This manuscript entitled "Increase in urban flood risk resulting from climate change – The role of storm temporal patterns" draws readers' attention towards importance of storm temporal pattern in urban flood modelling under altering climatic scenario. Given the frequent reporting of urban floods across the globe this study provides useful insight to urban flood modellers. The manuscript fits the aim and scope of HESS quite well, and can be accepted provided authors address the following comments with required modifications and justifiable responses.

We thank the reviewer for their time. We also thank the reviewer for their favourable assessment of the manuscript content and results presented. We address the reviewers concerns in turn with our responses in italics. Please note that the author comment (AC) and Proposed Changes in Manuscript (PCiM) based on the comments are indicated as such separately for each comment.

Major comments

MC1R2

Why did authors choose a 50-year return period storm? Why not 10, 20, or 25 years return period that is much common for urban flood modelling studies? Or why not 100 year return period?

AC-The model was setup in year 2000 and has been continuously updated and maintained over the 15+ years based on the prevailing 100-year 24-hour rainfall event for that catchment. Atlas 14 V8 has updated the rainfall depths such that the previous 100-yr rainfall depth is now the 50-year rainfall depth. Since this paper looks at relative impacts to peak flood depths based on rainfall patterns and future climate conditions and does not project absolute flood depths, the authors selected to use the old 100-yr rainfall as the base rainfall event with the correct current reference of a 50 year event. The substantial effort to update the model to accommodate the new 100-year rainfall depth would not have provided an incremental value in the results.

MC2R2

RCP 8.5 scenario is derived using the most pessimistic assumption and is very unlikely given the ongoing worldwide efforts to curb the carbon emission and green initiatives. Though such studies using RCP 8.5 gives mind boggling figures, these remain very unlikely. A more likely scenario could be RCP 4.5 should have been used along RCP 8.5 to encompass the effects of climatic change. Secondly, authors carried out the study for projected period for 2081-2100 skipping the intermediate time frames. Is there no significant results during 2025-2050 or 2051-2080? Though the results would be much pronounce in the later part of the century, intermediate time frame should also be discussed. Authors must explain the rationale behind selecting worst case climatic scenario i.e., RCP 8.5 and also come up with the reasoning to skip RCP 4.5 and selection of specific time frames for such modelling exercises for potential users. Additional details related to exercise can be provided in supplementary materials.

AC-As suggested, the authors did an additional analysis for the case of RCP 4.5, looking at a temperature change of 3^0C . The following table illustrates that the trend in results are similar to the RCP 8.5 scenario for all cases as expected. Understandably, the impact to flood depths is not as significant as when looking at a 5^0C increase in temperature. The main goal of the paper is to demonstrate the importance of accounting for the changes expected in temporal patterns of rainfall, which looks at relative impacts.

We wish to note that there is literature suggesting that we are tracking on a RCP8.5 scenario (Peter. G et al 2013) and indeed many forecasts suggest greater temperature increases over land. The authors agree that there should be rigorous thought on how far out and what level of climate impacts should be considered when selecting a threshold for design or when setting absolute flood depths.

PCiM- The following table will be added in Supplementary Information with explanatory narrative.

Table S1- Results showing normalized flood depths around the mean at each location for a projected temperature increase of 3 deg C.

	Current (normalized)				
	A	**B**	**D**	**C**	**G**
Q1-10	0.58	0.15	0.65	0.53	0.33
Q1-50	-0.28	-0.07	-0.08	-0.11	-0.16
Q1-90	-0.31	-0.10	-0.23	-0.24	-0.37
Q3-10	-0.14	-0.04	-0.19	-0.12	-0.07
Q3-50	-0.03	-0.01	-0.18	-0.08	0.03
Q3-90	0.18	0.07	0.03	0.01	0.24
	Projected patterns (normalized)				
	A	**B**	**D**	**C**	**G**
Q1-10	0.60	0.16	0.67	0.54	0.33
Q1-50	-0.21	-0.06	-0.05	-0.04	-0.09
Q1-90	-0.31	-0.10	-0.19	-0.21	-0.38
Q3-10	-0.05	-0.02	-0.15	-0.06	0.03
Q3-50	0.11	0.02	-0.07	-0.02	0.16
Q3-90	0.27	0.10	0.08	0.06	0.25
Change in Mean	*0.07*	*0.02*	*0.05*	*0.04*	*0.05*

	Projected patterns and volumes (normalized)				
	A	**B**	**D**	**C**	**G**
Q1-10	0.98	0.38	1.36	0.73	0.49
Q1-50	0.34	0.14	0.04	0.09	0.25
Q1-90	0.04	0.03	-0.15	-0.15	-0.09
Q3-10	0.47	0.16	0.15	0.03	0.27
Q3-50	0.91	0.36	0.60	0.23	0.34
Q3-90	0.91	0.36	0.60	0.23	0.34
Change in Mean	*0.61*	*0.24*	*0.44*	*0.19*	*0.27*

MC3R2

The study employs the modelling component in a big way to derive the conclusions, however, there is no discussion made on how the modelling framework was setup. Catchment sizes in the modelling setup varies from 0.25 sq km to 22 sq km that makes almost 90 times change in smallest and largest catchment. Interestingly, unlike river basin scale studies in urban drainage modelling catchment boundaries are not demarcated by their natural topography as the interceptor drains divert the runoff water omitting the natural stream lines. How the authors have discretised such vastly different sized catchments? Authors should discuss how the impervious area is estimated to include in modelling framework, and other parameters used in the modelling exercise should be tabulated. Did authors fed the existing storm sewage network into the model to rout the flow from a particular sub-catchment to outlet or directed them directly to the outlet from the subcatchment? Also discuss how the model was calibrated and validated. A separate section on model setup is highly warranted to make the manuscript more informative.

AC- As mentioned in the response above, the model used in the study was set initially in year 2000 and has been continuously maintained and updated to include the latest available landuse/landcover and stormwater infrastructure information. The model includes all components of stormwater conveyance within the catchment including sewers, open channels and storage areas, along with street overflows. Highly detailed delineation of both sub-catchment boundaries and impervious area was done using a high resolution DEM, development construction and grading plan overlays and aerial imagery within a GIS environment. All surface runoff is fed into the appropriate inflow points of the hydraulic conveyance system. The model has been validated and used to design major capital improvement and flood mitigation projects over the years. The following link connects to a report that discusses extensive model validation work based on an extreme storm. http://www.swwdmn.org/pdf/projects/completed/2006%20Stormwater%20Modeling%20Report_HDR.pdf

PCiM – A paragraph on the model build as explain above will be added at line ###. The following references will be added in the manuscript as citations.

Model Development and related information:

Hettiaracchchi, S, and W. Johnson (2006), Stormwater modelling Report, HDR Project No. 32072, [available online: [http://www.swwdmn.org/pdf/projects/completed/2006%20Stormwater%20Modeling%20Report_HDR.pdf]

The following is an additional publication that discusses flood mitigation projects analysed using this model.

Hettiarachchi. S, Beduhn. R, Christopherson. J Moore. M, Managing Surface Water for Flood Damage Reductio, World Water and Environmental Resources Congress 2005, May 15-19, 2005 | Anchorage, Alaska, United States, doi-10.1061/40792(173)321

Many of the projects listed here are based on using this model.

http://www.swwdmn.org/projects/

MC4R2

Line 266-267 and Figure 4: "The rainfall-temperature pairs were binned on 2 degree temperature bins . . ." Does it mean that binning was done by counting the number of rainfall events and their corresponding magnitudes at each 2 degree temperature interval? What does the height of each bin depict? What do the count and precipitation magnitudes from primary and secondary y-axis show?

AC-The first reviewer also commented on the clarity of this paragraph. We believe some confusion arose from the histogram in Figure 4 and having two sets of axes. The histogram would have effectively only shown every second bin (as the binning is performed using two degree bins with overlapping steps of one degree).

PCiM- Lines 264-270 will be expanded to read as follows and Figure 4 will be replaced with the figure below:"Using established methods (Hardwick Jones et al., 2010a; Utsumi et al., 2011; Wasko and Sharma, 2014), the volume scaling for the 24 hour storm duration was calculated using an exponential regression. The results are presented in Figure 4. First, daily rainfall was paired with daily average temperature. The rainfall-temperature pairs were binned on 2°C temperature bins, overlapping with steps of one degree. For each 2°C bin a Generalized Pareto Distribution fitted to the rainfall data in the bin that was above the 99th percentile to find extreme rainfall percentiles (Lenderink et al., 2011; Lenderink and van Meijgaard, 2008). Extreme percentiles below the 99th percentile (inclusive) were calculated empirically. A linear regression was subsequently fitted to the fitted log-transformed extreme percentiles and used as the rainfall volume scaling (Figure 4). Hence the volume (V) is related to a change in temperature (T) by

$$V_2 = V_1(1+\alpha)^{\Delta T}$$

Where α is the scaling of the precipitation per degree change in temperature."

