible costs or reduced co-benefits) and requiring reconstruction (tangible costs).

The assessment the exposure of assets consists in: i) identifying those elements at risk that would be affected by a flood scenario, and ii) estimating the value of the exposed assets or value at risk (Merz et al., 2010). The identification of the elements at risk is done by combining the GIS layers of flood maps with the layers of elements at risk (Faudi et al., 2015). If relative damage functions are used and the value of the exposed assessed is needed, the estimation of the value of the exposed assets (value at risk) can be done using statistics on property values, income and population, construction costs, insured values, etc. When assessing the cost of elements at risk (cost base), either replacement or depreciated/repair costs are used (Gerl et al., 2016). However, the correct practice to avoid overestimation of costs is using depreciated values instead of replacement costs (Merz et al., 2010; Balbi et al., 2013). When absolute damage functions are used, there is no need to have the value of the exposed assets (Cammerer et al., 2013). But in this case, taking into account the global inflation is a complex issue, notably during the update of the calculated damage.

6.3. Vulnerability assessment using damage functions

Direct damage costs are directly related to the assets' susceptibility to the hazard intensity (Merz et al., 2010). The vulnerability/susceptibility analysis consists of establishing a relation between the hazard intensity and the damage caused to each element at risk. This implies using stage-damage functions for each element at risk (flood damage or flood loss models).

Damage functions, stage-damage functions or susceptibility functions represent the relationship between the characteristics of the hazard (or other properties in a multivariate correlation, like height, time) and the damage cost caused by the hazard to a specific type of asset (called element at risk). Meyer et al. (2012) review studies using stage damage functions to assess the direct costs of different types of hazards, including floods and droughts. Merz et al. (2010) review studies assessing direct damages for flood hazards, while Brémond et al. (2013) review those studies that focus specifically on the agricultural sector. In damage functions, hazards can be characterised by one or more parameters, such as water depth, duration of flood, speed and sediments/debris in the case of floods (Merz et al., 2010; Brémond et al., 2013).

Two types of functions are commonly used: relative stage damage functions and absolute stage damage functions (Merz et al., 2010; Balbi et al., 2013). Relative damage functions express the damage as a percentage of the asset value of the element at risk, while absolute functions already incorporate the asset value (Cammerer et al., 2013). The second option, consisting of using absolute damage functions, does not enable to adapt and refit a case specific damage function based on standard, reference damage functions.

There are several options relating the damage models to be used:

a) Developing ad-hoc damage functions.

b) Using previously estimated damage functions for the area of study.

c) Transferring damage functions developed for other areas or for larger spatial extents.

Damage functions/models for floods can be developed for each type of element at risk either empirically using empirical data on real damage losses from past events or hypothetically from "what-if analysis" (synthetic approach) using expert assessment or conceptual/abstract functions, or a combination of both (Merz et al., 2010; Cammerer et al., 2013; Pistrika et al., 2014). The empirical approach has the advantages of providing more objective and realistic assessments, allowing for the assessment of the impact of damage mitigation measures and better accounting for the variability of impacts, while the synthetic approach allows assessing damages for different levels of the hazard magnitude (e.g. different water depths) and provides functions that can more easily be transferred and use in other areas to provide estimates that can be more easily compared (Smith, 1994; Merz et al., 2010).

In any case, developing damage functions implies both defining the parameters that determine the damage and relating those parameters to the observed or hypothesized level of damage caused. Merz et al. (2010) distinguishes two types of parameters that determine the damage: i) the parameters that characterise the intensity flood event (such as water depth, flow velocity, level of sediments/debris, etc.), and ii) the parameters that characterise the vulnerability/resistance of the elements at risk (e.g. type, size, structure, materials of the building).

However, the majority of studies use depth-damage functions, which only consider water depth as the parameter defining the intensity of the flood hazard (Merz et al., 2010; Jongman et al., 2012; Cammerer et al., 2013; Meyer et al., 2013). As Cammerer et al. (2013) points out, this is acceptable for static floods in lowlands but not for dynamic floods in mountainous regions where the flow velocity and the debris/sediment load of water are major factors to be considered. CCR damage modelling takes into account the water level for riverine floods whereas it considers surface run-off intensity for urban floods and non-riverine floods

(Moncoulon et *al*. 2014). Similarly, the relevant parameters can be different for each type of element at risk. For example, while flood damages in buildings are strongly dependent on water depth, in agriculture they are mainly dependent on the date/season and duration of the flooding (Merz et al., 2010).

CCR has strong expertise on damage assessment and natural hazard modelling from macro to community scales. This knowledge is linked to the CCR role in the French national natural disaster compensation scheme: estimating losses of an event and analysing exposure on insurance companies' portfolios, on CCR (in case of reinsurance needs) and on the State (in case of last resort intervention needs). CCR risk modelling expertise is not a stand-alone work, CCR has several national scientific partners which provide their expertise for specific natural hazards:

- BRGM: expertise in storm surge and drought
- IRSTEA: expertise in flood modelling
- Meteo France: expertise in floods, drought and hurricane modelling

As remind, above damage functions are built for each hazard. The infographic below clarifies principle of damage assessment, for each hazard models, from data inputs to estimated losses. A natural catastrophe (re)insurance model is based on three units:

1. Hazard unit: for modelling the physical hazard;
2. Vulnerability unit: for geocoding insured assets and their insured value;
3. Damage unit: for linking hazard unit to vulnerability unit to calculate insured costs of each natural catastrophe.

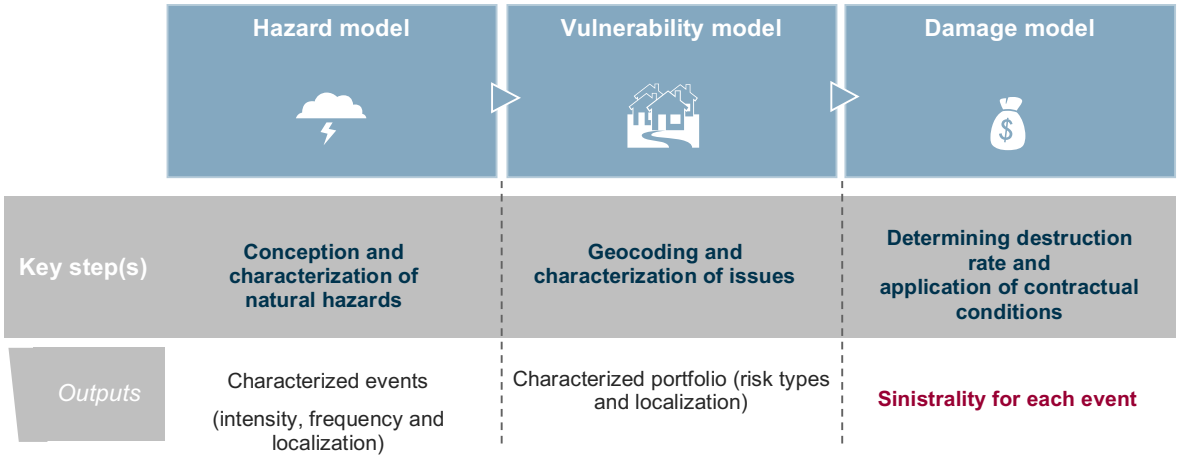
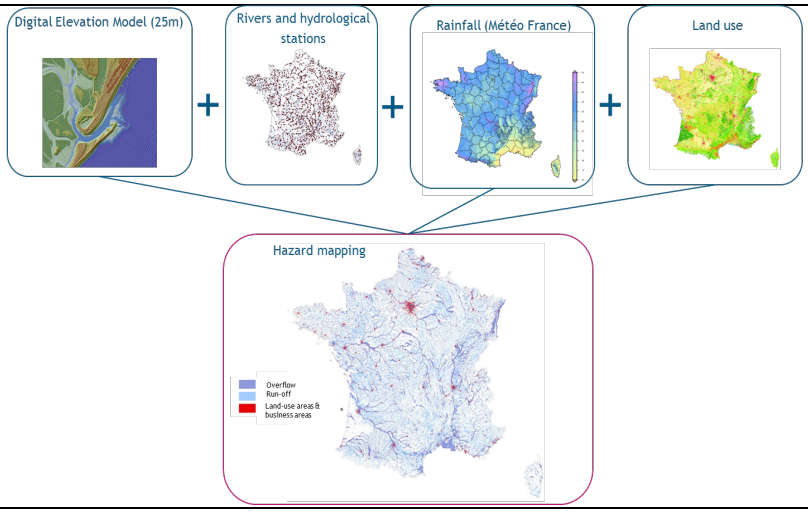
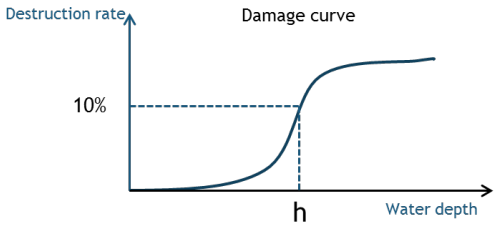


