

We would like to thank **Referee #1** for his/her interest in the topic and for valuable comments to improve the manuscript. A point-by-point response to the comments is as follows.

R: Referee

A: Authors

General comments:

R: The main flaw of this paper is poor grammar, which thus makes for poor readability. As a suggestion, the authors should have the manuscript examined and modified to shorten sentences and reduce the superfluous use of adjectives. Some examples have been stated in the comments, but the manuscript has to be checked as only few examples have been picked.

A: We agree with this comments. The revised manuscript has been **DEEPLY** modified accordingly.

R: P7829L10-13 statement seems misleading, the RRA methodology presented here is not used for economic evaluation or social assessment, but rather the outputs of the RRA can be integrated into these assessments, see Fig.2 and P7834L15-18.

A: We do partially agree with this comment since in P7834L15-27 the role that the RRA plays with general conceptual framework of the KULTURisk methodology and its clusters of analysis is quite well explained. **HOWEVER, further clarifications have been included in the text.**

R: P7838L13-22 seems at variance with the statement that the methodology is adaptable. Thus, accordingly, what are the limitations of this proposed methodology?

A: Actually, the mentioned limitations were referred to the methodology suggested by Jonkman et al. (2008) rather than to the KR-RRA. To clarify the meaning of this paragraph, we propose to modify it as follow:

In 2008, Jonkman et al. provided an in-depth review of current available methods, tools and approaches for the estimation of loss of life due to different types of floods (e.g. for dam breaks,

coastal floods, tsunamis), that are normally based on empirical data of historical flood events only, without any physical direct approach. Furthermore, the same authors proposed a brand new method to estimate the risk related to the breaching of flood defences in the Netherlands and for similar low-lying areas. Despite being robust and scientifically sound, the method proposed by Jonkman et al. looks very case-specific and rather difficult to apply to a wide range of geomorphological situations and different water related hazards, as the KR-RRA is intended for.

R: P7854L2-5 the authors make reference to RRA as being an old methodology (P7835L4-10), thus the novel concepts of the KR-RRA methodology should be clearly stated?

A: We agree with this comments. To clarify the meaning of this sentence, we propose to modify it as follow:

The paper proposes a state-of-the-art methodology, based on the Regional Risk Assessment approach and shaped on the framework of the European Flood Directive, for the integrated assessment of water-related hazards at the regional scale (i.e. meso-scale) on multiple receptors/elements at risk (i.e. people, economic activities, natural and semi-natural systems and cultural heritages).

R: P7842L20-26 The statement seems to either misplaced or unclear, as the KR-RRA methodology is being presented!

A: We agree with this comments. To clarify the meaning of this sentence, we propose to modify it as follow:

In general, the above mentioned authors remarked a lack of multidimensional and dynamic approaches, and outlined some key issues that need to be addressed by an ultimate risk assessment methodology. It is worth to notice that some of these issues have been addressed by the KR-RRA, in particular as far as the involvement of end users, transferability of methods, spatial approach (GIS based) and hazard dependency are concerned.

R: P7846L22-24 The statement is unclear, based on the scale of the land-cover classification data, the agricultural buildings may be identified as buildings. Thus, the damage would be categorised as damage to buildings (depending on the intersection of the buildings and the hazard).

A: We agree with this comments. To clarify the meaning of this sentence, we propose to modify it as follow:

Specifically, the aim of the RRA methodology for agriculture is to define the percentage of the harvest loss due to a flood event, without any consideration about the damage to agricultural buildings since these have been already considered along with the assessment to the Economic Activities, see sect. 3.5.1.

R: P7854L28 The KR-RRA method seems to be a methodology to evaluate the benefit of risk prevention rather than showing that prevention is accountable? please comment

A: In fact, the methodology can compare different scenario where different prevention measures (both structural and/or non-structural) are implemented. Therefore, the prevention is accountable in the sense that the KR methodology can quantify, both in physical and monetary terms, the risk avoidance due by these measures. **However, further clarifications have been included in the text.**

Minor comments

A: We agree with these comments. **The revised manuscript has been modified accordingly.**

We would like to thank **Referee #2** for his/her interest in the topic and for valuable comments to improve the manuscript. A point-by-point response to the comments is as follows.

R: Referee

A: Authors

General comments:

R: (...) In accordance to this aim, its flexibility really allow its adoption to different case studies, but only to individuate particular criticisms in flood prone areas at the meso-scale: the implementation of the Flood Directive at the micro-scale requires inevitably a more detailed analysis.

A: We agree with this comments. **The revised manuscript (conclusions) has been modified accordingly.**

R: Regarding its use to measure the benefits of different scenarios, it is immediate to understand how it can compare scenarios with different hazard magnitude, but it is not clear how it compares different settings of (structural and especially) non-structural mitigation and adaptation strategies.

A: The methodology allows the comparison of different scenario where structural and/or non-structural adaptation measures are considered. These measures can affect (change) both the hazard magnitude as well as the exposure and vulnerability patterns. For example, the installation of an Early Warning System allows to decrease the vulnerability of the area (AV, see Eq. 3) and, therefore, the relative risk to people, while the re-calibration of the river cross section can contribute in decreasing the hazard metrics (water depth and velocity). **However, the revised manuscript has been modified accordingly.**

R: In the introduction you put the accent on the importance of an interdisciplinary approach between socio-economic sciences and geosciences, but only in Section 3.1 you explain that RRA considers just physical/ environmental risks (as an eventual input of successive social and economic analysis).

A: We do partially agree with this comment. In fact, this concept is well introduced in the abstract (P7829L9-13). In general, the proposed interdisciplinary approach is declined and actively used within the whole KULTURisk conceptual framework, where the RRA methodology takes its roots, developed and proposed (see Figure 2). **However, the revised manuscript has been modified accordingly.**

R: In general, the procedure show a high degree of subjectivity specifically when many equation derived for local situations are extrapolated to a general use. Could the authors supply some clarifications in term of procedure generalization?

A: The procedure generalization is performed when considering the risk estimation (in terms of hazard, exposure and vulnerability patterns) that are receptors-dependant and, in most of the cases, based on experimental studies. A certain degree of subjectivity is unavoidable, and the scope of the paper is to propose and integrated and comprehensive methodology for an overall (risk) assessment at the meso-scale level. As agreed above, the implementation of the risk assessment at micro-scale requires a more detailed analysis and, probably, a different (refined) set of equations. **However, the revised manuscript (conclusions) has been modified accordingly.**

Specific comments:

R: Section 3.4.1: There is a graph or a scale to understand which range of H_{people} indicates high or low hazard level for people?

A: No, the normalization procedure is performed for this purpose: to compare and rank the different hazard and risk levels.

R: Page 7840, last word: it's table 7, not 6!

A: We agree with this comments. **The revised manuscript has been modified accordingly.**

R: Section 3.5.1: At meso-scale it's ok to consider the same classes for all residential and commercial building, but is it sufficient for public buildings as hospitals, schools, airports..?

A: Yes, since at this scale only the physical (in)stability of buildings is assessed, without any consideration of the specific function and service they provide. **However, further clarifications have been included in the revised manuscript.**

R: Section 3.5.2: You don't consider the water depths when evaluating risk for infrastructures. Which is the lower boundary condition? (a water depth equal to 5 cm on roads has to be considered in such an analysis?)

A: Lower boundaries are not considered at the moment, since the "out-of-service configuration" is assessed and this depends on the specific drainage capacity of the roads-railway network, very difficult to assess at meso-scale level. However, if data were available, an in-depth analysis could be reasonably performed and a lower boundary to characterize the functionality of transport infrastructures could be pointed out. **However, further clarifications have been included in the revised manuscript.**

R: Section 3.5.3: You don't consider flood duration while assessing risk to agriculture. Maybe you could, at least, consider the topography and the consequent stagnation to increase susceptibility scores, as you do after for natural and semi-natural systems.

A: We agree with this comments. This aspect could be considered in a revised (updated) version of the methodology. **However, further clarifications have been included in the revised manuscript.**

R: Section 3.6.1: The final susceptibility score to natural systems is given by experts: there is not an objective way to calculate it considering the elements which influence it? Moreover: when you introduce the "probabilistic or" function, you can refer to the appendix A (at the end of the paper, where you explain it).

A: We agree with this comments. **The revised manuscript has been modified accordingly, with new tables and scores.**

R: The paper is, in general, well organized and clear, apart: Section 2 “Approaches and tools on flood risk assessment” could be probably merged with the Introduction Section 3.3: there are only references but nothing new on the methodology.

A: We do agree with this comments, **Section 2 has been merged with the Introduction**

We would like to thank the **Editor** for his interest in the topic and for valuable comments to improve the manuscript. A point-by-point response to the comments is as follows.

E: Referee

A: Authors

E: Two Reviewers have provided a number of constructive comments to this paper. They both considered the study of good scientific significance and quality, while suggested a minor revision of the manuscript. The authors have already replied with a comprehensive response. Thus, I recommend submitting a revised manuscript to HESS after addressing all comments as stated in the response. In addition to the Reviewers' comments, I think it would be worth discussing more a possible limitation of the proposed method: its inability to explicitly capture the dynamics of water-related disaster risks emerging from the (still largely unexplored) feedbacks between physical and social processes (see e.g. socio-hydrology). In a rapidly changing world, risk changes significantly over time.

A: We agree with this comments. **The revised manuscript has been modified accordingly (conclusions)**

The KULTURisk Regional Risk Assessment Methodology for water-related natural hazards. Part ~~1~~: ~~physical~~Physical-environmental assessment

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Abstract

In recent years, the frequency of catastrophes induced by natural hazard has increased and flood events in particular have been recognized as one of the most threatening water-related disasters. Severe floods have occurred in Europe over the last decade causing loss of life, displacement of people and heavy economic losses. Flood disasters are growing as a consequence of many factors, both climatic and non-climatic. Indeed, the current increase of water-related disasters can be mainly attributed to the increase of exposure (increase elements potentially at risk in floodplains area) and vulnerability (i.e. economic, social, geographic, cultural, and physical/environmental characteristics of the exposure). Besides these factors, the ~~strong-undeniable~~ effect of climate change is projected to ~~radically-strongly~~ modify the usual pattern of the hydrological cycle by intensifying the frequency and severity of flood events both at local, regional and global scale. Within this context, it becomes urgent and ~~dramatically~~-relevant the need of ~~promoting-and~~ developing effective and pro-active strategies, tools and actions which allow to assess and (possibly) to reduce the flood risks that threats different relevant receptors. Several methodologies to assess the risk posed by water-related natural hazards have been proposed so far, but very few of them can be adopted to implement the last European Flood Directive (FD). ~~This paper e-present study~~ is intended to introduce and present a state-of-the-art Regional Risk Assessment (RRA) methodology to appraise the risk posed by floods from a physical-environmental perspective. ~~evaluate the benefits of risk prevention in terms of reduced environmental risks due to floods~~. The methodology, developed within the recently ~~phased-out~~completed FP7-KULTURisk

1 Project (Knowledge-based approach to develop a cULTUre of Risk prevention – KR) is flexible
2 and can be adapted to different case studies (i.e. large rivers, alpine/mountain catchments, urban
3 areas and coastal areas) and spatial scales (i.e. from the large river to the urban scale). The FD
4 compliant KR-RRA methodology is based on the concept of risk being function of hazard,
5 exposure and vulnerability. It integrates the outputs of various hydrodynamic~~s~~ models (hazard)
6 with ~~site~~o-specific bio-geophysical and socio-economic indicators (e.g. slope, land cover,
7 population density, economic activities) to develop tailored risk indexes and GIS-based maps for
8 each of the selected ~~targets-receptors~~ (i.e. people, buildings, infrastructures, agriculture, natural
9 and semi-natural systems, cultural heritages) in the considered region. ~~It further compares, by~~
10 ~~comparing~~ the baseline scenario with alternative scenarios, where different structural and/or non-
11 structural mitigation measures are planned ~~and eventually implemented~~. As demonstrated in the
12 twin paper (Part ~~H2~~, Ronco et al., 2014), risk maps, along with related statistics, allow to identify
13 and prioritize relative hotspots and targets which are more likely to be affected by flood~~s~~ and
14 support the development of ~~relevant-and~~ strategic adaptation and prevention measures to
15 minimizing flood impacts. ~~Moreover~~In addition, the ~~outputs-outcomes~~ of the RRA ~~methodology~~
16 can be ~~eventually~~ used for ~~a further the socio-economic evaluation-assessment of different damages~~
17 ~~(e.g. tangible costs, intangible costs) and for the social assessment~~, considering ~~tangible and~~
18 ~~intangible costs as well as~~ the benefits of the human dimension of vulnerability ~~(i.e. adaptive and~~
19 ~~ecoping capacity)~~.

21 1. Introduction

22 Extreme weather and climate events, the physical contributors to disaster risk, interacting with
23 exposed and vulnerable human and natural systems, can lead to severe catastrophes (IPCC, 2012).
24 Floods are the most threatening water-related disaster that affects human ~~s, their livfes, and~~
25 ~~properties-properties and infrastructures~~ (Hewitt, 1997; Penning-Rowse~~ll~~ et al., 2005; Balica et al,
26 2009; Bates et al., 2008; Kubal et al., 2009), ~~growing with an increasing occurrence~~ as a
27 consequence of many factors both climatic (increase heavy precipitation, changing in water natural
28 cycle) and non-climatic (land use change, increases in population, economic wealth and human
29 activities in hazard-prone areas and urban development). The combination of ~~dramatic-severe~~
30 consequences, rarity, and human as well as physical ~~determinants-factors~~ makes disasters difficult
31 to study ~~,-h~~However, there are scientific evidences of an increased ~~d-in~~ precipitation intensity, which
32 implies that extreme floods events might become more frequent (~~Mitchell, 2003~~, Hirabayshi et al.,
33 2013). At the same time, consequences for disaster related risks and impacts related to floods might
34 be exacerbated due to increase exposure and vulnerability of elements at risk linked to population
35 dynamics and the associated economic and urban development in flood-prone areas. ~~Thus, even if~~

~~not considering climate change factors connected to increase frequency of floods disaster, an increase of these catastrophic events may be expected (Mitchell, 2003).~~

In fact, differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes. These differences shape differential risks from climate change (IPCC, 2014).

In Europe, floods, storms and other hydro-meteorological events account for around two thirds of the damage costs of natural disasters, and these costs have increased since 1980, according to EEA (2012). Between 1998 and 2009, in particular, Europe suffered over 213 major damaging floods that ~~have~~ caused ~~some~~ 1126 deaths, the displacement of about half a million people and at least €52 billion in insured economic losses, including the catastrophic floods along the Danube and Elbe rivers in the summer of 2002 (see Fig.1) (Barredo, 2007).

Fig.1

Traditionally, the European floods control and management practices have been focused on reactive practices and largely relied on control of floods through structural measures, only later supported by sporadic non-structural measures. ~~Now~~Currently, it is widely recognized that a paradigm shift is required to move from defensive to proactive action towards a culture of prevention by managing the risk of and living with floods (Annamo and Kristiansen, 2012). The latest concept is also supported by the recent outcomes of a study from Viglione et al. (2014) that demonstrate the relative importance of several socio-cultural-anthropogenic drivers for the (temporal) characterization of the vulnerability patterns in selected communities.

In this context, the European Flood Directive (FD) 2007/60/EC (2007) represents an ad-hoc legislative framework ~~which specifically to~~ support the development of proper flood management strategies, in order to reduce the adverse consequences for human health, the environment, cultural heritage and economic activities ~~resulting from~~ such calamities. ~~According to the FD. By distinguishing clearly between hazard and risk maps, the FD asks for a more sophisticated analysis of natural hazards and moves some steps head towards the improvement of notions and concepts of risk management. In particular, risk assessment studies and relative maps shall allow enable~~ the visualization of the spatial distribution of (flood) risks in the specific (flood) scenario, by considering the risk as the combination of hazard, exposure and vulnerability and ~~pointing out (cit.): “the potential adverse consequences associated with flood scenarios”~~, by quantifying in particular, the number of people and economic activities potentially affected. Eventually, while it is indisputable that the European Union ~~emanated-published~~ a set of general reports which aim to support the current EU regulations, a lack of integrated, ~~specific~~ criteria, methodologies and tools

1 concretely supporting their practical implementation at the regional scale has been widely
2 recognized.

3 In fact, several methodologies have been developed in order to assess flood risk; the choice of one
4 methodology over another largely depends on the objectives of the analysis, availability of
5 datasets, peculiarities of the context of application, level of detail to be achieved, dimensions of
6 risk to be addressed. Cirella et al. (2014) recently published a comprehensive review and
7 classification of current approaches and methodologies for the assessment of risks posed by a wide
8 range of water-related natural hazards (coastal storms, tsunamis, river floods, avalanches,
9 landslides, etc.). Based on different indicators and criteria (e.g. hazard of concerns, conceptual
10 framework, analytical approach, role of experts and stakeholders, elements at risk, spatial scale,
11 input and output, tools and models used, uncertainties, etc), the review demonstrated that there are
12 very few examples of methodologies that consider the complete suite of elements at risk pointed
13 out by the FD encompassing the entire varieties of risk dimensions (i.e. physical/environmental,
14 social and economic) (Di Baldassarre et al., 2009; Di Baldassarre et al., 2010; Rotach et al., 2012).
15 Most of the available methodologies, in fact, only targeted “classical” receptors, such as buildings,
16 or infrastructures or population (e.g. Clausen and Clark, 1990; Citeau, 2003; Forte et al., 2005;
17 DEFRA, 2006; Büchele et al., 2006; Kubal et al., 2009), that are usually analysed separately, in
18 monetary terms and related damages only, neglecting the coexistence (and synergies) of multiple
19 receptors living in the same geographical region. Moreover, while most of the approaches made a
20 considerable use of GIS-based tools both for computational and outcome purposes, they were
21 mainly developed for very specific contexts at a very local scale, with an high level of complexity
22 and data demanding (e.g. Forte et al., 2005; Meyer et al., 2009; Kubal et al., 2009, Forster et al.,
23 2008), and they can hardly be employed for a wide range of case studies. A recent attempt has
24 been made by Balica et al. (2009) in proposing an innovative parametric approach for the
25 estimation of the vulnerability of a system by using only few (readily available) parameters related
26 to that system.

27
28 ~~Available risk-based methods, in fact, have been developed in recent years but they are fragmented~~
29 ~~across different scientific disciplines (e.g. engineering, environmental sciences, economics and~~
30 ~~social sciences), geographic and policy contexts; they focused mostly on flood hazard mapping~~
31 ~~(Di Baldassarre et al., 2009; Di Baldassarre et al., 2010; Rotach et al., 2012) while comprehensive~~
32 ~~approaches (i.e. integrating environmental, social and economic perspectives) are poorly~~
33 ~~represented (Cirella et al., 2014). In fact, these approaches are mainly focused on the analysis of~~
34 ~~the consequences and damages of floods on specific receptors—for instance, population, buildings~~
35 ~~or agriculture (Clausen and Clark, 1990; Citeau, 2003; DEFRA, 2006)—neglecting the coexistence~~

1 ~~of multiple receptors living in the same geographical region. Furthermore, B~~ by acknowledging
2 different roots of the vulnerability paradigms, embedded in multidisciplinary theories
3 underpinning either a technical or social origin of this concepts, ~~Papathoma-Kohle et al. (2011)~~
4 ~~and~~ -Fuchs et al. (2012) stated that methodologies for structural, economic, institutional or social
5 vulnerability assessment should be inter-woven in order to enhance its understanding.
6 ~~Furthermore~~In general, efforts to reduce exposure to hazards and to create disaster-resilient
7 communities require intersection among disciplines and theories, since human actions cannot be
8 seen independently from environmental features, and vice-versa (Hufschmidt et al., 2010).
9 Moreover, the current and future flood risk assessments are also characterized by considerable
10 uncertainty, which needs to be addressed and clearly communicated to decision-makers
11 (Peppenberget al., ~~2012~~2013). Finally, as suggested by Montanari et al. (2013) through the new
12 “Panta Rhei-Everything Flows” paradigm for hydrological disciplines, ~~now~~-the new challenge is
13 to look at these (hydrological) processes as a changing interface between environment and society,
14 whose dynamics are essential to set priorities for a (proper, effective and sustainable)
15 environmental management, through an interdisciplinary approach between socio-economic
16 sciences and geosciences ~~in general~~.

17 Accordingly, there is the need to develop a comprehensive risk assessment methodology that could
18 integrate information coming from deterministic ~~as well as~~and probabilistic flood forecasting, ~~as~~
19 ~~well as the~~ with the multi-faceted physical/environmental, social and economic aspects of
20 exposure and vulnerability, in order to evaluate ~~flood risk~~the consequences of floods for different
21 ~~receptors~~/elements at risk, as required by the ~~Floods~~-Directive. In this paper, the physical-
22 environmental dimensions of risk ~~has~~have been assessed by considering the hazard, exposure and
23 vulnerability analysis-components of flood risk analysis.

24 ~~After a rapid overview of the current approaches on flood risk assessment, t~~The paper will
25 introduce both the conceptual framework and, in particular the computational procedure used to
26 assess the physical-environmental (relative) risk posed by floods to a selected cluster of receptors.
27 Before coming to the conclusion, the article will also present a simple but effective algorithm,
28 based on Multi Criteria Decision Analysis, to combine the receptor-related relative risk into a
29 single general (total) risk index. The (ultimate) objective of the methodology, successfully applied
30 in the several case studies across Europe Sihl river valley in Switzerland (see the twin paper, Part
31 H2, Ronco et al., 2014), is to identify and prioritize areas and targets at risk in the considered
32 region, in order to evaluate the benefits of different risk prevention scenarios to support relevant
33 stakeholders ~~and decision makers~~ in science knowledge-based (land-use) planning and decision
34 making.

