Reply to Interactive comment on "Relating stable isotope and geochemical data to conclude on water residence times in four small alpine headwater catchments with differing vegetation cover" by
M. H. Mueller et al.
Anonymous Referee #1

Reply:
We thank the anonymous referee #1 for his comments and discussion of our manuscript, which we considered carefully. Please see below for our detailed answers and suggested revisions (in red).

Referee comment:
The paper aims to investigate the importance of vegetation cover on water residence times and geochemical response in runoff. For this, 4 micro catchments are sampled and compared.

Major comments:
I think this is an interesting study showing with interesting data. However, am not convinced that the conclusions drawn from the data / findings presented in the best way - at this stage. I think the focus / main message of this paper could / should be different.

Referee comment:
For example, I don't think one can draw any conclusion whether catchment size has or has not an influence on transit times if all sampled catchments are less than 1 km2.

Reply:
We are aware that our range of catchment size is small as we stated on p. 11026 l. 28. The stable isotope time series from the larger Reuss catchment (132 km^2) was used to qualitatively compare catchments of different size (see p. 11018, l. 16 and p. 11026 l. 26). We will revise our statements to make this point. The influence of catchment size was not the main focus of our manuscript, but we still think it an interesting result.

Referee comment:
Secondly, a clear landscape / environment context is missing. What I mean by this is that its crucial to put all case studies you cite from the literature into a correct context – what scales were investigated, what landscape evolution took place – as this is crucial to be able to contextualise the actual catchment response.

Reply:
We agree with you that we strongly summarized the cited references. In order to put our study into a 'landscape context' we will add more information to the cited references.

Referee comment:
Thirdly, I am also not convinced that just 4 sites really allow any conclusion to be drawn regarding "correlations". Particularly, as most "relations" reported are extremely weak.

Reply:

We are totally aware of the fact that four replicates are not enough to get statistically significant results and more catchments would be desirable. Nevertheless, we think the investigated catchments can give us information on how mean water transit time* is influenced by the catchments' characteristics. We do not had the means of a regional monitoring program with 10 or 20 catchments. Besides, before you start such a program it is necessary to evaluate pre-studies, which we did in our approach. We added the 'correlation' plot (Figure 7) in order to visualize our findings: high variability of catchment characteristics versus low variability of mean water transit times. It was not our intention to stress the statistical (non-)significance of our results. We will be clear about this in a revised version of the manuscript.

> *In the following, and also in the revised manuscript, we will use the term 'mean water transit time' instead of 'mean water residence time'. Please see also comments in review #2.

Referee comment:
I also get the impression too many results and messages are presented rather than focussing on one "take home" message based on a clear "story".

Reply:
In our study we aimed to conclude on the hydrological behavior of four different small mountainous catchments taking different aspects into account, which we think give useful additional information e.g. on flow paths in our systems. In order to address your comments/questions we will condense some of the results and conclusions. This will help streamlining our manuscript.

Referee comment:
Using isotopic and geochemical tracers in conjunction is nothing new – and it is not clearly presented what the novel contribution of this paper is.

Reply:
We are aware that the techniques and their combined use we applied are not new to the literature. The aim of our study was to give more insights into catchment response controls and especially the functioning of small mountainous headwater catchments and the influence of encroaching shrub vegetation as one of the controlling factors. In order to be more specific on this point we will add more information. (also see comments and replies on 'objectives of the study')

Referee comment:
In my opinion, this study's most interesting results are in terms of the snow sampling, fractionation etc. So, as a suggestion, I wonder whether the paper (title etc) should rather focus on "Importance of snow, fractionation and vegetation on isotope dynamics in mountainous microcatchments" or something along these lines. I would also show the high resolution snow sampling (if it was conducted). There are not many studies on isotope measurements in snow – so that in itself would be an interesting result.

Reply:

We thank you for this suggestion. As stated on p. 11010 l. 27 we conducted snow sampling along the valley in three consecutive winters. We will include the snow data in the revised manuscript

Referee comment:
All aspects of uncertainty are also ignored. There is such a wealth of literature out there now on transit times, transit times distribution, and time-variant transit times which need to be at least discussed. Some kind of error and uncertainty assessment is necessary (even if its as error bars or Standard deviations). There are limitations to using "mean transit times" – MTTs are still an incredible useful concept but need to be presented correctly.

