# Submission hessd-11-3083-2014

## Reply to Anonymous Referee #1

by M.A Gusyev, D. Abrams, M.W. Toews, U. Morgenstern and M.K. Stewart.

*Comment:*
*The manuscript describes an application of the USGS particle tracking software MODPATH to characterize conservative solute transport of tritium through five catchments in New Zealand. The first moment (mean travel time) is used to characterize the manner in which the catchment alters the precipitation time series input signal, compared to the measured tritium concentrations at stream gaging locations. The particle tracking approach is compared to an approach using the solute transport software MT3DMS. The two approaches are also compared using a set of small 1D, 2D, and 3D synthetic basins.*
*The manuscript is well written, and logically and carefully presents its point. It is a good example of a modeling methodology, comparing two different approaches under both real-world and synthetic circumstances. I think the manuscript should be published in HESS, after minor revisions and technical corrections.*
Response: We thank the Anonymous Referee for the positive and constructive comments that allowed us to highlight the novelty of our work and to improve the presentation of our findings in the revised manuscript.

*Specific Comments:*
*1) The authors should consider the following applicable references*
*1A) Dagan & Nguyen (1989), Journal of Contaminant Hydrology "A comparison of travel times and concentration approaches ..."*
*1B) Goode (1996), Water Resources Research "Direct simulation of groundwater age"*
*1C) Jury (1975), SSSAJ "Solute Travel-time Estimates " (parts I and II)*
Response: We thank the Referee for suggesting these references. We referenced Goode (1996) in our previous work Gusyev et al (2013) and added Goode (1996) as a relevant reference to this study. We added the following text:
on page 3086 Line 14: "Goode (1996) demonstrated differences in groundwater ages due to dispersion in an idealized 1-D aquifer settings, but he did not constructed transit time distributions at the groundwater discharge points."
on page 3094 Line 3: add reference (Goode, 1996)
We also considered Dagan and Nguyen (1989) as well as Jury (1975) (parts I and II) but found that those manuscripts were outside of the scope of our study.

*2) page 3091 line 10: "ground watersheds do not always coincide with surface* *watersheds"*

*2A) should this be "groundwater watersheds"?*

Response: We fixed the typo as suggested by the Referee.

*2B) The extent of the model domain was chosen to coincide with surface watershed boundaries. What implications does this have for the flow to or from other watersheds into the modeled domain?*

Response: The result of this assumption is that we cannot simulate the exchange of groundwater between our study and neighboring watersheds. Certainly we acknowledge that the use of surface watershed boundaries to define no flow boundaries is a rather arbitrary selection, but it is a necessary and a commonly used practice to limit the size of the modeling domain. We expect this exchange of water to be small due to the groundwater flow direction towards the lake in the western Lake Taupo catchment. More importantly, we anticipate that only the longest transit times (which would be found along the watershed boundary) are impacted, which would minimize any errors observed in our frequency distributions and tritium response curves. We thank the Referee for the question.

3) *p 3092 l 9: "purely advective MTTs from MODPATH" While it is true that MODPATH doesn't consider non-advection transport processes explicitly, any simulation will experience "numerical dispersion" or "grid dispersion" due to the discretization of reality. This is discussed in reference to the representation of streams and rivers using 80-m square model cells elsewhere in the manuscript.*

Response: We agree with the Referee and removed the word "purely". We also replaced "numerical dispersion" by "coarse discretization" on page 3097, line 12.

*Figure 4(a-f): It may be useful to plot concentrations on a log y-axis, since the variability related to the bomb peak (1960s) is really the only thing that can be clearly seen, and the data basically are crammed into the corner of the plot. Much of the discussion in the text is about details that are hard to make out in the linear-scale plots. Log scale would show both the highs and lows.*

Response: We followed Referees' suggestion to plot tritium concentrations on a log y-axis and separated in-sets in Figure 4b-f. We also combined Figure 4a and Figure 3a-c into one plot, which was indicated by Referee #2.

*5) The manuscript quantifies comparison between mean travel times (the first moment of the concentration breakthrough at the observation location) for the different watersheds and modeling approaches. The manuscript then also makes qualitative comparisons of "shape" (e.g., p 3094 l 5). Quantified comparison of higher moments (variance, skewness, kurtosis) might be more meaningful and less subjective.*

Response: We thank the Referee for this suggestion. This statistical analysis of higher moments is indeed well-suited for quantitative comparison of transit time distribution shapes and also allows us to better explain the difference between the two methodologies in a quantitative manner. We will add the following text on page 3094 Line 3092. Note that this text refers to a revised Table 1, see the end of this document.

"We conducted quantitative comparisons of the five CFDs by calculating higher moments, which required unfolding the datasets by appropriately weighting MODPATH transit times by groundwater recharge and MT3DMS transit times by river discharge. In all cases, the mean transit time differs by less than 10% between the MODPATH and MT3D methodologies (see Table 1). This is expected, as both methods take into account the entire range of transit times in the watershed. While the MODPATH method considers each particle explicitly, the MT3D method utilizes the average of transit times discharging to an individual sink cell. In other words, the very short and very long transit times are only implicitly included in the distribution developed with MT3D via their influence on the mean at individual sink cells. As a result, the variance for all CFD's developed with MT3D is less than the variance of the respective MODPATH CFDs (Table 1).