35

~~2. Approaches and tools on flood risk assessment~~

~~Several methodologies have been developed in order to assess flood risk; the choice of one methodology over another largely depends on the objectives of the analysis, the availability of dataset, the peculiarities of the context of application, the level of detail to be achieved, the dimensions of risk to be addressed. Cirella et al. (2014) recently published a comprehensive review and classification of current approaches and methodologies for the assessment of risks posed by a wide range of water related natural hazards (coastal storms, tsunamis, river floods, avalanches, landslides, etc.). Based on different indicators and criteria (e.g. hazard of concerns, conceptual framework, analytical approach, role of experts and stakeholders, elements at risk (receptors), spatial scale, input and output, tools and models used, uncertainties, etc), the review demonstrated that there are very few examples of methodologies that consider the complete suite of elements at risk (receptors) pointed out by the FD through an integrated and multidisciplinary approach, encompassing the entire varieties of risk dimensions (i.e. physical/environmental, social and economic). Most of the available methodologies, in fact, only targeted “classical” receptors, such as buildings, or infrastructures or population (e.g. Forte et al., 2005; Büchele et al., 2006; Kubal et al., 2009), that are usually analysed separately, in monetary terms and related damages only. Moreover, while most of the approaches made a considerable use of GIS-based tools both for computational and outcome purposes, they were mainly developed for very specific contexts at a very local scale, with an high level of complexity and data demanding (e.g. Forte et al., 2005; Meyer et al., 2009; Kubal et al., 2009, Forster et al., 2008), and they can hardly be employed for a wide range of case studies. A recent attempt has been made by Balica et al. (2009) in proposing an innovative parametric approach for the estimation of the vulnerability of a system by using only few (readily available) parameters related to that system. Finally, as affirmed by Papatoma Kohle et al. (2011) and Fuchs et al. (2012) that recently revising the current approaches in vulnerability assessment, only through a multidimensional and dynamic approach, the overall aim of reducing natural hazards risk can be achieved.~~

2. The KULTURisk Regional Risk Assessment (KR-RRA) methodology

2.1. Conceptual Framework

The KULTURisk Conceptual Framework (KR-FWK) developed by Giupponi et al. in [2013-2014](#) within the above mentioned project, shaped the basis for the development of the presented methodology to evaluate the benefits of risk prevention. By considering three main tiers of analysis, namely (1) the Physical/Environmental Regional Risk Assessment (RRA), (2) the Social and (3) the Economic ~~valuation of potential consequences~~ Assessment, the Conceptual Framework has been built upon the consolidated formalization of risk being a function of hazard, exposure,

1 and vulnerability, defined as: i) hazard, as “the potential occurrence of a natural or human-induced
2 physical event that may cause loss of life, injury, or other health impacts, as well as damage and
3 loss to property, infrastructure, livelihoods, service provision, and environmental resources”
4 (IPCC, 2012); ii) exposure, as “the presence of people; livelihoods; environmental services and
5 resources; infrastructure; or economic, social, or cultural assets in places that could be adversely
6 affected” (IPCC, 2012); iii) vulnerability, consisting of susceptibility as a Physical/Environment
7 (P/E) component, and adaptive & coping capacities as the Social component. The P/E component
8 is captured by the likelihood that receptors located in a considered area could potentially be
9 harmed.

10 The above described elements are combined to calculate the Risk delineated as the combination
11 of the probability of a certain hazard to occur and of its consequences.

12
13 *Fig.2*
14

15 The presented study only ~~addressed~~addresses the first tier of the analysis, namely the Regional
16 Risk Assessment (RRA) that considered the flood hazard and the physical/environmental
17 dimension of vulnerability (i.e. susceptibility) to identify and classify physical/environmental risks
18 associated to floods for different receptors. The others two tiers are grouped into a single cluster
19 of assessment, namely the Socio-Economic Assessment (SERRA) ~~developed by Giupponi et al.~~
20 ~~(2013)~~, where the information utilised for the RRA are merged with other social and economic
21 indicators and monetary values of the assets at risk (Giupponi et al. 2014). The RRA provides an
22 estimation of the physical/environmental risks that can be used as input for the social and economic
23 tiers of analysis. These tiers can be used separately (i.e. considering only the social or the economic
24 dimension) or sequentially (i.e. estimating the effects of the social and value indicators, together
25 with the physical/environmental ones, on the expected costs).

26 27 **2.2. Regional Risk Assessment: background, features and objectives**

28 Since its first applications in 1997, the RRA approach has been successfully used at a variety of
29 sites across the world, including marine coastal areas, fjords and hydrographic basins habitats
30 (Landis and Wiegers, 1997). The RRA is aimed at providing a quantitative and systematic way to
31 estimate and compare the impacts of environmental problems that affect large geographic areas
32 (Hunsaker et al., 1990), by considering the presence of multiple habitats, multiple sources
33 releasing a multiplicity of stressors impacting multiple endpoints (Landis, 2005). Specifically with
34 the aim to rank potential impacts, targets and areas at risk from water-related natural hazard at
35 regional scale, the KR-RRA integrates four steps of analysis, as follow:

- 1 - hazard assessment is aimed at characterizing the flood pattern by means of relevant metrics (e.g. flow velocity, water depth, flood extension) coming from hydraulic models, (deterministic or probabilistic) according to different scenarios to be investigated (baseline or alternative);
- 2 - exposure assessment is aimed at identifying the elements at risk. This step requires the analysis of land use/land cover datasets for the localization of people, environmental resources, infrastructures, social, economic and cultural assets that could be adversely affected by a flood;
- 3 - susceptibility assessment is aimed at evaluating the degree to which the receptors could be affected by a flood hazard based on physical/environmental site-specific information;
- 4 - risk assessment combines the information about a certain flood hazard scenario with the exposure and susceptibility of the examined receptors, providing a first evaluation of risks ~~related to each receptor~~ through the computation of a relative risk score. Risk scores varies from 0 (i.e. no risk) to 1 (i.e. higher risk for the considered area). The ranges for risk classes can be defined using different methods (e.g. Equal interval, Jenks optimization) and qualitative classes should then be assigned to them (i.e. low, medium, high risk). After the normalization of the receptor-related risk, a total (integrated) risk index is calculated by means of Multi Criteria Decision Analysis (MCDA) functions.

17 As suggested by the Flood Directive (2007/60/EC), the KR-RRA methodology considers the following receptors:

- 19 1. People;
- 20 2. Economic activities, including: i) Buildings, ii) Infrastructures, iii) Agriculture;
- 21 3. Natural and semi-natural systems;
- 22 4. Cultural heritage.

23 As depicted in Fig.3, the main outputs of the RRA are GIS-based maps of receptor-related risks and of the total risk.

25

26 *Fig.3*

27

28 The KR-RRA method has been developed for analysis at the meso-scale level, adopting the land use/land cover classes proposed by the CORINE Land Cover, as major spatial units of reference (Büttner et al^{EEA}, 2006⁷). However, it is flexible to be applied at different spatial levels (i.e. the macro or the micro scales) based on the purposes of the assessment, the geographical extent of the case study and the level of detail of input dataset. The methodology can be applicable in different problem contexts, case studies and spatial scales with the aim to provide a benchmark for the implementation of the Floods Directive at the European level. In addition, GIS-based maps and outcomes result useful to communicate the ~~potential~~ implications of floods in non-monetary terms

35

1 to stakeholders ~~and decision-makers and administrations~~ and can be a basis for ~~the a knowledge-~~
2 ~~based~~ management of flood risks ~~as they can provide with~~ information about the indicative number
3 of inhabitants, the type of economic activities, natural systems and cultural heritages potentially
4 affected by flooding. Concluding, the KR-RRA methodology allows to identify and prioritize areas
5 and targets at risk in the considered region and to evaluate the benefits of different prevention
6 scenarios.

7 In the next paragraphs, the computational procedure to estimate the relative risks, receptor-by-
8 receptor, will be introduced, starting from the initial setting of the hazard scenario.

10 2.3. Scenario Development

11 In general, the proper selection of robust and reliable ~~hazard~~ scenarios, defined as the plausible
12 ~~image-outcome~~ of a possible future system state under different circumstances (baseline or
13 alternative scenario), is primary for the quality and the robustness of the risk assessment
14 (Mazzorana et al., 2009) since it allows the comparison of different (risk) scenario and, therefore,
15 to evaluate the benefits of risk prevention measures. In fact, several approaches can be followed
16 in scenario development, depending on level of detail, data availability and degree of experts
17 involvement. For example, ~~Scholz and Tietje (2002) and~~ Mazzorana et al. (2009) provided a useful
18 insight about the various scenario planning procedure and approaches by classifying the scenario
19 analysis in three different types, among holistic (experts elicitation), model analysis (based on
20 system modelling) and Formative Scenario Analysis, based on qualitatively assessed impact
21 factors and tested in different case studies. When combined with conventional modelling, the last
22 one, ~~initially proposed by Scholz and Tietje (2002),~~ by meeting basic, operational and
23 multidimensional principles and integrating bounding uncertainties, represents a robust technique
24 for the development of reliable future hazard scenarios. ~~The According to KR-RRA, asks for~~ a
25 preliminary analysis and screening of different ~~hazard~~ scenario (baseline and alternative) ~~is~~
26 ~~required. It should be~~ based on different hazard magnitude, probability and/or alternative settings
27 where structural and non-structural mitigation and adaptation measures are planned. ~~These~~
28 ~~measures can affect (change) both the hazard as well as the exposure and vulnerability patterns.~~
29 ~~For example, the installation of an Early Warning System allows to decrease the vulnerability of~~
30 ~~the area (AV, see Eq. 3) and, therefore, the relative risk to people, while the re-calibration of the~~
31 ~~river cross section can contribute in decreasing the hazard metrics (water depth and velocity).~~
32 ~~Finally, it is worth to notice that the proposed approach but it~~ does not provide ~~or suggest~~ a
33 particular (bounded) method for scenario construction, rather it takes advantages from available
34 techniques and models, depending on their applicability and reliability to the specific case study.

2.4. Physical/environmental risk assessment to people

River floods have the potential to cause serious risk to people and are considered as the most threatening water-related disaster that affects humans ~~life, their lives and properties~~ (Hewitt, 1997; Penning-Rowsell et al., 2005; Balica et al., 2009; Kubal et al., 2009). Both river and coastal flooding affect millions of people in Europe each year; these events have a series of severe consequences influencing on human health through drowning, heart attacks, injuries, infections as well as psychosocial ~~consequences-effects~~ (Fig. 4) (www.eea.europa.eu). During the past 10 years, floods in Europe have killed more than 1000 people and affected 3.4 million others (Jakubicka et al., 2010). Nevertheless, it is difficult to classify which deaths are actually associated with a flood. Immediate flood deaths are best recorded, but deaths during clean-up and longer-term mortality associated with flooding are often not recorded as such (Menne and Murray, 2013).

Fig.4

In 2008, Jonkman et al. provided an in-depth review of current available methods, tools and approaches for the estimation of loss of life due to different types of floods (e.g. for dam breaks, coastal floods, tsunamis), that are normally based on empirical data of historical flood events only, and not physically-based. Furthermore, the same authors proposed a new approach to estimate the risk related to the breaching of flood defences in the Netherlands and for similar low-lying areas. Despite being robust and scientifically sound, the method proposed by Jonkman et al. looks very case-specific and rather difficult to apply to a wide range of geomorphological situations and different water related hazards, as the KR-RRA is intended for.

