Revisions to manuscript: "Understanding runoff processes in a semi-arid environment through isotope and hydrochemical hydrograph separations" by V. V. Camacho et al.

Once again, we would like to thank the referees and editor for the constructive comments. Below, we present the initial authors' response (AR) and the revisions made to the manuscript (Rev) taking into consideration the editor's and referees' comments (RC).

Revisions made as suggested by Anonymous Referee #1

(1) RC: The paper entitled "Understanding runoff processes in a semi-arid environment through isotope and hydrochemical hydrograph separations" by V.V. Camacho et al., represents an interesting work to understand the different processes governing runoff response in a South African catchment. It summarizes the results of the application of isotopes and hydrochemistry to 4 flood events to separate the hydrographs and investigate the main surface and groundwater sources. However, my feeling is that the paper is not adequate in its actual form to be published in HESS due that authors have tried to explain very complex hydrological processes with data gathered for just 4 floods, a fact that I consider totally insufficient.

Rev1.1: Table 6 with number of events analysed per study was included in the discussion section (reference in page 16 lines 15-16).

AR: The authors agree that the amount of data is a limitation in making inferences in defining and quantifying runoff processes in the Kaap catchment. Moreover, insights into the understanding of runoff process were obtained for a particular rainy season (sampling started in November 21st 2013 and ended in February 4th, 2015). The events sampled are different from each other considerably with respect to peak flow, duration, and intensity allowing studying the runoff responses to particular rainfall events.

Past studies have also demonstrated valuable insights from investigating runoff processes in a storm by storm basis. For instance Burns et al. (2001) determined the geographic runoff contributions in the Panola Mountain catchment occurring from two storm events. Similarly, McGlynn et al. (2003) estimated hillslopes and riparian zones contributions to total streamflow for two storm events in a catchment in New Zealand. A brief table is provided below showing the range of events sampled in previous isotope tracer studies. The authors believe that although no final conclusions can be withdrawn from the limited amount of data, it is important to publish the results obtained for further synthesis of runoff studies and to obtain an overall understanding of runoff processes in the distinctive regions.

Study	Citation	Number of events
Hydrograph separation using stable isotopes, silica and electrical conductivity: an alpine example	Laudon et al. (1997)	5
The role of soil water in stormflow generation in a forested headwater catchment: synthesis of natural tracer and hydrometric evidence	Bazemore et al. (1994)	2
Quantifying contributions to storm runoff through end-member mixing analysis and hydrologic measurements at the Panola Mountain Research Watershed (Georgia, USA)	Burns et al. (2001)	2
On the value of combined event runoff and tracer analysis to improve understanding of catchment functioning in a data-scarce semi-arid area	Hrachowitz et al. (2011)	28
Quantifying uncertainties in tracer-based hydrograph separations: a case study for two-, three- and five-component hydrograph separations in a mountainous catchment	Stefan Uhlenbrook et al. (2003)	4
Hydrograph separations in a mesoscale mountainous basin at event and seasonal timescales	Stefan Uhlenbrook et al. (2002)	2
Identification of runoff generation processes using combined hydrometric, tracer and geophysical methods in a headwater catchment in South Africa	Wenninger et al. (2008)	3
Runoff generation in a steep, tropical montane cloud forest catchment on permeable volcanic substrate	Muñoz-Villers et al. (2012)	13
Quantifying the relative contributions of riparian and hillslope zones to catchment runoff	McGlynn and McDonnell (2003)	2
Dynamics of nitrate and chloride during storm events in agricultural catchments with different subsurface drainage intensity (Indiana, USA)	Kennedy et al. (2012)	2
Investigation of hydrological processes using chemical and isotopic tracers in a mesoscale Mediterranean forested catchment during autumn recharge	Marc et al. (2001)	3

