On the modeling of significance for flood damage assessment

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1. Introduction

Comprehensive estimation of losses is important both ex-ante and ex-post flood events. Ex ante, the interest lies in the identification of the most suitable mitigation measures; having a reliable figure of the "total damage" and also its "composition" due to direct physical, indirect and other types of damages on the several exposed sectors (see below), is important for appraising the cost-efficiency of alternative mitigation options. This is clearly a fundamental aspect of any "flood risk management plan" as required by the recent Flood Directive [1]. On the other hand, being able to estimate the "total loss" after an event is equally important to support the emergency management and to decide priorities for reconstruction and for compensating victims.

Ideally then, all flood damages should be taken into account in risk assessment; as set out in Table 1 which lists all types of likely damages from flooding. The table synthesizes current knowledge from available literature (for a review see [2,3]) and current practices (i.e. flood damage assessment software, e.g. HAZUS-MH, HEC-FIA, and established methodologies, e.g. [4]), and classifies damages according to both the exposed sector and their nature (i.e. direct/indirect/intangible). A pragmatic approach is adopted according to which damages are classified into direct and indirect, tangible and intangible losses [4–8]. Within each of these categories further classification is possible in line with sectors of affected items such as damage to the residential sector, industry, people, infrastructure, etc. [9]. Table 1 points out that flood damage consists of all the harmful effects of a flood on a community: impacts on people, their health and their belongings, impacts on public infrastructure, cultural heritage and ecological systems as well as impacts on industrial production and the competitive strength

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Table 1
Flood damages in case of flood, adapted from Molinari [28].

Sector	Types of damage	Examples
Residential	Structure + contents (direct) Indirect Intangible	Carpeting, painting, furniture Clean up, temporary housing Loss of memorabilia
Commercial	Structure + contents (direct) Indirect Intangible	Carpeting, painting, stock, machinery Loss of income, additional cost, sandbags, pumps Loss of memorabilia
Farming	Physical damage (direct) Indirect Intangible	Livestock, crops, machinery Loss of income, repair fences, remove debris Loss of memorabilia
People	Physical (direct) Intangible	Death, injuries Stress, anxiety
Public	Structure + contents (direct) Service interruption (indirect) Intangible	Carpeting, painting Health, school services Loss of "sense of community"
Infrastructure	Physical (direct) Service interruption (indirect)	Lines, bridges, water tanks, plants Electricity, water supply, traffic
Environment	Ecological (direct) Service interruption (indirect) Intangible	Ecosystems Tourism, recreational activities Loss of "sense of community"
Cultural heritage	Physical (direct) Service interruption (indirect) Intangible	Museums, churches, historical buildings Tourism, recreational activities Loss of "sense of community"
Event costs	Warning + emergency (indirect) Intangible	Evacuation, warning, shelters, sand bags Loss of trust

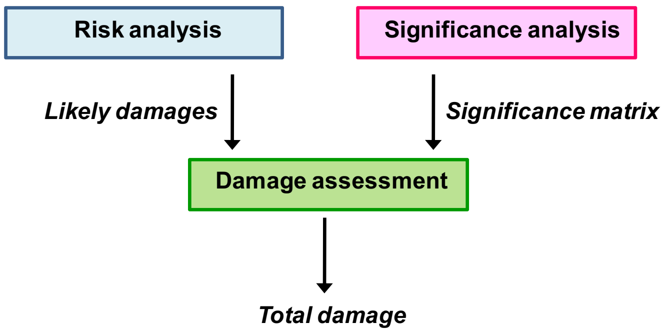

Fig. 1. Context of damage assessment (single column, color on the web only).

Table 2
investigated contexts and sample size

Context	Stakeholder (s)	Spatial scale (L)	Objective, temporal scale (o/T)	Number of interviewees		
				Italy	Australia	Total
A	Regional	Region/state	Ex-post, months to years	3	1	4
B	Regional	Affected area	Post-impact emergency, aftermath	3	1	4
C	Regional	Municipality	Planning, several years	0	1	1
D	Local/mayor	Municipality	Ex-post, months to years	1	0	1
E	Local/mayor	Municipality	Post-impact emergency, aftermath	1	0	1
F	Local/mayor	Municipality	Planning, several years	1	1	2
G	Provincial authority	Province	Ex-post, months to years	1	0	1

Table 3

Significance matrices deriving from interviews results. Matrices report damage significance against context (A, B, C, D, E, F, G) and country (IT–Italy, AU–Australia). "n.s." indicates that the category was not surveyed. In italic bold there are differences between countries.