Reply:
We are aware of the limitations of using mean transit times and we will include a section with discussions on the assumptions and hypotheses related to 'mean transit times' and 'time-variant transit times'.
In our manuscript we showed the sensitivity of the applied model (Fig. 5), which gives information on the uncertainty of the model (parameters). Additionally the model input (stable isotope time series and 'infiltration coefficient') is prone to uncertainty due to various processes (e.g. fractionation). This was discussed in sections 3.2.2 to 3.2.5. But as commented by the referee we did not consider these uncertainties quantitatively. We will include more details on the involved uncertainty in presenting modelled ranges of the mean water transit times.

Referee comment:
I would also suggest that an overall aim of the paper and specific objectives are formulated.

Reply:
On p. 11008 l. 16 we 'hypothesized that shrub encroachment could alter water flow patterns in the unsaturated zone and possibly could influence water residence times'* and we also included information how we use additional information (e.g. geochemistry) to interpret our findings about mean water transit time.

*will be changed to 'mean water transit times' in the revised manuscript.

Referee comment:
Figure 3 is quite important – but very difficult to read. I would firstly suggest to include discharge and precipitation time series – to allow contextualisation (pre-ebent and event conditions etc). Secondly, I would probably present this as a panel figure, i.e. one plot for each of the 4 sites, but same axes to allow comparison. I had difficulties to interpret some of the results – simply because I couldn't read some of the figures very well.

Reply:
Our aim was to allow easy, direct comparison of the 4 micro catchments, therefore we combined the data in one graph. We are aware that unfortunately legibility was reduced by this. In Figure 4 we gave the measured and modelled stable isotope time series of stream water in single graphs to allow a detailed interpretation of the data. Nevertheless

we will consider restructuring Figure 3 in order to include precipitation and discharge data.

Referee comment:
Overall, I would recommend streamlining this m/s. Decide clearly what is the focus and main findings of this study (land use effects? Environmental change? Vegetation and evapotranspiration? Fractionation? Snow effects?). Following this, please focus the introduction and discussion section on the chosen topic or issue. As the m/s stands at the moment, the authors tried to cover a lot of topics, and by doing so missing out on some of the most relevant, recent international literature and discussions.

Specific comments:
Abstract: The abstract as it stands is unclear. There are no findings reported about influence of vegetation on transit times.

Reply:
At the end of the abstract we conclude that in our study the vegetation is of minor importance regarding the mean transit time. But maybe we misunderstand your comment?

Referee comment:
Introduction:
I think the authors would benefit from reading "Kendall, C., McDonnell, J. J. (eds) (1998). Isotope Tracers in Catchment Hydrology. Elsevier Science Publishers. 816p." which is an excellent introduction into isotope hydrology.

Reply:
Thanks, we sure have read this book.

Referee comment:
p. 11006, l.24 change "circulating" to "residing"

Reply:
We will change the expression.

Referee comment:
p. 11007: This whole section on example studies and previous findings needs clear contextualisation. For example, the "role of landscape structure and topography as controlling factors..." is not "still debated" rather different studies at different spatial scales and – most importantly – landscapes with different evolution (e.g. "young" topographically very active landscapes vs ancient landscapes....) showed different findings, i.e. controlling factors. This is very important to be clear about this.

Reply:

We will certainly check all our references and will be clear about what "is still in discussion" and what are clear unambiguous findings. As mentioned in our earlier reply to your comment we will give more details on the cited references.

Referee comment:
Second example: l19: "They argued that they found more freely draining soils..." should be "In such ancient, formerly glaciated landscapes free-draining soils are usually found at steeper hillslopes..."

Reply:
Thanks, will be changed.

Referee comment:
p. 11008: the section on land use effects on runoff generation is a bit basic – and just textbook knowledge. I think if you want to introduce issues on land use and its effects on runoff generation processes you should cite some more of the recent state of the art literature.

Reply:
Our aim of this study was to investigate the controlling factors on mean water transit times (of base flow) and especially the influence of shrub encroachment, which takes places in the Swiss Alps. We therefore only cited some aspects of the literature to show that – in the context of 'vegetation cover' – there already exist several studies* on runoff generation processes (short time scales – e.g. storm events) but to our knowledge only few* studies looking at longer time scales (base flow). We are aware that this section therefore resulted in a quite general overview. In order to give more specific information we will refer to some more literature.