Not only do the MODPATH CFDs explicitly include very short transit times, but these very short transit times have a higher frequency than any other range of transit times. This is indicated by the progressive decrease in slope of the CFD as transit times increase. In other words, the peak in the frequency of transit times occurs with times that are shorter than the mean, resulting in a large positive skew (Table 1). The MT3D CFDs has the impact of these more frequent short transit times implicitly represented in the average value at each cell. As a result, the MT3D CFDs have a positive skew as well, but they are smaller than the respective MODPATH CFDs. Similarly, because of the higher frequency of short transit times, the kurtosis is always higher in MODPATH than in MT3D."

*6) All the figures would be clearer if larger axis label, axis ticks, and legend text fonts were used. Line weights could be heavier in Figures 2-4. When the figures are shrunk down to fit into the small journal format, the text becomes hard to read (especially the inset figures in Figure 4), and there is plenty of white space in the figures otherwise.*

Response: We agree with the Referee's comment and have improved the appearance of Figures in the revised manuscript.

*Technical Corrections: ————————————————–*

*1) page 3085 line 24: "simulated" -> "simulate"*

Response: We deleted the text as suggested.

*2) p 3086 l 10: delete "the" before "Trout"*
Response: We deleted the text as suggested.

*3) p 3086 l 16: "models" -> "model"*
Response: We kept “models” and removed “a”, as suggested by the Referee #2.

*4) p 3087 l 18: move "MODFLOW" to second word (before "groundwater flow")*
Response: We moved the text as suggested by the Referee.

*5) p 3088 l 22: "grid" -> "cell"*
Response: We corrected the text as suggested by the Referee.

*6) p 3088 l 23: delete "custom" (are there non-custom Python scripts?)*
Response: We deleted the text as suggested by the Referee.

7) p 3088 l 25: add "the" before "VMOD"
Response: We added “the” as suggested by the Referee.

*8) p 3090 l 8: is the "1" before "year ˆ{-1}" part of the number? (i.e., should there be a space between the "62" and "1"?) Is this number of significant digits in lambda necessary or appropriate?*
Response: “1” is the typo and has been removed in the revised manuscript. The number of significant digits is relevant to input in the numerical model to represent the tritium half-life of 12.32 years (Morgenstern and Taylor, 2009). We added the text on page 3090 line 8 after *"yearˆ{-1}"*: “, which represents the tritium half-life of 12.32 years (Morgenstern and Taylor, 2009).”

*9) p 3093 l 27-28: "can be attributed to the fact that" -> "is because the"*
Response: We replaced the text as suggested by the Referee.

*10) p 3094 l 4: "are very similar in scale of MTTs" -> "have very similar MTTs"*
Response: We replaced the text as suggested by the Referee.

*11) p 3095 l 2: delete "Note that"*
Response: We deleted the text as suggested by the Referee.
*12) p 3095 l 8: "ubiquitously" -> "uniformly"*
Response: We replaced the text as suggested by the Referee.

*13) p 3099 l 1: "convoluted" -> "convolved"*
Response: We replaced the text as suggested by the Referee.

*14) p 3099 l 19: delete "It should be noted that"*
Response: We deleted the text as suggested by the Referee.

*15) p 3099 l 20-21: delete "It is noted that"*
Response: We deleted the text as suggested by the Referee.

*16) p 3100 l 1: delete "It is very important to note that"*
Response: We deleted the text as suggested by the Referee

*17) Table 1: Is there a way to make it clearer that "MTT, years" is a column heading that spans three columns?*
Response: We followed Referee's suggestion and completely rearranged the Table 1. In the new Table 1, we also included values of variance, skewness and kurtosis for MT3DMS and MODPATH as well as % difference between MT3DMS and adjusted MODPATH values.

| Parameter | CFD | WLTC catchment | | | | |
|---|---|---|---|---|---|---|
| | | Omori | Whanganui | Kuratau | Waihaha | Whareroa |
| MTT, years | MODPATH | 3.16 | 6.36 | 7.51 | 10.35 | 16.10 |
| | MT3DMS | 3.29 | 6.10 | 7.05 | 9.48 | 15.11 |
| | % Difference | 4.26 | -4.04 | -6.16 | -8.36 | -6.15 |
| Variance | MODPATH | 15.97 | 106.91 | 176.37 | 268.98 | 392.20 |
| | MT3DMS | 3.94 | 33.69 | 39.25 | 62.62 | 100.37 |
| | % Difference | -75.34 | -68.49 | -77.74 | -76.72 | -74.41 |
| Skewness | MODPATH | 2.49 | 3.33 | 3.80 | 3.10 | 2.02 |
| | MT3DMS | 1.19 | 1.53 | 1.56 | 0.94 | 0.14 |
| | % Difference | -52.38 | -53.93 | -59.06 | -69.67 | -92.97 |
| Kurtosis | MODPATH | 9.34 | 14.85 | 20.40 | 13.13 | 5.65 |
| | MT3DMS | 2.17 | 2.04 | 3.13 | 0.76 | -1.13 |
| | % