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# **The economics of hydro-meteorological disasters: approaching the estimation of the total costs**

Stefano Balbi<sup>\*a,b</sup>, Carlo Giupponi<sup>b</sup>, Roland Olschewski<sup>c</sup>, Vahid Mojtahed<sup>b</sup>

*Hydro-meteorological disasters have caused increasing losses in recent years. Efficient risk reduction policies require accurate assessment approaches, with careful consideration of costs, beyond direct tangible costs, which are commonly used in practice. Faced with possible risk reduction scenarios, limited financial resources require an improvement in the quality of cost estimation, thereby contributing to an efficient allocation of resources. This paper focuses on the concept of total costs of hydro-meteorological disasters, based on direct and indirect as well as tangible and intangible cost categories. These categories are defined and explained, supported by a comprehensive review of economic valuation methods. Based on this information, practice relevant suggestions are made concerning the most appropriate methods for different cases in terms of scale, availability of data and of technical resources. Our survey also provides critical insights to drawbacks of flood risk estimation, which need to be addressed and carefully dealt with in any future research in this area.*

**Keywords:** hydro-meteorological disasters; total cost; risk reduction; economic valuation; intangible costs; indirect costs.

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# 1. Introduction

A disaster is defined as the outcome of a hazard negatively impacting a social-ecological system (Okuyama and Sahin, 2009; EEA, 2010). The magnitude of the disaster is directly related with the intensity of the hazard as well as with the exposure and the vulnerability of the social-ecological system (Crichton, 1999). However, disasters can be assessed in many ways: number of deaths, number of building collapsed, kilometres of roads destroyed, money loss due to the disruption of economic activities, etc. Ideally all these elements should be comprised in a total cost assessment but practically most of the times only direct and tangible costs are considered to estimate the economic losses.

Economic losses due to natural disasters have been increasing in recent years (Downton and Pielke, 2005; WB-IEG, 2006; Bower et al., 2007; CRED, 2007; 2008; 2010; Okuyama and Sahin, 2009, UNISDR, 2009). When expressed as a portion of gross domestic product (GDP) estimated losses in developing regions, and particularly in the small island states, are generally higher than those in developed regions (IPCC, 2011). Although overall losses have been increasing worldwide over the past few decades, fatalities have decreased in developed countries, but increased in the developing countries (Dore and Etkin, 2000). Further, it is possible that global environmental change will affect natural disaster risk by increasing the frequency of extreme events (IPCC, 2012).

This paper focuses on hydro-meteorological hazards, and in particular on river floods, because they are certainly the most costly hazard. Okuyama and Sahin (2009) show that in a global sample of 184 disasters over the last 47 years, 25% of the total losses came from hydro-meteorological disaster, while 40% of total losses are due to geophysical disasters such as earthquakes. However, several aspects considered in this study, can also be applied to the valuation of other hazard types.

In Europe, river flooding is the most dangerous natural hazard in terms of economic losses (EEA, 2010). Between 2003 and 2009, 26 major events produced direct economic losses of about EUR 17 billion and 320 human fatalities. The increased losses over the past decades are due to an increase of population and assets in the exposed areas (EEA, 2010). Indeed, integrated flood risk management has become a priority for the European Union (e.g., EC, 2007; EFAS, 2010).

The magnitude of the costs of disasters is co-determined by the ability of affected individuals and communities to absorb or cushion against hazards (Rose, 2004b). However, until the 1990s, disaster management was primarily focused on the response of governments, communities, and international organizations to deal with the consequences of disasters after they occurred. Nowadays the focus has been significantly shifted to the role of knowledge and preparedness (UNISDR, 2004). The reason is twofold: (a) disaster occurrence is subject to intrinsic uncertainty and this will be exacerbated by climate change; and (b) the magnitude of a disaster increasingly depends on the behaviour of the affected people and their ability to adapt. This is why the discourse of scientific communities related to “disaster risk reduction” (DRR) and “climate change adaptation” (CCA) is progressively converging to the issues of vulnerability, adaptation, resilience and ultimately integrated risk management.

At a global level the United Nations International Strategy for Disaster Reduction is promoting the development of a process that shifts the focus from the protection against hazards to the management of hazardous risk, through the Hyogo Framework for Actions (UNISDR, 2005). The same process has been reinforced at the European level, where, in the case of floods, particular emphasis is put on non-structural mitigation measures (Green et al., 2011). This becomes even more relevant in view of the expected changes in future climate. Including climate change in the DRR framework improves the analytical framework because climate change is likely to bring hazards for which experience does not exist yet (UNISDR, 2004). In general, it could significantly affect the main features of hazardous events, in terms of magnitude, return period, geographical distribution and scale, etc. For instance, heavy precipitation is likely to increase at the

northern and mid-latitudes in winter and an increase in the magnitude and/or frequency of rain-generated floods is anticipated in some catchments (Trenberth et al., 2007; Bates et al., 2008; IPCC, 2011).

The rising costs of natural disasters make it a high priority to improve the quality and the reliability of the assessment approaches to comprehensively inform mitigation and risk management policies (Mysiak and Markandya, 2009). Here, valuation clearly is a useful way to summarize the available information and economic assessment is usually the preferred approach, given that there is a tendency that political arguments have a higher impact when backed up by monetary figures (Economist, 2006). In the case of hydro-meteorological disaster risk reduction, economic valuation is of great relevance for public policy in that it may help to determine the relative advantages of different possible measures. One may argue that most of the times a detailed estimation of direct tangible costs is sufficient to compare and justify the choice of alternative risk reduction measures, in particular when structural risk reduction measures are combined (e.g., dikes, dams, embankments, etc.). Whether this still holds when it comes to evaluating the benefits of non-structural measures and of preparedness is an open issue, since, for instance, the importance of intangible and indirect costs and benefits might substantially increase.

For example, an early warning system might only partially reduce the amount of direct tangible costs (e.g., you can move your car but not your house), but it can:

- i) save the lives of many people (direct intangible costs);
- ii) change behavior of people by avoiding long lasting traumas (indirect intangibles costs);
- iii) prevent evacuation costs (indirect tangible costs).

In the following sections, we define the concept of total cost and build on the various categories of costs presenting specific examples for hydro-meteorological disasters. Section 2.1 is dedicated to tangible costs, while Section 2.2 is focused on intangibles. Section 3 deals with valuation methodologies traditionally applied to the estimation of different costs and the research gaps in the quest for a comprehensive total cost assessment. In the last section, we draw some conclusion of this review exercise, highlighting several challenges for total cost estimations.

## **2. The total cost of hydro-meteorological disasters**

The concept of total cost goes beyond traditional assessment exercises (e.g., Albala-Bertrand 1993; Wind et al., 1999), because it aims at determining the overall burden on a socio-ecosystem imposed by a disaster. In public economics it is approximated by the concept of social cost (Coase, 1960), which is symmetrical to that of total economic value (Freeman, 1979) used in environmental economics to estimate the benefits provided by natural resources.

The 'true' costs of disasters include costs (incl. benefit losses), which are difficult to identify and to quantify (Downton and Pielke, 2005). It comprises all direct, indirect, tangible and intangible costs. Direct costs are the costs due to the damages provoked by the hazard and which occur during the physical event; indirect costs are those induced by the hazard but occurring, in space or time, apart from the physical event. Tangible costs are those deriving from the economic impacts. Their estimation has been matter of a well-established body of research in the field of economics of natural disasters (NRC, 1999). Intangible costs are those values lost due to a disaster, which cannot, or are difficult and/or controversial to, be monetized, because they comprise non-market values (NRC, 1999). Intangibles mainly pertain to impacts on people and on the environment.

A comprehensive total cost assessment should also take into account the distributional effects of the disaster costs and of the policies to mitigate them (Mysiak and Markandya, 2009). A pre-requisite is the definition of the spatial and temporal boundaries of the assessment (Merz et al., 2010). As the World

Bank (2010) points out, economic impacts may not all be adverse, especially in areas outside the flood zone. For example, a flood might devastate a community. At the same time, nearby communities might experience economic benefits, since the flood might trigger business opportunities that cannot be exploited by the flood-affected companies. As reported in Pielke (2000) the 1993 US Midwest floods impeded barges to navigate the river. Because of this lack of barge traffic, several trucking companies gained about 13 million US\$ in additional revenue due to the increased demand for road transportation.

Van der Veen (2004) distinguishes among micro-, meso- and macro- spatial scales. This is, on the one hand, related to the spatial extent of the damage assessment. On the other hand, there is a methodological distinction of these approaches in their need for aggregation. The net effects of disasters will vary across the scales of aggregation: individuals, firms, communities, regions and nations (Scanlon 1988; Cochrane 2004).

Similar considerations hold concerning the temporal scale. Floods can cause long-term consequences, such as health effects, which are not captured if a too short time horizon of the damage assessment is chosen (Merz et al., 2010). In case of full monetization of such negative impacts the choice of the appropriate discount rate remains one of the most controversial issues in literature.

A summary of the main costs of hydro-meteorological disasters is presented in Figure 1. Given the definition of total cost, we framed the problem into four quadrants resulting from the categories of tangibility - characterized by market values - and directness - characterized by contiguity in the space and time of the occurrence of the hazard. However, for the purpose of this paper, we emphasize the distinction between tangible and intangible costs (i.e. respectively the right and the left quadrants of Figure 1).

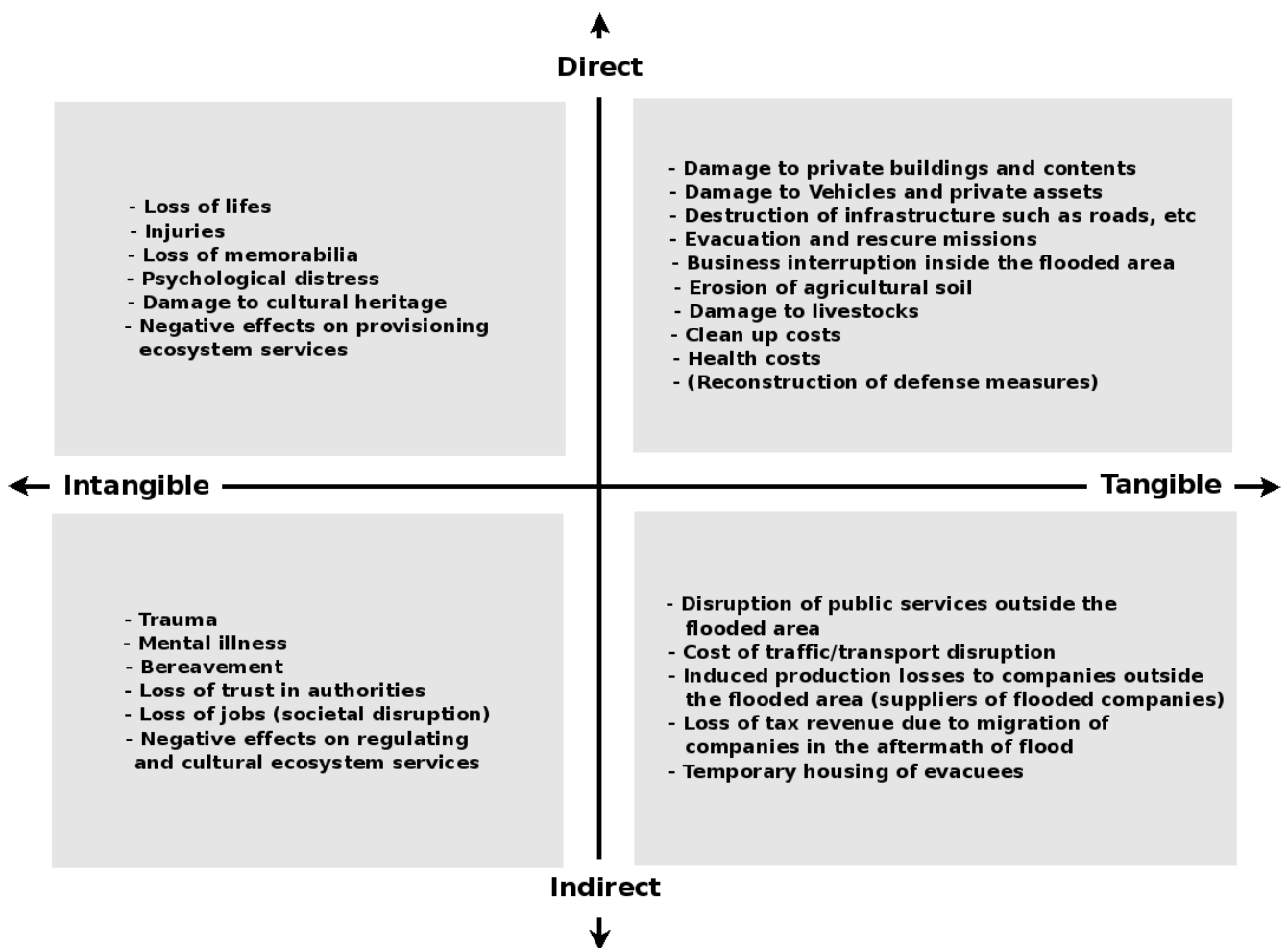


Figure 1: Total costs of hydro-meteorological disaster (adapted from Penning-Rowsell et al., 2003; Jonkman et al., 2008 and Merz et al., 2010).

## 2.1 Tangible costs

Tangible costs can be measured as direct losses of economic assets or stocks as well as the consequential indirect effects on the economic flows, such as GDP or consumption (ECLAC, 2003). There has to be a clear distinction between stocks and flows. The economic impacts can be identified as direct when stocks are impacted and indirect when flows are affected (Benson and Clay, 2003; Cavallo and Noy, 2010).

In principle, each economic loss can be estimated either as a change in the stock or as a change in the flow (Rose, 2004a). The practice is to calculate whatever is easier to estimate. The stocks are counted as existing stocks (i.e. before the floods) directly impacted at a specific time (i.e. during the flood event). These stocks can also include the stocks for future production. In addition floods may induce a stop of production during the floods and afterwards, during the recovery phase. The losses of what could have been produced are preferably measured as losses to flows (Green et al., 2011). If both stock and flow values are used in the assessment, an essential rule is to monetize each individual component of a damage of any category either by stock values or by flow values (Messner et al., 2007). Including both for one component would lead to double counting.

However, double counting is frequent in practice (Cochrane, 2004) also because the relationships between direct and indirect costs are not easy to capture (Heinz Center, 2000; BTE, 2001). Following the “Source - Pathway - Receptor - Consequence” approach (Gouldby et al., 2005), which is adopted in flood damage assessments, it is common to distinguish between first, second, and third order effects depending on the contiguity of the consequence to the occurrence of the hazard. Direct costs would derive from first order consequences. Indirect costs would derive from higher order consequences.

First order consequences are located in the flood area and they would potentially depend on the contact with water (Green et al., 2011). Direct costs of this type would include the value of damages to physical assets in the flooded area, but also the costs for emergency services, including public spending for evacuation and clean-up, and health costs. The costs for emergency services are easily measurable and often outweigh the remaining direct economic costs (Penning-Rowsell and Wilson, 2006).

Consequences of the second order may also unfold indirectly, affecting receptors near to the flood area and altering their activities (Green et al., 2011). This kind of consequences might depend on the network structure of the system rather than on the receptor’s spatial proximity to the flood. For instance, if a minor road is flooded, it may induce indirect effects within a few kilometres. But if a railway is flooded, it may have consequence hundreds of kilometres around. If an international airport is flooded it will affect other parts of the world. Indirect costs of this type would include the costs due to the disruption of production and to traffic diversion.

The third order consequences are related to what is happening after the flood and during the recovery phase (Green et al., 2011). Indirect costs of this type would include: decline in investments, drop in national/regional income, opportunity costs of flood-related budget expenditure, increase in food imports, etc.

However, reconstruction can also lead to positive economic consequences: new investments may lead to a boom during the disaster recovery phase. Much depends on the availability of capital within the impacted area or from outside (Olsen and Porter, 2011).

### 2.1.1 Direct tangible costs

After determining the costs of the emergency services, the second step of any hydro-meteorological disaster assessment is to evaluate the costs of damages to the physical properties and economic assets. In general, and especially for large-scale disasters, it is not possible to assess the damage for each single object, because

there is no information on the damages to every object and/or because such a detailed assessment would require a huge effort. Therefore, elements at risk are pooled into classes, and the damage assessment is performed for the different classes, whereas all elements within one class are treated in the same way (Merz et al., 2010).

A central idea in flood damage estimation is the concept of stage-damage functions. They relate damage for the respective element at risk to the characteristics of the inundation (i.e. the flood maps and the land-use maps reflecting the type and the density of objects at risk) (Wind et al., 1999; NRC, 2000). For physical assets such as buildings (contents and structure) two functions are commonly used: the relative (e.g., Kreibich et al., 2010) or the absolute function (e.g., Prattenthaler et al., 2010). The absolute function consists in establishing the damage function for a particular asset in monetary terms either in relation to the building or per unit area. The relative function provides the susceptibility expressed as a percentage of the total value of the assets.

Direct costing methodologies are quite well-established in the literature, but there still seems to be a mismatch between the relevance of the damage assessment and the quality of the available models (e.g., the stage-damage functions) and datasets.

### *2.1.2 Indirect tangible costs*

Indirect economic costs are those costs induced by direct damages and spread throughout the economic system (Merz et al., 2010) both in space and in time. The limitation of accessible primary data have led to attempts to measure indirect damages using economic models that have long been utilized for economic forecasting such as (1) regional econometric models, (2) input-output models (I/O), and (3) computable general equilibrium (CGE) models (Rose 2004). Such kinds of models study the propagation of direct economic effects and lead to a total indirect cost estimate. As shown in Okuyama and Sahin (2009), different kinds of disasters have different direct-to-indirect costs multipliers ranging from 0.86 to 0.96. The transferability of multipliers might be considered as a step towards a more accessible estimation exercise.

With regard to the temporal dimension, a major part of the analyses on indirect costs has focused on the effects of floods on income or gross domestic product (GDP) (Green et al., 2011). Some of the main findings are that:

1. The effects of floods on growth might be significant in the short-term but insignificant in the medium and long term (Albala-Bertrand, 1993);
2. There are positive effects after the disaster (i.e. recovery booming) if aid is provided (Merz et al., 2010).

However, social costs of disaster are not accurately represented by the change in the GDP (EC, 2009). In this respect GDP is a misleading measure of welfare. For example, while flood risk reduction expenditures are counted in social cost assessment, at least part of them will, at the same time, be included positively in the calculation of GDP (EPA, 2008). Other indicators of welfare might be more appropriate For instance Rodriguez-Oreggia et al. (2010) found that there is a significant impact from natural disasters on reducing the Human Development Index (HDI) and also on increasing poverty levels. In particular, in developing countries, given their relatively high level of vulnerability, floods may have significant negative consequences. An increase in indebtedness and trade imbalances can often be observed (Albala-Bertrand, 1993). Moreover, the frequency of floods is one of the main factors that impede sustained development in flood prone areas (UN, 2008). Other indirect costs might include the cost of inflation due to negative effects on the supply system (Cavallo and Noy, 2010).

Concerning the spatial dimension, it has been argued that the aforementioned traditional economic system modelling techniques are inappropriate for simulating natural disasters and that those must be substantially revised in order to produce reliable estimates of indirect effects (Merz et al., 2010). Given the



interconnectivity of economies and globalization, the causes and consequences of a disaster can be connected through complex networks. This may require computational algorithms for modelling supply shocks, post-event supply constraints and time phased reconstruction in disaggregated spatial settings (e.g., Van der Veen and Logtmeijer, 2005; Yamano et al., 2007).

At the same time, other semi-quantitative approaches have explored the potential of stakeholders' inclusion and expert knowledge elicitation. Pfurtscheller and Schwarze (2010) developed a simplified vulnerability scorecard system to raise awareness of indirect effects in regional disaster management (Merz et al., 2010).

## **2.2 Intangible costs**

Intangible costs such as losses of human lives, cultural heritage, and ecosystem services have been largely neglected in the field of economics of natural disasters even though there is great body of work on the value of statistical life and on the evaluation of environmental goods (Krutilla and Fisher, 1985; Viscusi and Aldy, 2003).

These costs are more difficult to estimate for two reasons: (1) it might be difficult to identify them (e.g., what is the effect of a flood on an ecosystem?) (2) it might be difficult, controversial and inconvenient to monetize them. Apart from the ethical issues involved, for instance, in valuing human lives there exist a series of biases in the valuation of non-market goods, which depends on the methods applied. For example, some of these methods make use of hypothetical scenarios, which can undermine the credibility of results. Further, non market valuation methods other than benefit transfer, might be highly resource and time consuming when there are multiple intangible costs to be taken into account in a single assessment, as it frequently happens at the meso-scale.

On the one hand, it could be accepted that intangible costs remain unmonetized, and thus are referred to as impacts. On the other it is mandatory to identify and include them in any assessment that has the ambition of being realistic and comprehensive. In the following, we distinguish between impacts on people and impacts on the environment.

### *2.2.1 Impacts on people*

Beside the economic loss, potential impacts on individuals are: mortality, injuries, diseases (e.g., diarrhoeal, vector-borne) and infections, chemical pollution, nutrition and displaced population (Few et al., 2004). Only a small part of these impacts is captured by direct health costs. Psychological or mental health impacts are also recognised and are related to various flood impacts such as the stress of the flood itself, the evacuation, the disruption to life and household and the loss of memorabilia and personal belongings (Tapsel and Priest, 2009). Loss of cultural heritage is a further potential impact which can be associated to, but it is barely approximated by the damages to historic physical assets, as certain disaster might affect the folklore, traditions, language, and knowledge of the involved communities. However, social benefits can also arise from the redistribution of assets and income in a community after a disastrous event (McSweeney and Cooms, 2011).

Indeed, in the public opinion, the tribute of lives is unanimously recognized as the most important impact of any disaster. In the last ten years, high losses of lives due to floods have mainly concerned developing countries, while in Europe the risk of dying directly by flood is relatively low. The main factors of risk are given by the high velocity and high depth associated with debris, which involve a loss of stability in the water and increase the risk of drowning. Time lag is also crucial as it constrains the potential time of warning and evacuation. Local circumstances (e.g., presence of shelters, type of buildings, time of the day, seasonality, warnings) play a strong role (Green et al., 2011).

Including mortality in a cost-benefit analysis implies the quantification of human lives in monetary terms. A comprehensive review of this issue is beyond the scope of this report, and thus, we refer to the literature on the value of statistical life, which is a concept widely applied for the evaluation of many health and safety initiatives (Jonkman and Vrijling, 2008; Doucouliagos et al., 2011).

Current economic approaches limit the assessment of social capital to the level of the individual. Typically the number of flooded households is considered and eventually a specific factor is applied to adjust the number to the population size. However, negative effects can also result from floods such as social disorganization due to the loss of life, refugees, loss of trust in the authorities leading to the ruin of local economy or even to political change and instability (Green et al., 2011). For instance, repeated “false positive” flood alerts may undermine the trust in local authorities and impose an evitable load of stress to the population.

### *2.2.2 Impacts on the environment*

Floods are natural phenomena that are related to characteristics of the specific catchment. The environment of a catchment is a mosaic of interdependent ecosystems, which develops around the prevailing water regime. Ecosystems and species can also be considered as hazards’ receptors. Floods (and landslides) also have ecological effects, which might be favourable. Favourable effects include, for example, the benefits from the water and sediments that floods bring to wetland areas, thereby enhancing these locations as bird habitats. Floods thus help to maintain the natural character of these areas and the biotic diversity that they support (FLOODsite, 2009). Unfavourable effects occur where floods invade areas with water intolerant ecosystems, or where floods lead to erosion or deposition of sediments to the detriment of the species normally based there, or where flood waters disperse pollutants that adversely affect floodplain habitats and/or their species (FLOODsite, 2009).

Floods may move good soil from one place to another, or bury cropland under sediments, significantly affecting its fertility in positive or negative terms. For plants, the seasonality is the most critical factor. Regular flooding of dry land during the growing season is undesirable but outside the growing season is relatively unimportant. Further, if a flood increases the availability of a nutrient in an area where naturally the soil is nutrient poor, then the result may be to change the species composition (Green et al., 2011). Thus, it is crucial to determine when and where a flood will have beneficial effects on the existing ecosystems and when it will have harmful effects. Many decisions involve environment-to-environment trade-offs such as the preservation of a dry land ecosystem or the enhancement of a wetland ecosystem (e.g., Leschine et al., 1997). This might imply the evaluation and prioritization of the ecosystem services (Alcamo et al., 2003). Primary sector activities such as agriculture, forestry, fisheries and hunting depend on a wide range of provisioning and regulating services that together shape the natural capital on which these sectors depend (Chiabai et al., 2009). The potential decrease in the quality of soil and the loss of soil structure are definitely to be considered as intangible environmental impacts.

Considering the environmental implications of catchment and floodplain management options for hydro-meteorological disaster risk reduction may also be relevant. These could include changes in run-off and flood characteristics in each compartment of the catchment.

## **3. Valuation methodologies**

In the first part of this section, we briefly review the main cost estimation methodologies, which have been applied to hydro-meteorological disasters. The methods reported here, and summarized in Table 1 in the Appendix, could be divided into three main clusters of valuation techniques: (1) market-based (MB), (2) non-market-based (NMB), and (3) traditional and integrated economic system modelling (T&IESM). In

Table 1 (Appendix) the capacity of each method in addressing the different categories of costs is considered. Additionally, the appropriateness of each method with regard to scale, data and resources availability is analysed. One reference for each method and a typical example are provided.

### 3.1 Market-based approaches

This set of methods uses market-based indicators in cases, where the environmental goods and services can be associated with competitive markets (Eftec, 2010).

The market price method is mainly used to estimate the economic value of any product or service that is bought and sold in commercial markets. It can be used to value changes in the quantity or quality of a good or service. The estimation starts with assessing the quantity people purchase at different prices (demand curve) and the quantity supplied at different prices (supply curve). In the case of quality change, one observes a change in the market demand function for a good or service (consumer's surplus) and a change in benefits or losses of producers (producers' surplus). The sum of surpluses represents the total net economic benefit of a good or service in a market (Logar and van den Bergh, 2012).

A production function approach (also known as dose-response) estimates a function that specifies the output of a company, an industry or the whole economy based on the combination of inputs (Logar and van den Bergh, 2012). Econometric analysis is used to relate output to inputs. The same approach can be used to derive inverse demand functions based on the observation of consumers' behaviour. An important caveat of this method is that production functions are often not known as precisely as needed.

The cost of restoring the environment to its original state is estimated by applying the replacement cost method (Brouwer, 2006). The replacement or repair cost approach assumes that the costs of replacing or repairing an ecosystem good or service represents a reasonable estimate of its value. On the one hand this method is often seen as a lower bound to the real value of the good or service (Logar and van den Bergh, 2012). On the other hand this method is often used for very detailed analysis at the micro-scale, where the costs can easily be overestimated if the depreciated values of the elements that need to be replaced are not taken into account.

The appropriateness of these methods is limited to cases, where there are markets or where shadow prices can be estimated, thus they may not be used to estimate non-use values<sup>1</sup>.

### 3.2 Non-market based approaches

Although many environmental or cultural goods and services are not traded in the market, their characteristics affect demand of other goods and services, which are traded in the market (Eftec, 2010). These goods are generally a subclass of public goods, which are defined by non-excludability and non-rivalry. For determining their damage potential, the public value has to be estimated on the basis of people's preferences. The non-market value of environmental or cultural goods can be decomposed into several sub-categories. We need to distinguish between 'use value' and 'non-use value' of these goods (Arrow et al, 1993). The total use value generated by the site is the sum of the all individual visitors' willingness to pay (WTP) for using the commodity. Narrowing the value of cultural and environmental goods to the use-value often leads to a bias for globally important sites as their direct users often comprise more than local residents.

The non-use value estimation might be motivated by the aim to cover the fact that a site is available for others to visit (altruistic value), or the site is preserved for future generations (bequest value), or the

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<sup>1</sup> Non-use value (also known as passive value) refers to the value of a good or commodity for those who do not directly consume the good but benefit from its existence.

current non visitor might decide to become a visitor in the future (option value), or simply the site is preserved even if no one ever actually visits it (existence value) (Throsby, 2003; 2007; Iacob et al., 2012). Researchers are advised to embed questions regarding bequest, existence and option values in their questionnaires to avoid under-estimation of economic value of environmental or cultural goods. Considerations of all the above-mentioned motives expand the extent of the market, and include a larger number of potential national or international contributors.

The three following methods rely on this assumption and thus are known as surrogate market or revealed preference methods.

i) The avertive behaviour and defensive expenditures technique is focused on averting inputs as substitutes for changes in environmental characteristics (EPA, 2008).

ii) Travel cost method originally proposed by Hotelling (1947) uses questionnaires to elicit the transport costs and the time value for implicitly assessing the price of an environmental service (Brouwer, 2006; EPA, 2008). This method can be further developed along two lines:

The zonal travel cost method due to Clawson and Knetsch (1966) splits the visitors into groups based on distance of visitors given their point of origin from the recreational site. In the next step, the demand curve is based on the reaction function derived from the average travel cost and the number of visits from each zone. The area under the demand curve represents the consumer surplus, which approximates monetary value of visiting the site.

The individual travel cost method, which attempts to estimate the demand of the recreational good for each individual at a given site. This method is more appropriate, when the travel costs of visitors from the same zone might vary from person to person. Once the individual demand functions are aggregated, an aggregate demand function is derived. This method has several practical problems as shown in Bedate et al. (2004).

For hydro-meteorological disasters the travel cost method might be well suited to estimate the costs of traffic disruption (Green et al., 2011).

iii) The hedonic price method is applicable to environmental and cultural attributes likely to be capitalized into the price of housing and/or land (Brouwer, 2006). This method employs the differences in the prices of marketed goods to derive the value of environmental and cultural characteristics (EPA, 2008). Thus, market distortions can bias the obtained prices. Ruijgrok (2006) employing hedonic price method studies the price of 591 residential houses near to a historical zone in the Netherlands. He estimated a benefit of 21.6 Million € for the cultural heritage conservation.

Both travel cost and hedonic price methods are based upon revealed preferences and make use of multivariate regression technique. Alternatively, methods related to stated preferences are based on interviewing the final beneficiaries and derive their surplus value changes.

The following three methods are applied to estimate economic values where there are no market-based prices and consumer behaviour data (Eftec, 2010).

i) The contingent valuation method (CV) is used to evaluate non-market resources with a structured survey. CV uses questionnaires, which are functional to collect respondents' WTP and/or willingness to accept compensation (WTA) with respect to an environmental damage (Green et al., 2011). The economic values estimated via CV are contingent upon a hypothetical market or governmental plan. Thus, the data generated this way is based on hypothetical scenarios. Some of the main problems with this method are: (a) the strategic bias, when respondents intentionally give responses that do not reflect their "true" values; (b) the costs of the studies; (c) time constraints (the practical implementation of the CV could require six months to a year); (d) the self-reported WTP is significantly higher than actual WTP (Seip and Strand, 1992); (e) difficulties with determining the scope of the market; (f) inconsistency with the assumption of rational choice

(Kahneman and Knetch, 1992); (g) budget constraints is often not reminded in the studies. Despite the drawbacks, it is considered the only method for estimating non-use values. For example, Ruijgrok (2006) using CV method estimated the benefits of recreation and bequests to be 1.22 € (per visit) and 11.88 € (per year per household) respectively based on 380 interviews that he conducted. Out of 380 respondents, 85.2% were willing to pay for preservation of cultural heritage in their area. Furthermore, considering the 2.8 million direct users living in the three provinces nearby, the total bequest value was estimated near € 34 million per year.

ii) In choice experiments the individuals have to compare different alternatives described by an array of attributes, including a cost or price attribute (Olschewski et al., 2012). The set of possible choices has an important impact on the results and may be difficult to handle for the respondents (McFadden et al., 2005). As for the CV, it is required to have a substantial knowledge of econometric analysis and statistics (Brouwer, 2006).

iii) Life satisfaction analysis is a typical multidisciplinary approach. This method makes use of surveys to ask people to assess their current level of happiness. Economic values are determined based on the respondents' answers and additional socio-economic indicators such as: income level data and environmental conditions. This data is processed with econometric modeling techniques (e.g., regression analysis) (Clark and Oswald, 2002; Logar and van den Bergh, 2012).

