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Interactive comment on "Review Article: A Comparison of Flood and Earthquake Vulnerability Assessment Indicators" *by* Marleen C. de Ruiter et al.

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General comments We would like to thank the reviewers for their very valuable comments. We acknowledge the fact that we were not clear enough in defining the scope of our paper and in particular our usage of a narrow definition of vulnerability and the focus on single-hazard type risk assessment models. We recognize that this may have caused confusion and therefore we have made the following general changes: âĂć We included a more explicit explanation of the scope of our paper: to conduct a literature review comparing methods for quantitatively assessing vulnerability in flood and earthquake risk assessments within which we look at both physical and social vulnerability aspects. âĂć Therefore, we have increased the depth of our analyses by adding 22 citations to support our statements and to bring more balance in the physical and social aspects of vulnerability in risk models. We included references suggested by the reviewers, such as: o Alexander, D. (1997). The study of natural disasters, 1977–97: Some reflections on a changing field of knowledge. Disasters, 21(4), 284-304. o Tate, E. (2012). Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Natural Hazards, 63(2), 325-347. o de Sherbinin, A., & Bardy, G. (2015). Social vulnerability to floods in two coastal megacities: New York City and Mumbai. Vienna Yearbook of Population Research, 131-165. o Cardona, O. D. (2004). The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. Mapping vulnerability: Disasters, development and people, 17. o Cardona, O. D., & Carreño, M. L. (2011). Updating the indicators of disaster risk and risk management for the Americas. IDRIM Journal, 1(1), 27-47. âĂć We have removed contradictory comments to this goal.

Reviewer #3 This manuscript proposes a comparative review of the vulnerability indicators that have been recently used in flood and earthquake vulnerability assessments, while distinguishing physical and social vulnerability indicators. The approach is based on a literature review of recent studies or vulnerability models, and the manuscript discusses which types of indicators are used in flood or in earthquake studies, and whether some lessons are to be respectively gained from these two fields. The intent of the authors to examine and harmonize the research outcomes of several disciplines (i.e. earthquake risk and flood risk, engineering community and socioeconomic community) is a timely and welcome effort, which should be of high interest for the audience of the NHESS journal. âĂć We thank the reviewer for the positive feedback and thorough comments, and are pleased that they value the scientific relevance of our research to the NHESS journal's audience. The reviewer provides several very useful comments/suggestions for revisions and we have addressed these in the revised manuscript, as per our responses to each comment below.

However, this review lacks context, in the sense that the objective of the vulnerability assessment is not clearly specified: Is it for a risk or loss analysis? With the quantification of what type of impacts (direct or indirect, tangible or intangible, etc.)? Short term or long term risk? Is resilience taken into account? The various references and studies that have been selected to extract vulnerability indicators are mentioned in the tables without any information on their objectives and context. As a result, the conclusions of the review are undermined by this limitation, since – in its present form – it is not possible to exactly know why some vulnerability indicators have been taken into account or omitted by the various studies/models. Moreover, the paper concludes that some vulnerability indicators from earthquake analyses should be taken into account for flood analysis (and vice versa), whereas there is no proof or demonstration that such indicators would actually be relevant or useful for the subsequent risk analysis: this highlights once again the need to specify the aim and context of the so-called "vulnerability assessment". âĂć We agree with the reviewer that we had not clearly stated our scope and objectives. Therefore, and in line with comments made by the other reviewers, we have elaborated on this. For example:

[63] In this paper, we limit our scope to risk assessment models that use the natural science approach to assessing vulnerability. While acknowledging the studies that further subdivide vulnerability into resilience and susceptibility, or that consider resilience to be vulnerability's counterpart (e.g. Fuchs 2009), we will only assess vulnerability as it is defined by UNISDR (2009).