In addition to the data collected during the rainy season 2013-2014, historical hydrological and water quality data was analysed during this study to obtain a better understanding of the catchment such as the flow behaviour during dry and wet conditions, spatial distribution of hydrochemical parameters and the hydrochemical signature of baseflow. Hydrological data included precipitation rates (daily precipitation rates from 2001 to 2012 at four rain gauges), evaporation rates (daily rates from 2003 to 2012 from four stations) and stream flow for the Kaap outlet (daily average flows for 51 years with 5% missing values) and its tributaries; Queens (daily average flows for 63 years with less than 1% missing values), Suidkaap (daily average flows for 45 years with 3% missing values), and Nordkaap (daily average flows for 42 years with 6% missing values). The studied historical water quality parameters included electrical conductivity, pH, calcium potassium, magnesium, sodium, chloride, calcium carbonate, fluoride, nitrate, phosphate, and silicon from eleven stations along the Kaap River and tributaries. Data was obtained from the Department of Water Affairs - South Africa (DWA) who sampled these stations in a weekly basis starting in 1969 at the Queens, Noordkaap, Suidkaap tributaries and at the Kaap outlet. Weekly samples were obtained at most stations until 1983 when the sampling frequency was changed to once per month up to the fieldwork started for this study.

(2) RC: I also consider that the format, structure and redaction of the paper is more adequate for a technical report, or a final report of a research project rather than for a scientific piece of work. The introduction is quite repetitive (see lines 19-29 of page 978 and 1-3 pag 980) and there are some paragraphs useless (see lines 3-13 page 980); in case you include them, they should be moved to the study area.

Rev1.2: Lines 19-29 of page 978 and 1-3 of 980 of previous manuscript were rewritten to avoid repetition, and lines 3-13 in page 980 were moved to the study area section.

AR: Lines 19-29 of page 978 will be re-written in the revised manuscript to avoid repetition in the introduction. Lines 1-3 pag 980 are in the study area, as well as lines 3-13 page 980. Careful revision will be made of the entire section to make it more concise.

(3) RC: Results should be explained deeply (probably they are not as they are not very remarkable). For example, regarding the section 4.4, what about the temporal variability of the hydrochemical variability? Why do they increase in time (from the 1st to the last flood)?

Rev1.3: Section 4.4 was strengthened and temporal variability of hydrochemical parameters explained

AR: The first flood was the largest event sampled reaching a peak flow of 124 $m^3 s^{-1}$ where a larger contribution of “direct runoff” water was observed. In contrast, the later events had smaller peak flows of 27.6, 6.5 and 7.1 $m^3 s^{-1}$ for events 2, 3 and 4 respectively. Thus a greater dilution effect was observed for event 1 that was a large and relatively short duration event.

(4) RC: Concerning section 4.6, I consider totally necessary a more detailed and accurate study of the differences between "old water" and "groundwater"; by the way, what do you consider as "old water"?

Rev1.4: Old water and groundwater concepts were further explained (section 4.6)

AR: The definition of Klaus et al. (2013) was used for this study stating that pre-event water (or old water as referred in this section of the study) is the water stored in the catchment before the rainfall event. The aim of this section is to discuss the possibility that the catchment stores water during the rainfall season and when sampling old water, it may not be representative of groundwater but it may be water stored from the same rainfall season but from previous rainfall events. Old water for the hydrograph separation was assumed to be the river water just before the rainfall event. Groundwater was not sampled from boreholes during events. However, the groundwater signature was obtained from historical data.

(5) RC: Concerning section 4.7, I consider that lines 12-22 of page 990 are irrelevant, they do not provide any interesting result.

Rev1.5: Section 4.7, lines 12-22 moved to the methods section as part of the end-member mixing analysis.

AC: Lines 12-22 describe the hydrochemical characterization of the end members. This description will be moved in the revised manuscript to the methods section as part of the end-member mixing analysis.

(6) RC: As the results, discussion should be improved a lot. It is mainly based on describing Figure 10 and Table 6 which to my understanding add nothing to the paper, they are divulgative rather than scientific; if not, where are the final values (at least approximations, order of magnitudes)?

Rev1.6: Figure 10 and Table 6 were deleted

AC: The aim of figure 10 and table 6 was to suggest the runoff flow paths in the Kaap catchment considering the landuse, topology and geology of the area. Although the conceptual diagram is not an accurate representation of the Kaap catchment, it presents the dominant landuses, and geological formations that explain the hydrochemical behaviours observed at the different spatial locations. Table 6 aims to summarize the dominant runoff processes obtained from the hydrograph separations and field observations. It is possible to add the ranges of runoff contributions obtained but these were not included since these results are representative of the wet season investigated and not of the dry season.