(*we will rewrite our formulation in the revised manuscript)

Referee comment:
p. 11008: Please formulate clear objectives.

Reply:
As stated earlier, on p. 11008 l. 16 we 'hypothesized that shrub encroachment could alter water flow patterns in the unsaturated zone and possibly could influence water residence times'* and we also included information how we use additional information (e.g. geochemistry) to interpret our findings about mean water transit time.

*will be changed to 'mean water transit times' in the revised manuscript.

Referee comment:
Section 2: Were discharge and precipitation (amount) measured? I suggest to add these data – and also show e.g. in Fig. 3.

Reply:

Yes, precipitation amount and discharge was continuously measured during the snow free periods at the individual catchments. Additionally precipitation amounts are available from a station of 'MeteoSwiss' throughout the whole observation period. We will include additional information in the revised manuscript.

Referee comment:
Section 2.3. I am not sure whether the authors are familiar with all the recent literature on transit time modelling, and uncertainties linked to transit time model parametrisation. E.g. Kirchner et al., 2001; Hrachowitz et al. 2010; Botter et al. 2008; Godsey et al., 2010; Hrachowitz et al., 2011 etc.
How did you consider and incorporate uncertainty in your data and model structure?

Reply:
The given numbers of mean water transit times (e.g. Table 3) are the best fit for each catchment respectively. The sensitivity analysis (Figure 5) was performed with one set of input parameters (stable isotope time series, precipitation amount, 'infiltration coefficient; see formulae 2 and 4) by choosing different mean transit times. As stated above, we will include more details and a quantitative estimate on the model (input) uncertainties. We will give ranges of mean water transit times considering ranges of model input uncertainties.

Referee comment:
Section 3 results:
p/ 11017: "The isotope signal was reflected in the streamwater..." please show this clearly in a figure – thats an interesting finding.

Reply:
Here we refer to Figure 3 (and 4) were the influence of the more negative stable isotope values of the snow(melt) was reflected in the stream water. We will refer once more to Figures 3 and 4

Referee comment:
p. 11017, l. 25: "data not shown" – I think it would be valuable for this study to show these data. In this context, please also consider other studies on high resolution tracer data (e.g. Birkel et al., 2012)

Reply:
We will include the data from the snow melt period of 2012 of the two mentioned micro catchments in the graphs.

Referee comment:
p. 11019, l. 10 "This can be either due to heavy rain..." see my comment about Figure 3: the reader needs to see the time series of discharge and precip to actually be able to draw his/her own conclusions.

Reply:
We will give additional information on precipitation amounts and discharge of the micro catchments. Moreover we will add a comment on the snow melt which could also influence the pattern of the modelled stable isotope values of stream water. Model tests revealed that underestimation of the snow melt component (that means 'too positive'

stable isotope values of snow) could also lead to the observed OVERestimation of measured stable isotopes of stream water (see 11019 l. 9).

Referee comment:
L 14, same page: "drier periods..." again, are these drier conditions shown anywhere?

Reply:
See above. Additional information will be given.

Referee comment:
l. 15-20: how can it be that the residence times are the same in Wallenboden and Chaemleten, when isotopic signatures is much more damped in Wallenboden? Is something wrong with your model parameters?

Reply:
According to the goodness-of-fit measure (sigma value), the mean transit times are the same. This has to do with the uncertainty of the model input parameters. We conducted additional modeling tests with modified input data, that is to say stable isotope time series of precipitation (data not shown). For example, we systematically increased the influence of the snow (melt) component by reducing the originally measured stable isotope values of the bulk snow samples. In other words, we simulated the fractionation of stable isotopes which occurs during snow melt. The first melt water subsequently is enriched in the lighter isotopes (also see our reply on the comments of referee #2). These tests revealed the importance of the snow component. Subsequently the best fit was obtained with a longer mean water transit time for Wallenboden than for Chämleten and the overestimation of the measured stable isotopes values in autumn 2011 by the model was reduced (the longer mean transit time yielded a more dampened curved). In our results we presented in the manuscript we defined the stable isotope value of the bulk snow samples as the snow melt input. We are aware of the uncertainty introduced by doing so. We will consider including more details about the uncertainties which will result in a range of mean water transit times for each catchment rather than one single value.

Referee comment:
Sections on evapotranspiration: pls read papers Brooks J R et al. 2010. Ecohydrologic separation of water between trees and streams in a Mediterranean climate, Nat. Geosci., 3, 101–104, doi:10.1038/ngeo722; and Muñoz-Villers LE, Mc- Donnell JJ. 2012. Runoff generation in a steep, tropical montane cloud forest catchment on permeable volcanic substrate, Wat. Resour. Res., 48, W09528, doi:10.1029/2011WR011316.

I am aware that the climate in these catchments is totally different to your sites, however, differences in seasonality might have similar effects on fractionation etc. You should be at least aware about these recent findings.

Reply:
We thank you for the suggested literature. We will discuss the influence of vegetation in more detail.

Referee comment:

Section 3.23. Please see recent literature on time variant transit times.

Reply:
We are aware of the drawbacks of assuming the mean transit time to be time-invariant. Nevertheless we think that our approach can give us useful information on the hydrology of the investigated catchments since we inter-compare four micro catchments in the same valley under the same boundary conditions (e.g. climate and geology). However, we will add a discussion on the assumptions of the time-invariant approach and its implications.

Referee comment:
Section 3.24: large parts of this section could come in methods – rather than results.

Reply:
We will transfer parts of this section to the 'material and methods' section and include the actual results of this section to section 3.2.1.

Referee comment:
p. 11026, l. 14... or you have to conclude that these indices are simply not relevant at scales of _0.5 km2 and less.

Reply:
Yes, we agree with your conclusion, indicated by the addition of '…at our sites….' in the text (p. 11026 l. 14). We will consider rephrasing this sentence to point that out more explicitly.

Referee comment:
Section 3.4.2 this section seems a bit out of context. If main findings (following the title) are on vegetation effects – how does link?

Reply:
We think that this section (also together with the section on geochemistry) helps to interpret the modeling results on mean water transit times. It gives additional information to an integrated picture of the functioning of our catchments. We tried to look at the catchments from different perspectives and also check our conclusions for plausibility, which in our opinion is possible by including these data.

Referee comment:
p. 11028, l. 17-19: try to avoid such "listing" of a number of papers. Rather cite these studies regarding specific issues (as again, all of them were conducted in very different landscape context, at different scales etc).

Reply:
We will reduce the number of references and concentrate on the most 'important' ones and add more detailed information on specific issues.

Referee comment:
Please conclude your discussion section with a clear statement of the wider implications of your findings.

Reply:
In our 'Conclusions' we refer to some more general implications of our findings. But we agree with you that we did not structure this section well enough. We will revise the paragraph, starting with the most important findings, that answers our hypothesis (regarding the effect of vegetation), and give this more emphasis. This will then be followed by a shorter paragraph on our findings regarding the influence of water transience in the deeper bedrock etc.

Recommended literature by the referee:

Birkel C, Soulsby C, Tetzlaff D, Dunn SM, Spezia L. (2012) High-frequency storm event isotope sampling reveals time-variant transit time distributions and influence of diurnal cycles. Hydrological Processes. DOI: 10.1002/hyp.8210.

Botter, F., F. Peratoner, M. Putti, A. Zuliani, R. Zonta, A. Rinaldo, and M. Marani (2008), Observation and modeling of catchment scale solute transport in the hydrologic response: A tracer study,Water Resour.Res., 44, W05409, doi:10.1029/2007WR006611.

The first chapter by Buttle in "Kendall, C., McDonnell, J. J. (eds) (1998). Isotope Tracers in Catchment Hydrology. Elsevier Science Publishers. 816p"

Kirchner, J. W., X. Feng, and C. Neal (2001), Catchmentâ˘AR˘ scale advection and dispersion as a mechanism for fractal scaling in stream tracer concentrations, J. Hydrol., 254, 82–101, doi:10.1016/S0022-1694(01) 00487-5.

Hrachowitz M et al. (2010) Physical interpretation of parameters in the gamma distribution: implications for time-variant transit time assessment in catchments. Water Resources Research, doi:10.1029/2010WR009148.

Hrachowitz M et al. 2011. Sensitivity of mean transit time estimates to model conditioning and data availability. Hydrological Processes 25: 980–990. DOI: 10.1002/hyp.7922.

Rodhe, A., L. Nyberg, and K. Bishop (1996), Transit times for water in a small till catchment from a step shift in the oxygen 18 content of the water input, Water Resour. Res., 32, 3497–3511, doi:10.1029/95WR01806.