The results presented by Wang and Wu are encouraging. However, I have several questions for the authors, in the hope that it will lead to an interesting discussion.

Dear Prof. Sivapalan: Thank you for your insightful comments which indeed lead to interesting discussions.

1. They refer to the work of Melton and then Madduma Bandara, which led Abrahams to combine the results of these earlier studies and present a U-shaped relationship between Drainage Density and the P-E Index of Thornthwaite. The interesting aspect of this relationship is that in both very arid and humid conditions the drainage density is high, and somewhere in the middle it goes though a minimum. Abrahams explains the minimum in terms of the armoring provided by vegetation. How do the authors reconcile their result with that of Abrahams? Especially, why is not the drainage density high as Melton found? I suspect that this has something to do with the definition of perennial drainage density. Is this correct?

   Thank you for your comments and questions. The U-shape relationship between drainage density and the *P-E* index of Thornthwaite is based on total drainage density (D_d) which combines both perennial stream (D_p) and temporal stream (intermittent and ephemeral streams) which is denoted as D_t. The minimum of D_d has been explained as the trade-off between the erosion effect of runoff and impeding effect of vegetation (Madduma Bandara, 194; Abrahams, 1984). Here, we decompose the total drainage density into D_p and D_t according to the flow duration in the channels. As shown in Figure 1, perennial stream reflects the hydrologic response at the mean annual scale, and temporal stream reflects hydrologic response to climate at seasonal and event scales. From humid to arid region, D_p monotonically decreases as mean annual runoff coefficient decreases as shown in Figure 2. However, D_t is usually dominant in arid regions, i.e., temporal stream density increases with aridity index. The increase of temporal stream is due to the runoff variability at the finer temporal scale such as seasonal and event (high flows) scales. At

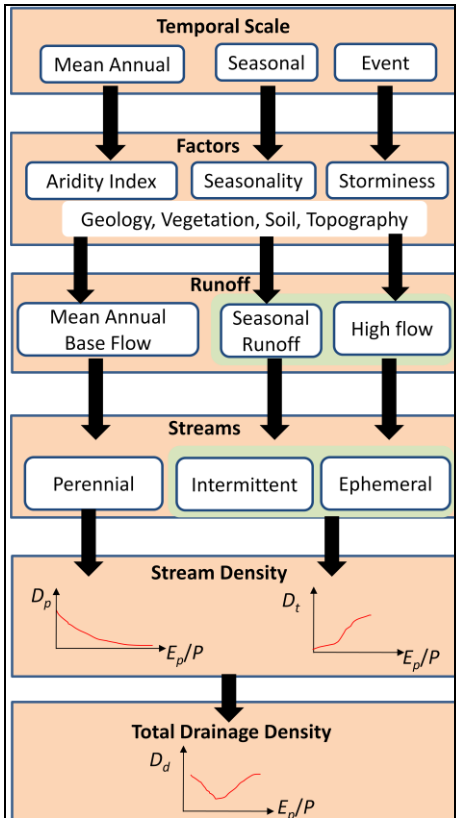

Figure 1: The dependence of perennial and temporal streams on hydrologic responses at different temporal scales

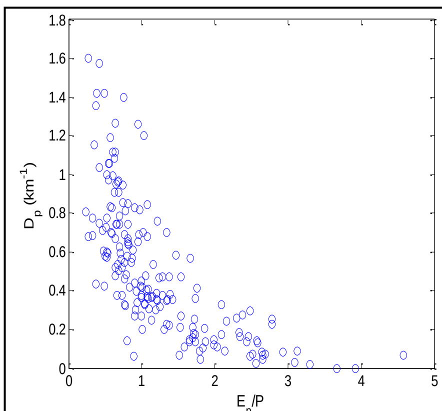

Figure 2: The observed perennial stream density versus climate aridity index

the energy limited region, the decrease of D_p dominates the trend of total drainage density; at the water limited region, the curve of D_p ~E_p/P becomes flat and the increases of D_t dominates the trend of D_d. The total drainage density decreases then increases from energy-limited to water-limited regions. Therefore, the observed U-shape by Abrahams (1984) can be alternatively explained by the trade-off between runoff generation at the mean annual scale and the runoff generation at the finer temporal scales.