Figure 2. Units of a natural catastrophe (re)insurance model

<table>
<tr><td>Data inputs</td><td> 
</td></tr>
<tr><td>Flood model</td><td>ARTEMIS deterministic model linked to a probabilistic or stochastic model: it analyses portfolios' exposure (simulates consequences for a large number of events with a probability of occurrence) and combines: runoff model (water volume, surface velocity)
• overflow model (spread of water)</td></tr>
<tr><td>Vulnerability database</td><td>Based on insurance data, aims to describe location and characterisation of insured "risk" based on insurance policies. Vulnerability data includes: insured value, risk location, flood, building type, industrial activity</td></tr>
<tr><td>Outputs: Damage model</td><td>Combined outputs of hazard models and vulnerability data on the basis of statistic distribution (claims frequency and destruction rate)
Damage curves calibration is based on in-depth data on sinistrality and insured assets. Those data are collected from CCR's ceding companies for more than 15 years.
 

Example: For a h water depth, the asset will be damaged at 10% of its value.</td></tr>
<tr><td colspan="2">Estimated losses
At different scales (community, municipality, county, national) and for different insurance market portfolios</td></tr>
</table>

As commented, damage models/functions are calibrated and validated ex-post using data from real past events, expert knowledge and/or conceptual/synthetic functions (e.g. deterministic relationships between hazard and damage). Data from past events can be estimated using different sources, such as; insurance claims (generally extrapolated to complete missing data, an example can be found on the CCR website https://erisk.ccr.fr/faces/erisk-accueil.jsp); and post-event feedback (that can be found in REX), particularly for non-insured losses to have a global economic loss asset. Damage models need to be calibrated and validated on a well-known damage loss event set. Calibration and validation can be done on two distinct event sets: one for calibration and one for validation, both real past event sets with a known amount of damages.

Once a damage model has been validated ex-post, it can be used, within its calibration range and with different sources of input data, for ex-post or ex-ante assessments (Rose, 2004; Meyer et al., 2012). Ex-post assessment aim to estimate damages from real recently occurred events. Ex-ante data is generally used to simulate:

- Stochastic event sets to have an exhaustive knowledge of the exposure;
- Extreme hypothetical events that have never occurred (such as a centennial flood that is a reference for flood zoning in France) or occurred in the distant past before data recording.

A difficulty when assessing exposure to non-necessarily occurred extreme events is, in that case, to use a damage model outside its calibration area (for more extreme events generating specific damages): for example, in 2017, many commercial models have underestimated the losses due to Irma, Maria and Harvey hurricanes (category 5 on Saffir-Simpson scale) due to their calibration on lower category hurricanes.

6.4. Transferability of flood damage functions

Beyond the difficulties in developing damage functions, a major problem highlighted in the literature is the limited transferability of damage curves (Merz et al., 2010; Cammerer et al., 2013). In the case of NAIAD, not all partners have the expertise to develop their own ad-hoc damage functions. If there were not damage functions available for the specific area of study, the best alternative would be obtaining synthetic damage curves using expert assessment or conceptual functions. However, a more affordable alternative would be using synthetic damage functions developed for other areas or for larger spatial extents (Cammerer et al., 2013; Merz et al., 2010; Jongman et al., 2012; Gerl et al., 2016), for example at country level, as long as these are available for similar types of elements at risks.

6.5. Damage cost calculation

As commented, the relative damage functions provide the relative damage caused to each element at risk based on the magnitude of the specific hazard (represented by the hazard's intensity parameter/s). The total damage for each individual element at risk is obtained multiplying its asset value by the relative damage (not necessary if absolute damage functions are used). The total damage from a given flood hazard is obtained aggregating the individual damage across all elements at risk of all types. Some examples of empirical assessments of flood damage using damage functions can be found in Jongman et al. (2012), Cammerer et al. (2013), Rojas et al. (2013), Molinari et al. (2014), Carrera et al. (2015), Watson et al. (2016), Naulin et al., (2016), Molinari et al. (2017) and Scorzini and Frank (2017).

6.6. Obtaining flood damage-probability curves

Flood damage models allow assessing the damage caused by specific or hypothetical flood events that are characterised by one or more parameter, but they can also be used to assess the risk of flood or flood exposure. Flood risk assessment consists in combining the hazard characteristics and the damage evaluation with the probability of occurrence of the hazard event to obtain damage-probability curves or flood-risk curves (Rojas et al., 2013; Foudi et al., 2015). Damage-probability curves relate flood damages with their probability of occurrence. In addition to the parameters characterising the hazard intensity, the hazard event should be also characterised in probabilistic terms (Figure 3).

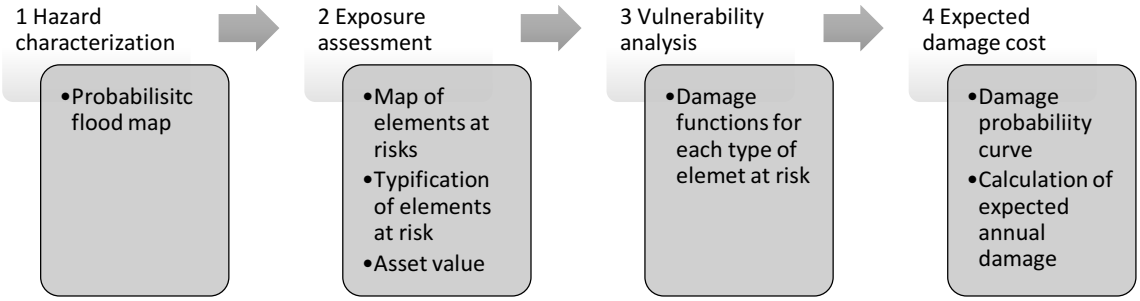


Figure 3. Steps in flood risk assessment

The flood risk curve of damage-probability curve will be obtained by linking the damages resulting from each potential flood event with its annual probability. The expected annual

damage would be calculated as the area below the damage-probability curve (Faudi et al., 2015). In the case of NAIAD, damage-probability curves will be the basis for the calculation of the insurance value of NBS (Figure 4). Examples of flood risk/exposure assessments at different spatial scales can be found in Lugeri et al. (2010), Feyen at al. (2012), Rojas et al. (2013), Jongman et al. (2014), Moncoulon et al. (2014), Foudi et al. (2015) and Naulin et al. (2016).