Sector	Type of damage	Significance (SI)													
		ContextA		Context B		Context C		Context D		Context E		Context F		ContextG	
		IT	AU	IT	AU	IT	AU	IT	AU	IT	AU	IT	AU	IT	AU
Residential	Structure+contents	1	1	1	1	n.s.	1	1	n.s.	1	n.s.	1	1	1	n.s.
	Indirect	1	1	0	0	n.s.	1	1	n.s.	0	n.s.	***0***	***1***	1	n.s.
	Intangible	0	0	0	0	n.s.	1	1	n.s.	1	n.s.	1	1	0	n.s.
Commercial	Structure+contents	1	1	0	0	n.s.	1	0	n.s.	1	n.s.	1	1	1	n.s.
	Indirect	1	1	0	0	n.s.	1	1	n.s.	0	n.s.	***1***	***0***	1	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	1	n.s.	1	1	0	n.s.
Farming	Physical damage	1	1	0	0	n.s.	1	1	n.s.	1	n.s.	1	1	1	n.s.
	Indirect	1	1	0	0	n.s.	1	1	n.s.	0	n.s.	1	1	1	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	1	n.s.	1	1	0	n.s.
People	Physical	1	1	1	1	n.s.	1	1	n.s.	1	n.s.	1	1	1	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	1	n.s.	1	1	0	n.s.
Public	Structure+contents	1	1	1	1	n.s.	1	1	n.s.	1	n.s.	***1***	***0***	1	n.s.
	Service interruption	1	1	***1***	***0***	n.s.	1	1	n.s.	0	n.s.	***1***	***0***	1	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	1	n.s.	1	1	1	n.s.
Infrastructures	Physical	1	1	***1***	***0***	n.s.	1	1	n.s.	1	n.s.	1	1	1	n.s.
	Service interruption	1	1	1	1	n.s.	1	1	n.s.	1	n.s.	1	1	1	n.s.
Environment	Ecological	1	1	0	0	n.s.	1	1	n.s.	0	n.s.	***1***	***0***	1	n.s.
	Service interruption	***0***	***1***	0	0	n.s.	1	1	n.s.	0	n.s.	0	0	0	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	0	n.s.	1	1	0	n.s.
Cultural heritage	Physical	1	1	***1***	***0***	n.s.	1	1	n.s.	0	n.s.	1	0	1	n.s.
	Service interruption	***0***	***1***	0	0	n.s.	1	1	n.s.	0	n.s.	0	0	1	n.s.
	Intangible	0	0	0	0	n.s.	1	0	n.s.	0	n.s.	1	1	0	n.s.
Local authorities	Warning+emergency	1	1	0	0	n.s.	0	1	n.s.	1	n.s.	0	0	1	n.s.
	Intangible	0	0	***1***	***0***	n.s.	1	0	n.s.	0	n.s.	0	0	0	n.s.

of the affected economy [10]. Note that Table 1 also includes costs of warning and emergency management (as well as intangible costs like loss of trust in local authorities because of poor decisions) among flood damages. Although they are not strictly damages, their contribution to the total economic loss from a flood event is significant. Their inclusion is thus advisable when damage assessment is tailored to cost-benefits analyses [3].

Taking into account of all items in Table 1 is not feasible in practice. The first problem arises from a lack of standardized models to estimate indirect and intangible damages as well as damage to specific sectors like environment and cultural heritage (see [2,11] for a review). For this reason, damage assessments have traditionally focused on physical damage to buildings (for which standardized tools exist, i.e. depth-damage curves). Secondly, even if models were available, considering all damages implies extensive efforts that increase with the accuracy required by the analysis. Thus a simplified approach would normally be advantageous.

Guidelines and common sense suggest that attention should be focused only on those damages which have the greatest impact, i.e. the "significant" damages. It is sensible that people would choose risk management strategies according to their capacity of reducing significant damages, disregarding those ones which mainly influence non significant losses. Accordingly, cost-benefit analyses (and by extension damage assessments) should focus primarily on significant damages. The question arises as to what damage is significant when?

This paper examines this question, being the identification of what constitutes damages for the purpose of the particular assessment. Significance was assessed by means of confidential interviews with stakeholders; this paper describes and conceptualizes the collected information. In Section 3 a model is proposed to describe damage significance. Then interviews are described, the latter being addressed to test and improve the model. Collected data are finally elaborated in terms of knowledge about damage significance and its explicative variables. In Section 4 interviews results are discussed and a case study is supplied in order to apply survey findings to a real damage assessment. Section 5 supplies a critical analysis of previous results and identifies the potential of and priorities for future research. The conclusions synthesize the main findings of the paper.