(7) RC: Moreover, discussion seems be a compilation of sentences of papers already published in similar locations (see lines 21-26 of page 991 and 1-10 of page 992) rather than discussing the actual results of the paper, which are quite obvious by the way (see lines 1-2 of page 993).

Rev1.7: Discussion section was shortened

AC: The author's intention with this section was to make a synthesis of works for obtaining an overall understanding on the governing hydrological processes that generate runoff processes in semi-arid regions. Moreover, the authors agree that this section can be shortened.

(8) RC: I am aware the work that you have already done and the difficulty of gathering data in Africa, but I consider that to publish this it is totally necessary to generate more results, give them more relevance and significance and especially, discuss them accordingly to the importance of the journal. However, I encourage you to do it and submit again the paper to HESS which, I guess, is the correct journal to publish these results.

Rev1.8: Please see initial response below

AC: The authors are grateful for the referee's suggestions. Moreover, as mentioned by the referee, the generation of data is a costly and difficult process and not publishing these results would be detrimental to the general understanding of runoff processes in distinct regions other than the northern hemisphere. Data was carefully collected in this study and contributes to the larger database of data in Africa that can later be synthetized leading to more findings and more research questions to answer. The authors will consider a more focussed discussion of the results in the revised manuscript.

Revisions made as suggested by Anonymous Referee #2

RC: I carefully read the manuscript (MS). In their MS the authors aim to study runoff generation processes in the Kaap basin South Africa which they refer to as semi-arid. Moreover, they aim at general statements on the validity of tracer-based hydrograph separation methods in semi-arid environments. I fully support the comments of referee#1, who concluded that the collected data is not enough to back up the conclusion drawn on complex runoff generation processes as presented by a conceptual model. But I have two additional major concerns why I think that this paper is not publishable in HESS. Those are detailed down below. However, after a general re-writing the data presented here could be used for another paper with another focus: e.g. a regional study on runoff generation processes. Its main finding might be useful for the region: "API dictates the event-water percentage during runoff events and hence one might hypothesize that the importance of quick, surface runoff processes is more important during wet conditions." In general, however, this is known for many humid areas (and Kaap during summer is humid, see below), why I propose to approach another journal with a more regional focus. I detail all my concerns down below in hope that they will be useful for the authors.

(1) The Kaap basin is not "semi-arid" There are two main ways to hydrologically define prevailing climate, e.g. by indices or by hydrological characteristics. Indices: According to Köppen-Geiger, Kaap lies in Cwb, which is generally temperate, only dry during the winter, if at all. Your study was undertaken during the wet summer. But hydrologically an even more relevant indicator is the division of annual precipitation (P) by potential evapotranspiration (PET). According to UNESCO the threshold for semi-arid is 0.5, for sub-humid is 0.65. Everything higher is truly humid. Using your data (p980) I arrive at 0.73, this assuming that your Class-A-data is corrected. If pan correction is necessary, P/PET will even be higher. Hydrological characteristics: Although the minimum daily flow is 0, there is still a monthly average of 0.8 m3s-1 after the dry season (p980). This indicates that periods of zero streamflow are very short and that your channels are not ephemeral which they should be, if you are in a really dry region. Another indication for a humid system is the fact that you have a gaining river system (p 987). This means there are constant flow paths through the subsurface, and constant baseflow (see above). Then a relevance of groundwater is logic

also during runoff events, because piston-flow mechanisms may activate existing subsurface flow paths. This is in accordance with your tracer results that show the dominance of pre-event water during runoff events. You state yourself that this well known for "semi-humid" regions (p977. This means that these results confirm existing knowledge from humid systems but do not contribute to process knowledge for semiarid environments, which you aim at.

Rev2.1: Included discussion in study area section (page 5, lines 6-11) of manuscript explaining the Kaap aridity index and added aridity index and long-term potential evapotranspiration maps to figure 2.

AR: The authors acknowledge that the Kaap catchment following the Köppen-Geiger classification is Cwa/Cwb, warm temperate with dry winter and hot summer. However, the study was initiated on the context of the Incomati Basin, which is overall semi-arid. Parts of the Kaap catchment, where MAP (Mean Annual precipitation) is below 700 mm a^{-1} and PET is over 1400 mm a^{-1} are actually semi-arid. The PET reported in the study on page 980 is the average over the last 10 years and is based on only four meteorological stations. The long term PET for Kaap (1950-2000) is 1500 to 1900 mm a^{-1} (see Atlas, 2005 and WR2005) which makes it mostly semi-arid as illustrated on the figures below (Aridity Index = Mean Annual Precipitation / Mean Annual Potential Evaporation Apan).

