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Discussions

Interactive comment on "Factors influencing stream water transit times in tropical montane watersheds" *by* L. E. Mu noz-Villers et al.

L. E. Mu noz-Villers et al.

lyssette.munoz@atmosfera.unam.mx

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Anonymous Referee #2

This manuscript aims to assess the control of physical properties on mean stream water transit times in a tropical setting. Although the analyses in the paper are very simple and basic techniques are used, little data from these environments are currently available and this work makes an important contribution in that sense. I would recommend the work for publication, considering the following points below:

Reply: We would like to thank you for your positive recommendation and helpful comments. Please find our replies to your comments below.

The authors comprehensively discuss their results in light of other findings elsewhere.

However, there is little discussion on the methods used and the caveats that come with these. There are three major issues that would be good if discussed.

1) Overall, there is a focus on base flows as these were sampled only. However recent work has shown that there can be a strong variability between MTTs of low and high flows. There is no mention of this in the discussion. I think this should be highlighted there and how this relates to potentially holding/breaking down relationships between physiographical properties and MTTS during storms vs base flow.

Reply: In catchments where runoff generation processes are dominated by near-surface or shallow lateral flow pathways, it will be important to carry out stream water samplings during high and low flow conditions to obtain representative estimates of MTTs. However, previous hydrological work at our research site has shown that baseflow is the dominant streamflow component ($\sim$ 90%). Furthermore, isotope and chemical-based hydrograph separation for a series of storms and for catchments dominated by different land covers showed that deep subsurface flow (mainly ground water sources) rather than near-surface or shallow lateral flow is the dominant pathway for runoff generation. The high permeability of the volcanic soils (Andisols) and the underlying substrate characterizing this region, as also shown in this paper, promotes vertical soil water percolation and recharge of deeper sources, leading to catchment rainfall-runoff responses dominated by groundwater discharge (Muñoz-Villers and McDonnell, 2012, 2013). The above supports why our sampling focused on stream baseflow. We will make this clear in Methods, citing the above-mentioned references. We will also make sure to refer to baseflow MTTs throughout the text.

2) One other key point is that the authors found no distinct differences in the isotope signatures of the streams, yet their model results have a large range of implied MTTs. How does this affect the uncertainty in the results? And is this simply a result of the different models which were used (which have different bias)?

Reply: For the calculation of MTTs, input data for the lumped TTD models consist of isotope time series of rainfall, meanwhile the isotope time series of baseflow are used for calibration. Hence, this procedure is different from the statistical method because it uses the temporal variation observed in isotope baseflow data to fit a TTD model and estimate a MTT from it. In this study, we used the most basic TTD models, which require only one or two distribution parameters to be optimized; note that the used models have been successfully applied in other studies (e.g. McGuire et al., 2005). As shown in Table 4, in 7 out of the 12 catchments baseflow MTTs were best estimated using the Exponential model. In two headwater catchments (MAT and SEC), baseflow MTT was best estimated using the Gamma model, which is a variant of the Exponential model. Using the Gamma model, we obtained MTT estimates of 2.6 years for the MAT and 2.7 years for the SEC; using the Exponential model, these estimates would have been 2.9 and 3 years, respectively. Hence, we obtained very similar MTT results using either the Exponential or Gamma model; this is because the optimized values of the ïĄą parameter (0.6-0.9) in the Gamma model approximated to 1 (i.e. the gamma distribution with alfa = 1 is equivalent to an exponential distribution (c.f. McGuire et al., 2005). Furthermore, since these nine catchments included those with the lowest and highest MTTs, it is unlikely that the obtained range of MTTs is an artifact of model selection. Finally, MTT estimates for the remaining three catchments as obtained with the Dispersion model were generally close to the overall average MTT. It should be noted that the TTD model that we reported for a particular catchment was the one that best fitted the observed baseflow data. We will emphasize this in the text. Furthermore, the selected models were identified as reliable TTDs because they provided predictions with relatively high fitting efficiencies and small uncertainty ranges. Parameter uncertainty was evaluated through the Nash-Sutcliffe E value (see Section 2.3), and Table 4 reports the values of the model parameters and the uncertainty bounds. In all cases, the obtained E values are indicative of a good predictive skill (> 0.5 to 0.7). Moreover, the overall efficiency of the TTD models was evaluated using the RMSE. In this case, the RMSE of the models was between 0.8 and 1.5 ‰ which indicates a good analytical reproducibility of the observed baseflow isotope data, considering that the isotopic

composition range was from - 50.2 to -41.0‰ across all catchments.

3) Many of the sampled subcatchments are nested and only stream samples for isotope data were taken. There is no indication of the relative contributions of runoff from the different parts of the catchment. For example, if the headwaters are contributing more than other subcatchments (could very well be considering the differences in precipitation), then this could bias the results in favour of the processes in those areas.

Reply: Due to accessibility problems and financial constraints, most of the headwaters and subcatchments in this area, as in other tropical regions, remain ungauged. Hence, we followed this approach because it relies primarily on tracer data, and hence is useful to broadly characterize the hydrological behavior of the studied catchments (McGuire and McDonnell 2006). Without measuring streamflow in the different catchments, it is difficult to say which ones could potentially contribute more than others. However, most precipitation falls where the first and second-order catchments are located (2,100-2,400 m asl), and it appears that this is where most groundwater recharge occurs, as inferred from previous water balance studies (Muñoz-Villers et al., 2012). To properly answer this question, more research work and effort should be done to quantify the stream flow contributions from different catchments, and to investigate the connectivity that could exist among sites.

The terrain analysis comprises of many standard techniques, hence I think section 2.4 can be condensed significantly. I would recommend to use either ‘watershed’ or ‘catchment’ consistently throughout the manuscript.

Reply: Despite some of the methods used to describe the terrain analysis are standard, we consider it important to explain to the readers how we defined the terrain parameters in terms of datasets and resolutions used, GIS software and processing. Although this may have made section 2.4 a bit longer, we think its length is still sufficiently short (19 lines). Following the reviewer’s recommendation, we will use the term ‘catchment’ consistently throughout the manuscript.

Some other minor comments:

10976, L7: change to ‘and related these to catchment’

Reply: We will make this change.

10976, L20-22L This sentence not clear. It suggests there is an effect of scale, while the results have shown there isn’t. Greatest difference between scales, or within the two groups?

Reply: We will re-phrase this sentence to make its meaning clear.

10977, L17: needs rephrased. Change ‘first’ to ‘for the first time’?

Reply: We will make this change.

10978, L8-9: are these of the same order of magnitude as Munoz-Villers and McDonnell 2012?

Reply: They were larger catchments from $\sim$1 to 77 km2. We will add this information in the text.

10979, L11: change to ‘the majority of monitored headwaters are located’

Reply: We will make this change.

10980, L3: ET not known as this elevation?

Reply: Indeed, no data on ET are available for this elevation.

10981, L13: What kind of correlation? Can you show what the measure of fit is?

Reply: It was a linear regression with an r2 of 0.95. We will add this information.

10982, L4: Explain why this is the best method?! e.g. why not nearest gauge, something along the lines of elevation corrected Thiessen polygons

Reply: We actually followed the McGuire et al. (2005) approach, matching the average

isotope signature of baseflow with that of rainfall, and so to identify the elevation at which most recharge occurs. Furthermore, this approach was supported by the fact that both the TG and SECP sites are located at those elevations in the LG watershed where probably most groundwater recharge occurs, as determined by previous water balance studies (Muñoz-Villers et al., 2012) (see L8-11). To complement the information in the text, we can add at the end of the sentence in L4 “by assuming that the mean isotopic composition of baseflow of each catchment reflects the average isotopic composition of rainfall (cf. McGuire et al., 2005)”.

