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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Discussion on key challenges facing the application of the conductivity mass-balance (CMB) method: a case study of the Mississippi River Basin" *by* Hang Lyu et al.

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Interactive comment on "Discussion on key challenges facing the application of the conductivity mass-balance (CMB) method: a case study of the Mississippi River Basin" by Hang Lyu et al. Anonymous Referee #2 Received and published: 22 August 2020

We highly appreciate Anonymous Referee 2 for extensive and generous comments on the manuscript and his/her generally positive impression of our work. Here we briefly respond to the points raised by his remarks.

1.In this study, more than 200 sites were included in the data analysis. However, some conclusions were drawn from the simple examination, which lacks the robust evidence of whether these conclusions will hold. For instance, A) the impacts of topography and altitude (Line 276) is concluded by a simple spatial plot (figure 7). In my view, such suggestion is acceptable, but not robust. I suggest the authors can make a scatter plot the correlation against the median elevation of sub-watersheds or other indices that can represent the watershed topography. B) Impact of anthropogenic factors. In this section, the authors only discussed the reservoir as an indicator of human interruption. Disapprovingly, authors only mention the evaporation. The reservoir/dam can provide substantial sources of water in the low flow periods. This may decrease the conductivity in streams and hence undermines the groundwater contribution to streams and leads to an underestimate of baseflow conductivity. Besides, there are other anthropogenic factors such as groundwater pumping and agriculture activities that affect the conductivity in streams and should be discussed in the manuscript.

Author's response: Thank you for your advice. We have made a scatter plot of the correlation against the elevation of sites (Fig.1), it can be found that with the increase of site elevation, the proportion of sites with a correlation coefficient less than -0.5 increased significantly, and it's consistent with our previous conclusions (most stations located in stream headwater areas, with an elevation above 1,500 m, a steep terrain and high elevation showed inverse correlations between flow and conductivity). However, the relationship between them does not strictly satisfy the inverse correlation, and we also found that there are also many sites below 1500 meters (especially 500 meters) that meet the requirements of the correlation coefficient (less than -0.5), these sites mainly located in the Ohio River Basin, the terrain of the basin is relatively flat and the altitude is low, the elevation of many sites located in stream headwater areas are still less than 500 meters, so the impact of elevation in this sub-watershed is not significant. More robust evidence will be added in the revised manuscript.

Impact of anthropogenic factors. We researched the relevant literature again. As the

Referee mentioned, “there are other anthropogenic factors that affect the conductivity in streams and should be discussed in the manuscript.” We found that changes in river conductivity can have many different causes, and the major impact processes include agriculture practices (such as fertilizer application), mining activity, the use of salts as deicing agents for roads (Miguel et al., 2013; Crosa et al., 2006; Palmer et al., 2010; Bäthe and Coring, 2011; Dikio, 2010; Kaushal et al., 2005). Besides, other anthropogenic factors such as discharge from industrial activities (Piscart et al., 2005b; Dikio, 2010), sewage treatment plant effluents (Silva et al., 2000; Williams et al., 2003; Lerotholi et al., 2004) or reduced river discharge due to damming (Mirza, 1998) can also cause the variation of conductivity. Admittedly, previous understanding of the impact of anthropogenic factors is one-sided. The influence of reservoir/dam will be revised and other factors will be discussed in the manuscript.

Miguel Cañedo-Argüelles, Ben J. Kefford, Christophe Piscart, Narcís Prat, Ralf B. Schäfer, Claus-Jürgen Schulz. Salinisation of rivers: An urgent ecological issue, Environmental Pollution 173 (2013) 157-167.

Crosa, G., Froebrich, J., Nikolayenko, V., Stefani, F., Galli, P., Calamari, D., 2006. Spatial and seasonal variations in the water quality of the Amu Darya River (Central Asia). Water Research 40 (11), 2237-2245.

Palmer, M.A., Bernhardt, E.S., Schlesinger, W.H., Eshleman, K.N., Foufoula- Georgiou, E., Hendryx, M.S., Lemly, A.D., Likens, G.E., Loucks, O.L., Power, M.E., White, P.S., Wilcock, P.R., 2010. Mountaintop mining consequences. Science 327 (5962), 148-149.

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Dikio, E.D., 2010. Water quality evaluation of Vaal river, Sharpeville and Bedworth lakes in the Vaal region of south Africa. Research Journal of Applied Sciences, Engineering and Technology 2 (6), 574-579.

Kaushal, S.S., Groffman, P.M., Likens, G.E., Belt, K.T., Stack,W.P., Kelly, V.R., Band, L.E., Fisher, G.T., 2005. Increased salinization of fresh water in the northeastern United States. Proceedings of the National Academy of Sciences of the United States of America 102 (38), 13517-13520.

Piscart, C., Moreteau, J.-C., Beisel, J.-N., 2005. Biodiversity and structure of macroinvertebrate communities along a small permanent salinity gradient (Meurthe river, France). Hydrobiologia 551 (1), 227-236.

Silva, E.I.L., Shimizu, A., Matsunami, H., 2000. Salt pollution in a Japanese stream and its effects on water chemistry and epilithic algal chlorophyll-a. Hydrobiologia 437 (1), 139-148.

Williams, M.L., Palmer, C.G., Gordon, A.K., 2003. Riverine macroinvertebrate responses to chlorine and chlorinated sewage effluents e acute chlorine tolerances of Baetis harrisoni (Ephemeroptera) from two rivers in KwaZulu-Natal, South Africa. Water SA 29 (4), 483-487.

Lerotholi, S., Palmer, C.G., Rowntree, K., 2004. Bioassessment of a River in a Semi-arid, Agricultural Catchment, Eastern Cape. In: Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, Cape Town, South Africa, pp. 338-344.

Mirza, M.M.Q., 1998. Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. Environmental Management 22 (5), 711-722.

2.The authors stressed that there is a large amount of watershed where CMB can not be applied. The following question is why this happens in this watershed? I assume that further tests are needed to answer this question. Based on my experience, I suggest the authors can test, but not limited to, the following variables: A) watersheds area, B) Watershed locations, C) snow and rain dominated hydrological regimes, D) Land cover and land use. E) Climate regions.

2.1 In Figure 8, authors only examined the relationship between correlation and watershed area in two sub-watersheds. Why don't you examine such relationship for all study watersheds? In smaller watersheds, low flows are mainly fed by groundwater. In contrast, there is always a large amount of surface runoff in the low flows period due to the spatial heterogeneity of climate. In my opinion, you could test all sub-watersheds as well as the entire Mississippi River Basin, and it can drive a threshold of watershed area, above which the CMB methods cannot be applied.

2.2 In this study, the authors concluded that headwater watersheds have a better relationship between discharge and conductivity. I assume this is likely due to differences in hydrological regimes, i.e., snow-dominated and rain-dominated. In upper streams, high flows are mainly stimulated by the snow-melt process (e.g., Dyer, 2008). They can be classified as snow-dominated watersheds, while lower watersheds are more likely to be rain-dominated systems. Two systems have a distinct hydrological process, and there is potential uncertainty whether there is a significant difference between the two systems. Dyer, J., 2008. Snow depth and streamflow relationships in large North American watersheds. Journal of Geophysical Research: Atmospheres, 113(D18).

2.3 Land cover and land use can be a factor. Forest cover and agriculture land use can have different conductivity concentrations. In the forest watersheds, Li et al. (2018) (in supplementary) showed that conductivity of baseflow and surface runoff did not change over time. In contrast, agriculture practices such as fertilizer application can influence the concentrations of conductivity and hence affect the CMB method accuracy.

2.4 Mississippi River basin is the large watershed. The basin has sizeable spatial heterogeneity of climate. The role of climate on hydrology, particularly for low flows are more pronounced in the larger watersheds. It is worth conducting an analysis of this topic. For simplicity, Climate North America (http://climatena.ca/) can provide climate data for the basin. In sum, further analysis is, for sure, needed to address the knowledge gaps as men- tioned above. Li, Q., Wei, X., Zhang, M., Liu, W., Giles-Hansen, K. and Wang, Y., 2018. The cumulative effects of forest disturbance and

climate variability on streamflow components in a large forest-dominated watershed. Journal of Hydrology, 557, pp.448-459.

Author's response: Thanks for your advice and experience. The suggestions and questions you have proposed are very good research topics, which are worthy of our special research from the aspects you mentioned in the future study.

2.1 Watershed area. We did try to obtain a threshold of watershed area aiming at all sub-watersheds, but the results are not ideal. We found that the watershed area in different sub-watershed is very different, the Missouri River basin, for example, has catchments below 9,000 km2 at all stations, while in the Arkansas River basin, there are many catchments greater than 30,000 km2. Therefore, only two sub-watersheds are listed and discussed in the manuscript. And to avoid confusion, other sub-watersheds will be discussed in the revised manuscript.

2.2 Hydrological or hydrogeological regimes? Or both of them? According to the distribution of correlation coefficient, we have made the conclusion that headwater watersheds have a better relationship between discharge and conductivity. As you mentioned, "this is likely due to differences in hydrological regimes, i.e., snow-dominated and rain-dominated". To solve this problem, we have further consulted relevant literature. A similar study in Upper Colorado River Basin suggest that there is typically greater baseflow yield in higher elevation watersheds (Rumsey et al., 2015), and Dyer(2008) found that in upper streams, high flows are mainly stimulated by the snow-melt process. But from these findings which are based on the major river basins in North America we still can't establish a relationship between hydrological regimes and the applicability of CMB method (quantitatively expressed by correlation coefficient between discharge and conductivity in our study). We still have the opinion that hydrogeological conditions are more dominant, there is a strong hydraulic connection between groundwater and surface water due to the erosion in upper streams under natural condition, and that the major direction of surface water-groundwater interaction is from groundwater to surface water. In this way, conductivity and streamflow data can accurately reflect the natural spatial and temporal variation. The differences in hydrological regimes, i.e., snow-dominated and rain-dominated will be discussed in our future study.

Christine A. Rumsey, Matthew P. Miller, David D. Susong, Fred D. Tillman, David W. Anning., Regional scale estimates of baseflow and factors influencing baseflow in the Upper Colorado River Basin. Journal of Hydrology: Regional Studies, 4 (2015) 91–107. Dyer, J., 2008. Snow depth and streamflow relationships in large North American watersheds. Journal of Geophysical Research: Atmospheres, 113(D18).

2.3 Land cover and land use factor. Thank you for your advice, and we are going to attribute the impact of different land cover and land use to anthropogenic factors, we think that CMB method maintains relatively high accuracy naturally, where less impact of anthropogenic activities happen there, such as forest cover land. In contrast, CMB method is relatively poorly applied to agriculture land with more human intervention to the hydrological process. This will be discussed in the revised manuscript.

2.4 The role of climate. Thank you for your advice, as you mentioned, the role of climate on baseflow are pronounced in the larger watersheds, which is a topic worthy of conducting a special research. We produced a superimposed map of climate zoning and the applicability of CMB method (Fig. 2). However, from this figure, it is difficult to summarize the influence rule of climate type on the applicability of CMB method. According to the website provided by the reviewer, we can further obtain meteorological data, and detailed analyze the influence of meteorological factors on the base flow in future studies. In sum, in order to confirm the reasons that some watershed where CMB can't be applied depends on an overall study in the future, thanks again to the anonymous reviewers for their suggestions.

3. One recommendation of this manuscript is that the parameters SCro and SCbf can be determined by the 99th percentile and dynamic 99th percentile methods. I agree with the authors to select the 99th percentile of conductivity. However, there is also a concern related to this recommendation. For the CMB method, the SCbf

is often corresponding to the lowest flows with potential time lags (Li et al. 2014; in your manuscript). With the recommendation of using the 99th percentile, it might be a chance that the 99th percentile does not correspond to the lowest flows. Therefore, this should be mentioned in the discussion.

Author's response: Thank you for asking the question that makes our research more rigorous. We have checked the parameters determined by dynamic 99th percentile method and didn't found the condition that the 99th percentile doesn't correspond to the lowest flows. But we have to admit that although the applicability of CMB method has been verified for a site before determining parameters, we still can't guarantee that a site where CMB method is applicable possesses parameters with no anthropogenic disturbance and corresponds to the lowest flows well. For example, the leakage of underground storage tank may last for a long time which will result in many extremely high conductivities that can't be avoided by 99th percentile method. Based on the above analysis, we will suggest in our revised manuscript that parameters should be checked after calculating by 99th percentile method to further avoid abnormal phenomena.

4. The title can be rephrased as "Key challenges facing the application of the conductivity mass balance method: a case study of the Mississippi River Basin". Author's response: Thank you for your advice and it will be rephrased in our revised manuscript.

5. Table 1 should be reorganized. It is meaningless to use the site number. I suggest the site characteristic such as watershed area, relief, slope, and climate, can also be listed in table 1. As such, the sensitivity can be compared with watershed characteristics. Author's response: Thank you for your advice and the Table will be reorganized in our revised manuscript.

6. The objective should be concise. In Line 85, "to resolve some of the questions". Please be more specific, which questions you are going to resolve in this manuscript. Author's response: The sentence will be modified to be more concise in the revised manuscript.