Table 4
Application of the significance matrix for Italy to a case study. Damage estimate changes along with significance of damage types within contexts.

Sector	Type of damage	Exposure [M€]	Potential damage [M€]	Significant damage [M€]											
				Context A		Context B		Context D		Context E		Context F		Context G	
				SI	Damage	SI	Damage	SI	Damage	SI	Damage	SI	Damage	SI	Damage
Residential	Structure + content	294	83	1	83	1	83	1	83	1	83	1	83	1	83
	Indirect	–	7	1	7	0	0	1	7	0	0	0	0	1	7
	Intangible	–	–	0		0		1		1		1		0	
Commercial	Structure content	577	125	1	125	0	0	0	0	1	125	1	125	1	125
	Indirect	–	10	1	10	0	0	1	10	0	0	1	10	1	10
	Intangible	–	–	0		0		0		1		1		0	
Farming	Physical damage	0	0	1	0	0	0	1	0	1	0	1	0	1	0
	Indirect	–	0	1	0	0	0	1	0	0	0	1	0	1	0
	Intangible	–	–	0		0		0		1		1		0	
People	Physical	–	–	1		1		1		1		1		1	
	Intangible	–	–	0		0		0		1		1		0	
Public	Structures + contents	n.a.	n.a.	1		1		1		1		1		1	
	Service interruption	–	n.a.	1		1		1		0		1		1	
	Intangible	–	–	0		0		0		1		1		1	
Infrastructures	Physical	25	10	1	10	1	10	1	10	1	10	1	10	1	10
	Service interruption	–	8	1	8	1	8	1	8	1	8	1	8	1	8
Environment	Ecological	n.a.	n.a.	1		0		1		0		1		1	
	Service interruption	–	n.a.	0		0		1		0		0		0	
	Intangible	–	–	0		0		0		0		1		0	
Cultural heritage	Physical	n.a.	n.a.	1		1		1		0		1		1	
	Service interruption	–	n.a.	0		0		1		0		0		1	
	Intangible	–	–	0		0		0		0		1		0	
Local authorities	Warning + emergency	–	21	1	21	0	0	1	21	1	21	0	0	1	21
	Intangible	–	–	0		1		0		0		0		0	
	TOTAL	**895**	**245**		**245 (100%)**		**83 (34%)**		**121 (49%)**		**228 (93%)**		**218 (89%)**		**245 (100%)**

2. State of art and problem statement

2.1. Recent literature

Some suggestions on the significance of types of damage in this context have been supplied by the FLOODsite project. The project report T09-06-01 [10] identifies direct damage to buildings and their inventories as the most important types of damage which should always be included in risk analysis. On the other hand, other damages like those to infrastructure, vehicles and agricultural sectors might be included, depending on the attributes of the flood in question (like velocity, time of the event, etc.). Finally, whether indirect damages are significant will depend in large part on the propensity of affected areas to suffer indirect effects or to induce indirect damage to the surrounding areas (e.g. because of the presence of highly concentrated and specialized industry or services, nodal points in communications networks, etc.). In this respect, Van der Veen and Logtmeijer [12] suggest three main criteria to assess the relevance of what they call systemic vulnerability of the economic system: redundancy and interdependency among sectors and between the latter and utilities and key services as well as transferability, that is to what extent a function can be relocated to another area or substituted by another entity within the economy in question.

The FLOODsite approach derives from an analysis of the weight that each category of damage had on the total economic loss for past flood events. However, social sciences highlight a somewhat different approach. The total value placed on each type of loss is subjective, in that it varies depending on individual priorities and is not simply that reflected by market prices. It is often the case that much greater value is placed on some items which have no obvious market or agreed value, such as human lives or a sense of identity. For example, one might expect that emergency services would place a very high value on loss of lives and discount other values including damage to livelihoods and environment; likewise, farmers and some business owners might place a very high value on losses of key business assets as they are essential for their livelihoods [13] and in many cases also their lifestyles and identity. From another point of view, it is also a technical question; when damage assessment is carried out to support cost-benefits analyses, it is sensible that analysts would consider only those damages which are pertinent to the stakeholder for which the analysis is carried out; thus, for example, mayors are not interested in the national economic loss, but would be concerned about local economic vitality.

The direct consequence of this is that damage assessment should be tuned to stakeholders' perspective: so as to say that there is not a unique definition of the problem at stake but each individual has his/her own perspective in defining and interpreting it [14]. Note that this is in line also with the approach adopted in the analysis of the impacts of other natural/anthropomorphic risks (see [15,16]) as well as with the point of view adopted by the FP7 ConHaz project, as included in [3] and highlighted during the workshop “Flood loss assessment” (London, 26th November 2010). The latter was organized by project partners just to explore the needs of different stakeholders in terms of questions that may be asked about the consequences of floods.

The implementation of multi criteria analyses (MCA) in flood risk management is based on this approach. However, MCA has traditionally focused on the choice of different risk reduction measures like dikes, polders, warning systems or planning strategies, see e.g.[17–23]. Only recently, some attempts have been made at implementing MCA in the production of flood risk maps [24–26], with the intent of weighting the different components of risk (e.g. social, environmental, economic) according to stakeholders' perspectives. Nevertheless, a question arises on how stakeholders weight such components.

2.2. Problem statement

Actually, two different contexts can be identified: the context in which damages occur and the context in which stakeholders act. Damage assessment requires the investigation of both (see Fig. 1).

The characterization of the context where damages occur is what is usually called risk analysis; the latter allows the identification and the assessment of all likely types of damages in case of floods (e.g. those in Table 1), by the analysis of the hazard, exposure and vulnerability features of the affected area. Risk analysis is beyond the scope of this paper.

The investigation of the second context aims instead at evaluating which of previously identified damages is actually significant for the stakeholder the assessment is carried out for. Such an investigation is a sort of prerequisite to any risk assessment as the latter is usually provided in terms of expected damage. The output of such an analysis should be a “matrix of significance”, in which a value equal to 0 (meaning no significance) or 1 (meaning significance) is assigned to each type of damage. Damage assessment should then be carried out only for those types of damage whose significance is 1.

This paper focuses on the investigation of significance, seeking to find an answer to the following questions: is it possible to model damage significance? Which variables play a role? From MCA's perspective, how stakeholders select types of damages to be considered in the analysis?

In fact, it is worth noting that a different exists between selecting the types of damage to be considered in risk analyses, according to the context under investigation, and weighting damages according to the disutility perceived by stakeholders with respect to each possible outcome (see also Section 5). For example, indirect damage to industrial firms should be significant for all the stakeholders dealing with the planning of risk mitigation strategies. Still, it can have a weight equal to 0 for an actor working in a rural area. Significance analysis focuses on the problem of defining contexts in which stakeholders act and coherently select important damages.

The systematic appraisal of damage significance could simplify damage assessment, enabling analysts to recognize at the beginning of the analysis which types of damage must be estimated and which can be ignored. From the point of view of MCA, this is equal to supporting or improving the structure of the MCA model by providing tools for criteria selection [27]. From another perspective, modeling significance would make even more transparent the decision making process about mitigation measures. Decision makers would be aware not only of what is considered (or not) as damage in estimates they are provided with, but also of which variables or factors played a role in the decision of discounting particular damages. This is an improvement with respect to MCA where often damages are weighted according to stakeholders' preferences without a clear explanation of the reasons for their choices.

As an example, the importance of significance arose during the discussion at a recent session on "Taking effective decisions with operational forecasting" at FLOODRisk 2012 conference in Rotterdam. The point under discussion was the feasibility of issuing early warnings in terms of expected risk level, instead of the common practice of expected hazard level. This is not trivial as the significance of expected risk changes according to the stakeholders concerned; for example, negligible damages for the community can be significant for private citizens. Thus, a question arises on how expected risk should be evaluated.

3. Methods

3.1. Developing a model of damage significance: the interviews

As a first step in understanding whether and how damage significance changes, confidential interviews with stakeholders were carried out. The main objective of the interviews was that of testing and improving a draft model for significance, as described by Eq. (1).

$$SI = f(s,o,T,L,C) \quad (1)$$

According to the model, significance (SI) depends on the value of the following variables

- stakeholder (s), i.e. people's role/responsibility; for example, stakeholders can be private or public. Among private, citizens, insurers and service providers can be identified. Public stakeholders include instead public bodies like civil protection, local authorities, etc.
- Objective (o), i.e. the objective of the assessment; damage assessments can be carried out for a variety of reasons: ex post to determine event's impact, ex ante to estimate potential damage in order to choose among different mitigation strategies, etc.
- Temporal scale (T), the time scale of the assessment, i.e. the time window the assessment considers following the occurrence of the event;
- spatial scale (L), i.e. the spatial domain of the assessment; damage assessments can be carried out from the very local scale (e.g. single building) to the very large scale (e.g. country level);
- location (C), i.e. interviewee's country. Roles and responsibilities vary from country to country, according to their institutional arrangements.