[98] The main goal of this study is to conduct a literature review comparing methods for quantitatively assessing vulnerability in flood and earthquake risk assessments and therefore does not aim to provide a comprehensive overview of all vulnerability indicators in the domain of floods or earthquakes. Instead we analyze only those indicators that have been addressed in both domains and systematically assess the differences in using those indicators in both flood vulnerability and earthquake vulnerability. We recognize that the study of cascading events is an important, emerging field as discussed extensively in Pescaroli and Alexander (2016), however our focus is on single

events only. Moreover, because the field of vulnerability assessment is wide (Adger, 2006; Birkmann 2007), we here focus on the two main types of quantitative vulnerability assessment methods: vulnerability indices and vulnerability curves. More specifically, we analyze which vulnerability indicators have been addressed in both methods that focus on either one of the two hazard types, and systematically assess the differences in using those indicators in both flood vulnerability and earthquake vulnerability. In comparing the fields of flood vulnerability with earthquake vulnerability, we hope that both fields can learn from each other's respective approaches, further developing vulnerability as an important component in risk modeling.

âĂć In agreement with the reviewer's comment, we added a section which discusses the four different impact types (direct, indirect, tangible and intangible) in more depth, as follows:

[142] Vulnerability indicators can be categorized in direct versus indirect indicators. Where the engineering community has mainly addressed direct (or physical) damage, the economic research community has mainly addressed indirect (economic) damages (Koks et al., 2015a). In recent years, it has become more common for damage models to integrate both approaches (Koks et al., 2015a). [. . .] Adger (1999) discusses how some indicators of vulnerability can also be both direct and indirect; such as social inequality which can be a direct measure of the coping capacity of a household or community to respond to a disaster but it can also be interpreted as an indirect measure of increased poverty and insecurity. Therefore, we have decided to omit the classification of indicators between direct and indirect as well as tangible versus intangible from this paper.

âĂć The reviewer is right, and we deliberately narrowed down our vulnerability research to exclude a focus on resilience as we are, as mentioned in our reply to the other two reviewers, cautious to open up a discussion regarding the differences between resilience, and susceptibility and how they relate to vulnerability. We now carefully explain our focus on susceptibility in the introduction and method sections, we focus on vulnerability as defined by UNISDR as pertaining to susceptibility. [59] There are two distinct paradigms in assessing vulnerability: the natural sciences and the social sciences (Roberts et al., 2009). The former considers the human system to be passive while exposed elements have varying vulnerability to a hazard which can differ in magnitude and is considered to be an active agent. In the social sciences approach to assessing vulnerability, the focus is on the coping capacity and resilience of the human system (Roberts et al., 2009). In this paper, we limit our scope to risk assessment models that use the natural science approach to assessing vulnerability. While acknowledging the studies that further subdivide vulnerability into resilience and susceptibility, or that consider resilience to be vulnerability's counterpart (e.g. Fuchs 2009), we will only assess vulnerability as it is defined by UNISDR (2009). [67] While acknowledging the studies that further subdivide vulnerability into resilience and susceptibility, or that consider resilience to be vulnerability's counterpart (e.g. Fuchs 2009), we will only assess vulnerability as it is defined by UNISDR (2009).

[213] The definition of social vulnerability is much debated (Birkmann 2007). Hinkel (2011) states that although the debate around the conceptualization of social vulnerability continues to exist, agreement seems to have been reached on social vulnerability being context-specific and place-based as defined by Cutter et al. (2003). In this paper, we therefore use the definition of social vulnerability as provided by Cutter et al. (2003) where social vulnerability consists of social inequalities (i.e. social factors that influence peoples' susceptibility) and place inequality (i.e. factors such as urbanization and economic vitality that impact the social vulnerability of a place).

[222] Birkmann et al. (2013) provide an extensive overview of vulnerability perspectives and discuss the framing of vulnerability by both communities the DRR and CCA communities. Since many risk assessment models use the concept of susceptibility in assessing vulnerability (Birkmann et al., 2013) and since this is in line with the UNISDR (2009) definition of vulnerability, we will exclude a focus on resilience as a separate concept.