~~In 2008 Jonkman et al. provided an in-depth review of available methods, tools and approaches for the estimation of loss of life due to different types of floods (e.g. for dam breaks, coastal floods, tsunamis), that are normally based on empirical data of historical flood events only, without any physical direct approach. Furthermore, the authors proposed a new method based on the subsequent assessments of hazard, exposure and vulnerability features, primarily developed for the risk related to the breaching of flood defences in the Netherlands and for similar low lying areas. Despite being robust and scientifically sound, the method looks very case specific and rather difficult to apply to a wide range of geomorphological situations and different water related hazards, as the KR-RRA is intended for.~~

The proposed KR-RRA approach, in fact, allows the assessment of flood risks to human health (i.e. in terms of potential fatalities and injuries) associated with a flood event, by making the best use of available information at the meso-scale (i.e. CORINE Land Cover polygons). For this reason it focuses on residential areas identifying them as major hotspots where people live

(Jonkman, 2008). In particular, the proposed approach is based on the methodology developed by Ramsbottom et al. for the UK Department for Environment, Food and Rural Affairs (DEFRA, 2006) for a wide range of case studies. This e-method was based on a multi-criteria assessment of factors that affect Flood Hazard, the chance of people in the floodplain being exposed to the hazard (Area Vulnerability) and ability of those affected to respond effectively to flooding (People Vulnerability).

2.4.1. Hazard, exposure and susceptibility assessments

The flood hazard classification considers the degree of impact and it is related to the specific physical characteristics of an individual (i.e. height, mass, age) which is identified by for different population typology typologies (i.e. children, elders and infirm/disable; adult woman; adult man). The flood hazard assessment step identifies water depth and velocity as relevant physical metrics, which are in direct (linear) relationship with the flood-hazard magnitude (i.e. when-as water depth and velocity increase, the flood-hazard score increases). Moreover, case-by-case, it is possible to consider also the presence of debris factor (i.e. floating material such as trees, cars, etc.) where it poses a threat to the lives-of people. The (flood) hazard to people is calculated using the following equation:

$$H_{people} = d \cdot (v + 1,5) + DF \quad (1)$$

Where:

H_{people} = hazard score for people

d = water depth [m]

v = velocity [m/s]

DF = debris factor [0;1]

Equation 1 allows to define a hazard map, in which the resolution depends on the outcomes and resolution of the hydraulic modeling and/or the historical dataset used to calculate and/or retrieve the physical metrics. The DF is scored requires the assignation of a value between 0 (i.e. low probability that debris would lead to a significant hazard) and 1 (i.e. high probability that the debris would lead to a significant hazard), according to different ranges of water depth and flow velocity (DEFRA, 2006).

The exposure assessment requires the localization of the people potentially affected by the hazard, that can be defined using census data of population density or the number of inhabitants per civic number within the residential areas, as Jonkman (2007) suggested. At any particular time, people may be present in various location (e.g. outdoors, indoors within a multi-storey building) that can be associated to different levels of risk. However, as stated above, the assumption is that all the

1 people are present in their homes at the low ground where people do not have safe areas as refuge.
 2 ~~However, f~~For a sake of simplification, coping capacity during the event (people that are able to
 3 evacuate and/or shelter, as well as the solutions implemented by local Authorities to manage the
 4 emergencies) and adaptive capacity before-after the event (solutions implemented by people and
 5 Authorities in order to deal with the hazard) are not considered by the RRA since these terms are
 6 fully enclosed in the subsequent cluster of the KULTURisk methodology, the SERRA one (see
 7 Giupponi et al., ~~2013~~2014).

8
 9 To characterize the susceptibility of people, namely the degree to which the receptors could be
 10 affected by the hazard, the KR-RRA methodology suggests to consider: i) the percentage of
 11 resident aged 75 years or over, and ii) the percentage of residents suffering from long term illness.
 12 These conditions are considered as factors that could increase the susceptibility because ~~aged~~
 13 ~~elderly~~ people can be more prone to health and stability problems in a flood event and also because
 14 many pre-existing medical conditions can increase the probability of health problems related to
 15 flooding and of death (e.g. mortality for hypothermia). The susceptibility score (Eq.2) is therefore
 16 calculated by summing these two indicators (DEFRA, 2006):

$$17 \quad SF_{people} = sf_1 + sf_2 \quad (2)$$

18 Where:

19 SF_{people} = susceptibility score for people (%);

20 sf_1 = % of people over 75 years;

21 sf_2 = % of people with disabilities.

22 The susceptibility assessment is based on census data allowing the assignation of a susceptibility
 23 score to each census unit (e.g. municipality, census district) and a creation of a related
 24 susceptibility map. Indicators and data sources for the assessment of hazard, exposure and
 25 susceptibility of people at the meso-scale are reported in Table ~~6~~7.

27 **2.4.2. Risk assessment**

28 The risk assessment ~~provides~~produces the spatial characterization of a (relative) risk index ~~that~~
 29 ~~allows~~to identify and rank areas and hotspots at risk within the studied area. ~~H~~Hazard (Eq.1),
 30 exposure and susceptibility (Eq.2) are used within the risk assessment to ~~compute~~ ~~provide~~ the
 31 number of people injured (R_1) and dead (R_2) during a flood event, as follow (DEFRA, 2006):

$$32 \quad R_1 = \frac{(2 \cdot E \cdot H_{people} \cdot AV / 100 \cdot SF_{people})}{100} \quad (3)$$

$$33 \quad R_2 = 2 \cdot R_1 \cdot H_{people} / 100 \quad (4)$$

34 Where:

- 1 $R_1 = \text{number of injuries};$
 2 $R_2 = \text{number of fatalities};$
 3 $E = \text{exposure (i.e. the number of people that can be potentially inundated)};$
 4 $H_{\text{people}} = \text{hazard score to people};$
 5 $AV = \text{area vulnerability};$
 6 $SF_{\text{people}} = \text{susceptibility score for people (\%)}.$

7
 8 As per the DEFRA (2006) approach, the area vulnerability (AV) is defined as the sum of flood
 9 warning, speed of onset and nature of area, ranging from 3 (i.e. low social vulnerability, high
 10 adaptive and coping capacity) to 9 (i.e. high social vulnerability, low adaptive and coping
 11 capacity). Moreover, in order to aggregate all the different receptor-related (relative) risks ~~in for~~
 12 ~~the computation of~~ the total risk, ~~this step requires~~ a phase of normalization aimed at rescaling the
 13 receptor-related risk scores into a common closed numerical scale (0-1) (~~Zabeo et al., 2011~~) ~~is~~
 14 ~~required~~ (Zabeo et al., 2011). The normalization is performed at CORINE polygon-scale; ~~where~~
 15 ~~this size spatial resolution has been~~ is selected according to the ~~degree of (spatial) resolution one~~
 16 ~~that characterize the of the data~~ available ~~dataset~~. For the people, the normalization is provided
 17 considering the number of people injured/dead and the number of people in the highest populated
 18 polygon, according to Eqs. 5 and 6:

$$19 \quad R'_1 = \frac{R_1}{\text{Number of people in the highest populated polygon}} \quad (5)$$

$$20 \quad R'_2 = \frac{R_2}{\text{Number of people in the highest populated polygon}} \quad (6)$$

21 Where:

22 $R'_1 = \text{normalized risk score for injuries};$

23 $R'_2 = \text{normalized risk score for fatalities};$

24 $R_1 = \text{number of injuries (Eq.4)};$

25 $R_2 = \text{number of fatalities (Eq.5)}.$

26 This normalization allows ~~to define~~ risk scores between 0 (i.e. no people injured/dead) and 1
 27 (i.e. all the people living in the highest populated polygon are injured/dead).

28

29 **2.5. Physical/environmental risk assessment to economic activities**

30 To fulfil with the requirements of the FD, the flood risk assessment related to economic activities
 31 has considered three relevant sub-receptors: buildings, infrastructures and agriculture.

32

33 **2.5.1. Physical/environmental risk assessment to buildings**

1 Floods have a potential massive impact on buildings infrastructures (e.g. to the structures and to
2 the indoor goods), particularly in populated areas, corresponding to residential and commercial-
3 industrial sites, triggering ~~dramatic-severe~~ (socio-) economic damages.
4 Papathoma-Kohle et al. (2011) and Fuchs et al. (2012) recently provided an insight of the current
5 approaches and future needs on vulnerability assessment of buildings, when ~~stricken-affected~~ by
6 water-related natural hazards. The most frequent approach concerned the use of (empirical) stage-
7 damage functions that linked inundation depth to expected losses, that is reliable method for
8 ~~standing-still~~ waters but do not consider the impact of flowing waters to the structures as relevant
9 indicator (Büchele et al., 2006). In general, the above mentioned authors remarked a lack of
10 multidimensional and dynamic approaches, and outlined some key issues that need to be addressed
11 by an ultimate risk assessment methodology. It is worth to notice that some of these issues have
12 been addressed by the KR-RRA, in particular as far as the involvement of end users, transferability
13 of methods, spatial approach (GIS based) and hazard dependency are concerned. It is worth to
14 notice that, without making any explicit reference the general concepts of the (complete) risk
15 assessment procedure, the authors remarked a lack of multidimensional and dynamic approaches
16 to this topic, and outlined some key issue to be addressed by an ultimate approach to this topic.
17 Some of these suggestions have been included into the KR-RRA, in particular as far as the
18 involvement of end users, transferability of methods, spatial approach (GIS based) and hazard
19 dependency are concerned. Finally, in the proposed KR-RRA the receptor is define by considering
20 the buildings footprint in the area as well as its economic use, according to the CORINE Land
21 Cover classes of industrial and residential areas. At meso-scale level, this classification allows to
22 define the percentage and the typology of buildings that could be ~~stricken-affected~~ by a flood event
23 with different degrees of structural damage.

24 25 **2.5.1.1. Hazard, exposure and susceptibility assessments**

26 ~~We should underline that t~~The above mentioned methods ~~offer~~ vulnerability assessment to the
27 buildings ~~were are~~ characterized, ~~to some extent,~~ by a consistent use of sophisticated physical
28 approaches and screening methods, only applicable ~~to at~~ the very local scale (micro-zonation). For
29 example, ~~by considering they consider~~ the damage related to different building typologies as
30 suggested by Schwarz and Maiwald (2008), or ~~by considering~~ the material construction and its
31 quality, the building level, the state of conservation, contamination and precautionary principles
32 (Büchele et al., 2006, Mebarki et al., 2012, Totschnig & Fuchs, 2013). Without excluding the
33 possibility of further future improvement, refinement and enhancement of the proposed KR-RRA
34 method by matching the level of detail and data availability required ~~by such approaches~~ with the
35 necessary portability of the same, some ~~degree of simplifications~~ and assumptions have been

1 ~~considered~~~~was necessary~~ in order to ~~develop and~~ fully apply ~~the~~ RRA methodology at regional
2 (meso scale) level, in particular as far as the ~~physical~~ vulnerability assessment ~~(susceptibility)~~ is
3 concerned.

4 Within the proposed KR-RRA, reference is made to the approach proposed by Clausen and Clark
5 (1990) where, by assuming that all the buildings are characterized by the same structure, the risks
6 ~~was~~~~has been~~ evaluated by directly considering the relationships between flood hazard classes and
7 potential structural damages (Fig.5).

8
9 *Table 1*

10
11 *Fig.5*

12 13 **2.5.1.2. Risk assessment**

14 Based on the classes proposed by Clausen and Clark (1990), the methodology allow~~ed~~ to ~~define~~
15 calculate the number (and percentage) and the typology of buildings affected by floods, classified
16 per typology and according to~~characterized by~~ different risk classes as defined in Table 1 ~~(i.e.~~
17 ~~inundation, partial damage, and total destruction)~~. ~~As shown in Table 1,~~ ~~†~~This method ~~provided~~
18 provides three risk classes (i.e. inundation, partial damage, and total destruction) differentiating
19 the potential consequences of floods in a qualitative way, based on thresholds determined by flow
20 velocity values and by the product between water depth and flow velocity (defined as intensity).
21 The risk assessment to buildings (R_3) allow~~ed~~ the estimation of the number, coverage~~surface~~
22 (km²) and the percentage of flooded buildings belonging to different uses (i.e. CORINE Land
23 Cover polygons related to residential, commercial-industrial areas) in each risk class ~~(i.e.~~
24 ~~inundation, partial damage, total destruction)~~ in the form of tables (summarizing the statistics) and
25 maps (highlighting the areas at different risks). Again, this step requires a phase of normalization
26 aimed at rescaling the receptor-related risk scores into a common numerical scale (0-1) (Zabeo et
27 al., 2011). The scores proposed in Table 2 ~~were~~~~have been~~ defined by the authors by using a
28 dedicated qualitative evaluation. Of course, different scores based on site-specific knowledge,
29 literature data and expert judgments, can be assigned during the application of the proposed
30 methodology.

31
32 *Table 2*

33 34 **2.5.2. Physical/environmental risk assessment to infrastructures**

1 Floods ~~can~~ affect infrastructures networks causing a loss of services (e.g. not practicable roads and
2 ~~connections~~ railways, no interruption of power supply, etc.) in addition to structural direct damages
3 (e.g. ~~cracks~~ damages to roads, bridges, destruction of power stations, etc. ~~collapse of the~~
4 highways). Studies of past flood events have showed that the majority of losses arise in urban
5 areas, due to impairment of structures, costs of business shut-down and failure of infrastructures
6 (EEA, 2010c; ADBI and The World Bank, 2010). ~~A very recent example comes from the severe~~
7 ~~flooding experienced in Central East Europe (June 2013) that had a significant cost for~~
8 ~~infrastructure-related businesses.~~ Evacuations, property damage and infrastructure closures are
9 amongst the challenges faced by those operating in a wide range of industries, including
10 manufacturing, retail, transport, agriculture and tourism. A very recent example comes from the
11 severe flooding experienced in Central-East Europe in June 2013, that had a significant cost for
12 infrastructure-related businesses.

13 According to the Flood Directive (2007/60/EC), the KR-RRA methodology allows to identify
14 roads and railways affected by flood hazard, by considering only the inundation of the
15 infrastructures as main impact of interest. In this sense, the risk should be considered as the loss
16 of services for the infrastructure during and after the event. ~~In fact, f~~For a sake of simplification,
17 the methodology does not consider any structural damages related to the flood event (damage
18 and/or collapse of roads, bridges, railways, etc.).

20 **2.5.2.1. Hazard, exposure and susceptibility assessments**

21 Based on these premises, the flood hazard assessment only considers the flood extension (flooded
22 area) as relevant hazard physical metric. Water depths and its lower boundary conditions are not
23 considered because of the scale of analysis and lack of specific literature on this topic. However,
24 if data and research were available, the characterization of the functionality of (transport)
25 infrastructures could be reasonably performed. The exposure assessment step focuses on the
26 spatial localization and distribution of the roads, railways and pathways. These objects are
27 geometrically characterized by their linear extension (length) rather than by their surface extension
28 (area). Finally, the susceptibility assessment step assigns the same score to the whole set of assets
29 (e.g. roads, highways, railroads). As for the buildings, at micro-scale level the physical
30 susceptibility assessment can be improved by considering the construction typology, functions and
31 dimensions of the considered infrastructure.

33 **2.5.2.2. Risk assessment**

34 Accordingly, the infrastructure-related risk (R_4) is calculated from the intersection between the
35 flood extension map and the road and railway atlas in order to identify and characterize the ~~items~~

1 infrastructures inundated by the flood event. In this case, the physical/environmental risk
2 assessment ~~step to for~~ infrastructures results in the estimation of the length (km) and the percentage
3 of infrastructures potentially affected by flood in each CORINE Land Cover polygon in the form
4 of tables (summarizing the statistics) and maps (highlighting the areas at risk). Again, this step
5 requires a phase of normalization aimed at rescaling the receptor-related risk scores into a common
6 numerical scale (0-1) (Zabeo et al., 2011). For infrastructures, the normalization is
7 ~~performed~~ ~~provided~~ considering the length of flooded ~~items~~ ~~infrastructures~~ in each polygon and the
8 total length ~~of infrastructures~~ within the same polygon, ~~provided by as by~~ Eq.7:

$$9 \quad R'_4 = \frac{R_4}{\text{Total length of infrastructures in the same polygon}} \quad (7)$$

10 Where:

11 R'_4 = normalized risk score for infrastructures;

12 R_4 = length of flooded infrastructures in each polygon.

13
14 The normalization assumes that if in a polygon all the infrastructures ~~are were~~ flooded, people
15 cannot secure their health and their goods (i.e. all the safety way are not accessible). The
16 normalization phase, ~~where~~ infrastructures-related risk score are between 0 and 1, moves
17 ~~towards is functional for the development-computation of the total risk index, infrastructures-~~
18 ~~related risk scores between 0 and 1 that are integrated in the calculation of the total risk index.~~

20 **2.5.3. Physical/environmental risk assessment to agriculture**

21 Floods can ~~potentially~~ damage crops that become oversaturated, but can also ~~provide~~ cause
22 damages to farmlands and infrastructures. These impacts can lead to economic damages both direct
23 and indirect (e.g. loss of agricultural soil due to erosion, scarcity of cereals, etc.) with only few
24 methodological approaches available for their (monetary) quantification (Dutta et al., 2003, Meyer
25 et al., 2009). Recent events in Modena Province (Northern Italy) confirmed the importance of
26 considering the massive floods impact ~~on to~~ the agricultural sector with 54M€ of losses ~~for the~~
27 ~~sole have been~~ caused by (only) 2 days of ~~heavy~~ rainfall in late January 2014 (ANSA, 2014). The
28 KR-RRA approach is aimed at mapping potential flood risk to agriculture ~~making the best use by~~
29 means of of ready-available information-data at the meso-scale level (i.e. CORINE Land Cover
30 polygons of the agricultural areas) to spatially characterize the pattern of relevant crops.
31 Specifically, the aim of the RRA methodology for agriculture is to define the percentage of the
32 harvest loss due to a flood event, without any consideration about the damage to agricultural
33 buildings since these have been already considered along with the assessment to the Economic
34 Activities, see sect. 2.5.1. Specifically, the aim of the RRA methodology for agriculture is to define

1 ~~the percentage of the harvest loss due to a flood event, without any consideration about the damage~~
2 ~~to agricultural buildings.~~

4 **2.5.3.1. Hazard, exposure and susceptibility assessments**

5 Based on the analysis proposed by Citeau (2003) concerning bibliographic data and in situ surveys,
6 the proposed assessment requires the identification of water depth and velocity as relevant physical
7 metrics to characterize the hazard. The exposure assessment step allows the localization of the
8 different agricultural typologies considered (i.e. vegetables, vineyards, fruit trees and olive groves)
9 in the case study area, according to the land use pattern provided by the ~~mentioned~~-dataset of
10 reference. Moreover, a set of thresholds for the hazard metrics have been established for different
11 agricultural typologies (~~e.g. vegetables, vineyards, trees~~) characterized by a different susceptibility
12 factor, also according to the seasonality (e.g. the spring, summer and autumn) (Table 3). For
13 example, ~~since~~-vegetables are more susceptible than fruit trees to inundation phenomena, therefore
14 their relative threshold for the flow velocity is lower for the former first ones. Nevertheless, updated
15 and site-specific thresholds can be established, when available, together with other relevant factors
16 to better characterize the susceptibility score, such as the water stagnation-

17
18 *Table 3*

20 **2.5.3.2. Risk assessment**

21 Within the risk assessment phase, giving the ~~flood~~-hazard thresholds provided by Table 3, it is
22 possible to define if an agricultural area is inundated (i.e. if the flood hazard values are below the
23 identified thresholds) or loss (i.e. if the flood hazard values exceed the thresholds) ~~due to a flood~~
24 ~~event~~ and therefore to calculate the total flooded agricultural area (km²) and the percentage of
25 agriculture typologies stricken-affected, in the form of tables, summarizing the statistics, and maps,
26 highlighting the areas at different risk levels. Specifically, the agriculture-related risk (R_5) is
27 calculated for spring, summer and autumn seasons by assuming that during the winter time there
28 are no cultivations exposed to the impact of flood. Therefore, for this season, it is only possible to
29 distinguish between inundated and not inundated agricultural areas. Finally, the normalization
30 phase provides values between 0 and 1, according to the authors' evaluation, as summarized in
31 Table 4. Local stakeholders and others can assign different scores based on site-specific
32 knowledge, literature data and expert judgments.

33
34 *Table 4*

2.6. Physical/environmental risk assessment to natural and semi-natural systems

Floods tend to degrade natural systems (i.e. natural and semi-natural ecosystems, protected areas, wetlands) by ~~removing-destroying~~ vegetation, degrading hill-slopes, river-beds, altering the pattern of erosion/sedimentation processes and the transfer of both sediment and nutrients. Other negative effects include loss of habitats, dispersal of weed species, release of pollutants, lower fish production and loss of recreational areas. Accordingly, the aim of the proposed KR-RRA methodology is ~~to identify~~characterize the degree to which ~~those~~ environmental systems (~~i.e. natural and semi-natural ecosystems, protected areas, wetlands~~) that can be affected by a flood event due to their physical characteristics (~~e.g. slope, vegetation cover, soil type~~) causing a permanent, or temporal, loss of ecosystems services.

2.6.1. Hazard, exposure and susceptibility assessments

Flood extension area (km²) has been selected as relevant physical metric to characterize the hazard impacting natural and semi-natural systems. Moreover, the exposure assessment allows localizing the receptor by considering the CORINE Land Cover classes related to forest, semi-natural areas and wetlands.

As far as the susceptibility assessment is concerned, following Pasini et al. (2012), a series of indicators have been selected to characterize the physical ~~intrinsic~~ characteristics of the analysed territory reflecting variations in the degree to which the natural and semi-natural systems may be affected by a flood event. These indicators are as follow:

- Vegetation cover

- Slope

- Wetland extension

- Soil type

~~(see Table 6)~~. Each susceptibility indicator is later classified and scored by expert judgment. For the vegetation cover ~~factor~~, for example, susceptibility classes are defined by considering different land cover typologies such as grass, shrub and forest. Specifically, the susceptibility of soil to floods increases when vegetative cover and slopes decreases (Preston et al., 2008; Torresan et al., 2012), ~~while the slope factor classes considers the range of possible slopes in the area by using the equal interval classification (Zald et al., 2006)~~. In fact, When it comes to ~~the impact of floods on natural systems to be intended as~~ loss of biodiversity and ecological value, especially in the medium-long term, environments characterize by lower slopes are more susceptible to floods since they are subject to water stagnation and therefore soil degradation, while steeper slopes are less

1 susceptible as they do facilitate the water evacuation (Preston et al., 2008). The same applies for
 2 the soil type ~~factor~~indicator, where classes and thresholds are established considering that the more
 3 waterproof soil type typologies are the most susceptible to flooding because they cannot drain the
 4 standing waters (Yahaya, ~~2008~~2010). Moreover, the higher susceptibility scores has been assigned
 5 to wetlands with lower surface area, which may be more sensitive to flood pressures than wider
 6 ones (Torresan et al., 2012). The relative classification of these factors is performed by using the
 7 equal interval classification (Zald et al., 2006).

