Authors' reply to interactive comment posted by Anonymous Referee #2 regarding the ESSD Discussion paper "Long-term weather, hydrometric, and water chemistry datasets in high-temporal resolution at the La Salle River watershed in Manitoba, Canada"

Dear Referee,

We appreciate your comments and suggestions to strengthen the manuscript. Please find below the answers to your comments.

General comments

1. Reviewer: *Long term hydro-climatic and water quality dataset are common in the Red River Basin and published in many articles. For example, South Tobacco Creek Watershed, Mauvais Coulee basin.*
   Authors: The Red River Basin (RRB) (spans over 122,730 km^2 and encompasses portions of Canada (provinces of Manitoba and Saskatchewan) and the United States (North Dakota, South Dakota, and Minnesota). Due to its spatial extent and its transboundary characteristics, it is difficult to generalize any trends in terms of data availability. While the weather and hydrometric records from the South Tobacco Creek Watershed and Mauvais Coulee basin are important, the authors argue that the availability of datasets in the RRB is far from complete to enable comprehensive hydrologic modelling, and that the availability of new datasets are important for the advance of water sciences in the region. Although extremely valuable locations to develop better understanding of cold regions processes, the characteristics of these watersheds differ significantly in terms of soils, slope, and degree of drainage modification in comparison the RRB east of the Pembina Escarpment. The Mauvais Coulee is more typical of the portion of the RRB above the Pembina Escarpment and the Prairie pothole region with the larger number of wetlands, more undulating topography, and soils with less clay content. The South Tobacco Creek watershed spans the escarpment, is naturally well drained, has shale parent material, and greater potential for subsurface flow. Watersheds with longer term data within the extensively drained, high clay soil portions of the RRB are rare despite the likely importance of these portion of the watershed as sources of P to Lake Winnipeg[1,2,3].

[1] Corriveau, J., Chambers, P., and Culp, J.: Seasonal Variation in Nutrient Export Along Streams in the Northern Great Plains, Water Air Soil Pollut, 224, 1-16, 10.1007/s11270-013-1594-1, 2013.

[2] Yang, Q., Leon, L. F., Booty, W. G., Wong, I. W., McCrimmon, C., Fong, P., Michiels, P., Vanrobaeys, J., and Benoy, G.: Land use change impacts on water quality in three Lake Winnipeg watersheds, Journal of Environment Quality, 43, 1690-1701, 10.2134/jeq2013.06.0234, 2014.

In addition, identifying locations where long term weather station data is available along with hydrometric and water quality is particularly challenging and data at an hourly time step is often unavailable[4]. The South Tobacco Creek Watershed is not a typical example of data availability in Canada. This watershed been the focus of scientific studies and research projects for more than 20 years, and has had a runoff/water sampling infrastructure since the early 1990s[5] and an intensive set of hydrometeorological observation for the same period[6].

2. Reviewer: *Section 6.2 need to be revised significantly. The scientific explanations are weak and not in touch with recently published research articles across the Red River Basin. The authors need to do a better job explaining Fig. 7d. I can see in Figure 7d: a hydrologic wetting period (91-98), a streamflow drought (02-04) and recent hydrologic wetting (2005-2013) with an occasional dry year such as 2007. This is consistent with other watersheds in the Red River Basin.*
Authors: Section 6.2 has been expanded and now includes the specific suggestions made by the reviewer.

3. Reviewer: *There are some interesting trends and features in C_Q relationship of Figure 9. These need to be analyzed in detailed and may be visualized in a different way.*
Authors: As stated in the Aims and Scope of the journal, any interpretation of data is outside the scope of regular articles. The purpose of the basic C_Q relationships presented in the manuscript is just to describe the major features of the dataset. Further exploring these relationships, therefore, is out of the scope of both the paper and the journal.

4. Reviewer: *What is unique about the La Salle River Basin? The authors should discuss the study in the context of the Red River Basin (northern) rather than a Canadian prairie basin.*
Authors: A very high proportion of the watershed used as cropland (87 %), an extremely level topography (slopes varying between 0.004% to 0.02%), soil

---

[3] McCullough, G. K., Page, S. J., Hesslein, R. H., Stainton, M. P., Kling, H. J., Salki, A. G., and Barber, D. G.: Hydrological forcing of a recent trophic surge in Lake Winnipeg, Journal of Great Lakes Research, 38, Supplement 3, 95-105, http://dx.doi.org/10.1016/j.jglr.2011.12.012, 2012.
[4] Hutchinson, M. F., McKenney, D. W., Lawrence, K., Pedlar, J. H., Hopkinson, R. F., Milewska, E., and Papadopol, P.: Development and Testing of Canada-Wide Interpolated Spatial Models of Daily Minimum–Maximum Temperature and Precipitation for 1961–2003, Journal of Applied Meteorology and Climatology, 48, 725-741, 10.1175/2008JAMC1979.1, 2009.
[5] AAFC: South Tobacco Creek/Steppler Watershed. http://www.agr.gc.ca/eng/?id=1297269073820.
[6] Mahmood, T. H., Pomeroy, J. W., Wheater, H. S., and Baulch, H. M.: Hydrological responses to climatic variability in a cold agricultural region, Hydrological Processes, 31, 854-870, 10.1002/hyp.11064, 2017.

texture mostly comprised of clays (as opposed to clay loam and loam textures to the west), the modest depressional storage (which contrasts to the "prairie pothole" region), and the intensive surface drainage in farmland are unique features of the La Salle River Watershed and contrast with other areas based on land use proportions and topographic relief. The watershed is also a prominent source of phosphorus in the Red River Basin, with reported concentrations of total phosphorus as high as 2.0 mg/L and total dissolved phosphorus as high as 1.2 mg/L. This information has been included in the revised manuscript.

5. Reviewer: *What is the unique contribution of this paper and how this study is different or similar with other watersheds in the Red River basin?*
   Authors: The La Salle River Watershed is one of the most important contributors of nutrients in terms of unit area, particularly phosphorus (about 0.28kg/ha), to Lake Winnipeg, the 10th largest freshwater lake in the world that has undergone accelerated eutrophication in the last decades as a result of hydrologic processes[7]. Due to the prominence of these processes to water and nutrient dynamics, hydrologic simulations represent a crucial tool for advancing the water science in this area. Weather and hydrometric time series at a fine time step are a fundamental requirement for physically-based hydrologic simulations. However, such datasets are not common and this paper describes methods to assemble, collect, extrapolate, gap-fill, and validate data collected from within and outside the study watershed. While the limitations of the dataset presented are discussed, the authors are confident that the datasets represent an advance for hydrologic simulations in the La Salle River Watershed and the methods used to create the dataset are transferable to other watersheds in the basin.

6. Reviewer: *Based on my literature review, there are lots of trend going on in Red River Basin to a recent change in hydroclimatic conditions (precipitation and streamflow since ~1990). Recent climate change in the form of increased precipitation in the Red River Basin is manifold and scale dependent (e.g. Coles et al., 2016; Mahmood et al., 2017; Todhunter 2016). Many studies reported the increased contribution of rainfall induced streamflow in the recent years at hillslope scale (Coles et al., 2016) and smaller watershed scale (Mahmood et al., 2017) while rainfall induced streamflow contribution is little at larger watershed scale. Likewise, Stefan and Novotny (2007) detected increased streamflow over last few decades in the eastern part of the Red River Basin to North. Ryberg et al., (2016) reported earlier snowmelt streamflow peaks in the northern NGP*

---

[7] McCullough, G. K., Page, S. J., Hesslein, R. H., Stainton, M. P., Kling, H. J., Salki, A. G., and Barber, D. G.: Hydrological forcing of a recent trophic surge in Lake Winnipeg, Journal of Great Lakes Research, 38, Supplement 3, 95-105, http://dx.doi.org/10.1016/j.jglr.2011.12.012, 2012.

areas and delayed summer streamflow in recent years likely due to recent climate change.

Authors: As indicated in the reply to Question#3, the Aims and Scope of the journal state that any interpretation of data is outside the scope of regular articles. Discussing trends represents an interpretation of the data and, therefore, do not apply to the present manuscript. However, the recent trends mentioned by the reviewer have been discussed in the introduction of the revised manuscript as a reason reinforcing the need to improve the understanding of the impact of changing climate and land use on hydrology in this region.

Specific comments

1. Reviewer: *Line 11: "La Salle River Watershed": It is kind of awkward to introduce the watershed name at the first line of the abstract. Why should we care about the La Salle River? It is better to frame the area as ~northern part of Red River Basin" in which La Salle River Watershed is a representative basin.*
Authors: Sentence adjusted, as suggested.

2. Reviewer: *Line 15: "physically-based modelling". I think these datasets are needed in all kind of hydrologic models including physically-based models. Better to say hydrologic models.*
Authors: Reworded, as suggested.

3. Reviewer: *Line 15-17: "The only hydrometric variable included in the dataset was stream discharge in a daily time-step, which is the usual time-frame for summarizing the results of long-term studies." Really? Daily time step are not adequate to detect rainfall runoff events in several basins of the Red River valley. For example, the rainfall runoff events in 2002, 2005, 2011 and 2013 need a sub-daily level observations to summarize them.*
Authors: We completely agree with the reviewer that sub-daily time steps are required for assessment of specific rainfall runoff events. However, the sentence mentioned refers to long-term studies, which encompass multiple events spanning over several years. In such cases, a daily time-step is usually adopted not only for summarizing the observations but even in the model framework (e.g. SWAT model).

4. Reviewer: *Trends (smoothed curves) shown in the figures are redundant as they are not statistically significant. I suggest removing all the insignificant trends from the figures.*

Authors: Although not statistically significant, the smoothed lines aid the reader in the identification of trends, especially in highly dispersed time series like temperature and water chemistry data. In fact, trends do not need to be statistically significant to be discussed, as opposed to difference among means.

5. Reviewer: *Line 51-55: It is worthwhile to mention that Mahmood et al., (2017) developed a detailed physically based hydrologic model at an agricultural field level spatial resolution on CRHM platform in South Tobacco Creek Watershed. They evaluated the model against distributed snow observations as well as multi-scale streamflow measurements during 2000-2011 period. Note that they utilized hourly air temperature, relative humidity, wind speed (Deerwood station) and rainfall (Twin watershed) to force the model. However, winter precipitation are only available at daily time step.*
   Authors: The dataset presented here has also been used in CHRM simulations in the La Salle River Watershed[8]. These efforts highlight the importance of such datasets. The citation for Mahmood et al. (2017) included along with Cordeiro et al. (2017) have been included in the revised manuscript to illustrate the modelling exercises that are facilitated through the existence of datasets such as the one presented here.

6. Reviewer: *Line 71: This sentence "Hydrometric data comprise another important input for hydrological simulations." does not mean anything. I am not sure what you intended to say here. Streamflow data is generally used to evaluate the hydrologic simulations. Delete or Revise the sentence.*
   Authors: The term 'hydrologic simulations' (as opposed to hydrologic modelling) was meant to have a broader sense here to include model assessment as one of its components. The sentence has been re-worded in the manuscript for clarity.

7. Reviewer: *Line 71 – 84: In this paragraph, the authors need also to introduce the uncertainty on the timing of the streamflow observations; when it starts and ends? Generally, streamflow measurements begin when the channel ice tend to break up during spring (~March), and ends with the development of ice cover at the onset of winter (~October).*
   Authors: This information had already been provided in lines 81-82.

---

[8] Cordeiro, M. R. C., Wilson, H. F., Vanrobaeys, J., Pomeroy, J. W., Fang, X., and The Red-Assiniboine Project Biophysical Modelling, T.: Simulating cold-region hydrology in an intensively drained agricultural watershed in Manitoba, Canada, using the Cold Regions Hydrological Model, Hydrol. Earth Syst. Sci., 21, 3483-3506, 10.5194/hess-21-3483-2017, 2017.

8. Reviewer: *Line 95-98: The authors need to write a much better rationale for selecting this watershed than the line "This watershed has been selected due to its importance as an object of recent hydrological simulations and its characteristics as an agriculturally-dominated tributary of the Red River, the primary nutrient source to Lake Winnipeg (McCullough et al., 2012; Yang et al., 2014; Corriveau et al., 2013).".*

    Authors: This section has been rewritten and now reads:

    "This watershed has been selected due to its unique characteristics and importance from a nutrient export perspective. The very high proportion of the watershed used as cropland (87 %), the extremely level topography (slopes varying between 0.004% to 0.02%), soil texture mostly comprised of clays (as opposed to clay loam and loam textures to the west), the modest depressional storage (which contrasts to the "prairie pothole" region), and the intensive surface drainage in farmland, are unique features of the La Salle River watershed and contrast with other areas in the Red River Basin with regards to land use proportions and topographic relief. The watershed is also a prominent source of phosphorus in the Red River Basin, with reported concentrations of total phosphorus as high as 2.0 mg/L (McCullough et al., 2012) and total dissolved phosphorus as high as 1.2 mg/L (Corriveau et al., 2013)"

9. Reviewer: *Line 84: Please add the citation Rasouli et al., (2014) and Mahmood et al., (2017).*

    Authors: Citations added, as suggested.

10. Reviewer: *Line 170: Not sure what this "regards to extreme events or local effects" means? Elaborate on extreme events and local effects.*

    Authors: Sentence reworded for clarity.

11. Reviewer: *Line 173: In "R2" R needs to in italic font (R^2).*

    Authors: Corrected, as suggested.

12. Reviewer: *Line 174: Is R^2 a good metric to determine mutual equivalency? Is there other coefficient or metric to verify this?*

    Authors: As stated in that paragraph and supported by citation[9], regression-based techniques are usually used for reconstructing temperature records, for which R^2 is the classical metric used for assessment. When more than one station is available for gap-filling, the source cited[9] recommends ranking the stations by R^2 and selecting the one with highest value. Since both stations in Winnipeg had the

---

[9] Tardivo, G., and Berti, A.: The selection of predictors in a regression-based method for gap filling in daily temperature datasets, International Journal of Climatology, 34, 1311-1317, 10.1002/joc.3766, 2014.

same R^2, they were assumed to be equivalent for the purpose of gap-filling. Also, it should be noted that only 1.1% of the records were infilled using the second station in Winnipeg (i.e. The Forks).

13. Reviewer: *Line 167 -180: It seems like from Figure 1 that the stations in Winnipeg are ~40 km away from the study site station. Moreover, land use/cover and surface processes are drastically different between Winning and LaSalle. I wonder whether there is another site available near study site having similar land use/cover.*
    Authors: As stated in Table 1, the actual distance is 47.9 km. Other stations were screened but the selection of the stations in Winnipeg was due to the length of the records, which most closely match the period of the dataset discussed here. Other stations around the study area only came into operation much later in time (e.g. 2004 for the University of Manitoba Research Station in Carman).

14. Reviewer: *Line 182 – 189: Comparing/gap filling relative humidity with stations in Winnipeg in the summer seasons are a bit of stretch as the cloud cover and storm system is spatially isolated and small in size. There is a very good possibility of contrasting climatic conditions (convective system) at many instances between study site and Winnipeg in the summer season. We can also see that R2 is lower than temperature. I think the AUTHORS NEED to clarify this issue and discuss them in this paragraph.*
    Authors: The authors agree that convective systems (i.e. thunder storms) are very spatially variable. However, we argue that the effect is more pronounced for precipitation than for relative humidity. This variable is much more stable across larger spatial distances, which is evidenced by the robust relationship (i.e. R^2=0.71). While not as strong as those of temperature (i.e. R^2=0.98) the relationship was still strong. This information has been included in the revised manuscript.

15. Reviewer: *Line 201-211: I am concerned about the same issue of Line 182-189 in the summer season. The spatially variable cloud cover results in different solar radiation values in the summer seasons. I think the AUTHORS NEED to clarify this issue and discuss them in this paragraph.*
    Authors: Wind speed is certainly more concerning than relative humidity due to the weaker spatial relationships with Winnipeg ($0.34 \leq R^2 \leq 0.48$). However, datasets from the Winnipeg stations were the best available. The issue is already discussed in the paragraph where the weaker correlations are mentioned and the rationale for selecting the linear regression approach over other alternatives (e.g. data transplanting) are discussed.

16. Reviewer: *The issues in Line 182-189 and 201-211 have direct and indirect consequences on physical based modeling.*
    Authors: The authors completely agree. However, we argue that those issues should not prevent the use of the dataset to promote the advance of hydrologic simulations in the region. While not perfect, we are confident that the dataset is robust and compiled using sound, proven statistical methods to address the missing records.

17. Reviewer: *Line 212 and section 3.2.5.*
    1. I am concerned that all the precipitation stations are outside the watershed (Figure 1). This may be fine for winter precipitation and multi-days rainfall events. However, this is a big issue for spatial representation of precipitation and physical-based hydrologic modeling in the spring/summer season (event duration for few hours). Is one or two station enough for the summer hydrologic modeling? Mahmood et al., (2017) discussed the model failures at smaller due to the inadequate spatial representation of summer rainstorm events due to lack of rain gauges. Since, summer runoff events have recently increased in the Red River Valleys (e.g. 2002, 2005, 2011, 2013 summers), the authors should discuss these issues and highlighted the limitations and challenges involved with this datasets.
    2. The authors need to discuss how precipitation (particularly winter) was measured? What kind of precipitation gauge does it use and what kind of wind-shield (Nipher? Alter?) does it use in winter? Has the winter precipitation data been adjusted for wind under-catch? Is this a volunteer climate station (using ruler) by Environment Canada? Snowfall in the prairie region tends to be under-reported by 50% due to wind under-catch. Discuss the uncertainty involved with precipitation measurements and potential consequences on physically based modeling.
    Authors: The risk of misrepresentation of thunder storms is acknowledged. However, the dataset was used by Cordeiro et al. (2017)[8] with good results in average and above average stream discharge years (including 2011 and 2013). That paper discussed the poor model performance in dry years and attributes it to difficulties in simulating low flows in small catchments as a result of upland storage and preferential flow. Thunderstorms generally do not generate runoff in the study area, which may contrast to the work reported by Mahmood et al. (2017) due to differences in relief. Cordeiro et al. (2017)[8], discussing the characteristics of long-term stream discharge in the watershed, noted that most of it is generated by spring snowmelt. This aspect has been discussed in the revised manuscript. The information about precipitation gauge has also been included. The Marquette, MB weather station used in this study for snow data is operated by Environment

and Climate Change Canada (Climate ID: 5021695). Solid precipitation is measured using a Nipher gauge. Snow on the ground is reported by a volunteer and is a measure of the total accumulated depth of snow on the ground regardless of whether there has been snowfall or not. It is measured once per day using the snow ruler. The under catch bias in the prairies is much lower than that in other regions of the country such as the Artic and Atlantic Canada. For example, the case studies investigated by Mekis and Vincent (2011)[10] indicates that the underestimation in Saskatchewan (6.8%) is much smaller than that in Newfoundland (20.8%) and Nunavut (30.4%), which could be considered substantial. Although Manitoba was not included in their analysis, it is reasonable to assume that the conditions in Manitoba would be similar to those in Saskatchewan due to similar weather. This discussion has been included in the revised manuscript.

18. Reviewer: *Line 244: It is unfortunate to see 2008 streamflow data is missing. To me, 2008 is an interesting year as high precipitation generates very little runoff. For example, in South Tobacco Creek watershed, 431 mm precipitation produced only 2 mm runoff which is consistent with other watersheds (such as Mauvais Coulee basin in North Dakota), in Red River basin.*
Authors: Unfortunately, equipment malfunctions resulted in loss of data so there was not streamflow available from WSC, as discussed in the manuscript.

19. Reviewer: *Line 349-350: "This result is consistent with other studies in the Canadian Prairies that report an increase in the number of low-intensity events (Akinremi et al., 1999)." I am not what the "consistent" means here? However, the authors did not compare decomposed hourly data with any real dataset/observations? I know that hourly rainfall observations are available for twin sub-watershed of the South Tobacco Creek basin. There was a big summer storm having few heavy rainfall days (Jun 9-11, 2002) but I do not whether system extended up to LaSalle River basin. In addition, it looks like there are events June and July 2005 extended up to La Salle River basin. Without comparing any real data, it is hard to comment whether it would work for physically-based modeling or not?*
Authors: Consistent meant 'in agreement'. Disaggregated precipitation has been compared to the closest dataset available from the Portage La Prairie Southport Airport station in the revised manuscript through boxplots (update in Figure 6). This is the station used to estimate the Bartlett-Lewis model parameters for disaggregation (section 3.3). However, the hourly observations in the Southport

---

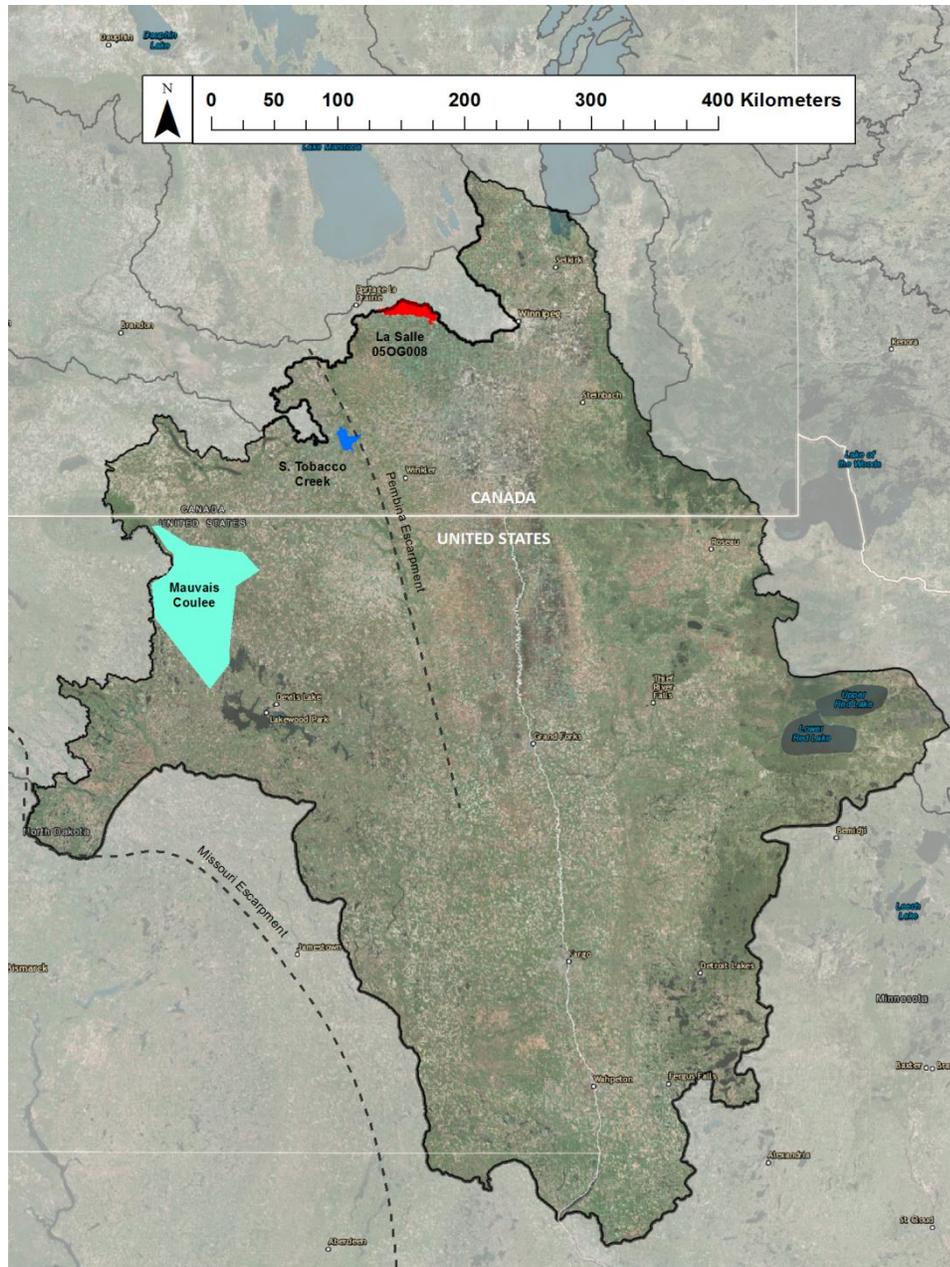
[10] Mekis, É., and Vincent, L. A.: An overview of the second generation adjusted daily precipitation dataset for trend analysis in Canada, Atmosphere-Ocean, 49, 163-177, 10.1080/07055900.2011.583910, 2011.

Airport station started in 2004; thus, the boxplots refer to that period only. The large daily precipitation events in June 2002 and June/July 2005 are both represented in the dataset presented in the manuscript (i.e. Marquette station).

20. Reviewer: *Line 302: Please mention that relative humidity is one of the major parameters to physically simulate evapotranspiration (particularly in the summer season) which set antecedent soil moisture before the onset of the winter season.*
Authors: Sentence added to the revised manuscript as suggested.

21. Reviewer: *Line 361-362: "This type of behavior is not expected and indicates potential issues with the hydrometric data since years with larger peak flows such as 2006 did not show these anomalies (Fig. 7c)." This does not make any sense. Fig 7c does not indicate something like what is stated in line 361-362. Streamflow data shown in Fig 7b and 7c are consistent with what we have observed in South Tobacco Creek, Mauvai Coulee Basin (North Dakota) and other basins in northern Red River Valley. The authors should not guess or speculate regarding this dataset. The main issue is a rainfall induced runoff in the summer has been increasing across the Red River Basin. The year 2005 is one of the prime examples of the dominance of snowmelt and rainfall induced streamflow. The 2006 winter is the warmest winter/spring in last 20 year.*
Authors: The sentence pasted in the comment is out of context if read by itself. That sentence and figure citation refers to 2006, where Figure 7c indicates that the hydrograph for 2006 is a typical hydrograph without any anomalies. The previous sentence refers to 2005, where Figure 7b shows a "flat top" hydrograph in July that suggests some sort of flow restriction such as flow through a culvert downstream of the gauging station. Please note that the peak flow in 2005 is smaller than the peak flow in 2006, suggesting that the anomalous hydrograph in 2005 was probably caused by some sort of obstruction in the river channel. This was the reason for removing (and flagging) that event from the hydrometric dataset, although the driving precipitation is present in the dataset. The authors would also like to clarify that the manuscript is a description of how the dataset was derived and not an analysis of weather pattern and runoff characteristics change. Thus, a discussion on the increasing summer runoff trends is out of the scope of the work.

22. Reviewer: *Line 427-428: Long term dataset is usually available for many watersheds in Red River Basin. For example: South Tobacco Creek (MB) and Mauvais Coulee basin (ND).*
Authors: As discussed in the answer to question #1 in the General comments, the authors are of the opinion that the dataset availability in the Red River Basin is far

from satisfactory to characterize all the contrasting features in the sub-catchments of such a large basin. The uniqueness of the study area is emphasized by Cordeiro et al. (2017)[8]. The authors agree that South Tobacco Creek and Mauvais Coulee basin have data and modelling results available, but the environment of these watersheds is very different from the La Salle River Watershed and are not characteristic of most of Red River Valley (as opposed to just being located in the broader Red River Basin). In fact, given the spatial extent of the Red River Basin (please see image below), it would be difficult to conceive that only two watersheds are sufficient to characterize the entire basin. The Red River Basin is about 284,000 km^2 in size, excluding the drainage area of the Assiniboine River. The Basin occupies portions of Minnesota, North Dakota and Manitoba and a small area of northern South Dakota. It is largely an agricultural area with rich lacustrine soils that were deposited over 9,000 years ago as the lakebed of Glacial Lake Agassiz. The basin is flanked in the east by the Canadian Shield and a transition from farmland to forest, lakes and wetlands. The expansive floodplain in the center of the basin surrounding the main channel of the Red River, often referred to as the Red River Valley, is extremely flat, with a slope that varies between 0.004% to 0.02%. This region is prone to large flood events that can cover several hundred square kilometers (e.g. approximately 1,984 square km was covered by overland flooding in May of 1997). The western portion of the basin is marked by the Pembina Escarpment and a transition to the "prairie pothole" region where depressional wetlands are common features on the landscape and dominant soil texture shifts to clay loam and loam rather than the clay that covers most of the Red River Basin.

23. Reviewer: *Figure 6: What is in Figure 6c? It is not mentioned in the caption.*
Authors: Figure 6 has been updated, as well as its caption.

24. Reviewer: *Figure 7d. What is annual water yield for 2002, 2003 and 2004. The legend is not consistent with the figure 7d.*
Authors: This figure has been changed to a stacked bar plot at request of another reviewer. The legend has been updated as a result of this change.