The interviews were aimed at evaluating the appropriateness of such variables and at clarifying their role in shaping significance. Nonetheless, gathered information was used to assign significance values, at least with respect to investigated contexts.

Interviewees were identified among the staff of several public authorities responsible for flood risk management, with which the authors collaborate or had collaborated with in the past. These included: emergency management and civil protection services, and local and national authorities (see Section 4). Their expertise varies according to the organization involved, from managers, to technicians and rescuers. No representatives from the private sector were interviewed. During the interview, people were shown a flood scenario (using hazard and vulnerability maps) relating to a flash flood event in a small town and were asked about which categories of consequent damage (using the categories in Table 1) they would consider significant (i.e. they would assess) and why. Likewise, interviewees were asked to indicate what would be (i) the objective of their estimation and (ii) the spatial and the temporal domain they would be interested in.

In total 14 interviews were conducted in Italy and in the state of Victoria in Australia (see Table 2), the objective being to investigate whether or not significance varies along with the jurisdiction under investigation. Note that the survey described in this paper is intended to be an exploratory study because of the limited sample size. Thus, whilst results can be considered indicative, further research is needed before generalizations can be made.

3.2. Data analysis

Looking for a significance model, a first question arises about whether explicative variables are independent or not (i.e. do links exist among them?). Our data show that a strong link exists between the objective of the assessment and the temporal scale of the assessment. This means that for any objective, the temporal scale of the analysis is well defined (see below). Thus the two variables can be reduced to one (i.e. o/T). No other relations were observed; however because of the limited sample size, the point requires further investigation.

According to our data, Eq. (1) can then be rewritten as:

$$SI = f(s, o/T, L, C) \quad (2)$$

which represents our significance model.

Eq. (2) indicates that significance varies along with the value assumed by the set of variables C, s, L and o/T. In detail, each combination of variables' values describes a particular context (see Fig. 1) in which stakeholders act.

As every variable can assume a variety of values, combinations are many; in the case under investigation, because of the limited sample size, we were able to identified only 7 combinations which are the contexts (identified in Table 2 by capital letters) analyzed in this paper. For them explicative variables assume the following values (see Table 2):

– stakeholder (s): interviewees were classified as representative of a regional or a province authority as well as a local authority/mayor. Given the different governmental apparatus of Italy and Australia, interviewees were assigned to the different classes according to observed similarities in roles and government. In detail, with “regional authority” we mean representatives from the Regions in Italy and representatives from the State of Victoria in Australia. “Province authority” refers to Provinces' representatives in Italy, while “local authority/mayor” includes representatives from city council authorities in Australia and mayors in Italy.
– Objective/temporal scale (o/T): three different “values” were observed. In the first one the objective is an ex-ante assessment for planning purpose; in this case, interviewees indicated that they would be interested in damages occurring also several years after a possible event. Second is a post-impact assessment for emergency management; in this case, interviewees stated they would be interested in damages occurring only during the event or in the aftermath. The final objective is an ex-post assessment for damage compensation; the time window for assessment spans, in this case, from the event to few months/years after the flood.
– Spatial scale (L): as regard the spatial domain, interviewees' answers span from their administrative boundaries (i.e. the whole region/state, the province, and the municipality) to the physical affected area, the latter being within one or more municipalities.

In fact, the variable “location” (C) was not included in the definition of contexts to investigate whether or not significance varies along with the jurisdiction under investigation, assuming the same set of values for other variables. “Location” can assume two values, being “Italy” or “Australia”. As shown in Table 2, some contexts were investigated only in Italy or in Australia (i.e. C, D, E, G) whilst others (i.e. A, B, F) were analyzed in both countries, although with different samples size.

Data were further analyzed in order to synthesize information on significance. A significance matrix was estimated for each context in Table 2. It is important to note that interviewees' results were not used to carry out a statistical analysis, first because of the limited sample size, and second as the interest does not lie in assessing weights to the different types of damage but on evaluating their perceived importance. Consequently, results were “interpreted” by the authors in order to clarify the logical framework according to which stakeholders assign significance, and finally to assign a score. From this point of view, an increased sample size would make the authors' work more robust but would not increase accuracy in significance estimates. Of course, this is not true when data are used to implement a statistical analysis of damage significance.