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âĂć While recognizing the ambiguity in categorizing vulnerability indicators, we acknowledge that we didn't provide sufficient theoretical underpinning of the framework used in our analysis and applied to our tables. We have addressed this as follows:

[124] Several studies have discussed the approach to and potential pitfalls in defining different indicator categories (e.g. Davidsson and Shah, 1997; Bruneau et al., 2003; Birkmann, 2007). Bruneau et al. (2003) suggest a framework for the quantitative assessment of seismic resilience consisting of the following four interrelated dimensions of community resilience for which there exist no single measure (note: their definition of resilience overlaps in part with the definition of vulnerability used in this paper): technical, organization, social, and economic. Davidsson and Shah (1997) acknowledge the necessity of the development of “an index of vulnerability”. Their Earthquake Disaster Risk Index (EDRI), a composite index, allows for the inclusion of different factors of vulnerability (i.e. physical infrastructure, population, economy and social-political system) (Davidsson and Shah, 1997). Davidsson and Shah (1997) too, acknowledge that factors (or classes) of vulnerability are not distinct entities and that there are many interactions, overlaps and contradictions between indicators from the different classes. While acknowledging the difficulties in categorizing vulnerability, using categories as used in many flood and earthquake vulnerability assessments, we classify vulnerability indicators in two main classes: (a) physical indicators that pertain directly to characteristics of the exposed assets, namely infrastructure and lifelines (including transportation infrastructure, utility lifelines, and essential lifelines) and buildings (including structural elements, occupancy, and environment related factors); and (b) social indicators, which include here: demographics, awareness, socio-economics, and institutional factors (e.g. Mileti, 1999; Cutter et al., 2003; Adger, 2006; Messner and Meyer, 2006; Roberts et al., 2009; Balica et al., 2012).

[177] The physical factor of vulnerability is the most thoroughly researched segment of vulnerability science, in part because physical vulnerability, or direct damage, is more easily quantifiable than social vulnerability (Notaro et al., 2014), and relates to

the physical vulnerability of the assets exposed to natural hazards – in our case floods and earthquakes. In accordance with several of the studies reviewed, we make a distinction in three main exposed assets: (a) infrastructure and lifelines; (b) buildings and their structural and occupancy components; and (c) environment (e.g. Davidson and Shah, 1997; Mileti 1999; Carreño et al., 2007; Douglas 2007).

[180] As mentioned, there are challenges in grouping indicators in distinct categories. Some studies perceive lifeline vulnerability as part of social vulnerability (e.g. Cutter et al., 2003; Holand 2014). For example, Holand (2014) defines lifeline vulnerability as the aspects of social vulnerability that are influenced by lifeline failure and he reviews common indicators used. He argues that there has been little discussion on how to measure lifeline vulnerability and distinguishes three lifeline indicator categories: (1) indicators addressing lifeline density and financial impacts caused by a natural disaster; (2) indicators measuring network redundancy and the potential for losing connectivity; (3) indicators measuring travel time to facilities that provide critical services. Many of the studies reviewed by Holand (2014) group lifeline indicators with built environment or other physical indexes.

[228] Reviewing the existing studies, there doesn't appear to be consensus on the aspects to include in social vulnerability. However, many studies incorporate different combinations of social indicators (such as vulnerable age groups, population density and population growth) with political, environmental and/or economic indicators (e.g. Davidsson and Shah, 1999; Cardona 2006; Peduzzi et al., 2009). Based on this, we here distinguish four main social vulnerability indicator groups: demographic, awareness and preparedness, socio-economic, and institutional and political vulnerability. However, as mentioned before, we recognize that indicator categories are not clear cut and overlaps continue to exist (Davidsson and Shah, 1997). Regarding the form, the paper would benefit from a better presentation of the review results. Section 3 quickly becomes a long list of repetitive sentences, detailing which vulnerability indicator or model is mostly used for flood and earthquake studies. Therefore it is difficult for the

reader to get a synthetic view of strong tendencies, which should be obtained from an in-depth analysis instead of solely a description of the content of the two tables. Moreover, one may argue that the availability of more or less advanced vulnerability models for flood or earthquake studies has a strong influence on the type of vulnerability indicators that are required – and thus collected in the various studies. âĂć As mentioned in our reply to reviewer two, we tried to have a balance between the number of earthquake and flood vulnerability models despite some research suggesting that there are more earthquake risk assessment models than flood risk assessment models. The tables, which we expanded on based on the reviewer's recommendations, attempt to create a comprehensive overview of the different indicators.

[266] At the time, Hollenstein (2005) reviewed vulnerability models for a wide range of natural hazards and found that there were far more earthquake vulnerability models (100+) than flood models (less than 20). We have aimed to include an equal number of earthquake and flood vulnerability models.