### **3.3 Traditional and integrated economic system modeling**

Different types of modeling of the economic system are also employed to explore in particular the indirect costs of a disaster. Most well established methods tend model abstract economic systems disconnected from the surrounding environmental systems. Other tends to loosely couple the different systems, finally some aim at a full integration.

Optimization models are used to provide mathematical solutions to problems that entail maximization or minimization of an economic objective subject to specific constraints. Given the problem's optimal solution, the model reveals the inputs' economic value. (In particular, linear programming can provide guidance regarding optimal (maximum value added) allocation of scarce post-event production capacity (Cochrane, 2004). It minimizes or maximizes an objective function by choosing a set of decision variables, under a set of linear constraints (like available technologies, productive capacities, fuel supplies and regulations) (EPA, 2008).

Regional econometric models represent historical trading patterns and are useful only in case that they reflect balanced and undistorted economies. Regional econometric models are based on panel data. These models include estimates on employment, wages, incomes, population, and prices of a specific region, and use equations that represent the interregional trade of the industry and the in-and-out migration flows. They are capable to explain how an economic change in one region spills over to other regions and creates a feedback effect in the original one (Greenberg et al., 2007).

Computable general equilibrium (CGE) analysis examines the economy-wide impacts of a change in a policy, technology, exports, or other exogenous factors (Logar and van den Bergh, 2012). CGE addresses the problem of uneven supply shocks and simulates the price system in a market economy. CGE models are useful to reproduce the economic losses as a percentage of GDP (Sahin 2011). However, the main purpose is to analyze the interactions between many and different economic agents each of which is represented by an equation (Greenberg et al., 2007; Logar and van den Bergh, 2012; Sahin, 2011). This method is suitable for macroeconomic assessments and for long-run equilibrium analysis, but it is based on several assumptions, such as (1) optimizing behaviour of consumer and producers (which is questionable under disaster situations), (2) market-clearing or (3) competitiveness of product and factor markets. Several attempts have

been made to couple CGE models with environmental models (e.g., climatic and hydraulic), however available CGE models still prove to be primitive tools that are ill-suited when capturing most environmental concerns (Scricciu, 2007).

Input-Output (I/O) models are built around a matrix that registers the use of factors of production (e.g., labor, capital, land) and other inputs in the production of specific goods. Thus it is possible to reflect the economic interdependencies within a macro-regional economy (Okuyama and Sahin, 2009), using a table that describes the interrelated flows of goods and factors of production over the course of a year. I/O econometric models integrate the conventional I/O models with econometric macroeconomic models. These models are often used to estimate the policies and regulations regional impacts, and also long-run impacts (EPA 2008). The I/O method can substitute CGE and it's easier to apply, although it is even more restrictive in terms of assumptions about production factors and technological change (Logar and van den Bergh, 2012). Social accounting matrixes (SAMs) are particular I/O matrixes that compile all the monetary flows among agents and sectors from a particular economy. They are widely used in the international development community to examine the indirect effects across different socio-economic agents, activities and factors at a very aggregated level (Okuyama and Sahin, 2009). However, these models assume fixed technology and productivity, making future transactions patterns identical to the current one (Greenberg et al., 2007). Further, they are incapable of capturing the price changes effects due to a disaster. The linearity and the rigid structure may lead to overestimation of impacts (Greenberg et al., 2007; Rose 2004; EPA 2008).

Integrated economic simulation tends to fully integrate the modeling of coupled human and environmental systems taking into account the socio-economic dimension amongst the others. Biophysical-agro-economic models provide comprehensive insights into the feedback effects between human activities and natural resources. When applied to the agricultural system they produce biophysical estimates of crop responses to climate events, with the use of spatially explicit models on different geographical scale. The obtained estimates are incorporated into socio-economic models to predict farmers' decisions (or decisions of other human agents, e.g., households), and then to aggregate these decisions at the market level to forecast changes in supply prices (Logar van den Bergh, 2012). Coupled hydro-meteorological-economic models constitute a well-established typology of these models. They have three components: (1) a hydro-meteorological component, (2) an economic optimization model, and (3) an institutional factor (Logar and van den Bergh, 2012). These models are mainly used to analyze the impacts of water allocation and they are used by different sectors under alternative policy scenarios. The currently developed integrated economic simulation models are more oriented towards the possibilities offered by the advances in computer science and yet partially implemented in the field of computational economics, social simulation, and ecology (Balbi and Giupponi, 2010). This approach studies the human society, the economy and the surrounding environment as interrelated complex systems that can be represented in their disaggregated form by employing a set of methodologies, most notably agent-based modeling, network theory and Bayesian networks, geographical information systems, etc. However, there still exist some scepticism about formalization, testing and use of this generative type of knowledge.

Finally, benefit transfer is a method that actually does not belong to any of the clusters presented and it is added here as it's often the simplest and most cost-effective way when other pertinent primary studies are available. Benefit transfer is the transfer of economic values estimated in an original study to a spatially and temporally different one. This practice is accepted when the characteristics and the context of the original study are similar to the new one. It is less time and resource consuming than the previous methods and therefore widely applied in meso and macro contexts where multiple single estimations would otherwise have been applied. Note that more refined benefit transfers exist (i.e. function transfer, meta-analysis) rather than simply applying previously estimated values.

## 4. Conclusions and perspectives

The concept of total cost is highly ambitious, because it aims at determining the total burden imposed by a disaster to a socio-ecosystem, including costs (incl. benefit losses), which are difficult to identify and quantify. It comprises all direct, indirect, tangible, and intangible costs. While most of the existing studies focus on one of the quadrants of the total cost matrix, we could not find any application aiming at comprising all of them. Intangible costs, in particular, have been widely neglected in the field of economic valuation of natural disasters.