In light of the above comments Figure 4 has been modified and the new figure is shown below. The histogram in the figure has been removed to prevent confusion as the fitted quantiles were not necessarily matching the histogram bins presented creating ambiguity in the results.

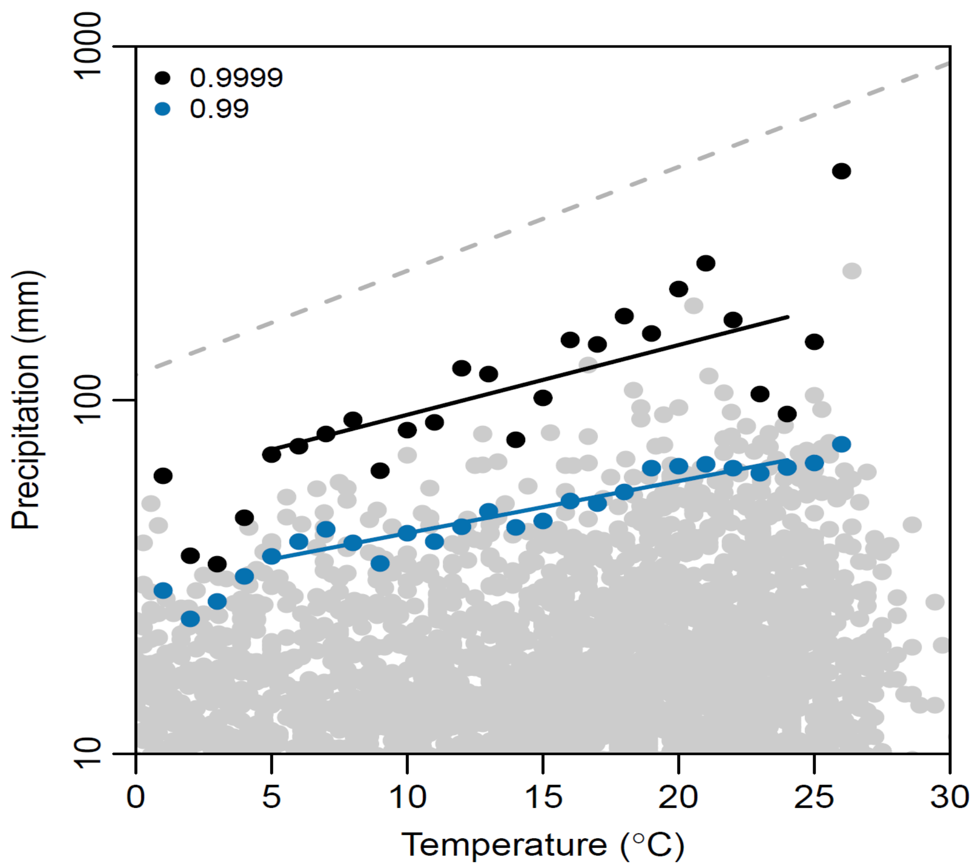

Figure 4 Scaling total volume of rainfall with temperature for Minneapolis (1901-2014 daily rainfall). Grey dots are rainfall temperature-pairs and the coloured dots are the extreme percentiles. The grey dashed line represents a scaling of 7 %.

MC5R2

In Line 339-340 authors say "The flood depths extracted from the model were first analysed to compare variability between temporal patterns and total rainfall depth. . ." SWMM is a 1-dimensional model and does not simulate the flood extent or flood depth. Though it simulates depth of water being flooded from a node, it depends on the adequacy of drainage network. While discussing the flood depth in relation to urban scenario, the depth of flood inundation should be used rather that the depth of total water flooded from a particular node or from the entire system. This aspect need some clarification.

AC- The review is correct in how SWWM typically shows flooded nodes and yes, the flood depth are dependent on the adequacy of the model. As discussed in the comment regarding the background and extent of the model build, extensive surface overflow routes from flooded areas as well as explicitly modelling street overflows and storage extents are included in the model geometry. This allows the resulting flood depths to take into account the flood extents as well, opposed to the typical funnel that SWMM uses at nodes. Additionally, majority of the reference locations are at local storage nodes that provide a good representation of flood extents. Storage nodes have depth/area curves that represent flood extents at each depth. Therefore, the results from this model provide a reasonably accurate representation of extents related to each flood depth.

PCiM- This discussion will be added to model discussion at line ##.

MC6R2

In Line 342-343 authors say "These sub-models show the variation in catchment response to runoff generated by different land use types. . ." There is no provision of feeding LULC information in SWMM, rather it takes percent pervious and impervious area. Different land use types gives a notion that model is simulating overland flow explicitly for residential, paved surfaces, parks, grassed land etc. How the different land use land cover type were incorporated in the model? Similarly, in Line 360 and 368 authors talk about "local storage/ local natural storage". How these storage was incorporated into the modelling exercise.

AC- Agree with the comment that SWMM does not have provisions to explicitly designate LULC in a runoff area. However, as discussed in response to comment 3, the model was setup in extensive detail using multiple layers of information that provide characteristic percentages of impervious area based on the built environment within each of the sub-catchments. By discretising to small areas, the model then is able to isolate the various landuse types within each catchment and generate a composite impervious percentage and a rate of runoff representative of each different landuse type. Local constructed storage refers to stormwater ponds that were built as part of rate and volume controls to meet post development rules requirements. Natural storage locations refer to existing ponds and lakes within the catchments. The storage information is added into the model as depth/area tables using the DEM and bathymetric survey (major storage locations) for natural storage locations and construction plans for constructed storage locations.

PCiM- N/A

MC7R2

Line 399-411 does not helps much and as a reader I find it less convincing how Fig 6(a) is different than Fig. 6(b) and how pronounce the difference is for temporal pattern case and total rainfall volume case. Moreover, visually Figure 6(a) and (b) are seems more or less identical with little change. It would be better if author can redraw them to convey their point. Perhaps, comparison of Q1-50 and Q3-50 in same graph for temporal pattern variation or total rain volume variation will help the readers' understanding. Also specific markers for different cases should be provided, as of now there are 4 squares and each belong to which requires a thorough reading. Make the image self-explanatory.

AC- We agree with the reviewer and we will redraw Figure 6 to convey the intended point. Figure 6 (a) and (b) attempts to illustrate the variation between temporal pattern vs volume of rainfall, and is not intended to show changes based on a particular, or each temporal pattern. The fact that Figure 6a and 6b are similar shows that this variability is generally independent of the temporal pattern chosen for the volume variability. That is to say, that the results are not skewed to be favourable by picking a single temporal pattern to examine the volume variability.

PCiM- Figure 6 (a) and (b) will be modified to emphasize the range of results as well as the comparison between current and projected results.

MC8R2

Fourth conclusion suggests the 'increase in potential flood risk purely due changes to "how it rains" as a result of climate change impacts'. This conclusion is drawn from the analysis shown in Fig 6 and Fig. 7. How the temporal pattern variation has a pronounce effect on flood risk as from the Fig. 6 gives almost same picture for temporal pattern for Q1 and Q3 rainfall, whereas from Fig. 7 also not much significant change can be noticed in the standardized flood depth due to current temporal patterns and projected patterns unlike Fig. 8, where the difference is really remarkable. An elaboration would help the readers' understanding.

AC-The reviewer is correct that the 4^{th} conclusion is based on the data that was used to generate Figure 7. This conclusion points to flood impacts that are due to projected temporal patterns. Whereas Figure 8 shows flood impacts due to projection of both temporal patterns and rainfall volumes.

PCiM-We will elaborate further within the discussion to improve how we convey this point.

MC9R2

Temporal pattern or distribution used from NOAA ATLAS should be discussed in short. It's not clear what does nth quartile at mth percentile means. It would be insightful if authors show it in figure.

AC- We agree with this comment as well as the comment by the other reviewer. Figure R1 will be added to the manuscript which shows the different patterns that were used in this manuscript.