8 Once susceptibility classes are defined, the assignation of ~~suseptibility~~the relative scores is
 9 provided by experts and local stakeholders following the linguistic evaluations reported in Table
 10 5, in order to classify their (relative) importance in the analysed area. Moreover, the expert could
 11 assign a weight to susceptibility factors indicators in order to represent their relative importance in
 12 the analysed area. The phase of scoring and weighting allows the normalization of the
 13 susceptibility indicators between 0 (i.e. no susceptibility) and 1 (i.e. the higher susceptibility in the
 14 considered region).

15 *Table 5*

16 Finally, the ~~suggested~~ susceptibility indicators are ~~then~~ aggregated through a Multi-Criteria
 17 Decision analysis (MCDA) function named “probabilistic or” (Kalbfleisch J. G., 1985, ~~details in~~
 18 Appendix A), which provides a single normalized score of susceptibility for homogeneous areas,
 19 as follow:

$$21 \quad S_{nat} = \otimes_i^n [sf'_i] \quad (8)$$

22
 23 where:

24 S_{nat} = susceptibility score of the cell;

25 \otimes = “probabilistic or” function;

26 sf'_i = i^{th} susceptibility factor score (classified in $[0,1]$).

27
 28 When applying the “probabilistic or” function (Eq. 8), if just one susceptibility factor (sf) assumes
 29 the maximum value (i.e. 1) then the susceptibility score will be 1. On the other sidehand, sf with
 30 low scores contribute in increasing the final susceptibility score: the more is the number of low
 31 susceptibility factor scores, the greater is the final susceptibility (details in Appendix A).

32 33 **2.6.2. Risk assessment**

1 Finally, in ~~the this risk assessment~~ step the hazard and the susceptibility scores are aggregated in
2 a relative risk score (R_6) to identify and prioritize ~~exposed~~ natural and semi-natural systems
3 potentially affected by loss of ecosystem services, as follow:

$$4 \quad R_6 = H_{nat} \cdot S_{nat} \quad (9)$$

6
7 Where:

8 R_6 = natural and semi natural systems related risk

9 H_{nat} = hazard score (~~1 in flooded area according to Table 6~~)

10 S_{nat} = susceptibility score calculated according to the “probabilistic or” function (Eq.8).

11
12 Table 6

13
14 ~~However, case study experts can assign different scores based on site-specific knowledge,~~
15 ~~literature data and expert judgments.~~ The results of the ~~physical/environmental risk assessment~~ to
16 natural and semi-natural systems, are grid based layers ~~wwhere cells are here it is possible to~~
17 ~~calculate the surface (km²) and the percentage of the flooded receptor inranked in different each~~
18 ~~risk classes class~~ (e.g. low, medium, high) ~~with in the form of~~ tables (summarizing the statistics)
19 and maps (highlighting the areas at ~~different risks~~). As for the other receptors, a phase of
20 normalization aimed at rescaling the qualitative risk classes (i.e. low, medium, high) ~~following the~~
21 ~~qualitative evaluations summarized in Table 6~~ is performed. ~~Again, case study experts can assign~~
22 ~~different scores based on site-specific knowledge, literature data and expert judgments.~~

23
24 ~~Table 6~~

25 26 **2.7. Physical/environmental risk assessment to cultural heritage**

27 Flooding can damage architectural heritage, historic buildings and sites as well as objects of art
28 ~~standing alone or firmly attached as an integral group of buildings~~. All these objects are subjected
29 to various forces (e.g. static or hydrostatic pressure, flow velocity and waves) and actions during
30 flood situations (Nedvěďová and Pergl, ~~2003~~2013, Drďácký, 2010). According to the Flood
31 Directive (2007/60/EC) which requires the localization of the potential cultural heritages affected
32 by floods, the KULTURisk-RRA method includes cultural heritage ~~as~~ a relevant receptor for the
33 integrated flood risk assessment.

34 35 **2.7.1. Hazard, exposure and susceptibility assessments**

1 It is worth to specify that the analysis of risk at meso-scale level is not oriented to the evaluation
2 of structural damages to cultural assets but only to the identification of ~~stricken-affected~~ (flooded)
3 items. Therefore, flood extension area (km²) is ~~identifies-identified~~ as relevant physical metric to
4 characterize the hazard assessment. The UNESCO World Heritage Convention ~~by UNESCO~~
5 (1972) distinguishes three different typologies of cultural heritages: monuments (which are of
6 outstanding value from the point of view of history, art or science), groups of buildings (separate
7 or connected buildings) and sites (which are of outstanding universal value from the historical,
8 aesthetic, ethnological or anthropological points of view). Spatially they can be considered as
9 points (i.e. monuments) and areas (i.e. buildings and sites) overlapping with the polygons of the
10 CORINE Land Cover.

11 Starting from the available information at the meso-scale (i.e. location and typology of cultural
12 heritages) and assuming that the cultural assets are affected in the same way by the flood, the
13 susceptibility assessment assumes a score equal to 1 for the entire suite of items-, separately or
14 attached as an integral group of buildings.

15

16 **2.7.2. Risk assessment**

17 The risk assessment ~~step~~ for the cultural heritages aims at providing the number of flooded
18 monuments, the ~~coveragesurface~~ (km²) and percentage of inundated cultural buildings and
19 archaeological/historical sites in the form of tables (summarizing the statistics) and maps
20 (highlighting the cultural heritages at risk). Accordingly, the cultural heritage-related risk for
21 single monuments (R_7) and sites (R_8) are calculated from the intersection between the flood
22 extension map and the cultural heritage map, in order to identify the number and surface of the
23 cultural assets inundated ~~by the flood~~.

24 For this receptor, the normalization phase is performed by considering the number of inundated
25 monuments in each CORINE Land Cover polygon and the totality of ~~assets monuments~~ lying in
26 the polygon most populated by cultural objects (Eq. 10). For coverage, -, as well as the cultural
27 sites flooded area (km²) in each CORINE Land Cover polygon and the total area (km²) of cultural
28 sites in the polygon more extensively covered by cultural assets (Eq. 11), are considered.

29

$$30 \quad R'_7 = \frac{R_7}{\text{total number of monuments of the polygon with the highest number of monuments}} \quad (10)$$

31 Where:

32 R'_7 = normalized risk score for cultural heritages (monuments);

33 R_7 = number of flooded monuments in each polygon.

34

$$R'_8 = \frac{R_8}{\text{cultural sites [km}^2\text{] in the polygon with the highest cultural site area}} \quad (11)$$

Where:

R'_8 = normalized risk score for cultural heritages (sites);

R_8 = cultural sites flooded area [km²], in each polygon.

Again, ~~when-if~~ more detailed information related to the cultural heritage (e.g. site-specific surveys and archives) ~~are-were~~ available, a deeper analysis at the micro-scale (structural damages) can be performed by considering further physical susceptibility indicators, such as the material construction, the state of conservation, etc.

Table 7

2.8. Total Risk Index

~~Total risk index is calculated by aggregating different receptor-related risks by means of Multi Criteria Decision Analysis (MCDA) method. The (very) final result of the KR-RRA-KR methodology is a GIS-based Total Risk Map which allows to identify and rank areas and hotspots at risk within the studied analysed area. and, therefore, to establish relative priorities for intervention, to identify suitable areas for human settlements, infrastructures and economic activities, and to provide a basis for land use planning. Total risk index is calculated by aggregating different receptor-related risks by means of Multi Criteria Decision Analysis (MCDA) method. The field of MCDA encompasses different methodologies aimed at integrating heterogeneous criteria and decision maker insights towards the selection of alternatives. Outranking methods and Multi Attribute Value Theory are the most popular approaches in MCDA. The first ones, based on direct comparisons, have been discarded because of the complex and time consuming inputs required from users (Vincke, 1992). Instead, MAVT methodology has been selected which allows a sound ranking with relatively low user requirements (Giove et.al., 2009).~~

The KR-RRA methodology uses the weighted average (Eq.12) as effective method of aggregation, that is useful in liner additive contexts only, where receptors' risk are considered to be linearly additive and ~~nor-neither~~ synergic ~~nor neither~~ redundant effects among risks and indicators are present. ~~Moreover, the assignment of weights to the proposed receptors is performed by experts and local stakeholder's consultation. The ranking process is supposed to give numerical priority to those whose flooding damaging consequences are considered as burdensome. In this sense, weighting is a typical political decision making process and the involvement of relevant stakeholders is seen as a fundamental prerequisite for its effectiveness (Yosic and Herbst, 1998)~~

1

$$2 \quad R_{tot} = \frac{\sum_{\forall r} w_r R'_r}{\sum_{\forall r} w_r} \quad w_i \in [0,1] \forall r \quad (12)$$

3

4 Where:

5 R_{tot} = total risk;

6 w_r = weight associated with the r -receptor-related risk;

7 R'_r = normalized risk score associated to the r -receptor-related risk.

8 The assignment of weights to the proposed receptors is performed by experts and local
 9 stakeholder's consultation. The ranking process is supposed to give numerical priority to those
 10 whose flooding damaging consequences are considered as burdensome. In this sense, weighting is
 11 a typical political decision making process and the involvement of relevant stakeholders is seen as
 12 a fundamental prerequisite for its effectiveness (Yosie and Herbst, 1998).

13 The final output is a Total Risk Map (with risk scores between 0 and 1) where classes has been
 14 defined using Equal Interval GIS tool (see Table 8). Risk scores are not absolute predictions about
 15 the risks related to floods, rather they provide relative classifications about areas and targets that
 16 are likely to be affected by ~~flood~~these events more severely than others within the same region.
 17 By facilitating the , and, as a consequence, to localizelocalization of hot spots at risk, such as
 18 hospitals, schools, harbours, railway stations, airports, protected areas, potential installations
 19 causing pollution, ~~etc.~~these maps support decision makers and local stakeholders towards a
 20 knowledge-based disasters management, as well as the planning of mitigation measures and land
 21 use. Finally, a more detailed analysis of the most affected areas could be performed by examining
 22 the specific receptor-related risks.-.

23

24 Table 8

25

26 **Conclusions**

27 The paper proposes a state-of-the-art methodology, based on the Regional Risk Assessment
 28 approach and shaped on the framework of the European Flood Directive, for the integrated
 29 assessment of water-related hazards at regional scale (i.e. meso-scale) on multiple
 30 receptors/elements at risk (i.e. people, economic activities, natural and semi-natural systems and
 31 cultural heritages).