âĂć In adjusting section 2, by removing section 2.2.3 and by rewriting section 3 we hope to have improved the flow of the paper leading up to the results. Specific comments 1. l. 155-160: Maybe the education level should be mentioned here as a vulnerability indicator, since it is discusser later on (Section 3). âĂć We agree that we could improve the flow by already mentioning education level in section two prior to discussing it in chapter 3. We therefore adjusted the paragraph which now reads:

[242] Research has shown that risk perception is an important factor for households to determine their level of preparation for natural hazard events (e.g. Balica et al., 2012; Bubeck et al., 2012). For example, the experience with previous events has a positive effect on the awareness level (Balica et al., 2009). In addition, access to information sources, such as TV, determines the knowledge and awareness of the hazard (e.g. Balica et al., 2009; Brink and Davidson, 2015). Education level was found to not only influence peoples' socio-economic vulnerability (e.g. Cutter et al., 2003) but also household awareness and preparedness levels (Rüstemli and Karanci,

1999; Shaw et al., 2004). 2. l. 210-213: The discussion on vulnerability curves for flood damage holds in three lines, while earthquake vulnerability curves are described in one page. The authors should clarify this discrepancy and state whether flood vulnerability models are much scarcer than earthquake ones (and why). âĂć This was an oversight on our behalf and we adjusted the section by adding the following discussion of curve based flood vulnerability models:

[330] There are many flood risk models that use vulnerability curves, such as Hazus-MH, the Multi-Coloured Manual (MCM), GLOFRIS, the Damagescanner and the European Flood Awareness System (EFAS) (Meyer and Messner, 2005; Jongman et al., 2012; Ward et al., 2013). The MCM by Penning-Rowsell et al. (2010) is the most advanced curve-based flood damage assessment method in Europe (Jongman et al., 2012). Similar to HAZUS-MH, the MCM is an object-based model where buildings are classified based on building usage (i.e. residential, commercial and industrial) (Meyer and Messner, 2005), however it uses absolute depth-damage curves to relate damage in British Pounds to water depth. The MCM does not include indirect flood damages but it does account for short and long flood durations (Meyer and Messner, 2005; Jongman et al., 2012). 3. p 6-7: There seems to be some confusion between vulnerability curves and fragility curves, which are not exactly the same mathematical object. Vulnerability curves are usually deterministic models that express a loss or damage rate with respect to a hazard parameter, while fragility curves are probabilistic models that provide the conditional probability of reach a given (discrete) damage state given a hazard parameter. The distinction between vulnerability indices and vulnerability curves is also debatable: for instance, the vulnerability assessment method by Giovinazzi et al. first generates a vulnerability index for the buildings, which is then used to generate a vulnerability curve. âĂć We agree with the reviewer that we didn't clearly state the difference between vulnerability and fragility curves and how we incorporated the latter in our study. We adjusted the relevant section which now reads:

[307] The vast majority of flood- and earthquake vulnerability assessment models are

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based on damage functions or fragility curves that relate the (mostly-) physical indicators described in Sect. 2.1 with hazard parameters (Douglas, 2007). In flood damage models, vulnerability is commonly calculated by relating flood depth to building or land-use type using vulnerability curves per exposed building- or land-use type. These curves provide estimates of potential damage. Occasionally, other hazard parameters such as velocity and duration are added (Merz et al., 2010; Jongman et al., 2012). Unlike most other hazard type risk assessments, earthquake risk assessments traditionally use fragility curves as a vulnerability, or expected damage, measure, in which probabilistic damage to, for example, buildings is related to a hazard parameter such as ground shaking intensity (Douglas, 2007). In this study, we grouped fragility curve based models with other curve based models.