7. Section 2.5, the meaning of the sensitivity and uncertainty should be elaborated more. For instance, larger values of sensitivity indicate higher sensitivity. A similar explanation is needed for uncertainty. Author's response: Thank you for your advice and the relative explanation will be added in our revised manuscript.

8. The language should be polished by the professionals before publication. Here I list some of the suggestions while I read the manuscript. First two sentences in the abstract. Suggestion: The conductivity mass balance (CMB) method has a long history of application to baseflow separation studies, which uses site-specific and widely available discharge and specific conductance data. Line 17, insert "in" ; the parameter in the method Lines 45-47, rewrite Line 125, the key parameters need to be calculated Line 140, for at least 5 years Line 147, delete unbroken Figure 8 is not clear. Please redraw. Author's response:

Thank you for your correction, all of them will be revised in the manuscript, and the language will be polished by the professionals before publication.

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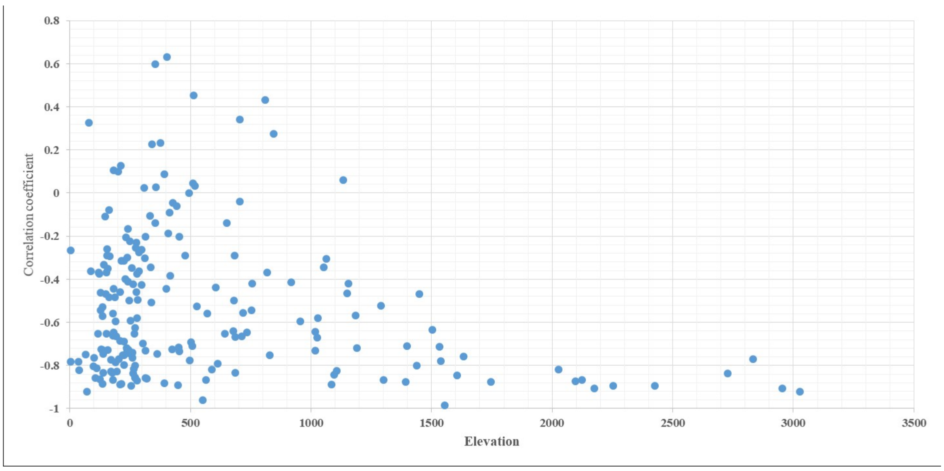

Fig. 1. Figure 1 Scatter plot of the correlation coefficient against the elevation of Mississippi River Basin monitoring sites

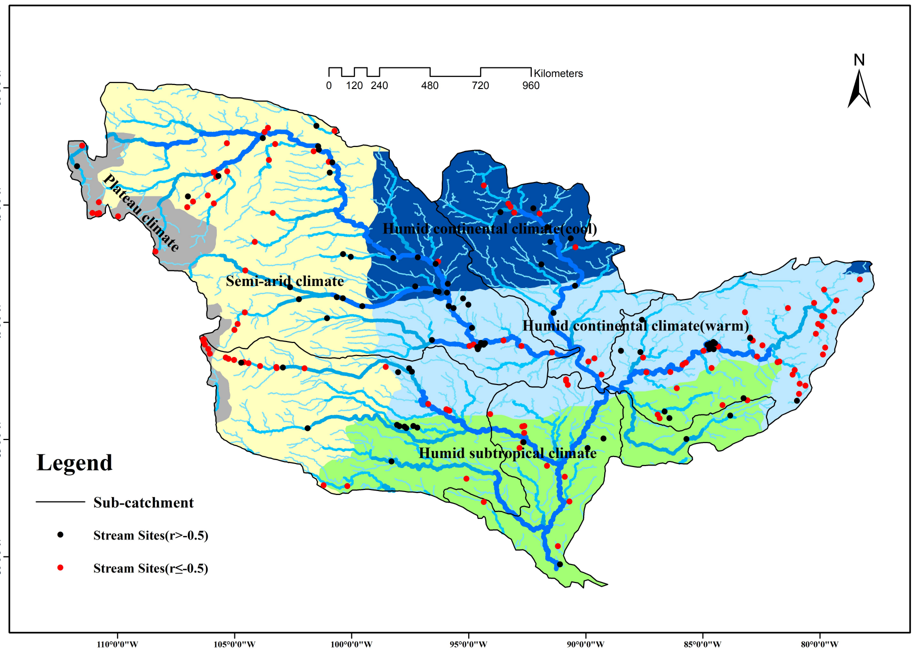

Fig. 2. Figure 2 Climate type and spatial distribution of correlation coefficients for the correlation between stream conductivity and discharge in the Mississippi River Basin