In practice, for each type of damage in Table 1, significance was assessed from the score of individual interviewees. When more than one interviewee was available for the same context, the mean value of individual interviewee scores was used to guide authors in the choice of significance values. For example, in Italy, for context A, only two of three interviewees considered indirect damage to commercial sector significant; the mean value for significance is $(1+1+0)/3=0.7$, rounded up to 1 in the matrix.

4. Results

Table 3 summarizes results, distinguishing between Italian (IT) and Australian (AU) results.

Table 3 shows, first of all, that significance actually changes along with the context. First, it is possible to observe that a specific type of damage can be significant (or not) according to the value assumed by the variables s, L and o/T (that is the context), even when C is not considered as an explicative variable. Considering, for example, only Italian data, Table 4 highlights that indirect damages are significant when the time frame of the analysis spans several years (e.g. in context A) but not when the assessment focuses on the impact phase (e.g. in context B), apart from disruptions of essential services. Likewise, intangible damages are significant when the assessment is carried out for planning purposes (e.g. in context F) but not when damages are estimated for monetary compensation (e.g. in context A). To be noted that these results are coherent with those expected by the authors on the bases of past experience working with planning and civil protection authorities.

Indirect damages are usually postponed in time so that it is reasonable that people do not care about them during emergency but only after the initial impact; likewise, it is sensible that people do not consider intangibles for compensation although this is questionable when loss of life is considered. In other cases, differences were observed between observed and expected results. For example, it is sensible that all types of damages are significant when the assessment is carried out for planning purposes, as for context F. On the contrary, a 0 score was assessed to certain types of damage. In cases like this, an increased sample size (e.g. only one interview was carried out for context F in Table 2) would have been helpful to better understand stakeholders logic and to assign a more robust value to significance.

The role of C (Table 2) is then evident; significance changes along with the governmental apparatus so that for a certain context (i.e. s, L, o/T) the same type of damage can be significant or not according to stakeholders' roles and responsibilities. For example, during the emergency (e.g. in context B), damage to infrastructure is a first priority for Italian regional authorities but not for the Australian authorities. Italian regional authorities are responsible for infrastructure maintenance; this is not the case in Australia, where responsibility depends on the type of infrastructure, with local councils often playing an important role. Again, coherence is observed between collected data and authors' expectations.

4.1. Application to the case study

Results in Table 3 were applied to a case study in order to verify how damage assessment results can actually change along with significance. In practice, potential damages are first estimated for each type of damage. Single values are then weighted according to observed significance (i.e. matrices) to get to a total (tangible) loss figure.

The case under investigation is the town of Sondrio, in the Italian Alpine region; the town is prone to flood risk because of the River Mallero which flooded several times in the past affecting the city center. The case study was chosen according to the availability of damage data; the area under investigation was the object of several studies by the authors so that a damage estimate is already available [28–32].

The bankfull discharge (i.e. the minimum river discharge above which flooding occurs) for the River Mallero in Sondrio has been estimated at 110 m^3/s [28]. A detailed damage assessment for several hazard scenarios exceeding such threshold value is available in Molinari [28]. In this paper, we refer to a medium severe hazard scenario for the city ($Q = 170\ m^3/s$). The objective of the case study is not to explain how single types of damages can be calculated but rather to highlight how damage assessment results can vary when significance is considered. However, for the sake of clarity, direct damage estimation was carried out by means of available depth-damage models while survey analyses and implicit models were used to estimate indirect damages. Intangible damages were not computed for a two reasons: the lack of adequate data and the authors' decision not to attempt to evaluate intangibles in monetary terms.

Table 4 reports case study results. The first column lists all types of damage as derived from Table 2 while the second column reports the economic value of exposed sectors. The value of public buildings, environmental goods and the cultural heritage is not available (n.a.) for the area under investigation while farming is not present in the city so that exposure is equal to 0.

Potential damage for each type is reported in column 3. Table 4 indicates that when all types of damage are considered significant the total amount of potential damage is about 245 M€ which is equal to 27% of assets at risk.

The last six columns report potential damage values for each of the investigated contexts in Table 2 that is potential damage when significance is taken into account. In practice, potential damages in column 3 are accounted or not according to the value of significance observed during interviews in Italy (see Table 3).