Figure 3 plotted the temporal stream density versus climate aridity index for the case study watersheds based on NHD dataset. The temporal stream density of the high-resolution NHD is 1:24,000, which is equivalent to DEM with 30-m resolution, is underestimated in some watersheds. Therefore, the total drainage density will be underestimated due to map coarse map resolution which cannot capture the small headwater streams. However, the underestimation of perennial stream density may not be significant since the headwater streams are usually ephemeral or intermittent. Melton (1957) reported the total drainage density (D_d) ranging from ~2 to ~100 km^{-1} where drainage density is a geomorphologic variable and represents valley density. The average hillslope length between divides and the first order valley (L_o) is related to drainage density (Horton, 1945), i.e., L_o =1/(2 D_d). Therefore the average hillslope length ranges from 5 m to 250 m for watersheds reported by Melton (1957). The watersheds reported by Melton (1957) are located in arid and semi-arid regions and temporal streams dominate the drainage network. Therefore, the perennial stream density or total drainage density in the NHD dataset is not high as the drainage density found by Melton (1957).

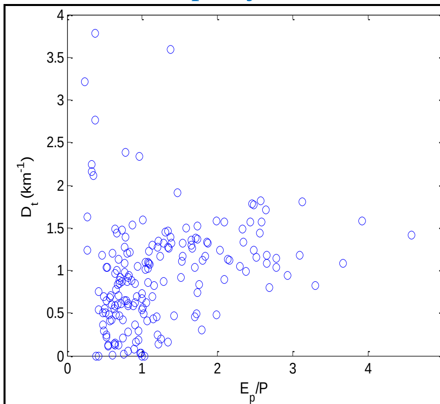

Figure 3: The observed temporal stream density versus climate aridity index

Even though the temporal stream density may be underestimated due to the spatial resolution of topographic map, Figure 3 shows the general increasing trend of D_t with E_p/P. The scatter is significant because the main controlling factors on D_t are seasonal climate and extreme rainfall events instead of mean climate. For example, in Figure 3 several watersheds with high D_t are located in humid regions. These watersheds are located in the State of Washington with low rainfall in summer and high rainfall in winter. Therefore, many streams dry out in summer due to the seasonal rainfall distribution. It will be interesting to investigate the controls of seasonal and extreme rainfall on temporal stream density.

2. I see a breakdown in the symmetry between the Budyko relationship and the drainage density relationship that authors have proposed. In Budyko, all variables are local, i.e., P, Ep, E, and Q, and so E/P, Q/P and Ep/P are estimated locally for each catchment. From what I can understand, in the authors’ work Dp/Dp* is no longer local, because Dp* is not local, but estimated as the maximum out of all 157 catchments. This creates a serious problem for the generality of the established relationship, unless they rationalize that they estimate the local maximum from the global maximum. This is problematic, to say the least.

3. Where is the role of geology? I would have thought that one of the factors that keep river flowing perennially is subsurface or groundwater flow (which will reflect the geology), and wouldn't that be a better variable to relate to perennial drainage density, whereas maximum drainage density will be governed by more extreme flows, and if one were to map the extent of drainage network during high flows you might get at the Dp*. I am bit surprised that both geology and floods are not explanatory variables in the estimated relationship.

For convenience, let's address the second and third comments together. Thank you for your insightful comments. We agree with you that high flow caused by extreme rainfall event is related to temporal streams (then the total drainage density D_d) as discussed in the first comment. The perennial stream density is dependent on the mean climate which is filtered by watershed characteristics, particularly geology. Therefore, it is better to compare the similarity between base flow coefficient (Q_b/P) and normalized perennial stream density. Figure 4 plots Q_b/P versus E_p/P. As expected, the data points are a little below Q/P versus E_p/P. However, the data clouds follow the similar trend. As shown in Figure 4, one Budyko-type equation, i.e., Turc-Pike, is fitted to the data points and the parameter value is 3.3.