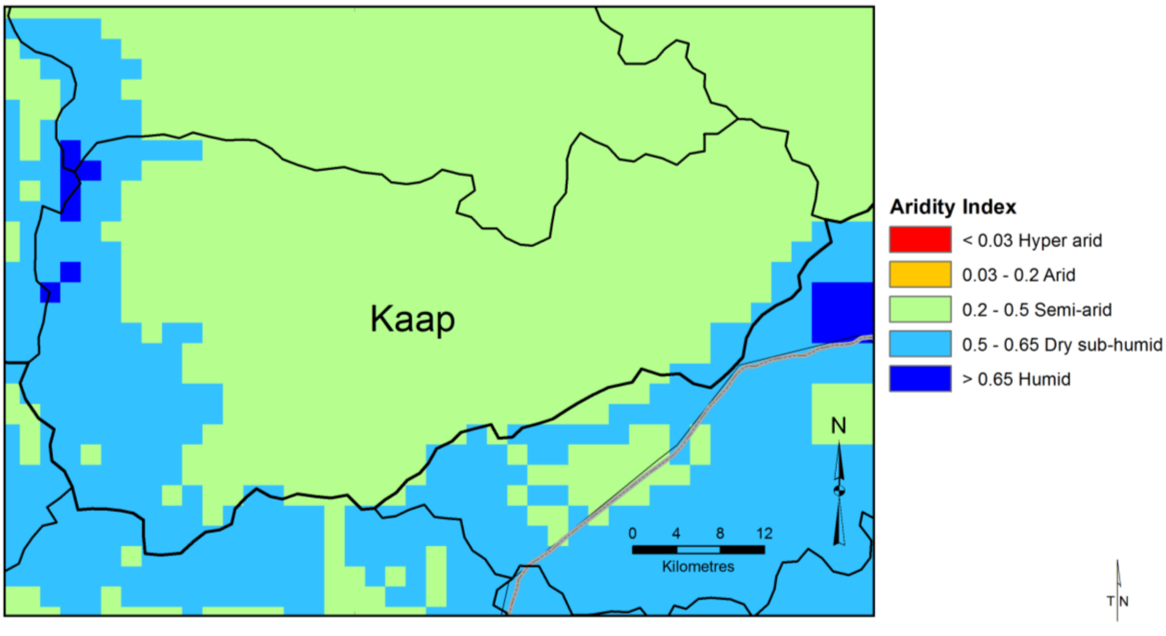

Figure 1. Aridity index in Kaap Catchment based on Mean Annual Precipitation and Mean Annual Evaporation

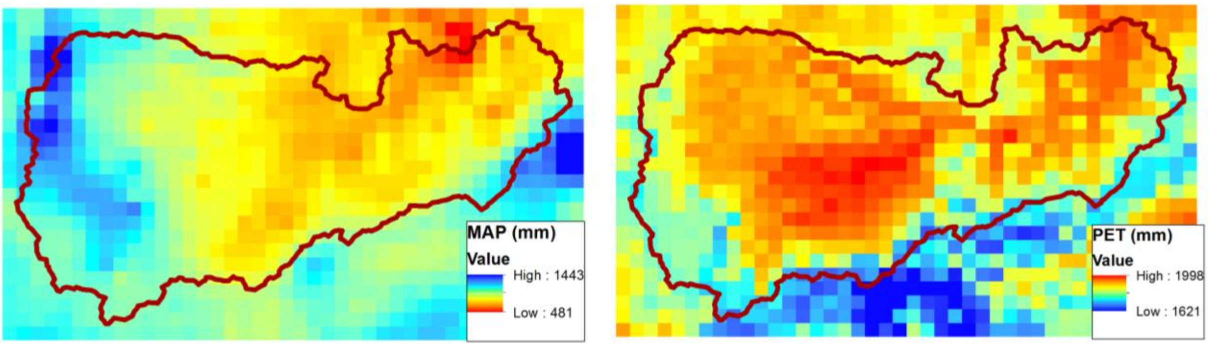

Figure 2. Mean Annual Precipitation and Mean Potential Evaporation (A-Pan) in Kaap Catchment

Supporting data for the creation of these maps was obtained from:

Lynch, S.D. and Schulze, R.E. 2007. Rainfall Database. *In:* Schulze, R.E. (Ed). 2007. **South African Atlas of Climatology and Agrohydrology**. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 2.2.