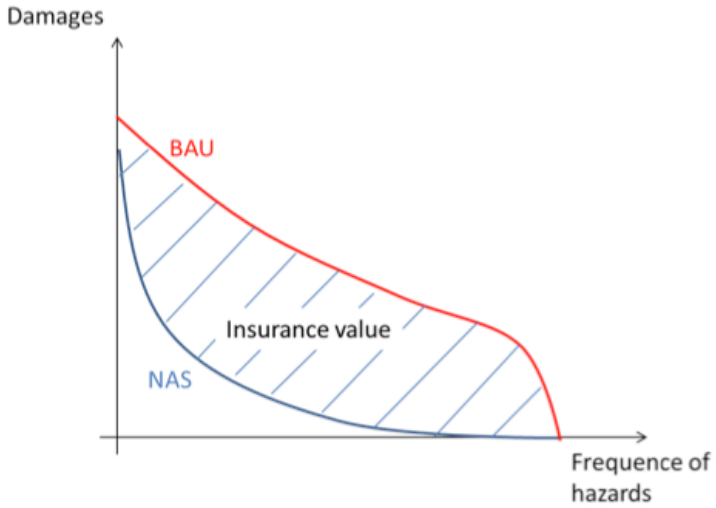


Figure 4. Obtaining insurance value of NAS from damage- probability curves

6.7. Flood damage cost assessment using insurance claim data

An alternative for developing damage functions is using insurance data (policies and claims). Some recent examples are the studies by Moncoulon et al. (2014), Naulin et al. (2016) and Watson et al. (2016). This method allows estimating the insured damages. Extrapolation can conduce to global economic damages based on the diffusion rate of insurance in the country and the specific risks covered / non-covered (see Lopez-Gunn et al., 2018, for more information on the European natural hazards insurance systems).

In most cases, the hazard characteristics used to develop damage functions are model outputs, due to the lack of real measurements of hazard intensity after a real event and to be able to simulate non-occurred events. For example, for floods, the level of water or run-off intensity for the elements at risk is simulated using a hydrological model. In this case, the hazard characteristics present the uncertainties of the hydrological models. The damage function developed on these input hazard values reflects the uncertainties of the hazard models. Thus, such a calibrated damage curve is strongly connected to the hazard model that was used for

calibration. **This specificity makes it difficult to use a given damage curve with a different hazard model (or a flood prone area for example). In such case,** at least, a comparison between the performances of different hazard models must be done.

To avoid the updating and transferability problems, the value of the elements at risk (insured risks) would be estimated based on its insured value and the damage curve outputs should be a relative destruction rate (expressed in % of the value of the elements at risk). This approach requires data on the elements at risk from insurance databases, including aspects such as the insured values, the location of the elements at risk, building features, the type of commercial, industrial or agricultural activity, the claims per hazard and element at risk, etc. (Moncoulon et al., 2014). **Based on the Lez demo, different classes of insured values will be proposed in order to help other demo sites with value of element at risks estimations.**

The damage model would be obtained by regressing the outputs of the hazard model (river flows, water levels, rainfall, etc.) and historical claim values, expressed as destruction rates, on an historical event set (Moncoulon, et al., 2014). The choice of the regression model will determine the curve shape. Working on destruction rate classes can also be a solution for a good estimate of the range of magnitude of the damages.

The calibration event set should be different from the validation event set, on which the total amount of insured damages is well described and the capacity of the model to reproduce a good estimate of these losses is evaluated (Moncoulon et al., 2014; Naulin et al., 2016).

In the case of the Lez demo site, the historical events from 2014 on the watershed will be used to calibrate a damage curve for the Lez river overflow. This damage curve will be used to assess the amount of damages for the same events with / without NBS effects. But this deterministic approach will be too restrictive: the effect of the NBS will be evaluated on a single event.

The best estimation of the effect of a NBS is the annual amount of damages avoided. The estimation of the annual amount of damages avoided requires accounting for flood risk/exposure, i.e. the simulation of a probabilistic event set that defines probabilities of the hazard results (e.g. river flow, flooded areas) (Moncoulon, et al., 2014). Indeed, the historical event set is generally not reach enough to determine a valuable annual effect. The annual amount of damages avoided is necessary to:

- Compare with the annual cost of the NBS
- Estimate the number of years necessary for the NBS to have a positive effect.
- To compare the NBS with grey infrastructures and to compare different NBS.

To conclude on the use of insurance data for damage curve calibration, the positive aspects of this method are the following:

- Generally robust analysis based on well-defined and homogeneous lines of business;
- Claim data correspond to the amount of damages really paid by the insured people and the insurers. These data can hardly be criticised on their quality
- Insured risks generally represent a large part of the global economic losses in Europe, although this depends on the particular insurance scheme and country;
- Claim data are good data for calibration (address level, street level data) and validation (the total value of claims can be extrapolated to the market and used as a target for damage calculation for a given event).

The negative aspects of this method are the following:

- Claim data are generally insurance property and strategic data (not mentioning the individual private life protection aspects) and will rarely be open source data;
- The details of the claims are very short and these data only allow a statistical approach (micro-scale and meso-scale).

6.8. Sources of uncertainty in damage assessment

Several sources of uncertainty are associated with the estimation of damage costs (Merz et al., 2010; de Moel and Aerts, 2011; Cammerer et al., 2013). The most relevant ones are the damage functions used and the asset values considered (de Moel and Aerts, 2011). A major source of uncertainty is related to the shape of the damage functions used and the way these have been developed. This is especially relevant for the use of functions that have been previously developed for other geographical areas. Cammerer et al. (2013) recommend using damage functions that have been previously validated with real observed data to test their reliability and their potential for transferability. The uncertainty arising from asset values can be accounted for by means of a sensibility analysis based on the range of asset values for each type of element at risk (Cammerer et al., 2013).

However, while uncertainty in absolute estimates of damage costs is large, proportional changes in damages with respect to the reference (BAU) situation have a much lower uncertainty (de Moel and Aerts, 2011). As the objective in NAIAD is assessing the potential of NBS for reducing water-related risk damages, the effect of uncertainties in the project's conclusions might be less relevant than initially thought.

6.9. Spatial scale of the damage assessment

The choice of the spatial scale of the damage model depends on data availability and the final use of the model. In principle, it is easier to move from micro-scale to meso and macro-scale

than the opposite. Nevertheless, micro-scale estimation is generally impossible to validate, extremely complex to run for thousands of buildings/infrastructures in town and full of uncertainties that are easier to reduce using meso-scale estimations.

The choice of spatial scale during model development must be done knowing the final use of the model. For example, to estimate the losses for insurance companies, meso or macro-scale are enough. To estimate a global amount of damages due to a given event, meso-scale is generally used. For NAIAD's objective (assessing the relative impact of NBS on risk exposure), meso-scale is probably enough. We should not forget that damage models are used for estimation of orders of magnitude of damages. Even if building scale data (micro-scale) are available for calibration and development of a damage model, an aggregation of these data can be done before calibration to reduce uncertainties and enable the use of the model in less favourable conditions.

6.10. Existing frameworks/models for the assessment of flood direct damage costs

This section discusses the main features of some existing frameworks that could be used for the assessment of flood direct damage costs in the NAIAD DEMOs, especially in those that do not have the expertise to develop their own damage functions. The final chosen ones will be presented in a latter section.

The software CLIMADA (https://github.com/davidnbresch/climada), running on MATLAB, is intended for probabilistic risk modelling and adaptation assessment at a global scale for several hazards, including droughts and floods. In the case of floods, relative damage functions are defined as functions of two parameters: the percentage of affected assets and the percentage of damage to assets (which depends on the hazard intensity, i.e. water depth).

Another well-known alternative is the Multi-coloured Manual (http://www.mcm-online.co.uk), developed by the University of Middlesex for the assessment of flood and coastal erosion damages in the UK (FHRC, 2017). It uses relative depth-damage functions developed by experts (synthetic damage curves) for a wide variety of elements at risk that are classified by type and age. It also allows estimating vehicle damages and evacuation costs, as well as direct and indirect costs.

Within the framework of the French "Programs of actions for the prevention of floods (Programmes d'actions de prévention des inondations, PAPI)", a full methodological guide for the multicriteria assessment of flood prevention measures (Christin et al., 2014) has been developed, which includes the assessment of direct and indirect costs of flood hazards. This

includes synthetic absolute depth-damage functions developed for residential, business, agricultural and public elements at risk at the French national level. Damage curves are functions of water depth and the duration of the flood. Damage curves for agricultural crops are also a function of the season. In addition, it proposes indicators for the assessment of both indirect and intangible costs (economic, social, environmental and cultural).

Table 3. Synthetic overview of some existing sources of flood damage functions

Name	Country / Area	Type	Housing	Industry/commerce	Agriculture	Infrastructures	Access	Link / conditions of availability
CLIMADA	World	Relative DF					Free	https://github.com/davidnbresch/climada
Multi-coloured Manual	U.K.	Absolute DF	€/m^2	€/m^2	€/m^2	€/m^2	Payment	http://www.mcm-online.co.uk
French Environment ministry DF	France (all)	Absolute DF	€/m^2 * time	x	€/ ha* time		Free, function to download	https://www.ecologique-solidaire.gouv.fr/levaluation-economique-des-projets-gestion-des-risques-naturels
JRC (Huizinga, 2007; Huizinga et al., 2017)	EU; World	Absolute & relative DF	€/m^2	€/m^2	€/m^2	€/m^2	Free	http://publications.jrc.ec.europa.eu/repository/handle/JRC105688
FLEMOCs	Germany	Relative DF	X	X	X	X		Seifert et al. (2010)
HIS-SSM and DSM models	Netherlands	Relative DF	X	X		X	Free	https://repository.tudelft.nl/islandora/object/uuid%3A015c62a1-558d-422c-8706-efc0e4db2fc3
Flemish Environmental Agency	Belgium	Relative DF	X	X	X	X		Vanneuville et al. (2006)
Jonkman at al. (2008)	Netherlands	Relative DF	X	X	X	X		Jonkman at al. (2008)
HAZUS-MH	U.S.	Relative DF	X	X	X	X	Free	http://www.fema.gov/hazus

Regarding other NAIAD countries, there also exist models for the Netherlands (HIS-SSM and DSM models) and in Belgium (model developed by the Flemish Environmental Agency), both developed for its use with aggregated land use data (Jongman et al., 2012). Jonkman at al. (2008) also developed flood damage functions for the entire Netherlands.

In the 2000s, the European Commission developed a European-wide model for flood risk assessment (Huizinga, 2007). It uses relative depth-damage functions for all EU-27 countries to compute direct damage costs. However, for most countries, damage functions for each type of asset are estimated as the average of the available functions for such type of asset (Jongman et al., 2012). More recently, the EU (Huizinga et al., 2017) has published an inventory of global flood damage functions for 214 countries worldwide, differentiated in six different categories (residential, industrial, commercial, agricultural, transportation and infrastructures). In the case of Europe, damage functions are the same as in Huizinga (2007). Damage estimation for most type of assets includes the value of damage to contents and inventory. These damage functions can be used in the corresponding DEMOs, unless a better option is available.

Another commonly used alternative is the Hazus Multi Hazard software (HAZUS-MH, http://www.fema.gov/hazus), developed by the U.S. Federal Emergency Management Agency (FEMA, 2009). It is based on an extensive database of relative depth-damage functions developed for buildings, infrastructures, public facilities, etc. It also allows for the estimation of indirect economic impacts (Scawthorne et al., 2006).

Last, while several DEMOs intend to use the ECO:ACTUARY platform for mapping data on ecosystems, climate, land use, etc., this initially appears as an option for them. ECO:ACTUARY will allow for the assessment of damages from hazards. In the case of flood hazards, ECO:ACTUARY will include relative damage curves that will be functions of the height of water in the flood and the height of the asset. These damage functions have been obtained from the existing literature (Mulligan et al., 2018). Nineteen different types of assets are considered: residential, industrial, cropland, pastures, and other type of public assets and infrastructures. The assets values are inferred from nightlight satellite images. However, ECO:ACTUARY can be used with alternative databases of assets and damage functions.

6.11. Vulnerability indicators approach

An alternative approach to damage/vulnerability functions is using vulnerability/exposure indicators (Papathoma-Köhle, 2016). This approach will be implemented in both the Lez and Brague demo sites. Exposure indicators are calculated and mapped at a defined spatial scale by crossing different chosen vulnerability parameters, such as slopes, urban context, drainage surface, land use, distance to the river, location inside or outside river flood prone area, etc.

These indicators will be validated on the French demos using CCR's insurance claim data. This method should be easily transferable from one DEMO to another in an urban flood context. Once validated, the maps of exposure indicators will be crossed with hazard maps, both with and without the effect of NBS, to obtain an estimation of damage losses in both cases and perform the cost-benefit analysis, as described in Graveline et al. (2017).

6.12. Assessment of direct business economic losses from flood hazards

The consequences of flood hazards for businesses can be various and ranked from less critical to more critical:

- **Positively affected** by a particular peaking demand linked to the event (bottles of water, electric lamps…) because the business sells goods or provides services that are particularly demanded during and after the event.
- **Negatively affected** in their functioning (supply, production or commercialization). It means adaptation of current practice is necessary, extra-costs can be observed to face the problem or the turnover is affected by a poor commercialization rate. It might be that no apparent market cost is observed because employee and management will cope with the modified conditions. However, there will be at least non-market impacts (stress, change of process…) due to the necessary adaptation in the face of the event.
- **Business interruption** e.g. production and/or commercialization are shut down and or the business is closed for a given period. In this case, the question of the future adjustment to recover baseline is open. It might be that no apparent market cost remains because of adaptation such as extra (free) workload in the following days. However, there will be at least non-market impacts (stress, change of process, extra hours' work) due to the necessary adaptation in the face of the event.
- **Business definitively closes.** The business does not endure the event for whatever reason (not insured, people affected)

Both market (in € and from an accounting point of view) and non-market impacts can be observed.