âĂć We acknowledge that a proper explanation of how we deal with studies that combine vulnerability curves and indices was lacking. We therefore added the following which also incorporates the suggested reference:

[273] It should be noted however, that in some studies an index is generated and subsequently incorporated in a vulnerability curve (e.g. Giovinazzi and Lagomarsino, 2004). In those cases, we classified the indicator used to construct the index in the index based models category. 4. l. 250-268: This sub-section (2.2.3) stands out from the rest of the section and is difficult to understand as it is (e.g. only two sentences to detail scaling issues). The authors should either remove it or ensure a better link with the previous sub-sections. âĂć We fully agree and in accordance with the comments of the other reviewers, we have removed this section. 5. There is very little mention of the non-structural components or building contents as vulnerability indicators, even though they are usually responsible for most losses in the case of floods. âĂć The reviewer is right to point out that this was missing from our analysis and we have therefore incorporated a discussion of non-structural components as follows:

[437] Within flood vulnerability assessments, some research has been conducted regarding non-structural damages and disaster risk reduction measures (e.g. building

regulations pushing for flood-proofing) to reduce building content damages (Dawson et al., 2011). However, rather than using a separate indicator, several models include content damage by adjusting the shape of the damage curve or changing maximum damage values. HAZUS-MH uses a 0.5 factor for estimating residential content damages in relation to structural damages (Scawthorne et al., 2006) and this factor has been used by other studies as well (e.g. Penning-Rowsell et al., 2010; de Moel et al., 2014). The Damagescanner, a curve based flood vulnerability assessment model, accounts for three types of flood-proofing measures (i.e. wet-proofing, dry proofing and a combination of the two) in assessing future potential for damages by adding damage reduction factors (0-1) (Poussin et al., 2012).

[365] Flood vulnerability assessments have seen a recent transition from focusing on traditional flood protection measures which aim to decrease the flood probability for an area to building-specific resilience measures (Ashley et al., 2007; Naumann et al., 2011). One example where this has been done is a study by Nikolowski (2014) which provides an overview of different ranges of building age and their flood vulnerability; structural (load carrying) and non-structural (mechanical) components; roof types; and building maintenance factors. For flood, vulnerability of building- or land-use types are often related to flood hazard indicators such as flood depth or flood velocity to estimate potential losses (e.g. Roos 2003; Barroca et al., 2006). 6. Table 2: There is no mention of the social indicators that have been identified in the SYNER-G project, for the development of shelter demand or healthcare demand models (no reference of this project in the table). See for instance Khazai et al. (2014). âĂć We acknowledge this shortcoming and have addressed it by including the suggested reference, as follows:

[529] Khazai et al. (2014) argue that for earthquakes, most often social vulnerability is integrated as a linear consequence function of physical damage (e.g. building damage causing casualties). For earthquake vulnerability, the index based SYNER-G framework designed by Khazai et al. (2014) integrates physical and social indicators where both are assumed to be a direct function of hazard intensity, physical

vulnerability and social vulnerability of the at risk population. For example, the expected number of post-disaster homeless people depends not only on the number of damaged buildings but also socio-economic indicators. Khazai et al. (2014) focus on including socio-economic indicators that can be quantified and harmonized at an EU-level and urban scale which led to the inclusion of more often used indicators such as household tenure (proportion of households living in self-owned or rented housing). Socio-economic indicators use aggregated data and are mostly used in index based vulnerability assessments rather than in curve based vulnerability assessments. 7. English language style: the grammatical construction 'noun-based noun' is abused throughout the paper, especially without a '-' in many instances. A good example is the sentence at lines 564-565. I advise the authors to correct this in order to simplify some sentences and improve general readability. âĂć We have read through the paper carefully and rephrased sentences that made use of that particular grammatical construction. Technical corrections - l.199: "and" is repeated twice. - l.357: "SYNER-G" instead of "SYNERG-G" - l.408: "take more indicators" instead of "make more indicators". - l.494: "damage models" instead of "damage modes". - l.517: "is introduced by" instead of "is introduces by". âĂć We thank the reviewer for pointing this out and have made the adjustments. References Khazai, B., Daniell, J. E., Düzgün, ÂÿS., Kunz-Plapp, T., & Wenzel, F. (2014). Framework for systemic socio-economic vulnerability and loss assessment. In SYNER-G: Systemic Seismic Vulnerability and Risk Assessment of Complex Urban, Utility, Lifeline Systems and Critical Facilities (pp. 89-130). Springer Netherlands. âĂć We thank the reviewer for this suggestion and have included this reference.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-45/nhess-2017-45-AC3-supplement.pdf

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