PCiM-Figure R1 will be added to the manuscript which shows the different patterns that were used in this manuscript. Further, the following text will be added at line 243-'The quartiles indicate the timing of the greatest percentage of total rainfall that occurs during a storm. First quartile would indicate that the majority of the rainfall including the peak will occur in the 1st ¼ of the duration, which is between hours 1 through 6 in the case of a 24-hour storm. The temporal distributions were also separated in Atlas 14 to determine the frequency of occurrence within each quartile to determine a percentile for each distribution." Will also add reference to Figure 4 in Appendix A5 of NOAA Atlas 14.

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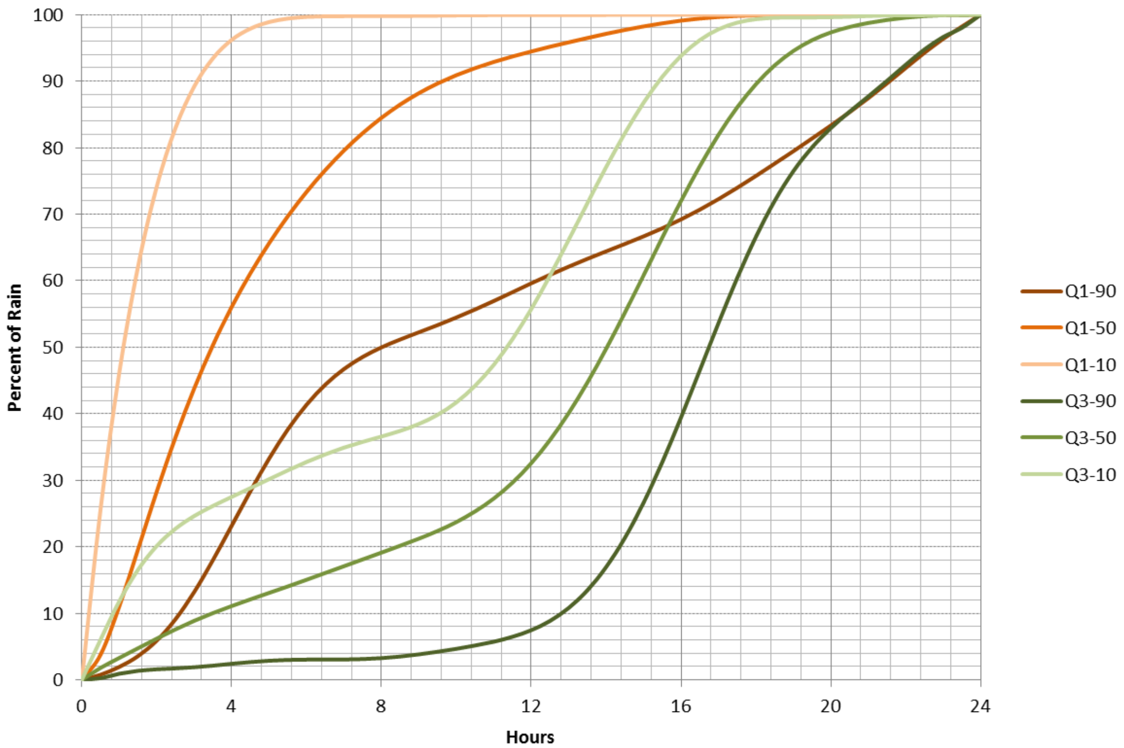


Figure R1. NOAA Atlas 14 temporal patterns used in the modelling

MC10R2

In Line 283, what does author mean by "current industry standard temporal distributions"?: Authors may like to use supplementary material space for elaborate discussion to clarify the doubt.

AC- Temporal patterns from design guidelines and standards are used throughout civil engineering and consulting industry for design flood estimation and these standards are commonly referred as 'industry standards'.

PCiM- To clarify what is meant by this the text at line 283 would be replaced with "temporal patterns for design flood estimation" instead of "current industry standard" and refer to the example of the NOAA Atlas 14 temporal patterns.

minor comments

C1R2

First line of abstract [Line 8-9] i.e., "Warming temp . . ." is almost repeated in [Line 18-19] i.e., "Current literature . . ."

AC- Agree and will remove the first sentence to prevent repetition.

PCiM- Edit first sentence as indicated.

C2R2

Fix the citation formats throughout the text, for example in [Line 89] the citation should be like Milly et al. (2007).

AC-Agreed and appreciate noting the need to adjust the citation.

PCiM- The citations will be edited appropriately so that the parenthesis occur in the correct location.

C3R2

Delete 'an' before EPA-SWMM in [Line 182], delete '2016' after EPA in [Line 185]

AC and PCiM- Thank you. Will perform these edits.

C4R2

Line 64: Correct the "Intensity/Duration/Frequency" as "Intensity-Duration-Frequency"

AC and PCiM-Will update paper to reflect suggested change

C5R2

Line 114-116: It would not be apt to link Uttarakhand and Kashmir floods in India with poor storm sewer design from Bisht et al. (2016). As these floods were caused by cloud burst and moreover the topography is hilly in that place. However, Bisht et al. (2016) discussed the Mumbai flood that can be aptly link with flood risk caused by inadequate storm drainage.

AC-The following is the text in the reference paper that seems to indicate the statement that we used in the current paper. "Climatic extremities coupled with haphazard human intervention and inadequate planning to handle high storm events led to Uttarakhand flood in July 2013 causing 580 deaths and over 5400 people missing in the aftermath of flood, loss of 9200 cattle and complete damage to 3320 houses (India: Uttarakhand Disaster June 2013). Heavy flooding due to unseasonal rainfall submerged Kashmir twice in a short span of 6 months, September 2014–March 2015, causing over 200 deaths alone in September 2014. Improper drainage system coupled with unchecked and ill-planned urbanization makes the region even more vulnerable to such disasters (The Times of India 2015; The Hindu 2015)." But, as the reviewer has provided more explicit detail on these events, we will update the sentence to reference the Mumbai flood instead of the more recent events.

PCiM- the reference flood event will be changed to the Mumbai flood of 2005

C6R2

Line 165-168: These line should come in the last of introduction section where authors generally list down the objectives or novelty of their work.

AC-Agree with comment as the authors intended section 2 to part of the overall introduction.

PCiM-The section numbers will be adjusted to better reflect that intention

C7R2

Line 231-232: Cite the NOAA ATLAS like any other technical report and list in the reference. Table 2: Use consistent unit for all the design rainfall.

AC and PCiM-Agree and will correct in the manuscript.

C8R2

Line 291: There is no reference for Figure SPM7(a)(IPCC 2014) in reference section. This Figure can be adopted from the source in the manuscript.

AC and PCiM- A reference will be added as per the reviewer's suggestion.