General motivations that are usually brought forward by experts to explain this gap are:

1. including these costs in an assessment is considered to be too challenging and resource consuming;
2. a one dimensional result might not be considered acceptable by a decision maker, especially when ethical implications are strong (e.g., aggregation of asset values and human life values);
3. the estimation of total costs could lead to the justification of any risk reduction investment in a cost-benefit analysis context.

However, all these motivations do not seem to capture the real essence of the problem. In fact, firstly, resource-consuming challenges are usually those boosting innovative solutions in the research arena. Secondly, ethical implications in valuing non-market goods have never constrained the research in environmental and health economics. Further, figures coming from different typology of costs could also remain non-aggregated in the total cost matrix framework. Finally, the third point may not hold when it comes to the valuation of trade-offs among non-structural measures of risk reduction.

The real justification of this gap might become clearer when adding the notion of scale to the discourse (i.e. micro, meso, and macro, according to the biophysical, administrative and temporal boundaries imposed to the system under analysis). Table 1 (Appendix) has made explicit the fact that it is extremely difficult to find methods that can efficiently cover all cost categories for all scales.

For instance, most of the methods (mainly NMB) that are widely implemented for the estimation of intangible costs are more appropriate for the micro-scale. However, micro-scale studies are often not suitable for capturing indirect effects, both in spatial and temporal terms.

With regard to the meso-scale, which is often of major interest for the water basin authorities, it becomes difficult to apply the same NMB methods to estimate intangible costs because this would require a lot of resources (e.g., these methods require time and money and cannot be generalized to diverse intangible assets). In those cases, it is cost-effective to end up using benefit transfer, at the expense of precision and methodological challenges. At the macro-scale the application of benefit-transfer is theoretically feasible, but often the analyses are carried out at a highly aggregated level, which makes it difficult to determine appropriate values. In other words, in many cases the estimation of total costs becomes accessible by using benefit transfer.

Valuation should always be tailored to the case study according to its boundaries and the available data. Consequently, a priori, no single methodological framework for a total cost assessment should be excluded. However, one might conclude that based on this review a peculiar role of benefit transfer emerges in the estimation total costs. This aspect deserves further research and discussion concerning the chances and limits of benefit transfer approaches in general as well as in the specific context of this paper. In particular, looking at how the existent scientific knowledge is sufficient and/or properly organized to facilitate the transfer of values for the estimation of total costs due to hydro-meteorological disasters is of main operational relevance.

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## Appendix

Table 1: Summary of selected cost estimation methodologies (adapted from Logar and van den Bergh, 2012)

Costing Methodology	Cluster	Dir. Tan.	Ind. Tan.	Dir. Int.	Ind. Int.	Sugg. Scale	Data need	Resources/ skills need	Typical application	Selected references
Market price	MB	<b>X</b>	<b>X</b>			Meso	Prices and quantities in the market	Fairly simple	Crop loss	Rayhan and Grote, 2010
Production function	MB	<b>X</b>	<b>X</b>			Micro	Output and parameters of prod. functions	Regression analysis	Value of a damaged input to economy	Nakano et al., 2011
Replacement cost	MB	<b>X</b>		<b>X</b>		Meso	Cost of replacing, depreciation factor	Fairly simple	Residential property damage	Middelmann-Fernandes, 2009.
Surrogate Market	NMB			<b>X</b>	<b>X</b>	Micro	Ad hoc surveys, values of properties	Regression analysis	Value of amenities at risk	Samarasinghe and Sharp, 2010
Contingent Valuation	NMB			<b>X</b>	<b>X</b>	Micro	Ad hoc surveys, census data	Regression analysis, field work	Value of increasing flood protection	Brouwer et al., 2009
Choice Experiment	NMB			<b>X</b>	<b>X</b>	Micro	Ad hoc surveys, census data	Regression analysis, field work	Value of an early warning system	Zhai et al., 2007
Life Satisfaction	NMB			<b>X</b>	<b>X</b>	Micro	Ad hoc surveys, census data	Regression analysis, field work	Stress of living in a flood prone area	Luechinger and Raschky, 2009
Regional Econometric Models	T&I ESM	<b>X</b>	<b>X</b>			Meso	Ad hoc surveys, transactions, consumption, etc.	Regression analysis	Cost of cascade effects in the aftermath	Takasaski et al., 2004
Computable General Equilibrium	T&I ESM	<b>X</b>	<b>X</b>			Macro	I/O and SAMs tables, elasticities, etc.	Modelling with ad hoc softwares (e.g., GAMS)	Cost of disruption of supply of critical inputs	Rose and Liao, 2005
Input-Output (SAM)	T&I ESM	<b>X</b>	<b>X</b>			Macro	Transactions, wages, consumption, taxes, etc.	Fairly simple	Cost of higher-order effects	Okuyama and Sahin, 2009
Integrated economic simulation	T&I ESM	<b>X</b>	<b>X</b>			Micro, Meso	Biophysical, hydrologic and socio-economic data	Ad hoc tools and programming skills	System level shocks and dynamics	Werner and McNamara, 2007
Benefit Transfer	N/A	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	Meso, Macro	Previous similar primary studies	Fairly simple, Regression analysis for refined solutions	Value of ecosystem services	Brander et al., 2012

Note to Table 1: Clusters of methods: market-based (MB), non-market-based (NMB), traditional and coupled economic system modelling (T&IESM). The Xes in bold identify the preferred field of application. Suggested scale can be Micro, Meso, and Macro as proposed in section 2.

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