Figure 5 plots D_p/D_p^* versus E_p/P where D_p^* is the maximum value of D_p among the 185 case study watersheds. The solid red line in Figure 5 is the same Turc-Pike curve as Figure 4. Therefore, similarity indeed exists between baseflow Q_b/P and D_p/D_p^*.

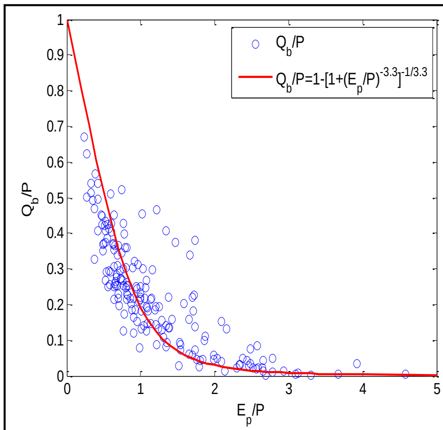

Figure 4: Q_b/P versus E_p/P, and the fitted complementary Turc-Pike curve

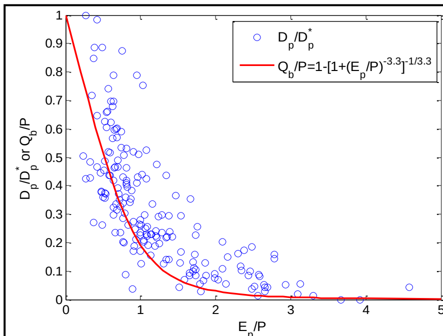

Figure 5: D_p/D_p* versus E_p/P and the fitted complementary Turc-Pike curve for Q_b/P versus E_p/P

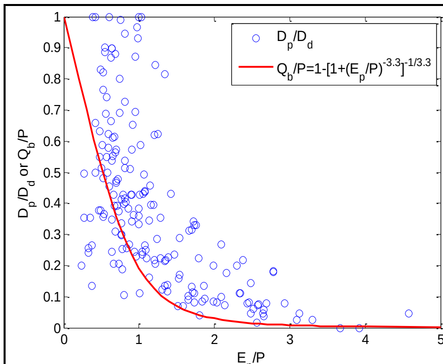

Figure 6: D_p/D_d versus E_p/P and the fitted complementary Turc-Pike curve for Q_b/P versus E_p/P

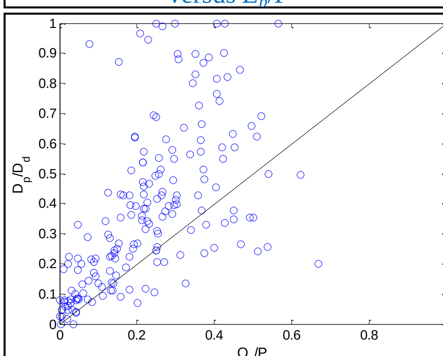

Figure 7: D_p/D_d versus Q_b/P

To generalize the relationship, the maximum perennial stream density D_p^* is replaced by the local maximum drainage density D_d. Figure 6 plots D_p/D_d versus E_p/P and the fitted complementary Turc-Pike curve for Q_b/P versus E_p/P from Figure 4. The data points are above the fitted line for Q_b/P. Figure 7 plots D_p/D_d versus Q_b/P directly, and the value D_p/D_d of is larger than that of Q_b/P. The underestimation of D_t and D_d can cause these. Therefore, the hypothesis on the similarity between Q_b/P and D_p/D_d as a function of E_p/P is promising. Further research is to collect accurate data in both perennial and temporal streams and test this hypothesis.