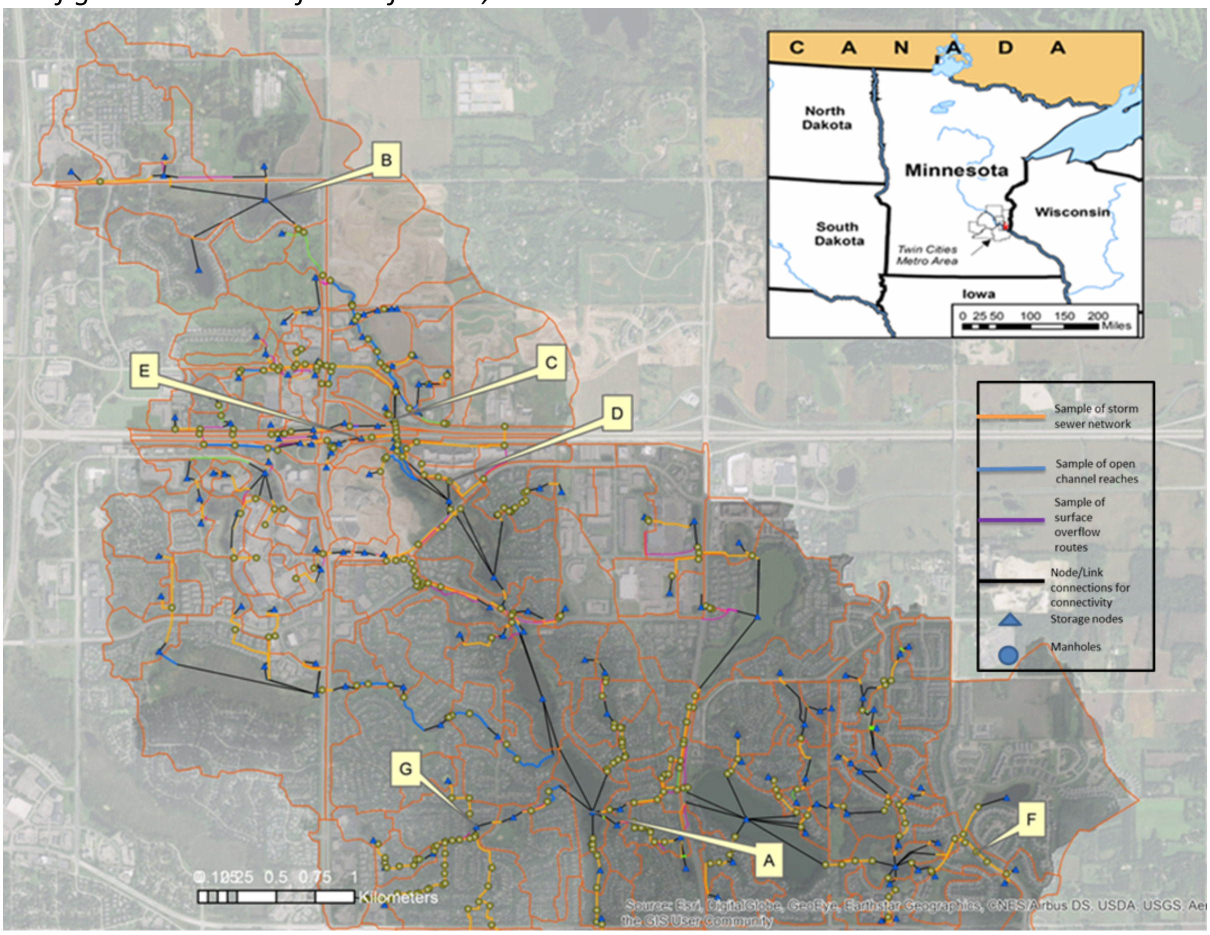
C9R2

Figure 1: What do those lines in Orange, magenta, and Black depict? Proper legends discussing each feature must be included with the figure to make it meaningful. The backdrop can be removed as it is making the image complex to understand.

AC- the Aerial background for the image provides important context the landuse within the catchment. The nodes and links represent the model layout. An explanation of the links and nodes along with the colour difference will be added along with adding the following legend to the figure.

PCiM-The following text will be added to the paper in line 220.
'The Orange links are example of the sewer network geometry in the model. The blue links represent reaches that are open channel. The magenta links are the surface overflow routes that capture flow that tends to flood in areas and spread outside the sewer network. The black links provides connectivity when the georeferenced locations of nodes are geographically different to the ends of some of the sewer network. The black links provide connectivity in the model.'

The figure will be modified as follows;



C10R2

Figure 6: Figure caption can be shortened as "Comparison of total volume of rainfall and temporal patterns variability impact on peak flood depth. Flood depth variation due to the 6 different temporal patterns with 160 mm of rain compared to 110, 160 and 210 mm of total rainfall over 24 hours distributed over (a) Q1-50 temporal pattern (b) Q3-50 temporal pattern. Flood depths were standardised by subtracting the mean at each location for ease of comparison"

A*C-Agree with the suggested change to Figure 6 caption and we will make the change.*

PCiM- Caption will be changed to;
Comparison of total volume of rainfall and temporal patterns variability impact on peak flood depth. Flood depth variation due to the 6 different temporal patterns with 160 mm of rain compared to 110, 160 and 210 mm of total rainfall over 24 hours distributed over (a) Q1-50 temporal pattern (b) Q3-50 temporal pattern. Flood depths were standardised by subtracting the mean at each location for ease of comparison.

C11R2

Figure 7: Increase the font size of legends.

AC and PCiM-Agree with comment and will update the figure appropriately

Reference

Bisht, D. S., Chatterjee, C., Kalakoti, S., Upadhyay, P., Sahoo, M., and Panda, A.: Modeling urban floods and drainage using SWMM and MIKE URBAN: a case study, Natural Hazards, 84, 749-776, 2016.

Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quere, C., Marland, G., Raupach, M. R., and Wilson, C.: The challenge to keep global warming below 2 [deg]C, Nature Clim. Change, 3, 4-6, 2013.