Impacts of future climate change on urban flood risks: benefits of climate mitigation and adaptations [MS No.: hess-2016-369]

Responses to review comments

REFEREE REPORT(S):

<u>Anonymous Referee #1:</u>

The article by Zhou at al tackles a very topical issue in the field of flood risk assessment, which deals with climate change, mitigation and adaptation measures. The research questions that the authors investigate is sound and meaningful, and it is particularly interesting as the benefits of adaptation and mitigation measures are evaluated numerically through a modelling framework (though their associate cost is not assessed). Now the bad news: the structure of the article is sometimes not so clear, due to missing links, lack of details in the methods, questionable assumptions and unclear interpretation of results. Also, the use of English, although sufficient, is sometimes sub-optimal, and could do with a revision by a native speaker. Please pay careful attention to the use of prepositions and of the "s" for plurals. I found a number of mistakes and inappropriate use. Nonetheless, I think that the article had good potential for being published, provided that the following comments are adequately addressed. Please pay special attention to the general comments, where substantial work is needed to improve parts of the description of methods, assumptions and evaluation of results.

<u>Response</u>: *We greatly appreciate the reviewer for the constructive comments and suggestions to improve our manuscript. In the revision, we have 1) added more details on the datasets and methods, 2) added more discussions on the assumptions and limitations, 3) modified the relevant statements and figures which are unclear or inaccurate, 4) invited a native speaker to proof-read the paper. More details of our responses to each comment are provided as follows.*

General comments

L 131-146: I would like to see some comments by the authors on the suitability of CMIP5 data for studies on urban flooding. Given the coarse resolution of CMIP5 (as they are global models), I'm sure that the entire study region is considerably smaller than 1 model grid cell. This poses some questions on how well extreme precipitation for modeling urban flooding is adequately represented by such datasets, given that such models are not able to represent local and short-lived storms commonly inducing flooding in small catchments. Intuitively one would say that downscaled projections with high resolution would be more suitable for this work, though that clearly depends on the data availability. Perhaps the authors can comment on that.

<u>Response</u>: *Thanks for the comments. As pointed out by the reviewer, bias would exist in global climate model (GCM) simulations especially at the local and regional scales. An alternative approach is to simulate the future climate using regional climate model (RCM) nested within a GCM. Such climate projections by RCM have added value in terms of higher spatial resolution which can provide more detailed regional information. However, various level of bias would still remain in RCM simulations (Teutschbein and Seibert 2012) and bias correction of RCM projections are required, e.g. the European project ENSEMBLES (Hewitt and Griggs 2004; Christensen et al. 2008). To run regional climate model is not within the scope of this study. Instead, we tend to use publicly available climate projection dataset. Here, we obtain climate projections from the ISI-MIP (Warszawski et al. 2014), which provides spatially-downscaled climate data for impact models. The climate projections were also bias-corrected against observations (Hempel et al. 2013) and have been widely used in climate change impact studies on hydrological extremes such as floods and droughts (e.g. Dankers et al. 2014; Prudhomme et al. 2014; Giuntoli et al. 2015; Leng et al. 2015).*

It should be noted that we used the delta change factor to derive the climate scenarios as inputs into our flood drainage model instead of using the climate projections directly. Specifically, we calculate the change factor between current and future climate projection simulated by GCMs and multiply them to observed time series to derive future climate scenario into our flood drainage model. This is because the relative climate change signal simulated by GCMs are argued to be more reliable than the simulated absolute values (Ho et al. 2012). What's more, we use an ensemble of GCM simulations rather than one single climate model in order to characterize the uncertainty range arising from climate projections. In the revision, we have added more discussions on this.

Reference

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L 169-182: I suggest expanding this section as I think there are some unclear points which prevents the reader from understanding some modeling steps, underlying assumptions, as well as from making the approach reproducible. For example, is q in eq. 1 the peak intensity? Which is the temporal resolution considered? Most climate datasets have 1 day as highest temporal resolution, but that would probably be rather coarse for urban flooding applications. How are then the hyetographs calculated from the q? Is it a simple rescaling based on their peak, keeping the same shape? Also, I see a lack of information on how climatic data is handled statistically to estimate storms/volumes with selected return period between 1 and 1000 years. For example, I see that the considered period for assessing future scenarios is 2020-2040, hence 21 years of data. Does it mean that return periods in the order of 1000 years are estimated from 21 years of data? Could the authors clarify on this? Can they provide ranges of uncertainty due to the undersampling of the climate variability in such long periods? Also, this should be mentioned in Sect. 4 as a further uncertainty source. Final comment is about eq. 1: could you briefly comment on how the parameters A, b, c, D are valid under a non-stationary climate? 4 parameters and just 2 variables sounds a lot for an empirical formula.