10982, L12: Why this approach when many others around? Does it fit your data best?

Reply: MTT studies often suffer from short isotope time series of rainfall, which yield nonunique model calibrations or uncertainty in the parameter estimates of the transit time distribution. To deal with this, the majority of the investigations extend their input time series using different methods (i.e. temperature records, seasonality in rainfall, or data from nearby long-term stations). At our site, precipitation shows a marked seasonal pattern (Holwerda et al., 2010; Muñoz-Villers et al., 2012). Rainfall isotope signatures also show a strong and consistent variation with rainfall amount (Goldsmith et al., 2012). Thus, we decided to generate a warm-up period required for the model simulations, repeating our measured 2-year rainfall time series 15 times following the approach of Hrachowitz et al. (2009, 2010); note that we already tested this method in previous MTT work at our site (cf. Muñoz-Villers and McDonnell, 2012). To complement the information, we can add something along these lines in this part of the text.

10984, L6: not ‘created’ but ‘derived’

Reply: We will make this change.

10984, L14: which criteria were used for selection?

Reply: This information is provided in L5-9.

10984, L16: change ‘description’ to ‘descriptions’

Reply: We will make the change.

10984, L17: n = 3 in total or 3 at each site?

Reply: Three undisturbed soil core samples at each site. We will clarify this in the text.

10985, L15-16: How does this relate to long term (or even 2006-2010) data? Could there be bias in your data as a result?

Reply: The average of 3,476 mm measured at the SECP site (2,100 m) is somewhat higher (9 %) than the average of 3,183 $\pm$ 306 (SD) mm measured at that same site between November 2005 and November 2009 (Goldsmith et al., 2002). No other data than those given here are available for the other sites. Nevertheless, the rather small difference with the 2005-2009 data suggests that the two years of data used in this analysis are representative of the longer term pattern.

10985, L24: p value results of which test?

Reply: Anova statistical test. To complement the information in the Methods section, the paragraph will read “Statistical differences in the isotope and d-excess values for rainfall and stream water across sites were performed using ANOVA tests. Statistical relationships between stream water MTT, soil hydraulic properties and landscape characteristics (land cover and topographic variables) were evaluated using Spearman’s rank order correlations. All statistics were conducted using Sigma plot software (version 12, Systat Software Inc.), and evaluated at the 0.05 confidence level.”

10986, L5: lagged by how much?

Reply: We will omit this text in the revised manuscript.

10986, L8: not statistically significant at all sites? And again, which test results?

Reply: Yes, not statistically significant at all sites. We will make this clear in the text.

For the second question, please see my reply to the previous comment.

10986, L10: But many of your sites are nested. Have you considered that this could be a result e.g. of the headwaters contributing the majority of water? Do you have any indication of how much water is coming from which parts of the catchments spatially?

Reply: Please see our reply to your similar comment above.

10987, L10: the highest proportion of what?

Reply: Of the above mentioned slope categories. We will make this clear in the text.

10987, L14-15: This sentence should be moved to methods - and explain why this is important?

Reply: We will move this sentence to the Methods section. The explanation given was to inform the readers what the measures/numbers indicate.

10991, top sentence needs rephrased

Reply: We were not sure which sentence the reviewer is referring to.

10992, L17: change ‘has’ to ‘have’

Reply: We will make this change.

Figure 1: This Figure is currently all a bit busy and it is difficult to make out the subcatchments. Why not focus on the study area only as the lower part of the catchment is not relevant for the study here. Also, what do the elevation labels refer to in A?

Reply: We included the lower part of the catchment to show the entire extent of the LG watershed. The elevation labels in Figure A are presented to give information about the elevation from the bottom to the top of the catchment. In response to the comment, we will increase the size of the figures and labels, and we will also re-arrange its content to make it easier to read.

Figure2-3: Swap order of Fig 2 and 3 - in the text you first refer to Fig 3, then 2.

Reply: We will make this change.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 10975, 2015.