Table 4 highlights that assessment results actually change along with the context. Potential damages equal the maximum loss only for two contexts (i.e. A and G) when damage assessment is carried out after the event in order to establish the overall impact of the flood: in this circumstance it is sensible that all types of damages are significant, as proved by interviews. In other circumstances the total potential damage is notably less. One could take as an example the context B, in which case damage assessment is tailored to emergency management. In such a context, as reported by interviewees, indirect damages are not considered significant because they are deferred in time and it is more important to assess whether or not the functionality of infrastructure is maintained to guarantee effective rescue activities and a rapid return to normalcy. Direct damage is considered significant as long as it helps identify the most vulnerable buildings on which rescue efforts should focus; accordingly, significance is 1 for direct damage to residential buildings, but 0 for direct damage to contents and commercial buildings. Likewise, decision makers are not concerned about warning and emergency costs in the middle of a disaster. As a consequence, potential damages decrease to 34% of the maximum loss. It is evident, however, that total figures in Table 4 cannot be strictly compared without the inclusion of neglected components; it is possible that neglected items (i.e. direct and indirect damage to public buildings, environmental goods and the cultural heritage) would change the total damage figures considerably. In the cases examined in this paper, however, we expect minor changes as significance shows limited variability for neglected damage. Physical damage to people is considered significant in every context so that, even if a monetary value is placed on people, it would not change the comparison among total damage figures. The weight of other intangibles should be further investigated.

5. Discussion

Results from the case study make explicit the importance of significance for damage assessment. On the other hand, interviews allow identification of which variables play a role in shaping significance.

According to the model in Eq. (2), it can be stated that significance is not "strictly" subjective; rather it depends on a set of variables which can assume pre-fixed values according to the problem faced by particular stakeholders. On the other hand, subjectivity is evident whereas, all variables being equal, two different interviewees give different answers about significance so that interpretation is required (see Section 3). As a result, a question arises about whether such evidence depends on the subjective attitude of interviewees (e.g. interviewees are more or less risk adverse) rather than on further explicative variables which are not considered by the model in Eq. 2. Some interviews highlighted, for example, the role of experience; experienced people tend to not consider some types of damage simply because they have not personally experienced that type of damage in floods they have dealt with.

At the same time, because of the exploratory nature of the survey and thus the limited sample size, some questions arise.

The first is that some interviewees gave no significance to those damages they were unable to evaluate; Smith and Ward [33] described this as the risk "of emphasing what can be measured rather than what is important". This is typically the case for intangibles. It would be interesting to further investigate the point and to evaluate whether or not significance would change if interviewees are aware of suitable valuation models. Results show that intangible damages are usually significant in the long term (i.e. for planning or ex-post assessment); however due to previous consideration their importance in the aftermath of events should be further analyzed.

Second, during interviews, we observed that some people gave significance to certain types of damages only because they are usually included in "traditional" damage assessment. This is the case, for example, for direct damages in the residential sector. As most of the existing, standardized tools for damage assessment refer to this sector, damage to residential dwellings is always computed in damage assessment. The real significance of such damage is however questionable. The residential sector can be significant, for example, if one considers the damages due to the Elbe flood in 2002, which mostly affected urban areas. In other contexts, the weight of residential sector can be less significant. As an example, one could think about the flood which hit the area of "Le Cinque terre" in Italy, in November 2011. The area, which is a UNESCO site, comprises small villages and basic infrastructure. Tourism is a crucial activity not only for the local economy itself but for the whole region. In such a context, it is sensible that regional authorities would put more weight on indirect damages (e.g. tourism disruption) rather than on direct damages to exposed buildings. Likewise, a recent study carried out by authors on the flood that hit the Umbria region (Central Italy) in 2012 [34] shows that the residential sector weights for 2% of the total damage in the Region. Traditional damage maps focusing on damage to the residential sectors can be misleading for setting mitigation risk priorities at the regional level.

Despite present limits, results provide evidence of (i) the need for a deeper knowledge of significance as well as (ii) the importance of its systematic analysis, as a first step of damage assessment. It is evident that significance cannot be neglected, mainly when damage assessment is used within cost-benefit analysis in order to compare and choose different prevention measures. The case study highlighted that damage assessment results can change significantly when different contexts (and thus significance values) are considered. Thus, decision makers must be aware of which kinds of damages are included or not in estimates they are provided with and also of which variables play a role in the inclusion of particular damages. This would make the whole decision problem more transparent and reliable. On the other hand, the decision problem would also become more controversial whereas different stakeholders views should be explicitly taken into account through different damage estimates. It is clear, however, that such an increase in the complexity of the decision problem cannot be avoided. In the last two decades most national and international policies strived for the active involvement of all interested parties as key to reach shared, feasible and successful solutions for flood risk management (see, for example, the Hyogo Framework for action 2005–2015 [35], the European Floods Directive [1], the Victoria Floodplain Management Strategy in Australia [36]). In this regard, the systematic appraisal of significance can actively support the participation of all interested parties in the decision making process.