Response: *Thanks for the comments. In this study, we adopt the storm intensity formula (SIF) to derive the precipitation input into our drainage model. The SIF is a standard approach for rainfall design in urban drainage modeling in China, as well documented in the National Guidance for the Design of Outdoor Wastewater Engineering (MOHURD, 2011). Specifically, the SIF is used to describe an Intensity-Duration-Frequency (IDF) relationship, which is well used in the literature for estimating rainfall design hydrographs through the Chicago Design Storms (CDS) approach (Berggren et al., 2014; Cheng and AghaKouchak, 2014; Panthou et al., 2014; Willems, 2000; Zhou et al., 2012). More details can refer to Smith (2004) for the derivation of CDS from an IDF relationship. In China, the procedures for applying SIF to obtain CDS design storms are outlined in the National Technical Guidelines for Establishment of Intensity-Duration-Frequency Curve and Design Rainstorm Profile (MOHURD, 2014) and have been well adopted for Chinese urban drainage designs (Wu et al., 2016; Yin et al., 2016; Zhang et al., 2008; Zhang et al., 2015). Therefore, the method for using the SIF to generate CDS design storms for our SWMM modeling study is reproducible and valid for drainage modeling.*

The technical details of SIF and derivation of CDS rainfall are given as follows. As shown in the Equation 1, the q is the average rainfall intensity, t is the storm duration and P is the design return period. The typical temporal resolution in SIF is minutes for urban drainage modeling. A, b, c and D are the regional parameters governing the IDF relations among rainfall intensity, return period and storm duration. For a given return period, the SIF can be fitted into the Horner's equation (2004) as shown in Equation 2:

$$q = \frac{A(1 + Dlg(P))}{(t + b)^c} \quad \text{Eq. (1)}$$

$$i = \frac{a}{(t + b)^c} \quad \text{Eq. (2)}$$

The synthetic hyetograph based on the Chicago method is computed using Equation 2 and an additional parameter r (where $0< r <1$) which determines the relative location of peak intensity (with respect to time), $t_p=r*t$. The time distribution of rainfall intensity is described after the peak $t_a = (1-r)*t$ and before the peak $t_b=r*t$ by Equation (3) and (4), respectively. Specially, i_b is the instantaneous rainfall intensity before the peak, and i_a is the instantaneous rainfall intensity after the peak.

$$i_a = \frac{a[\frac{(1-c)t_a}{(1-r)} + b]}{(\frac{t_a}{(1-r)} + b)^{1+c}} \qquad \textit{Eq. (3)}$$

$$i_b = \frac{a[\frac{(1-c)t_b}{r} + b]}{(\frac{t_b}{r} + b)^{1+c}} \qquad \textit{Eq. (4)}$$

In this study, we considered 10 return periods, i.e., the 1, 2, 3, 10, 20, 50, 100, 200, 500 and 1000-year events. A 4-hour rainfall time series is generated for each return period at a 10-minute interval based on Equations 1-4. The A, b, c and D parameters governing the SIF shape were obtained from the local weather bureau, which fits the historical precipitation distribution for the study region. In the revision, we have added more details about the methods.

As for the generation of future climate scenarios, we first calculate the change factor for each return period. Specifically, for each year, the annual maximum daily precipitation was determined for both historical and future periods. Then, the generalized extreme value (GEV) distribution is fitted separately to the two sets of daily values (Coles 2001; Katz et al. 2002). The goodness of fit was tested by calculating the Kolmogorov–Smirnov and Anderson–Darling statistics. The value corresponding to each return period is derived based on the GEV distribution and the changes between future and historical periods are calculated as the change factors (as shown in Table 1 in the text). The change factor for each return period is then multiplied to the historical design CDS rainfall time series to derive future climate scenarios for the model. We acknowledge that to estimate the changes in extreme precipitation events involves inevitable uncertainties especially for return periods beyond the length of the data, e.g. 1000yrs as pointed by the reviewer. Hence, caution should be exercised when interpreting the results for return levels beyond the data length. However, we'd like to mention that "return period" is intrinsically a statistical measurement derived based on probability density function (PDF) of historical data in extended period. That is, it represents a recurrence interval which is an estimate of the likelihood of an event (in our case, a flood) indicated by the PDF. Depending on the historical period used, the return period could vary if the time series is not stationary. Nevertheless, a 1000-year return period can be derived from 21-year time series based on its definition by using a PDF. We have added discussions on this in the revision.

We agree that climate variability range would be under-sampled, although five climate models are used to show the possible ranges. In the revision, we use the boot-strap sampling technique to address the uncertainty range of under-sampling climate variability. We have added discussions on this in the revision.

The parameters A, b, c, D are derived from sub-hourly rainfall data and provided by local weather bureau. The four parameters which describe the Intensity-Duration-Frequency (IDF) relationship in the study region are assumed to be constant without considering its non-stationary features in a changing climate. To derive the parameter in the future period requires hourly precipitation data, which are not readily available. Hence, the IDF relationship is assumed to remain stable in the future and only changes in the daily mean intensity are considered. Given the above limitations, we acknowledge that our modeling results mainly represent the first-order potential climate change impacts on urban floods. Future efforts should be devoted to the representation of dynamic rainfall changes at hourly time step taking into account of non-stationary climate change. We have added more discussions in the revised manuscript.