The literature is relatively scarce concerning the topic of the costs resulting from the economic losses of business activities when they are affected by the consequences of floods. For business interruptions (closing), in the case of floods, the most used approaches are using sector-specific reference values (e.g. daily lost added value per worker, per area, etc., depending on statistical data availability), comparing the economic output between hazard and non-hazard years, or directly estimating the production losses as a percentage of physical building costs (Meyer et al.,

2012). A reference study on the major Seine Flood by OECD reviews quantitative and qualitative impacts for instance mentioning the number of companies and employees affected (OECD, 2014). Graveline & Grémont (2017) develop an economic resilience indicator that integrate both market and non-market impacts, as well as dynamics of recovery, to have an integrated picture of the long-term impact that integrates inherent and adaptive resilience.

In NAIAD, the DEMOs will develop tailored methodologies that are adapted to their available data. We suggest addressing the assessment of this damage costs component with a short survey to businesses to understand their consequences in terms of activity. The survey can be found in Annexe 1. The survey sampling should be stratified based on a typology of businesses and services (incl. municipal services) and the sample size tailored to the available execution time. The typology should differentiate at least between (i) primary sector (farming & resource extractions), (ii) industry, and (iii) services.

7. Assessment of direct damage costs in drought events

In the case of droughts, the steps to follow when assessing direct damage costs are similar as presented for the case of flood hazards. The major difference is the assessment of vulnerability to the intensity of the drought hazard.

The most common approaches to assessing direct drought damage costs are those based on market valuation techniques, such as the avoided cost approach, the replacement cost approach, the production function method and the market price method (Logar and van den Bergh, 2013). The market price method would consist in computing the changes in the prices and quantities produced of the goods and services affected by the drought (UNISDR, 2017). However, this is only applicable for the estimation of occurred drought events.

Market prices can be also used to estimate damage functions, which relate the economic impact of drought with the drought intensity (Gil-Sevilla et al., 2010, Gil et al., 2011; Lopez-Nicolas et al., 2017; Giannikopoulou et al., 2017). The economic impact can be obtained from economic statistics, while drought intensity can be characterised using climatic/hydrological data and drought indicators (see Kallis, 2008, for a discussion of drought indexes). Most commonly, in drought damage functions, hazards are characterised by parameters such as duration and some intensity index (Giannikopoulou et al., 2017). In the case of agricultural damages, the economic impact can be measured using statistics on the value of agricultural production, crop yields, crops prices, etc. The direct impacts of drought on agriculture can also be estimated using biophysical crop models. Crop yields obtained for a given set of climatic variables would be translated into economic values using crop prices or integrated in agro-economic models (Logar and van den Bergh, 2013).

Another approach is the Ricardian method, which consists of regressing land values on climatic indexes and other variables that may influence land values (Kallis, 2008). The coefficients of the estimated functions could be used to compute the cost of drought scenarios.

Last, in the case of irrigated agriculture, the direct impacts of drought can be estimated using agro-economic models, which, as damage functions, can be integrated in a hidro-economic framework (Iglesias et al., 2007).

In NAIAD, drought hazards are only considered in the Medina and Lower Danube DEMOs. The proposed approach is estimated damage functions using historical data on crop yields and prices, farm income and climatic variables, but this will ultimately depend on the quality of data available. In the Medina DEMO, there are damage curves developed by AgroSeguro, but their availability for the project is not yet confirmed.

For the estimation of business interruption costs in the case of droughts, the most common approach is the analysis of specific events by comparing the annual value of production in drought years with that of non-drought years (see Martin-Ortega et al., 2012, for an example).

8. Assessment of indirect damage costs

Recall NAIAD's definition of indirect damages is losses induced by direct damages and business interruption outside the hazard event either in time and/or space. Similarly to the direct business activity damages, there are both market and non-market costs that can be observed. The estimation of indirect damage costs is more complex, as it requires accounting for the induced economic impacts of the hazard beyond the area directly affected by it. The **indirect market impacts** are propagated along the distribution or supply chain. From a methodological point of view, options are either to collect data on past events (from statistical data or ad-hoc surveys) either to rely on macro-economic methods such as input-output, computable general equilibrium or econometric models (Cochrane, 2004; Merz et al., 2010). Rose (2004), Okuyama (2007) and Hallegate and Przyluski (2010) provide critical discussions of each approach. Although these methods provide more comprehensive assessments, the number of empirical applications in the case of floods and droughts is very small compared to studies assessing direct damage costs. Some examples are Jonkman at al. (2008) that assess both direct and indirect costs of flood damages in the Netherlands using stage-damage functions and input-output approaches respectively, Carrera et al. (2015) that estimates direct and indirect impacts of a flood in the Italian Po Valley, and Schulte in den Bäumen et al (2015) that estimate indirect losses from floods in Germany using Multi-Regional Input-Output modelling. Examples of the estimation of indirect damages from drought events are Pérez and Barreiro-Hurlé (2009) and

Martin-Ortega et al. (2012). Table 4 summarises the estimates for both direct and indirect costs from these studies, as well as the ratio between both cost components.

Table 4. Some estimates of direct/indirect costs from the literature

	Reference	Country / Area	Year	Directly affected area	Direct cost estimate	Indirect costs estimate	Ratio indirect/ direct
FLOOD	Jonkman at al. (2008)	Netherlands	2000 simulated event (catastrophic)	370 Km^2	23,740 M€ (6.5% of GDP); (*) BIC: 11%	2.5-5% of GDP	0.385-0.770
	Carrera et al. (2015)	Po Valley (Italy)	2000, simulating water depths	1183 Km^2	4,000-10,300 M€	647-1,955 M€ (*)	0.19-0.22
	Schulte in den Bäumen et al. (2015)	Several German Landers	2013	n/a	10,000 M€	5,473 M€ (*)	0.55
DROUGHT	Pérez y Barreiro-Hurlé (2009)	Ebro basin, Spain	2005	n/a	482 M€ (farming and energy)	478 M€	0.99
	Martin-Ortega et al. (2012)	Barcelona, Spain	2007/08	11,775 Km^2	404 M€	378 M€	0.94

BIC: Business interruption costs; (*) Includes business interruption costs.

The use of macro-economic models to assess the indirect economic avoided damages is beyond the scope of NAIAD as those models are not available in NAIAD DEMOs. Thus, a first reflection should happen on whether the DEMO needs to include those types of damages. If the area affected by floods has a small economic importance (this can be measured by GDP of the area on GDP of the country) than indirect impacts can be neglected because the connected areas will be able to reorganize easily with limited impact. If the area has a major importance than the indirect impacts cannot be neglected. In this case, we recommend taking an interval for this ratio and apply it to direct damages to estimate indirect monetary damages. According the literature (see Table 4) this ratio is between 0,2 and 1. We can assume that the higher the GDP share of the area is the higher the indirect cost: this assumption should help DEMOs decide on a coefficient.