Schulze, R.E., Maharaj, M. and Ghile, Y. 2007. Climatic Zonation. *In:* Schulze, R.E. (Ed). 2007. **South African Atlas of Climatology and Agrohydrology**. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 3.3.

Schulze, R.E. and Lynch, S.D. 2007. Annual Precipitation. *In:* Schulze, R.E. (Ed). 2007. **South African Atlas of Climatology and Agrohydrology**. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 6.2.

Schulze, R.E. and Maharaj, M. 2007. A-Pan Equivalent Reference Potential Evaporation. *In:* Schulze, R.E. (Ed). 2007. **South African Atlas of Climatology and Agrohydrology**. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 13.2.

(2) RC: Mix-up of concepts for hydrograph separation

Tracer-based hydrograph separation is your promoted method for the study of runoff generation processes. There is, however, no clear separation of different concepts. Tracers can be used to separate event from pre-event waters (mainly isotopes) or to distinguish runoff source areas (mainly hydrochemical tracers). However, they should not be used to separate direct runoff ("quick-flow") from base flow. While the latter mainly stems from groundwater and contains pre-event waters, direct runoff must not be used as a synonym for event water or surface runoff components, like you do in **p988 (l20-21)** and in the discussion section. Just in humid systems (as in the Kaap during the wet summer, see above) most of the runoff response (i.e. quick flow or "direct runoff") is made of pre-event components. You mix these concepts also for existing studies you cite: I just checked one (Hrachrowitz et al. 2011): They did not find "direct runoff contributions of 9%" in Tanzania as claimed (p 992) but rather showed the dominance of pre-event water during runoff events.

Rev2.2: Runoff components defined in methods section (page 9, lines 16-24) and definition revisited in results section (page 13, lines 16-21)

AR: The intention of the authors was to differentiate the quick flow components (in this study referred as direct runoff) from baseflow components coming from groundwater sources. Direct runoff was defined according to the conceptual model by S. Uhlenbrook et al. (2000) where direct runoff (fast runoff component) is generated from direct precipitation on the stream channel, overland flow from sealed and saturated areas and from highly fractured outcrops. Furthermore in this study, the Kaap deep groundwater component is the portion of runoff generated from deeper highly weathered granite aquifers, and the shallow groundwater component is the intermediate component from perched groundwater tables. The authors recognize the need to clarify these concepts in the revised manuscript and to amend the references made in the cited studies.

(3) RC: Other concerns (chronological order):

P977 ll18-22: You summarize characteristics of dry areas. These are true but additionally to the fact that they are not relevant for your system (see above), I do not agree that all of them per se pose a particular challenge to runoff generation studies, just the opposite may be true, e.g.: if you have sparse vegetation, interception is less important; if groundwater is truly deep, surface –groundwater interaction is only in one direction; and if surface runoff is lacking, is there any runoff process to be studied?

Rev2.3: The authors have re-written p977 12-22 of the previous manuscript proceeding with caution with respect to complexity of runoff studies in semi-arid areas (page 3, lines 1-2).

AR: The system studied is within a semi-arid sub-humid zone, as shown on the response to previous comment. It is true that there is a smaller component of streamflow compared to other hydrological fluxes such as rainfall or evaporation. But the fact that the precipitation and evaporation flows have such high intra and inter-annual variability makes the streamflow flux very sensitive and runoff generation processes more complex to study, because as the reviewer already indicated, the system quickly changes from semi-arid to humid during the wet season.

P977-978: Kendall and McDonnel 1998 is a brilliant textbook on isotopes in hydrology but no adequate reference for processes in arid and semi-arid hydrology.

Rev2.4: Citation removed

AR: The authors agree with this comment and the citation will be removed from page 977

P978: The sparse nature of vegetation does not add to the complexity of evaporation, rather does vegetation variability.