4. Overall, more questions are raised as you discuss the results of the paper. It is surprising, and yet confounding, and I would expect the authors to rationalize their results better, especially in respect of the previous work of Abrahams (1984).

Thank you. See responses to Comment 1. We will include this discussion into the revision.

5. It is a fairly simple paper, yet I found an unsmooth presentation – many statements were repeated. I would expect them to give a more polisher presentation. I can understand the amount of work that would have gone into the analysis, but it will also be nice to present some real catchments to contrast the drainage densities found and a schematic figure to illustrate the difference between Dp and Dp* (in the same catchment).

Thank you for your comment which indeed lead to interesting discussions and improve the manuscript significantly. Figures 8-12, which will be added to the revised manuscript, show the perennial and temporal streams from 5 watersheds with Ep/P of 0.27, 0.65, 1.5, 2.0, and 4.6. The value of D_p/D_d deceases from 0.5 to 0.04.

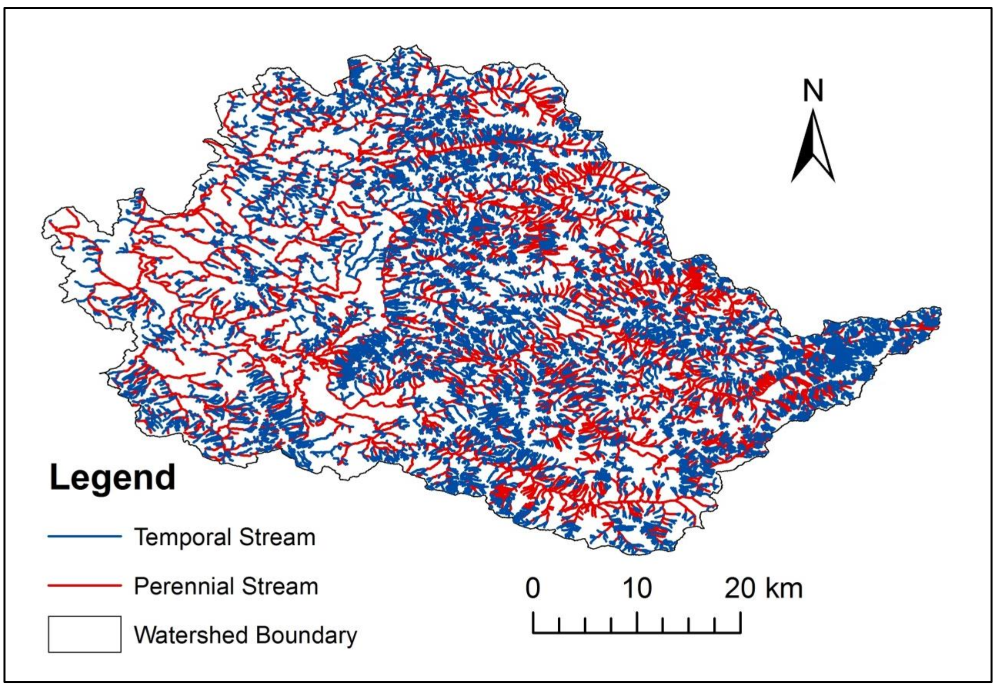

Figure 8: The temporal stream and perennial stream of Snoqualmie River watershed in State of Washington (USGS gage ID: 12149000) with E_p/P=0.27, D_p/D_d =0.50.