9. Assessment of intangible damage costs

Intangible costs include loss of life, effects on health (physical and psychological), environmental damages and cultural and historic damages. While numerous studies on the field of the economic analysis of natural disasters have assessed tangible costs (see Meyer et al., 2012, for a review of studies), the issue of assessing intangible or non-market damages has barely been addressed. Markantonis et al (2012) and Meyer et al. (2012) review methods for the economic valuation of the intangible damages of natural hazards. Concerning the **environmental damages**, these are the same methods used for the economic valuation of environmental goods and services, which will be used in NAIAD for the assessment of the co-benefits of NBS, and that are commented in detail in deliverable 4.4.

In NAIAD, we recommend these types of damages are integrated qualitatively in the multicriteria analysis, when significant, and are subjected to a specific qualitative analysis in every DEMO. The identification and assessment of qualitative impact can be assessed through interviews or even workshops. See Naiad methodology for more information.

10. NAIAD DEMOs proposed methodology

According data, resources and skills, different methods will be implemented in the NAIAD DEMOs to assess avoided cost of damages. This part presents the general approach to damage assessment that will need to be adapted and tailored to each DEMO.

Based on the literature review presented upfront, DEMO can tailor a method according the steps suggested in the following stepwise methodology. Keep in mind that the final ambition of the task is to assess avoided damages. The DEMOs are able to integrate in this general approach the estimation they did with Eco:actuary or any other.

1- Detail in the typology of damages presented in Tables 1 and 2 what is relevant for the DEMO and the elements at risk that will be assessed. This must be justified according to the importance of damages.
2- Describe the available damage functions (DF) along the typology of assets and specify what damages they include and don't include. In case there were not DFs available for the area of study, DF for the country could be used (e.g. DFs in Table 3).
3- For the damages that cannot be assessed by DF, detail the approach of the estimation (qualitative/ survey, insurance data, indicators approach, etc.). At this stage, a table adapted from Tables 1 and 2 should present the components of damages that will be assessed and the method with which they will be assessed.
4- Characterize the hazard(s) considered to assess damages and physical impacts of hazards.

   a. Return periods or reference real events (see Figure 2)
   b. Determine the metric (e.g. water height and duration, drought intensity and duration)
   c. Produce/collect the hazard intensity maps in the reference situation and for the NAS scenario(s) (e.g. water heights envelop)

5- Elaborate a GIS database according elements at risk considered (minimum for floods: housing, commercial & industrial buildings, public infrastructure, farming for flooding)
6- Direct damage assessment (see Figure 1):
   a. Asset valuation of elements at risk (optional, depends on which type of DF used, not necessary for absolute DF like the one used in France)
   b. Cross the assets & the DF & the envelops to assess direct damages of each of the scenarios
   c. Complement with elements at risk that are not covered by DFs (e.g. infrastructures…) while surveying municipalities[2] & infrastructure operators.
7- Indirect damage assessment (delayed in space & time, tangibles)
   a. Check what DFs include to avoid double counting of local indirect (delayed in time) damages
   b. Choose a ratio of indirect / direct damages and argue if no macro-economic model is available (see section 8)
8- Avoided quantitative damage
   a. Combine direct and indirect damages at different spatial units
   b. The difference will produce the avoided damages for the event assessed or for the different events (or return periods).
   c. Integrate the avoided damages on the different events to produce a mean annual avoided damage (see Annex 1)
9- Intangible or qualitative impacts
   a. Based on the typology in Tables 1 and 2, identify the intangibles that the DEMO ambitions to address
   b. According to the available resources and time, determine whether the survey will be done on one hot spot or all hot spots (flood- or drought-affected areas in the DEMO)
   c. Implement the survey (telephone and field)

[2] Municipalities are responsible for cleaning after the event and can help estimating the cost of cleaning (outside of private properties). They should also be aware if not responsible for major infrastructure impacts (shutdown or perturbation of roads, water and sanitation network, electricity, telecommunication) and about general consequences on the municipality of particular events of floods. Their internal organisation (administration, school, security…) has potentially be affected and through that the economy or living of people.

d. Conclude on avoided qualitative damages according scenarios and physical impact scenarios

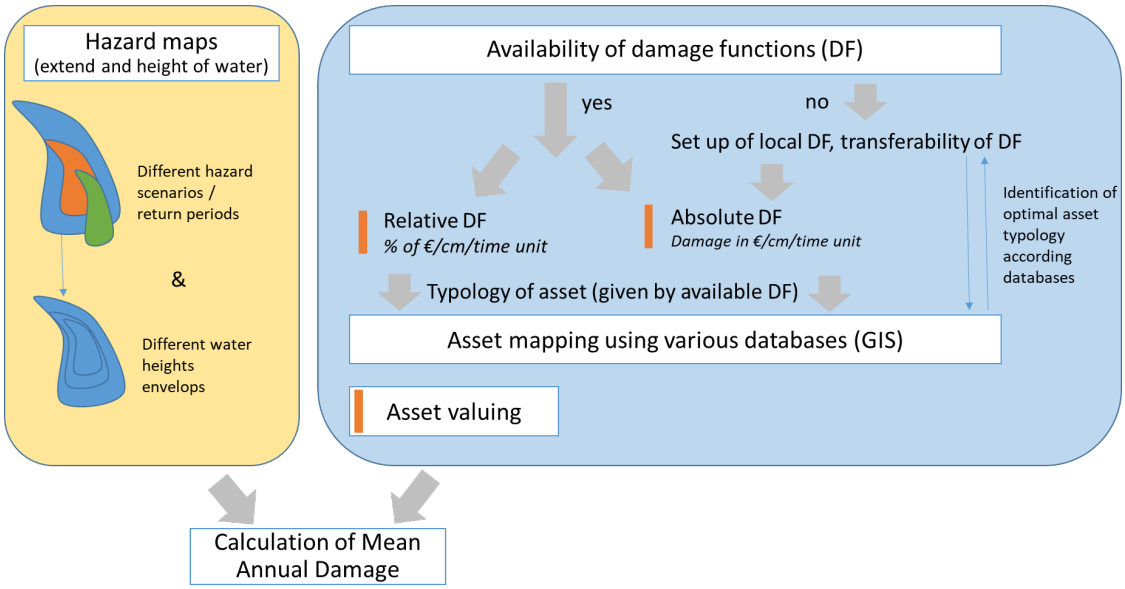


Figure 5. Overview of the proposed approach for tangible direct damage assessment

11. Concluding remarks

The assessment of damage losses is a very challenging task according to the various data dependant and methodological stakes. The estimation of avoided damages, which is the perspective of NAIAD eliminates some challenges as the interest is not on the total, absolute value but on a difference. The exact same method should thus be used to assess reference or scenario damages. Only components of the total damage that are affected by the project or scenario should be accounted for. This should guide the identification of types of damages to be considered.

12. References

Balbi, S., Giupponi, C., Olschewski, R. & Mojtahed, V. 2013. *The Economics of Hydro-Meteorological Disasters: Approaching the Estimation of the Total Costs*. Bilbao, Spain.

Bouwer, L. M., Papyrakis, E., Poussin, J., Pfurtscheller, C., & Thieken, A. H. (2014) The Costing of Measures for Natural Hazard Mitigation in Europe. Natural Hazards Review, **15**(4), 1–10.

Brémond, P., F. Grelot, & A.-L. Agenais. 2013. Review Article: Economic evaluation of flood damage to agriculture - Review and analysis of existing methods. *Natural Hazards and Earth System Sciences* 13:2493–2512.

Cammerer, H., Thieken, A. H., & Lammel, J. (2013). Adaptability and transferability of flood loss functions in residential areas. *Natural Hazards and Earth System Sciences*, *13*(11), 3063–3081.

Carrera, L., Standardi, G., Bosello, F., & Mysiak, J. (2015). Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modelling. *Environmental Modelling and Software*, *63*, 109–122.

Christin, N., Peinturier, C. & Magnier, C. (2014). Analyse multicritères des projets de prévention des inondations. Guide méthodologique. Commissariat Général au Développement Durable (CGDD), Paris.

Cochrane, H. 2004. "Economic loss: myth and measurement." *Disaster Prevention and Management* 13:290–296.

FEMA (2009). Multi-hazard Loss Estimation Methodology. Flood Model HAZUS1MHMR4 Technical Manual. Federal Emergency Management Agency (US).

Feyen, L., Dankers, R., Bódis, K., Salamon, P., & Barredo, J. I. (2012). Fluvial flood risk in Europe in present and future climates. *Climatic Change*, *112*, 47–62.

FHRC (2017). Flood and coastal erosion risk management: Handbook for economic appraisal 2017. Flood Hazard Research Centre. Middlesex University, London, UK.

Foudi, S., Osés-Eraso, N., & Tamayo, I. (2015). Integrated spatial flood risk assessment: The case of Zaragoza. *Land Use Policy*, *42*, 278–292.

Gerl, T., Kreibich, H., Franco, G., Marechal, D., & Schröter, K. (2016). A review of flood loss models as basis for harmonization and benchmarking. *PLoS ONE*, *11*(7), 1–22.

Giannikopoulou, A. S., F. K. Gad, E. Kampragou, & D. Assimacopoulos. 2017. Risk-Based Assessment of Drought Mitigation Options: the Case of Syros Island, Greece. *Water Resources Management* 31:655–669.

Gil-Sevilla, M., Garrido, A., & Gomez-Ramos, A. (2010) How to link agricultural productivity, water availability and water demand in a risk context: a model for managing hydrological risks. Spanish Journal of Agricultural Research, **8**(S2), S207–S220.

Gil, M., Garrido, A. & Gómez-Ramos, A. 2011. "Economic analysis of drought risk: An application for irrigated agriculture in Spain." *Agricultural Water Management* 98:823–833.

Graveline, N., Joyce, J., Calatrava, J., Douai, A., Arfaoui, N., Moncoulon, D., Manez, M. De Ryke H., Zdravko K. (2017). "*DELIVERABLE 4.1: General Framework for the economic assessment of Nature Based Solutions and their insurance value"*. EU Horizon 2020 NAIAD Project, Grant Agreement N°*730497*.

Graveline, N., & Gremont, M. (2017). Measuring and understanding the microeconomic resilience of businesses to lifeline service interruptions due to natural disasters. *International Journal of Disaster Risk Reduction*, *24*, 526-538.

Hallegatte, S., and Przyluski, V. 2010. *The economics of natural hazards: Concepts and methods*. World Bank, Washington D.C.

Huizinga, J., Moel, H. de, Szewczyk, W. (2017). Global flood depth-damage functions. Methodology and database with guidelines. EUR 28552 EN. doi: 10.2760/16510.

Huizinga, J. (2007). Flood damage functions for EU member states. HKV Consultants, Implemented in the framework of the contract #382442-F1SC awarded by the European Commission – Joint Research Centre.

Iglesias, E., Garrido, A. & Gómez-Ramos, A. 2007. "Economic drought management index to evaluate water institutions' performance under uncertainty." *Australian Journal of Agricultural and Resource Economics* 51:17–38.

Jongman, B., Koks, E. E., Husby, T. G., & Ward, P. J. (2014). Increasing flood exposure in the Netherlands: Implications for risk financing. *Natural Hazards and Earth System Sciences*, *14*(5), 1245–1255.

Jongman, B., Kreibich, H., Apel, H., Barredo, J. I., Bates, P. D., Feyen, L., … Ward, P. J. (2012). Comparative flood damage model assessment: Towards a European approach. *Natural Hazards and Earth System Sciences*, *12*(12), 3733–3752.

Jonkman, S. N., Bočkarjova, M., Kok, M., & Bernardini, P. (2008). Integrated hydrodynamic and economic modelling of flood damage in the Netherlands. *Ecological Economics*, *66*(1), 77–90.

Kallis, G.. 2008. "Droughts." *Annual Review of Environment and Resources* 33:85–118.

Logar, I., & van den Bergh, J.C.J.M. 2012. "Methods to Assess Costs of Drought Damages and Policies for Drought Mitigation and Adaptation: Review and Recommendations." *Water Resources Management* 27:1707–1720.

Lopez-Gunn, E. Zorrilla-Miras, P, Altamirano, M.A., Rijke, H. Marechal, R., Tacnet, J.M., Piton, G., Matthews, J. (2018). "*DELIVERABLE 7.1: Natural Capital Market integration portrait: From*

Climate Finance to Insurance – including European survey". EU Horizon 2020 NAIAD Project, Grant Agreement N°*730497*.

Lopez-Nicolas, A., Pulido-Velazquez, M. & Macian-Sorribes, H. 2017. "Economic risk assessment of drought impacts on irrigated agriculture." *Journal of Hydrology* 550:580–589.

Lugeri, N., Kundzewicz, Z. W., Genovese, E., Hochrainer, S., & Radziejewski, M. (2010). River flood risk and adaptation in Europe-assessment of the present status. *Mitigation and Adaptation Strategies for Global Change*, *15*(7), 621–639.

Mao, G., Onfroy, T., Moncoulon, D., Quantin, A. & Robert, C. (2016). Comprehensive flood economic losses: review of the potential damage and implementation of an agricultural impact model. E3S Web of Conferences. 7. 05003. 10.1051/e3sconf/20160705003.

Markantonis,V., Meyer,V., & Schwarze, R. 2012. Review Article "Valuating the intangible effects of natural hazards – review and analysis of the costing methods", *Natural Hazards and Earth System Sciences*, 12, 1633–1640.

Martin-Ortega, J., González-Eguino, M., & Markandya, A. (2012) The costs of drought: the 2007/2008 case of Barcelona. Water Policy, **14**(3), 539–560.

Merz, B., H. Kreibich, R. Schwarze, & A. Thieken. 2010. "Review article 'Assessment of economic flood damage.'" *Natural Hazards and Earth System Sciences* 10:1697–1724.

Meyer, V. et al. 2013. "Review article: Assessing the costs of natural hazards-state of the art and knowledge gaps." *Natural Hazards and Earth System Sciences* 13:1351–1373.

Molinari, D., Menoni, S., Aronica, G. T., Ballio, F., Berni, N., Pandolfo, C., … Minucci, G. (2014). Ex post damage assessment: An Italian experience. *Natural Hazards and Earth System Sciences*, *14*(4), 901–916.

Molinari, D., Menoni, S., Ballio, F. (2017). Flood Damage Survey and Assessment: New Insights from Research and Practice. Geophysical Monograph Series). American Geophysical Union & Wiley & Sons. 288 pages.