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Zhang, D., Zhao, D. q., Chen, J. n., and Wang, H. z.: Application of Chicago approach in urban drainage network modeling, Water & Wastewater Engineering, 34, 354-357, 2008.

Zhou, Q., Mikkelsen, P. S., Halsnaes, K., and Arnbjerg-Nielsen, K.: Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits, Journal of Hydrology, 414, 539-549, 10.1016/j.jhydrol.2011.11.031, 2012.

L235-250: Despite the authors' efforts to link the flood volume with flood risk and damage, I find inappropriate to call results in Figure 4 as "risk" and "damage". There is clearly a missing step in linking flood volume with some socio-economic indicator on the impact of floods. This also results in a biased evaluation of what is called "flood risk", which suggests in Figure 4 that the largest contribution is given by floods with 1-2 year return period. In reality, it may well be that a single 100-year flood induces a damage which is larger than 100 1-year floods. For this reason, I do not agree with the statement in lines 239-242. The authors should definitely clarify this part and spend some words on what are the consequences of their assumptions, if that is retained at all. In addition, the authors should clarify the relations between Fig 4a and 4b. I have the feeling that values in 4b are simply obtained by dividing numbers in 4a by their theoretical expected annual frequency indicated below each column. This would be incorrect as in this way you would be double counting all probabilities smaller than each considered class. You should instead apply the formula for piece-wise integral of flood damage versus the expected frequency of each class, hence considering the width of each bar (e.g., for the second column is 1/2-1/3, for the third one is 1/3 -1/10 and so forth).

Response: *Thanks for the comments. We agree with the reviewer that results in Figure 4 refer to the flood volume rather than "damage" or "risk" due to the missing linkage to the socio-economic conditions. We also agree that a single 100-year flood event could have larger impacts than 100 1-year floods. In the revision, we have deleted the word "damage" or "risk" and revised the statements in lines 239-242 and other relevant statements accordingly. The original Figure 2 which is used to illustrate the conceptual flood risks is also revised.*

Following the suggestion by the reviewer, we have revised the Figure 4b to show the piece-wise integral of flood volume corresponding to each frequency class (e.g. the width of first class is 1/1-1/2 and so forth).