32 ~~The paper proposes a state-of-the-art physical/environmental Regional Risk Assessment~~
 33 ~~methodology, developed within the FP7 KULTURisk Project and shaped on the framework~~
 34 ~~established by the European Flood Directive, for the integrated assessment of water related~~

1 ~~hazards at the regional scale (i.e. meso-scale) on multiple receptors/elements at risk (i.e. people,~~
2 ~~economic activities, natural and semi-natural systems and cultural heritages). The methodology is~~
3 ~~completed by a separate cluster devoted to the socio-economic assessment (see Giupponi et al.,~~
4 ~~2013).~~ For each of the selected receptors-elements at risk, and by making a considerable use of
5 Geographic Information Systems (GIS) tools, the methodology proposes a specific procedure for
6 the estimation of a (normalized and spatially distributed) relative risk index, based on the
7 subsequent levels of analysis, namely the hazards, exposure and vulnerability assessments.
8 Together with the GIS-based maps, the outcomes of the application are indicators and statistics
9 that quantify the risk for the considered receptors (e.g. number of people at risk, ~~km²-coverage of~~
10 ~~flooded infrastructures at higher risk, percentage of residential buildings and commercial buildings~~
11 ~~at risk, km²-of loss extension of flooded s agricultural areaslands,~~ etc.). Finally, the Total risk is
12 calculated by aggregating the different receptor-related risks by means of Multi Criteria Decision
13 Analysis (MCDA) through experts and local stakeholders' elicitation. The KR-RRA methodology
14 should not attempt to provide absolute predictions about flood impact. Rather, this instrument, by
15 means of MCDA and GIS-based tools, provides the ranking of the area, sub-areas and hotspots at
16 risk that are more vulnerable and possibly more ~~dramatically-strongly~~ affected by the flood within
17 the investigated region, to evaluate the benefits of different risk prevention scenarios (i.e. baseline
18 and alternative scenarios) where structural and/or non-structural measures are implemented. ~~(i.e.~~
19 ~~large rivers, alpine/mountain catchments, urban areas and coastal areas) and spatial scales (i.e.~~
20 ~~from the large river to the urban scale)~~ Finally, ~~w~~With the ultimate aim to underpin risk prevention
21 measures and, therefore, ~~to,~~ to communicate to decision makers and stakeholders the potential
22 implications of floods in non-monetary terms, the proposed KR-RRA methodology demonstrate
23 that prevention is accountable and its benefits are measureable, because ~~different scenario can be~~
24 ~~compared. it can quantify in physical terms the risk avoidance due by the proposed prevention~~
25 ~~measures considered by the different scenarios and settings. As a matter of fact, this adaptable~~
26 ~~practical methodology is both rigorous and flexible as it can be adapted to different case studies~~
27 ~~(i.e. large rivers, alpine/mountain catchments, urban areas and coastal areas) and spatial scales (i.e.~~
28 ~~from the large river to the urban scale).~~ On this base, investments on prevention by Public
29 Administrations can be better evaluated and shared with citizens, also in order to support the rising
30 of a culture of prevention in the whole society. In this sense, the proposed methodology represents
31 an important scientifically sound instrument towards the implementation of the Flood Directive in
32 different environments and contexts. Its flexibility really allow the application to different case
33 studies (i.e. large rivers, alpine/mountain catchments, urban areas and coastal areas) and spatial
34 scales (i.e. from the large river basin to the urban scale), but only to individuate particular
35 criticisms in flood prone areas at the meso-scale: the implementation of the Flood Directive at the

1 micro-scale requires inevitably a more detailed analysis. Moreover, it is undeniable that further
2 limitations of this methodology consist in its (relatively high) degree of (political) subjectivity
3 when assigning weights and scores by means of experts ‘elicitation. On the other side, as per the
4 2014 IPCC AR5 report, the expert judgement (using specific criteria) is used to “integrate the
5 diverse information sources relating to the severity of consequences and the likelihood of
6 occurrence into a risk evaluation, considering exposure and vulnerability in the context of specific
7 hazards” in order to cope with the fact that “data are seldom sufficient to allow direct estimation
8 of probabilities of a given outcome” (IPCC, 2014). Therefore, ~~Theis proposed approach~~
9 methodology can be further ~~developed and~~ improved by taking into consideration the ~~outcomes of~~
10 its application to different case studies, representing different hydro-climatic regimes and being
11 exposed to different types of water related risks, and the complex dynamics of feedbacks between
12 physical, social and political ~~the feedbacks that~~ relevant end-users, decision makers (and local
13 experts) ~~from relevant end-users frequently pose~~ (see the twin paper, Part-H2, Ronco et al., 2014).
14 Moreover, a ~~An~~ attempt towards the concept of dynamics in flood risk assessment by considering
15 the new insights of the spatial-temporal evolution pattern of the four ~~considered-methodological~~
16 steps, as proposed by Mazzorana et al. (2012) for the vulnerability assessment could be performed.
17 Again, the characterization of the vulnerability patterns for (selected) communities and areas
18 through the combination of different drivers, such as the collective memory, risk-taking attitude
19 and trust in protection measures, as proposed by Viglione et al. in 2014, represents a new,
20 challenging, frontier for the next generation of risk assessment methodologies, ~~could be~~
21 performed. ~~In a rapidly changing world, risk changes significantly across time, space and culture.~~
22 Finally, in order to propose a harmonized overall approach to risk prevention for natural hazards
23 other than floods, both the suitability and applicability of the overall KULTURisk methodological
24 approach to other types of risks (earthquakes, forest fires, etc.) will be analyzed in detail, through
25 the involvement of a number of experts in these fields.

28 **Appendix A: Mathematical background**

29 The “Probabilistic or” function (Kalbfleisch J. G., 1985) is expressed as:

$$30 \otimes_{i=1}^4 [f_i] = f_1 \otimes f_2 \otimes f_3 \otimes f_4 \quad (A1)$$

31 where:

32 $f_i = i$ -th generic factor f

33 The “probabilistic or” operator can be evaluated as follow, due to the associative and commutative
34 proprieties:

1 $f_1 \otimes f_2 = f_1 + f_2 - f_1 f_2 = F_1$ (A2)

2 $F_1 \otimes f_3 = F_1 + f_3 - F_1 f_3 = F_2$ (A3)

3 $F_2 \otimes f_4 = F_2 + f_4 - F_2 f_4 = \otimes_{i=1}^4 [f_i]$ (A4)

4 The process can be repeated until evaluating all operands.

5 If just a factor (f) assumes the maximum value (i.e. 1) then the result of the “probabilistic or” will
6 be 1. On the other side, f with low scores contribute in increasing the final “probabilistic or” score:
7 the more is the number of low factor scores, the greater is the final score.

8
9

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1 Table 1. Identification of the building-related risk classes according to different hazard thresholds
 2 for water depth (d) and water velocity (v), as proposed by Clausen & Clark (1990).
 3

Flood hazard threshold	Building-related risk classes (R_3)	Definition
$v \leq 2$ or $vd \leq 3$	Inundation	Damage similar to that caused by a natural low-velocity river flood. No immediate structural damage.
$v > 2$ and $3 < vd \leq 7$	Partial damage	Moderate structural damage, i.e. windows and doors knocked out. Little damage to the major structural elements of the building.
otherwise	Total destruction	Total structural collapse or major damage to the structure necessitating demolition and rebuilding.

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1 Table 2. Physical/environmental risk classes and normalized scores for buildings.

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Classes	Normalized scores
Not inundated	0
Inundation	0,2
Partial damage	0,6
Total destruction	1

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1 Table 3. Thresholds for the flood hazard metrics for different agricultural typologies in the
2 spring, summer and autumn seasons (adapted from: Citeau, 2003).

3

Agricultural typologies	Maximum water depth [m]	Maximum water velocity [m/s]
Vegetables	-	0.25 m/s
Vineyards	0.5 m	0.25 m/s
Fruit trees and olive groves	1 m	0.5 m/s

4

1 Table 4. Risk classes and normalized scores for the agriculture receptor.

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Risk classes	Flood hazard thresholds	Normalized scores
Not inundated	No flood	0
Inundated	Flood metrics values are below the thresholds	0.6
Destroyed	Flood metrics values are over the thresholds	1

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1 Table 5. Qualitative evaluations supporting the expert in the assignation of relative scores to
2 susceptibility and risk classes.

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Linguistic Evaluation	Score
Most important class	1
Weakly less important class	0.8
Rather less important class	0.6
Strongly less important class	0.4
Less important class	0.2
No susceptibility	0

1 Table 6. ~~Physical/environmental risk~~ Hazard classes and normalized scores for natural and semi-
2 natural systems

Classes	Normalized scores
Not inundated	0
Low	0.2
Medium	0.6
High	1

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1 Table 7. Summary of the indicators and data sources used to characterize the three steps of analysis
 2 during the application of the physical/environmental Regional Risk Assessment methodology at
 3 the meso-scale, for the selected receptors (P: People; B: Buildings; I: Infrastructures; A:
 4 Agriculture; NS: Natural and Semi-Natural Systems; CH: Cultural Heritage).
 5

Steps of the physical/environmental RRA	Indicators/metrics	Data sources	Receptors
Hazard	Water depth	Flood modelling	P – B - A
	Water velocity	Flood modelling	P – B - A
	Flood extension	Flood modelling and mapping	I – A – NS - CH
	Debris Factor	Land cover map	P
Exposure	Presence of people in residential areas	Census data, Land cover/Land use map	P
	Presence of buildings	Land cover/Land use map	B
	Presence of infrastructures	Road and railway atlas	I
	Presence of agricultural typologies	Land cover/Land use map	A
	Natural & semi-natural systems	Land cover/Land use map, Protected area map	NS
	Presence of cultural heritages	Regional technical map, UNESCO cultural heritage map	CH
Susceptibility	People over 75 years and infirm/disable/long term sick	Census data	P
	Vegetation cover	Land cover/Land use map	NS
	Slope	Digital Elevation Model (DEM)	NS
	Soil type	Geomorphologic/soil map	NS
	Wetland extension	Land cover/Land use map	NS

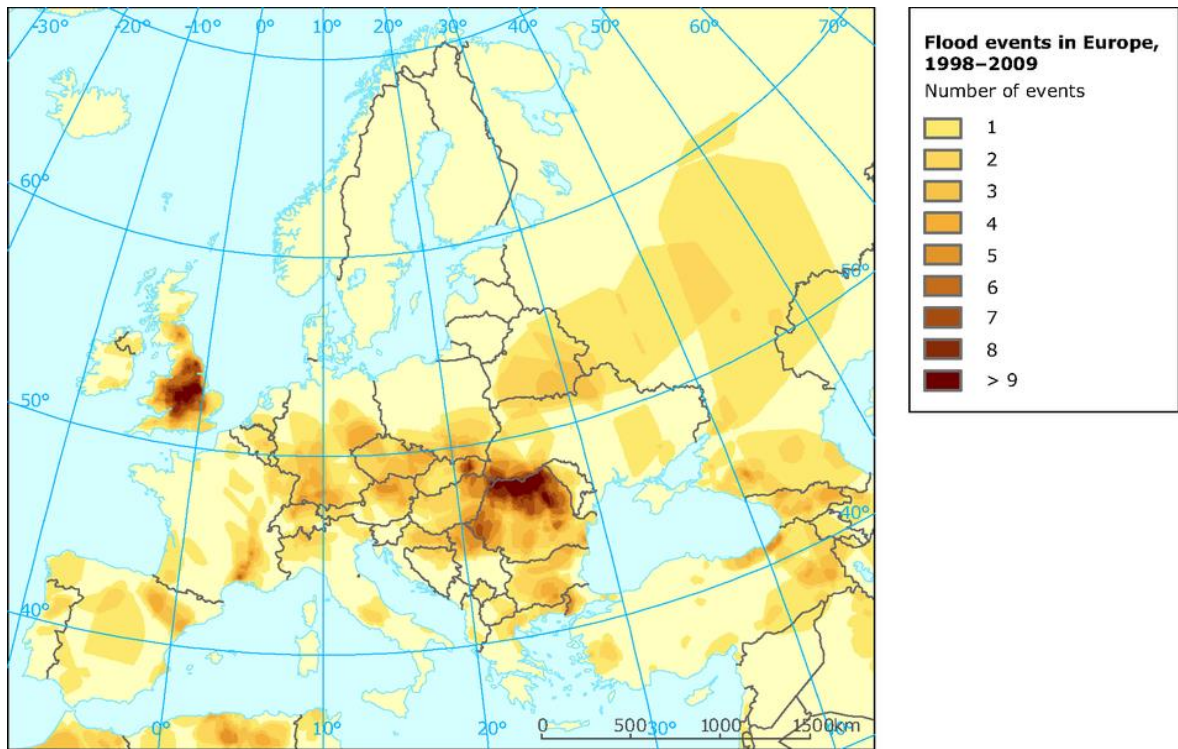
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1 Table 8. Risk classes score definition used to classify the total risk index (GIS Equal Interval
2 classification).