Rev2.5: Replaced spare nature of vegetation by spatial variability of vegetation

AR: The authors agree with this comment and the sentence will be rephrased in the revised manuscript.

P978: Among others, transmission losses are not relevant for your basin which you identified as gaining stream (see above). Hence the Kaap should not be compared to Saudi Arabia as well.

Rev2.6: Saudi-Arabia comparison removed.

AR: The authors agree that comparison of the Kaap with Saudi Arabia is not so appropriate, therefore it will be removed. However, transmission losses are important on the western part of the basin, towards the Kaap valley. This occurrence is more evident in the overall Incomati Basin, where downstream areas (e.g. Mozambique) benefits from transmission losses and return flows of upstream areas (Nkomo et al., 2004; Sengo et al., 2005).

P981: How can a method for crop evaporation be used for your land use types, what are the uncertainties?

Rev2.7: Please see response below

AR: We estimated the evaporation using the predominant land cover for each land use class from the Inkomati water availability assessment study technical report (DWAF, 2009d). These include plantations of pine and eucalyptus covering approximately 25% of the catchment area and crops such as sugar cane and citrus trees which cover only 6% of the catchment area while natural land-uses (Bushveld and grassland) cover approximately 68% of the catchment. The remaining 1% corresponds to urban zones. Thus, there are uncertainties in the evaporation, especially on the forest plantations where the actual evaporation is high as observed by van Eekelen et al. (2015) where plantations can have evaporation rates of 1151 mm a^{-1}. Moreover, our evaporation estimates are comparable to van Eekelen et al. (2015) were bush/shrub have actual evaporation of 661 mm a^{-1}.

P983/984: You used different sampling strategies (volume-based and temporal) for rainwater to obtain you event component. What is the exact difference and how different are your signatures? You only use SD for your error, the total difference would be more appropriate.

Rev2.8: Range of delta deuterium and delta oxygen-18 values added to revised manuscript (page 12 lines 4-5)

AR: The volume and time based sampling strategies were used for streamflow sampling. Bulk samples were obtained for the rainfall samples. Delta deuterium values ranged from a minimum of -30.2‰ to a maximum of -21.8‰ and delta oxygen-18 ranged from -5.14‰ to -3.72‰

P984: What are “In situ groundwater consultants”?

Rev2.9: Included link in revised manuscript

AR: A groundwater consulting firm (http://www.insituconsulting.co.za) that kindly provided borehole water quality data.

P990 (l8-9): Why does high potassium indicate vegetation influence?

Rev2.10: Explanation added to methods section (page 10 lines 2-7)

AR: The authors agree that this section needs more explanation in the revised manuscript. Next to the principle source of potassium, which is the weathering of minerals of silicate rocks, important origins for potassium are application of fertilizer and the decomposing of organic material. We assumed therefore that the mobilization of potassium is linked to the flushing of the soil and shallow subsurface layers of vegetated areas. That was also observed e.g. by Winston et al. (2002).

P990: You hypothesize a “shallow groundwater component” only by considering high potassium and “slightly less depleted” isotopes. There is no proof that this component really exists. Hence the results of the three-component separation are rather speculative, which is also true for the conceptual model of runoff generation.

P990: Why did you use +- 10% as errors of the groundwater end-members, why not +-20%, why not +- 30%? Your "shallow" groundwater component is rather virtual, see above.

Rev2.11: The alternative of using the analytical error of +/-0.2 mg l^{-1} for K and +/- 1.5 ‰ for 2H was considered. However, the +/- 10% was a more conservative error band for the groundwater components. This plus the overall uncertainty of the EMMA is explained in section 3.3.4.

AR: Because of the assumed end-member value of the shallow groundwater component we introduced a +-10% error of this component to indicate the uncertainty of this separation. We agree that this approach is arbitrary and we will try to find a better estimation of the error in the revised manuscript.

Figure 10/ Table6: I agree with referee#1 that these are highly speculative and not backed up by the data presented.

Rev2.12: Figure 10 and table 6 removed from manuscript

AR: As mentioned to referee#1, figure 10 and table 6 intended to summarize the runoff flow paths in the Kaap catchment including the landuse, topology and geology of area. Please refer to the AR for referee#1 for further response.

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