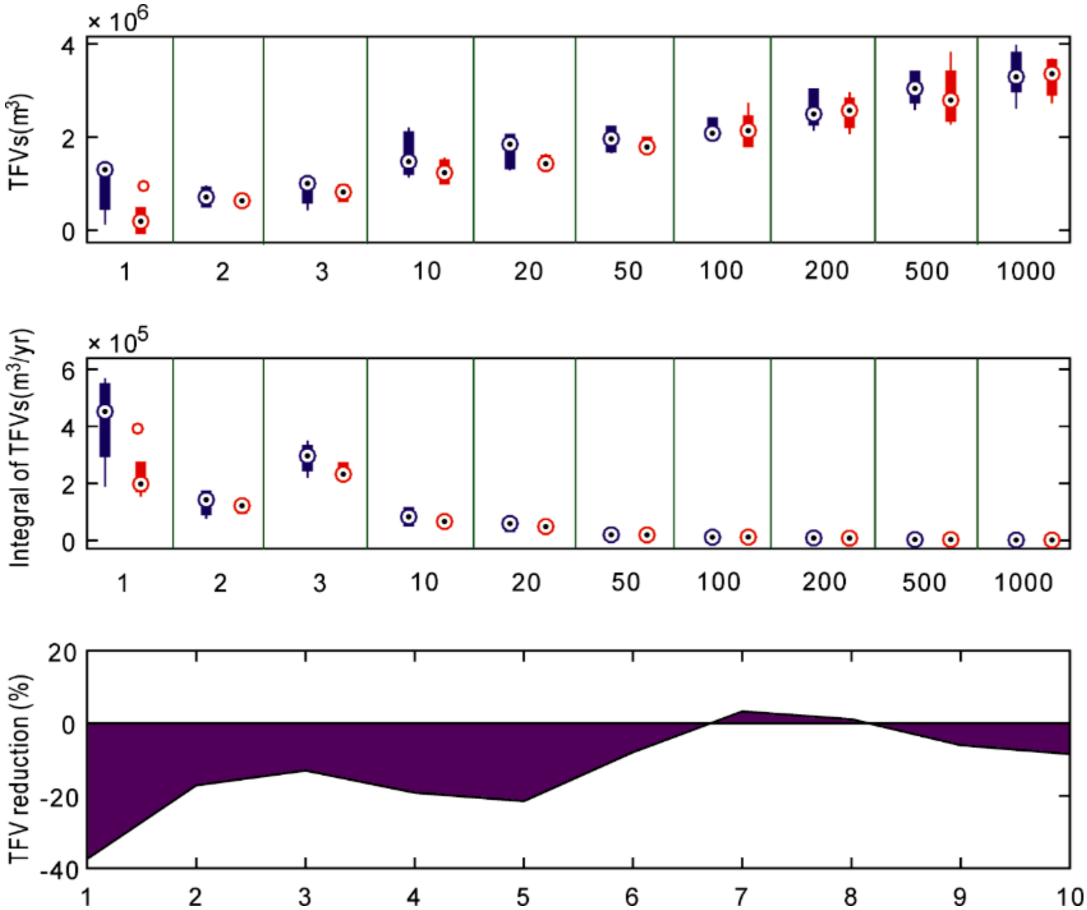

Figure 4 *Comparison of (a) flood volume, (b) total TFVs (i.e., the piece-wise integral of flood volume versus the expected frequency with changes in precipitation intensity of various return periods under RCP8.5 (blue) and RCP2.6 (red). (c) is for the reduced TFVs in percentage (i.e., benefits of climate mitigation) in RCP2.6 relative to RCP8.5 at various return periods.*

L 265-286: I find this part rather difficult to understand and suggest the authors to clarify some points and describe more thoroughly Figure 6 and its usefulness. First, the way changes (CTFV) are defined is not intuitive, as it is now defined as a multiplicative factor. Changes should be CTFV=(TFVc-TFVnc)/TFVnc. Also, why the current system is less sensitive to climate change than the adapted system (l 268-269)? I'm a bit puzzled by seeing that small changes in the 10-year precipitation intensity lead up to a 7-fold increase in TFV under the case of adaptation. Does it mean 7 times worse conditions or simply that the adapted system can hold more water, also because the catchment area is larger? Then I get confused on the definition of TFV: is it the total volume or simply the excess volume after filling completely the pipes system? I thought it's the second option, but now I'm confused. Please clarify in sect. 2c. In both cases it's difficult to assess how worse the conditions (i.e., the damage) would be under larger TFV in the adapted system, though I think a graph with such information is currently missing and could be added. Finally, please avoid 4 decimals in numbers at lines 270-271; 2 decimal digits are surely enough.

<u>Response</u>: *Thanks for the comments. We are sorry for the confusion. The TFV is defined as the total volume flooded from manholes without taking into account the outlet discharges, i.e., the excess water after filling completely the pipe system. As pointed out by the reviewer, the current drainage system is less sensitive to climate change. This is because the capacity of current drainage system is small, i.e. the excess water after filling completely the pipe system (i.e., TFVnc) is large. Given extreme rainfall events, the current system would be flooded completely, thus exhibiting less sensitivity to larger extreme rainfall events in the future. Therefore, the magnitude of changes in excess flood volume is smaller in the current system than the adapted system due to its large value of denominator in the calculation of CTFV (CTFV=(TFVc-TFVnc)/TFVnc).*

In order to better clarify this point, we have provided a table below summarizing the flood volumes of current and adapted drainage systems, with and without climate change. It is evident that for the present time, the flood volume of the adapted systems are much smaller than that in the current system due to capacity upgrades in the adapted systems to hold more water. For example, given a 10-year event, the flood volume for the present period (i.e., TFVnc) is 1041,230, 274,650 and 180,610 (m3) in current and the two adapted systems (highlighted in blue), respectively, while in the future period with climate change, the magnitude of flood volume (i.e., TFVc, highlighted in yellow) is similar among the three drainage systems. Therefore, the calculated changes in flooded volume (CTFV) in the future relative to the present period are much smaller in current system than adapted systems due to the larger value of denominator in the equation.

In the revision, we have 1) clarified the definition of TFV; 2) re-defined $CTFV=(TFV_c-TFV_{nc})/TFV_{nc}$ *following the suggestion, and updated Figure 6 accordingly (see Figure 6 below); 3) added more discussions on projected changes on TFV; 4) used 2 decimal digits for the numeric results throughout the text.*

Based on the suggested formula, the calculated CTFV for the three systems are 0.41, 1.75 and 2.29, respectively. The larger CTFVs in the adapted systems does not mean the worsened conditions. Rather, it indicates that the capacity (i.e., service level) of adapted system tends to become lower with climate changes while the current system has already reached its peak capacity in the present period and thus shows small sensitivity to climate change.