Risk Classes	Score
Not at risk	0
Very low	0 - 0.2
Low	0.2 - 0.4
Medium	0.4 - 0.6
High	0.6 – 0.8
Very high	0.8 - 1

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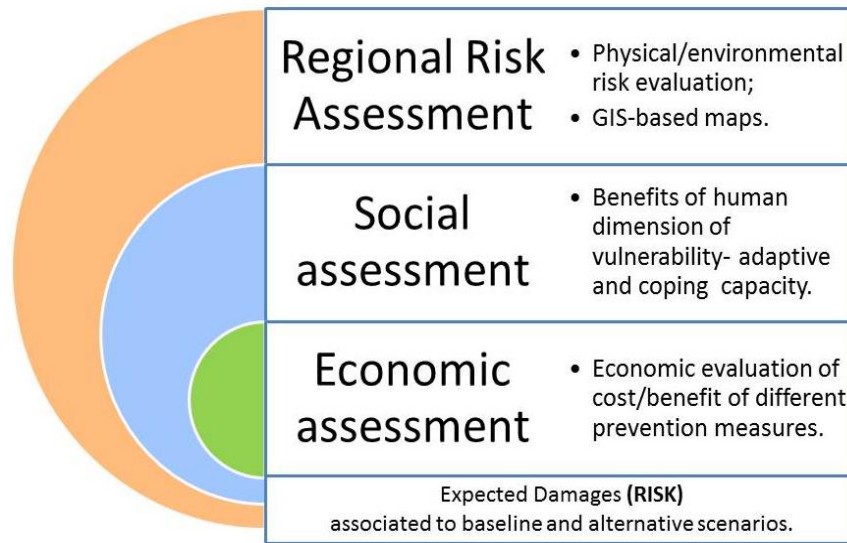
1 Figure.1. Occurrence of major floods in Europe (1998–2009); Source:;
2 <http://www.eea.europa.eu/legal/copyright>). Copyright holder: European Environment Agency
3 (EEA).



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1 Figure 2. Tiers of analysis for the implementation of the KULTURisk methodology to estimate
2 risk levels.

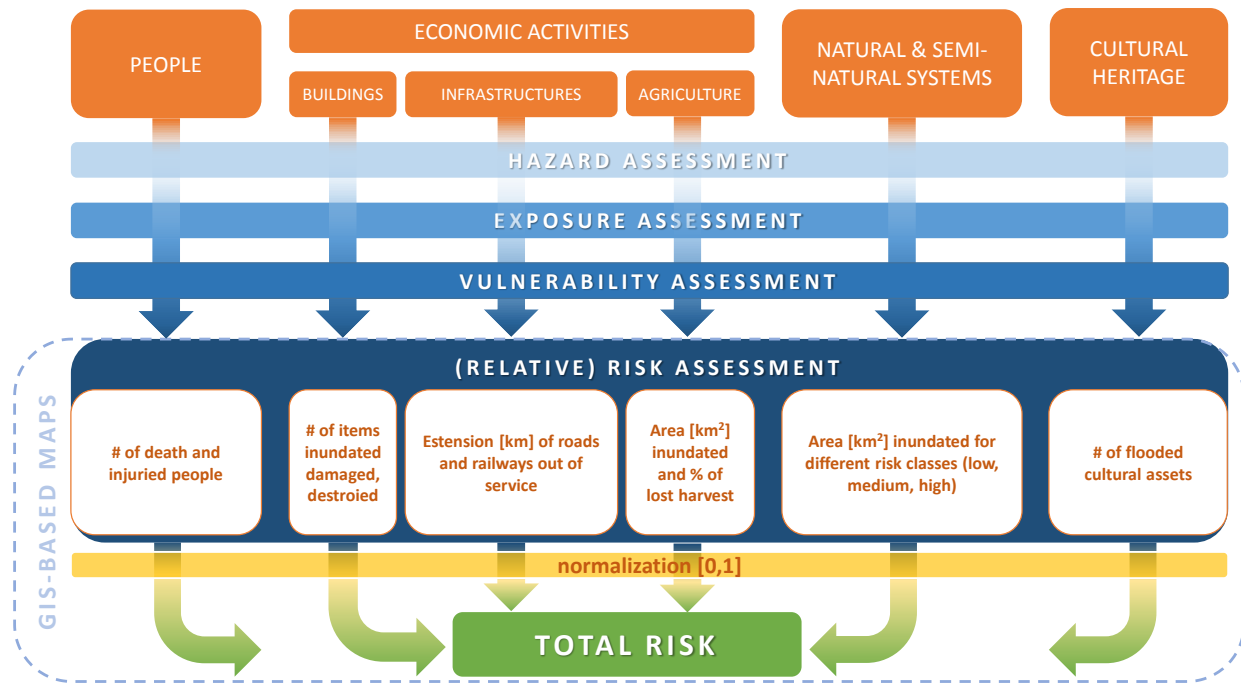
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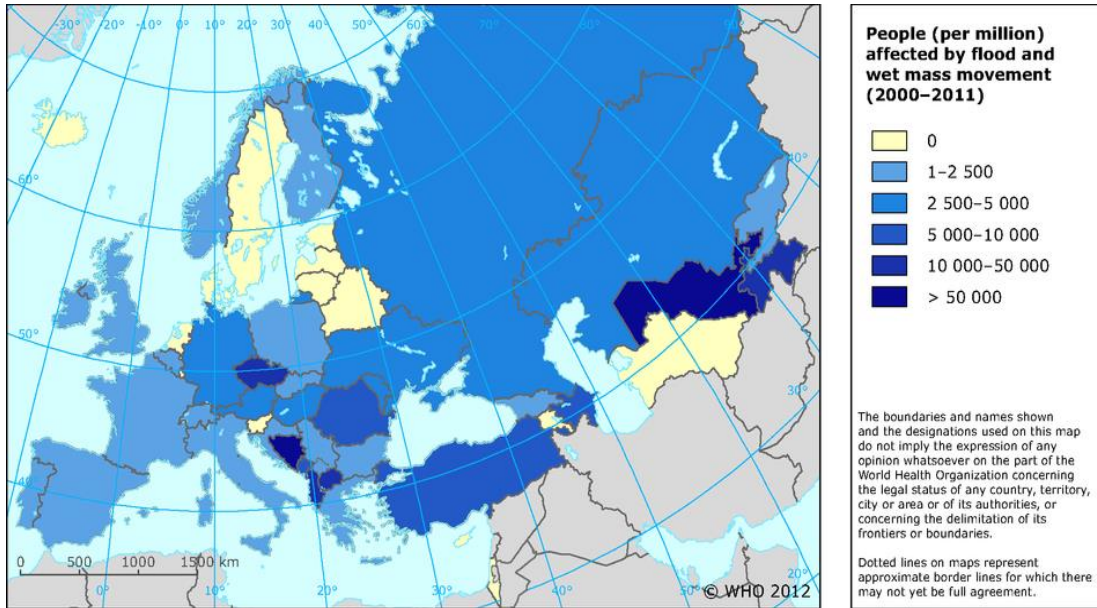
1 Figure 3. Physical/environmental KR-RRA, receptors, steps and outputs.



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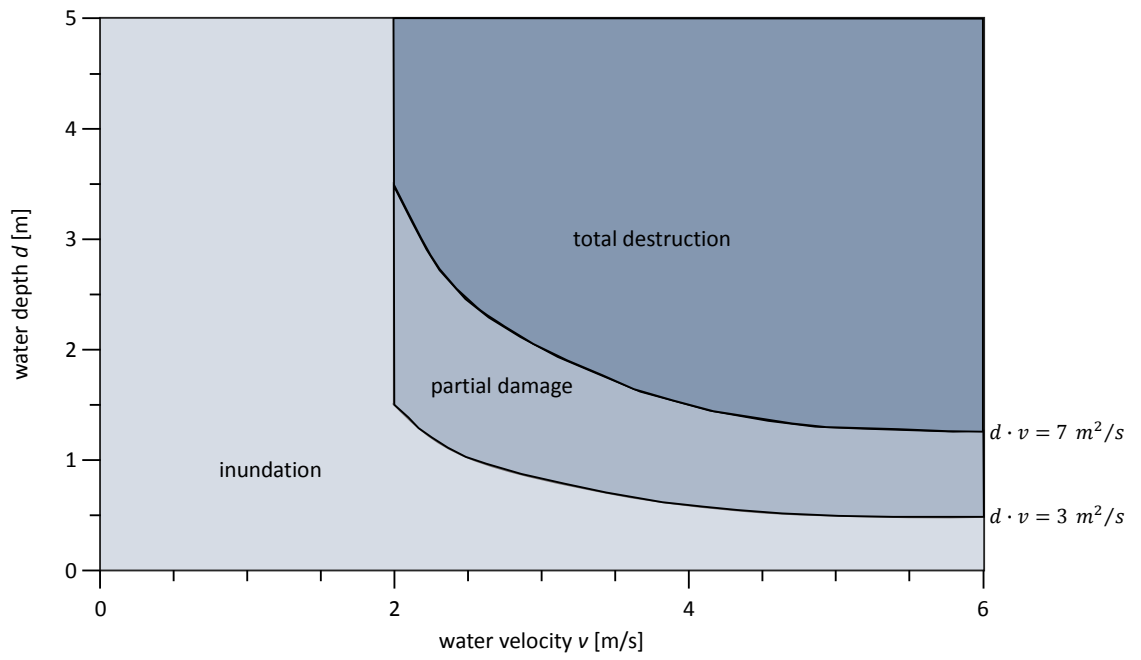
1 Figure 4. People affected by flooding in Europe from 2000 to 2011, per million population (WHO
2 European Region). Source: <http://www.eea.europa.eu/legal/copyright>). Copyright holder: World
3 Health Organization Regional Office for Europe (WHO/Europe)

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1 Figure 5. Identification of risk classes for different products of flow velocity and depth for
2 buildings (from Clausen & Clark, 1990).



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