It is clear then that a better model is advisable; the tool should clarify how explicative variables influence significance as well as whether, or not, links exist among these variables. Of course, it would be interesting to include in such a model also private stakeholders like lay people, private companies, insurers, etc. The objective should be the identification of prototypical contexts for which the value of significance and explicative variables is known. This way, referring to prototypes, analysts will be able to identify, from the beginning of the analysis, not only which types of damage should be estimated but also at which temporal and spatial scale. This would overcome another challenging issue for damage estimation being the identification of the most appropriate scales for the analysis. It is evident that assessment tools cannot be the same when local or regional scales are considered because different degrees of approximation are required; the choice of the most suitable temporal and spatial scales for the analysis as well as of the best assessment tool according to them are still a matter of concern [37].

Including significance in damage assessment is a first step towards the evaluation of risk mitigation strategies in terms of utility instead of cost-benefit ratio. Utility is used in decision theory to represent decision makers' subjective perception of gain/losses [38,39]. Assigning a utility is equivalent to defining a numerical rating (which usually ranges from 0, meaning no utility, to 1, meaning maximum utility) to every possible outcome to the stakeholder or, in other words, to characterizing a utility curve (or function) that reflects the value of such outcomes [40] according to stakeholder's subjective perspective.

In the context of damage assessment, the approach has been translated into "disutility functions" that define a numerical rating to every possible value of flood damage to a certain item [41]. Accordingly, risk management strategies should be chosen among those that minimize disutility functions.

The disutility approach is potentially powerful in the field of flood damage assessment and requires further research efforts; risk maps produced by means of MCA [24–26] can be considered an attempt in this direction. Besides bringing subjectivity into the analysis, the disutility approach allows comparison between tangible and intangible damages, by expressing impacts as dimensionless; this would meet the increasing concern in the risk-assessment community that non-monetary aspects should be included in flood damage assessment [42,43] as it is not the case when decisions are based on cost-benefit analysis. Significance is actually a "proxy" of disutility; significance analysis can be considered as the first step of any disutility assessment. From this perspective, further research on significance is advisable.

6. Conclusion

This paper is grounded on the idea that links exist among classes of damage to be included in damage assessment and stakeholders' perspective. As a result damage estimation requires not only the investigation of the context in which damages occur (i.e. hazard, exposure and vulnerability), but also the context in which decision makers (i.e. who make use of assessment's results) act.

In order to verify this assumption, significance was introduced as the importance stakeholders give to different types of damage. Then, interviews with stakeholders were carried out, the aim being to understand whether and how significance changes.

Information gathered by interviews highlights that significance varies along with the value of four explanatory variables: the stakeholder's role or responsibility, the objective of the assessment which is strictly connected with the time scale of the assessment, the spatial domain of the assessment and stakeholders' location. These variables define the context in which stakeholders act. Interviewees allow analyzing significance for 7 possible combinations of the explicative variables' values (i.e. 7 contexts), in Italy and Victoria, Australia. Observed values for significance were then implemented through a case study.

Despite the explorative nature of this paper, results corroborate the importance of a systematic analysis of significance, as a first step of damage assessment. The case study highlighted that damage assessment results can notably change when different contexts (and thus significance values) are considered. Thus, decision makers must be aware of which types of damages are included or not in estimates they are provided with, mainly when the latter are used within costs-benefits analysis in order to compare and choose different prevention measures. The appraisal of significance could make the decision making problem even more transparent by explaining why particular damages are include or not in the assessment.

Beyond the scope of the paper, interview findings stress the importance of improving present damage assessment methods. Indeed, one of the main factors currently influencing damage significance is whether or not damages can be quantified, even in non-monetary terms (see Section 4). This means that types of damage which would be potentially significant (like psychological/sentimental damage or political costs) are at present discounted by interviews simply because their quantification (and thus the comparison with other damages) is not possible. It is evident that this is a limiting factor for reliable damage assessment and efficient risk mitigation strategies.

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