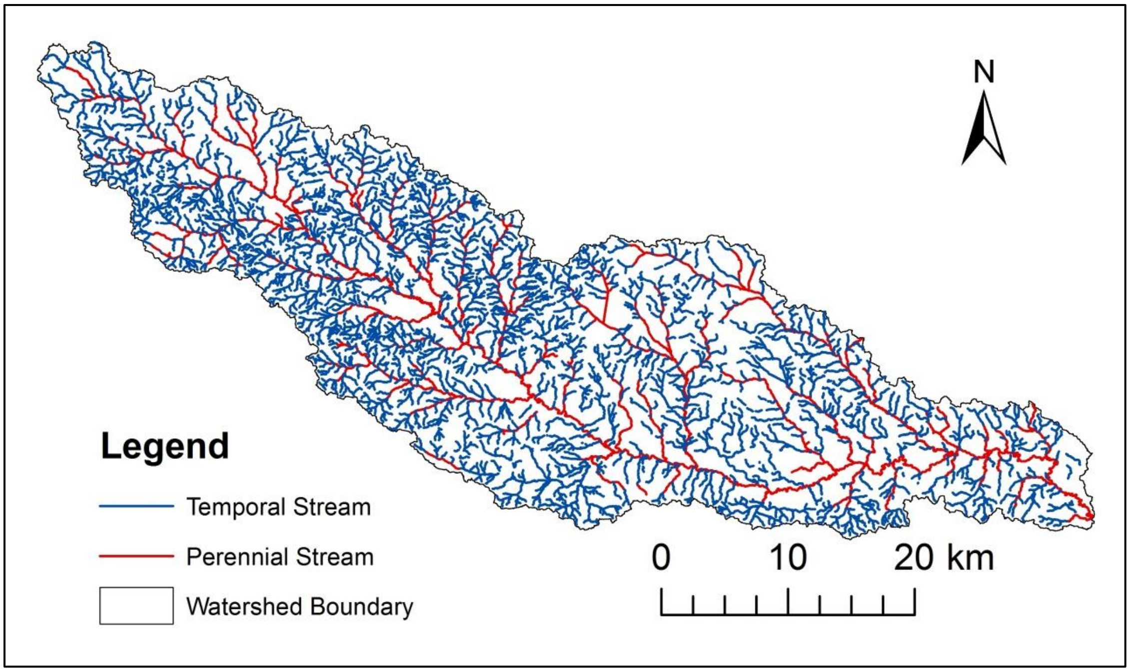

Figure 9: The temporal stream and perennial stream of Red Creek watershed in State of Mississippi (USGS gage ID: 02479300) with E_p/P=0.65, D_p/D_d =0.24.

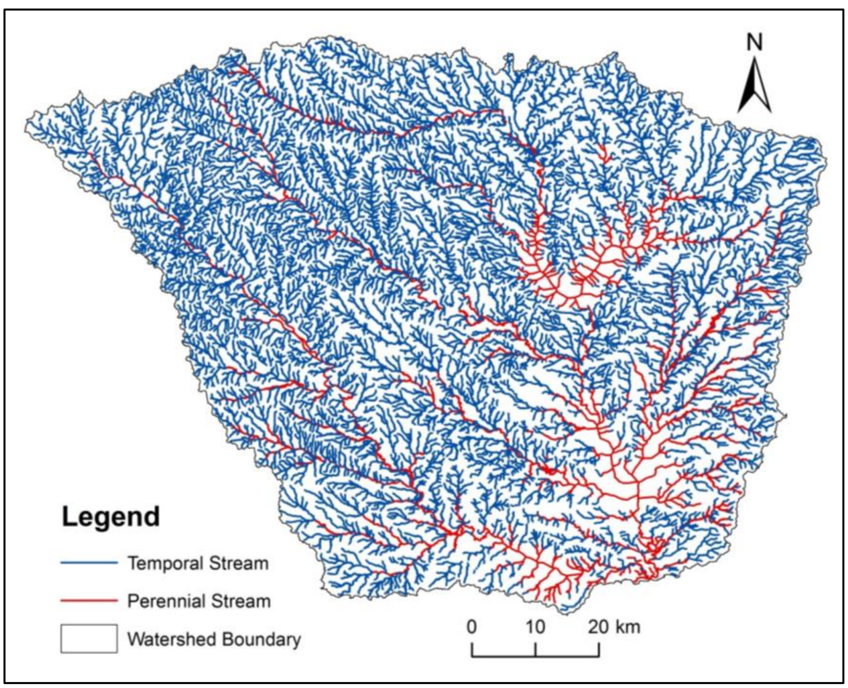

Figure 10: The temporal stream and perennial stream of Elm Fork Trinity River watershed in State of Texas (USGS gage ID: 08055500) with E_p/P=1.5, D_p/D_d=0.16.

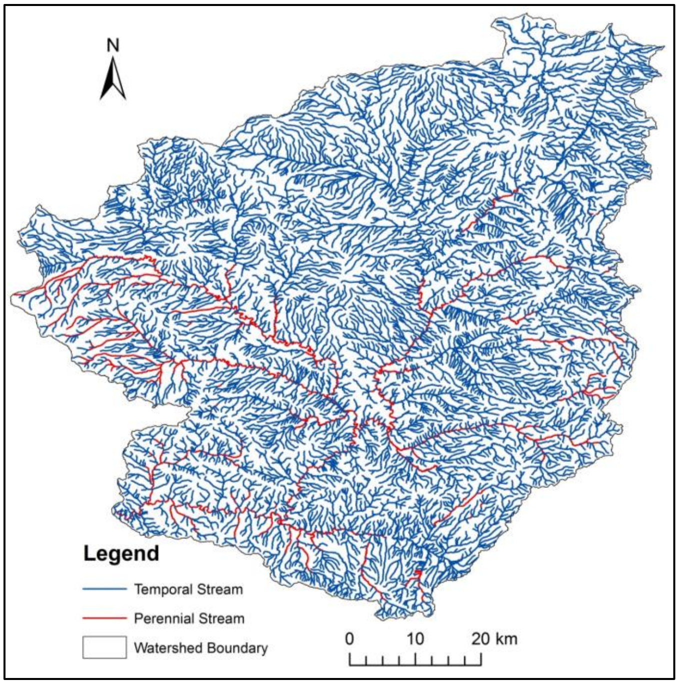

Figure 11: The temporal stream and perennial stream of Gila River watershed in State of New Mexico (USGS gage ID: 09430500) with E_p/P=2.0, D_p/D_d=0.08.

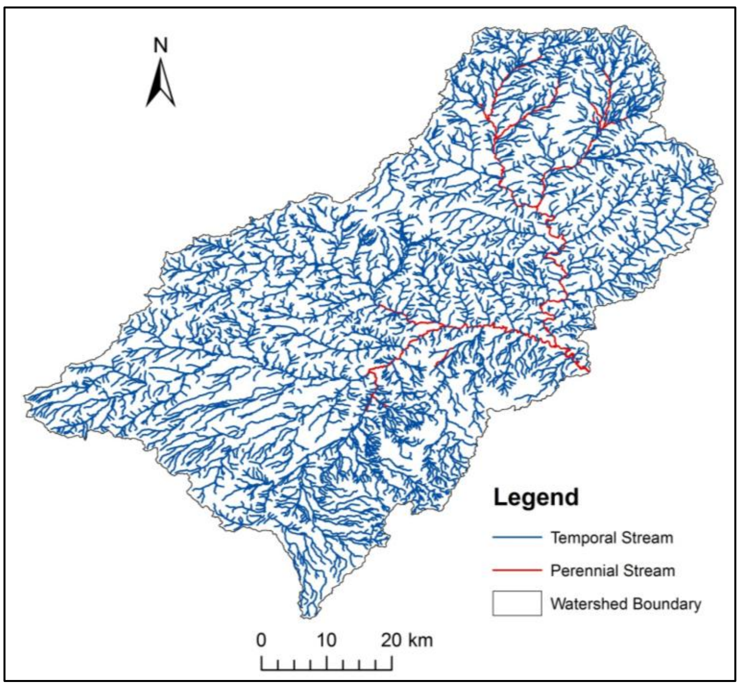

Figure 12: The temporal stream and perennial stream of Arroyo Chico watershed in State of New Mexico (USGS gage ID: 08340500 with E_p/P=4.6, D_p/D_d=0.04.