Moncoulon, D., Labat, D., Ardon, J., Leblois, E., Onfroy, T., Poulard, C., Aji, S., Rémy, A., & Quantin, A. (2014). Analysis of the French insurance market exposure to floods: a stochastic model combining river overflow and surface runoff, *Natural Hazards and Earth System Sciences*, 14, 2469-2485.

Mulligan, M, Burke, S., van Soesbergen, A., & Douglas, C. (2018). *DELIVERABLE 2.4: Guidelines for the pilot version of the Eco: Actuary policy support system*. EU Horizon 2020 NAIAD Project, Grant Agreement N°*730497*.

Naulin, J. P., Moncoulon, D., Le Roy, S., Pedreros, R., Idier, D., and Oliveros, C. (2016). Estimation of insurance-related losses resulting from coastal flooding in France, *Natural Hazards and Earth System Sciences*, 16, 195-207.

OECD (2013). Policy approaches to managing catastrophic risks: Floods and Droughts. A conceptual framework. Discussion Paper COM/TAD/CA/ENV/EPOC(2013)51. Organisation for Economic Co-operation and Development, Paris.

OECD (2014), *Seine Basin, Île-de-France, 2014: Resilience to Major Floods*, OECD Reviews of Risk Management Policies, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264208728-en.

Okuyama, Y. (2007). Economic Modeling for Disaster Impact Analysis: Past, Present, and Future. *Economic Systems Research*, *19*(2), 115–124.

Papathoma-Köhle, M. (2016). Vulnerability curves vs. Vulnerability indicators: Application of an indicator-based methodology for debris-flow hazards. *Natural Hazards and Earth System Sciences*, *16*(8), 1771–1790.

Pérez y Pérez, L. & Barreiro-Hurle, J. (2009) Assessing the socio-economic impacts of drought in the Ebro River Basin. Spanish Journal of Agricultural Research, **7**(2), 269–280.

Pistrika, A., Tsakiris, G., & Nalbantis, I. (2014). Flood Depth-Damage Functions for Built Environment. *Environmental Processes*, *1*(4), 553–572.

Rojas, R., Feyen, L., & Watkiss, P. (2013). Climate change and river floods in the European Union: Socio-economic consequences and the costs and benefits of adaptation. *Global Environmental Change*, *23*(6), 1737–1751.

Rose, A. 2004. Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation. Pp. 13–36 in *Modeling Spatial and Economic Impacts of Disasters*, edited by Yasuhide Okuyama and Stephanie E Chang. Berlin, Heidelberg: Springer Berlin Heidelberg.

Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., … Lawrence, M. (2006). HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment. *Natural Hazards Review*, *7*(2), 72–81.

Schulte in den Bäumen, H., Többen, J., & Lenzen, M. (2015). Labour forced impacts and production losses due to the 2013 flood in Germany. *Journal of Hydrology*, *527*, 142–150.

Scorzini, A. R., & Frank, E. (2017). Flood damage curves: new insights from the 2010 flood in Veneto, Italy. *Journal of Flood Risk Management*, *10*(3), 381–392.

Seifert, I., Kreibich, H., Merz, B., & Thieken, A. H. (2010). Application and validation of FLEMOcs – a flood-loss estimation model for the commercial sector. *Hydrological Sciences Journal*, *55*(8), 1315–1324.

Smith, D. I. (1994). Flood damage estimation - a review of urban stage-damage curves and loss functions. *Water SA*, *20*(3), 231–238.

UNISDR. (2017). Technical Guidance for Monitoring and Reporting on Progress in Achieving the Global Targets of the Sendai Framework for Disaster Risk Reduction: Collection of Technical Notes on Data and Methodology. United Nations International Strategy for Disaster Reduction, Geneva.

Vanneuville, W., Maddens, R., Collard, C., Bogaert, P., de Maeyer, P., & Antrop, M. (2006). Impact op mens en economie t.g.v. over- stromingen bekeken in het licht van wijzigende hydraulische condities, omgevingsfactoren en klimatologische omstandighe- den, Vakgroep Geografie, Universiteit Gent, Gent, Belgium, MIRA/2006/02.

Watson, K. B., Ricketts, T., Galford, G., Polasky, S., & O'Niel-Dunne, J. (2016). Quantifying flood mitigation services: The economic value of Otter Creek wetlands and floodplains to Middlebury, VT. *Ecological Economics*, *130*, 16–24.

Wilhite D.A. (ed). 1993. Drought assessment, management and planning. Theory and case studies. Kluwer Academic Publishers, Boston/Dordrecht/London.

Wilhite D.A. (ed). 2000. Drought: A Global Assessment.Vol.1&2. Routledge, London/New York.

Annex 1 – Survey for companies

To be completed on step 2 direct & indirect impact assessment

	Questionnaire for COMPANIES - Damage assessment including indirect & intangibles		
1	**Have your business or service ever be affected by a flood ?**	☐ Yes	☐ No : stop itw
2	Name of business / service and interview		
3	Short description of activity		
4	Number of employees (full time equivalent)		
5	Yearly turnover		
	General risk management		
5	Are you located in a specific flooded area ?	Yes ☐	detail
6	For what is your company covered by insurance ?		
7	Do you have strategies/solutions to reduce the consequence of floods (elevation, displacement, "batardeau" housing secutiry…)		
8	Do you have substitution solutions to any network shutdown (eletric generator, own access to water …) ?		
9	Do your business has a crisis management procedure ? In what does it consist?		

Can we talk about the worse flood/drought event you faced (or give the event you want to study) ?

10	What was the cause of this event ?	runoff	☐	river	☐
		groundwater discharge	☐		
11	Were you faced by the consequences of the flood ?	Directly	☐	Indirectly	☐

PART II

Questionnaire for COMPANIES - Damage assessment including indirect & intangibles

Following this event

if only affected indirectly go to question xx.

12 Can you describe **physically** the consequences of the flood in your business (water height, time with water, pollution) ?

	Description	Estimation of costs	Source of costs or method	Part of damage insured/reimbursed
building (walls...)				
furniture				
stocks				
engins				
vehicules				
Cleaning				
others, specify				

Impact on activity

13 affected - market

days with impact	loss of turnover in % or absolute value	
		Production interruption
		Selling interruption
		penalties
		increase of cost of production
		other ?

14 - Short term Impact on activity

affected - non market

		disorder in organisation
		Stress / danger of employees
		delays in delivering
		loss in reputation
		others, specify

Closing of business? If yes, how many days ?

why ?

Was some staff unable to come ?

On the long term, would you say you were impacted ?

No, we've done adjustments to cope and had no final accounting impact

15- Long term impact on activity

how did you manage? (solidarity, efforts of employees)

- solidarity of other businesses
- other form of solidarity
- efforts of employees
- other, specify

Yes, can you estimate in % or absolute value the loss (or gains) ?

Were you constraint to dismiss some staff ?

Was the sustainability of your business threatened ?

Have your buildings lost value ? (after reparations)

16 **In the last important event (precise)**

Did you call for public assistance ?

Is your activity depending from networks?

specify for production, selling, supply, the well being at work, other

	what for
water	
electricity	
road	

Have you faced other intangible impacts ?

Have you realized a "return on experience" reflexion/document?

What are the measures that have been taken following this last event?

Have you changed some processes or even strategy in your company?

Did you had damages that were not insured ? Which ones ? (business losses?)

Have you had other financial assistance then insurance ? Which one ?