***Table 1**: TFVs of current and adapted systems with and without climate changes*

Return period		**1**	**2**	**3**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**
Current system	*NC*	*363434*	*545594*	*662399*	*1041230*	*1280598*	*1604223*	*1855559*	*2113083*	*2464388*	*2740033*
	C1	*1311483*	*779030*	*1070807*	*1471180*	*1845707*	*2120890*	*2081960*	*2494516*	*3337794*	*3635804*
	C2	*138358*	*625172*	*763944*	*1151120*	*1309407*	*1676813*	*2313744*	*2916433*	*3302794*	*3292205*
	C3	*689945*	*710016*	*1003205*	*1343650*	*1447074*	*1819748*	*1922111*	*2424542*	*2907221*	*3224196*
	C4	*1322311*	*939202*	*1020153*	*1948310*	*1942896*	*2158862*	*2312024*	*2961595*	*3040893*	*3957185*
	C5	*1299874*	*508016*	*447533*	*2184984*	*2011414*	*1961587*	*2068387*	*2155563*	*2598096*	*2631549*
Pipe	*NC*	*0*	*0*	*0*	*274650*	*545548*	*902639*	*1191761*	*1454490*	*1825663*	*2107541*
	C1	*579100*	*66820*	*307628*	*754782*	*1177608*	*1465530*	*1424433*	*1853479*	*2753620*	*3048692*
	C2	*0*	*14683*	*58510*	*400927*	*576342*	*988731*	*1672038*	*2305916*	*2711960*	*2700636*
	C3	*30911*	*39643*	*236010*	*610572*	*720015*	*1151135*	*1260383*	*1791006*	*2295501*	*2631907*
	C4	*586820*	*175700*	*254039*	*1287942*	*1283153*	*1502586*	*1670054*	*2356962*	*2432769*	*3392554*
	C5	*564627*	*1288*	*647*	*1531861*	*1355232*	*1304201*	*1413665*	*1500109*	*1960429*	*1999834*
Pipe+ LID	*NC*	*0*	*0*	*0*	*180610*	*403742*	*735983*	*994636*	*1239575*	*1571403*	*1833913*
	C1	*435235*	*31853*	*205783*	*594395*	*981183*	*1247661*	*1207291*	*1602282*	*2407278*	*2683353*
	C2	*0*	*4374*	*27315*	*275503*	*432434*	*808381*	*1439073*	*2002787*	*2375242*	*2362011*
	C3	*10832*	*13901*	*152559*	*463675*	*568173*	*960769*	*1056741*	*1531386*	*1993485*	*2295640*
	C4	*442271*	*106856*	*165356*	*1082850*	*1077049*	*1280177*	*1437899*	*2042621*	*2123354*	*2966933*
	C5	*423441*	*723*	*536*	*1300494*	*1145087*	*1094680*	*1193045*	*1277930*	*1703625*	*1738962*

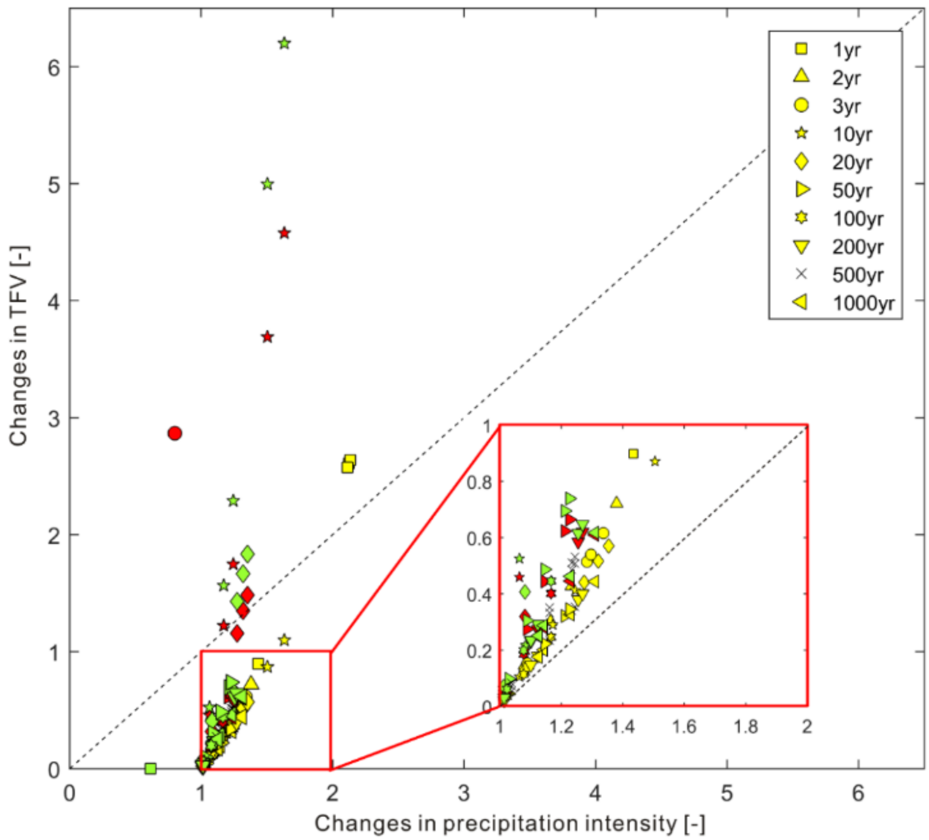

Figure 6 *Future changes in flood volumes (CTFV) relative to historical conditions under current drainage system (yellow) and two adaptation scenarios (i.e. Pipe in red and Pipe+LID in green) at various return periods.*

Specific comments

L 31: given the delay between submission and publishing I suggest removing "current" from the text. Same for line 81.

<u>Response</u>: *Done.*

L 32: I suggest removing "existing" in favor of "past", "recent," "literature" or similar

<u>Response</u>: *Done.*

L 40: "Based on the results" –> "Results indicates that"

<u>Response</u>: *Done.*

L45: This is an outcome of your research, hence I would not say it is "obvious" but rather something like "very likely" or "results clearly indicates::" or similar.

<u>Response</u>: *Thanks for the suggestion. We have revised it to "results clearly indicate"*

L 46: "greenhouse gas emissions"

Response: *Done.*

L 62: The sentence is not clear. Please specify units of the change and in relation to what (e.g., flood peak, precipitation intensity?)

Response: *Thanks for the suggestion. We have revised this sentence to "a 30% and 40% increase in the precipitation intensity is expected for the 10- and 100-year return period respectively ...."*

L 66-69 is again not clear. E.g., non-stationary changes reads awkward. Also, what do you mean by future hydroclimate?

Response*: Thanks for the suggestion. We have revised this sentence to "Therefore, it is important to investigate the performance of drainage systems in a changing environment and assess the potential flood damage for better adaptations"*

L71-77: As the article has a strong focus on mitigation and adaptation I suggest adding some relevant references in those areas. See the work by (Alfieri et al., 2016; Arnbjerg-Nielsen et al., 2015; Moore et al., 2016; Poussin et al., 2012) among others. The few ones currently listed in the article are somehow hidden in the conclusions.

Response: *Thanks for the suggestion. We have expanded literature review and incorporated the suggested references in the revision.*

References

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Poussin, J. K., Bubeck, P., H. Aerts, J. C. J. and Ward, P. J.: Potential of semi-structural and non-structural adaptation strategies to reduce future flood risk: Case study for the Meuse, Nat. Hazards Earth Syst. Sci., 12(11), 3455–3471, doi:10.5194/nhess-12-3455-2012, 2012.

L136-137: the sentence is currently hard to read. Please reformulate.

Response: *Done.*

L 140-144: The sentence is rather misleading, first because there is now a wealth of studies using ensembles of several GCMs, and second because "all five GCMs" sounds like if there were only five, while CMIP5 includes way more than that.

Response: *Thanks for the suggestion. In the revision, we have deleted the statement "Unlike most previous studies that only used data from one or two GCM in climate change impact studies on urban floods".*

L 151: Rainfall is a climatic data. Please clarify.

Response: *Done.*

L 176: there are –> we considered

Response: *Corrected.*

L 181-182: This sentence should be supported by data, graphs or a reference to publications showing the validation work against historical records.

Response: *Thanks for the suggestion. In the revision, we have updated Figure 5a (attached below) by adding a graph on the city land use condition (e.g., green spaces and traffic network) and records of historical flood locations obtained from local water authorities. It is shown that the simulated locations of overloaded pipelines are in good agreement with historical records of flood points.*

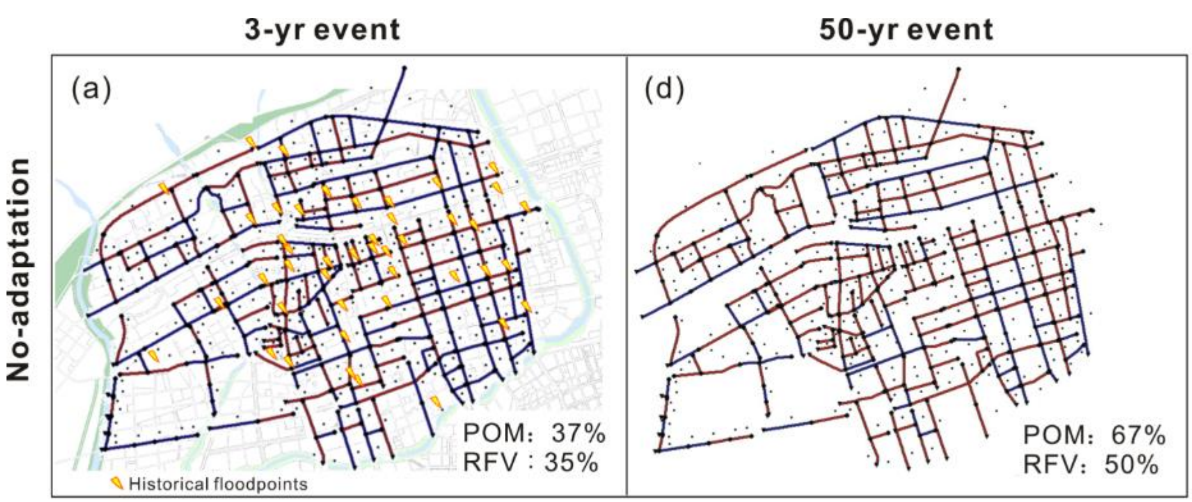

Figure 5 *Spatial distribution of overloaded pipelines (red color) induced by the 3-yr (left column) and 50-yr extreme events (right column) without and with adaptations. The total percentage of overloaded manholes (POM) and ratio of flood volume (RFV) are summarized.*

L 186-191: This part is difficult to read and understand. Please clarify and add some detail on how the TFV – return period relationship was derived. Figure 2 currently doesn't help a lot as it is too general, with no units nor tick marks. For example, if it the grey area is meant to indicate those events that contribute the most to the annual damage, then it should take at least 50% of the area under the curve in Figure 2, as its integral is proportional to the total flood risk.

Response: *Thanks for the suggestion. As responded to the third general comment, we have revised these sentences to make it more clear and concise. Figure 2 is also updated following the suggestions:*

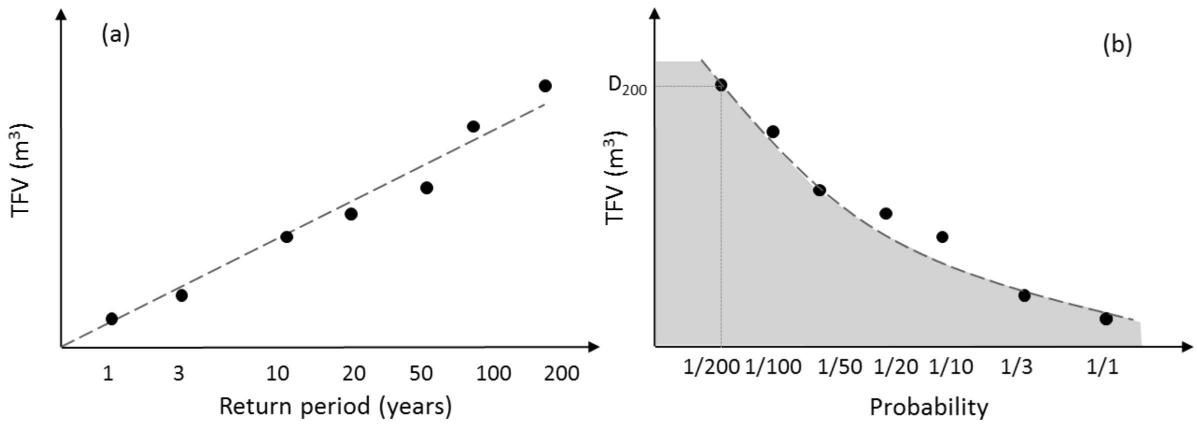

Figure 2 *Illustration of flood volume and average total expected TFVs as a function of return period under stationary drainage system. The grey area denotes the average total expected TFVs per year considering all kinds of floods.*

L 191- 195: This statement indicates a strong assumption which is not justified at this stage and sounds like a speculation. Perhaps the authors want to introduce what is later on indicated by their findings, but I think at this point this is unjustified, unless the point is supported by stronger evidence and/or some references.

Response: *Thanks for the comment. In the revision, we have moved these statements into the discussion section with reference added.*

L204-205: What is the extent of the enhancement of pipeline diameters in the adapted scenario? I couldn't find it anywhere in the text.

Response: *Thanks for the comment. The number of pipelines of the current and adapted system is 323 and 488, with a total pipe length of 251.6km and 375.4 km, respectively. In the adapted scenarios, the mean pipeline diameter is about 1.73m, which has increased by 53% compared to that in current system. We have clarified this in the revision.*

L230-231: Is this 52% a simple average of the percent changes shown in Figure 3? Then I suggest to clarify, as it doesn't necessarily mean the overall projected change in flood risk.

Response: *Thanks for the comments. In the revision, we have added more details on the changes, rather than showing the overall average value.*

L 254: More correctly "10 magnitudes of rainfall events".

Response: *Corrected.*

L 263: 19% should be 49%.

Response: *Corrected.*

L 332-333: Not just uncertainties but modeling assumptions as well.

Response: *Thanks for the suggestion. We have added more discussions on the assumptions in the revision.*

L 328-329: That's true but perhaps out of the scope of this article, as anyways there is no real damage model to evaluate economic flood losses.

Response: *Thanks for the comment. Yes, flood damage is not addressed in this study. We have added discussions on this in the revision.*

L 358-363: Following the discussions above one should be careful in calling these numbers "flood risk". Please adapt according to the indications in the discussion points above.

Response: *Thanks for the suggestion. We have changed "flood damage" or "flood risk" to "flood volume" throughout the text in the revision.*

L 605-606: I suggest including the period "2020-2040" in the caption for better understanding the graph.

Table 1: Which are the units in the table? Please specify units and the storm duration related to the precipitation intensity values listed (key parameter to understand such values).

Response: *Thanks for the suggestion. We have added the period "2020-2040" in the caption. Table 1 shows the future changes of precipitation at various return periods. It is dimensionless. The changes are multiplied to the present rainfall time series to obtain climate change scenarios as inputs to our model (see response to general comment 2).*

Figure 5: Please choose a more visible way of indicating overloaded pipelines, perhaps with a thicker line and/or a different color. Also the POM is currently mistakenly written as "NOM" in the 6 panels.

Response: *Thanks for the pointing out the typo. We have replaced "NOM" with POM. The illustration of overloaded pipelines is a direct output from the SWMM model. At present, it is not easy to highlight the pipelines given the hard-coded model user interface. Instead, we tried to update the figure with larger color contrast for better illustration. In addition, we have added city land use information (i.e., green spaces and traffic network) and records of historical flood pints obtained from the local water authorities in the updated figure.*

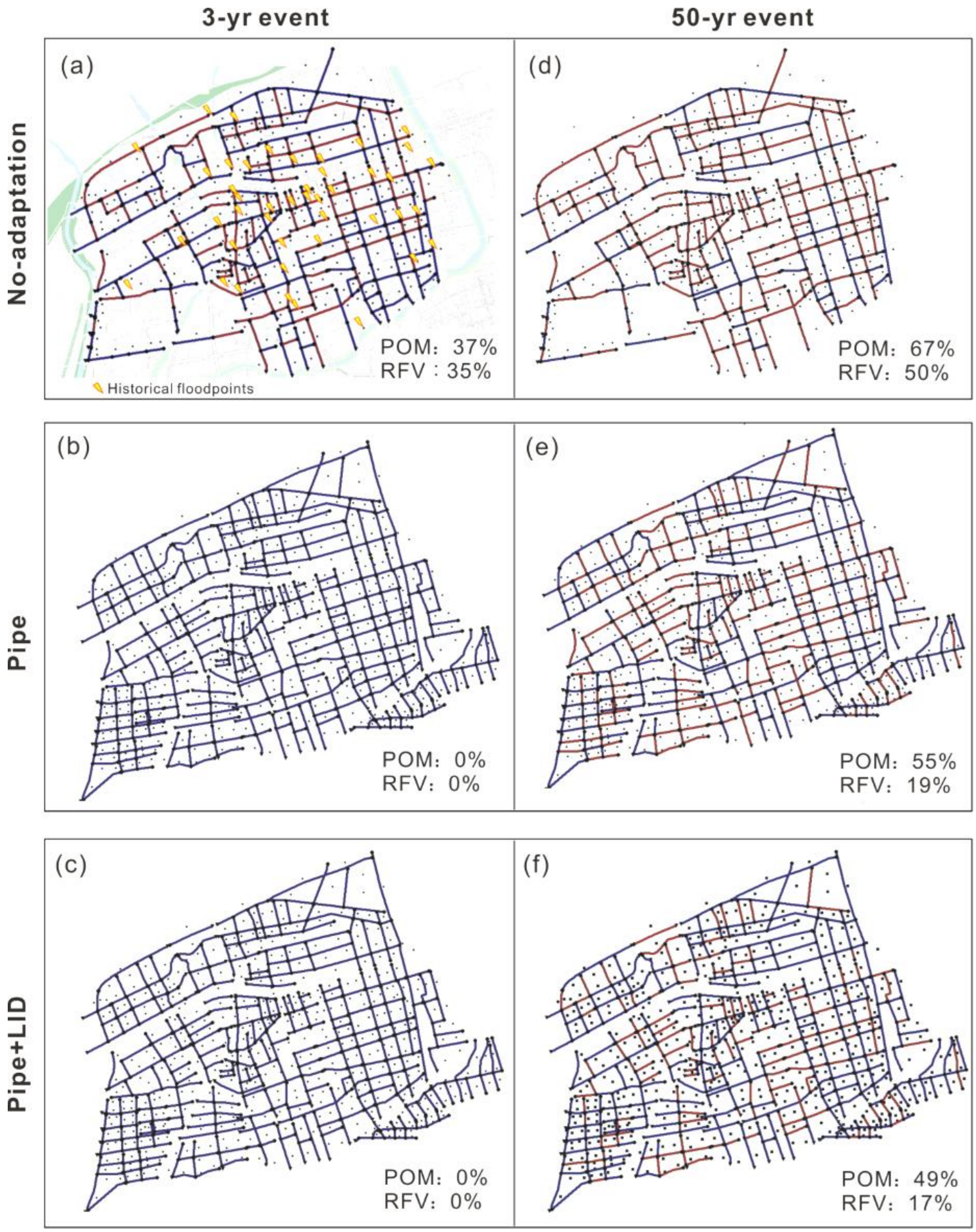

Figure 5 *Spatial distribution of overloaded pipelines (red colour) induced by the 3-yr (left column) and 50-yr extreme events (right column) without and with adaptations. The total percentage of overloaded manholes (POM) and ratio of flood volume (RFV) are summarized.*

Figure 6: Add units in the axis labels. E.g.: “[-]” for dimensionless. Also, note the typo in the x-axis label.

<u>Response</u>: *Thanks for the suggestion. We have updated the figure in the revision.*

Figure 7: Negative values for risk reduction means increasing risk. Please reverse graphs with positive values (plus fix the typo rish -> risk)

<u>Response</u>: *Thanks for the suggestion. We have updated the figure and corrected the typo in the revision.*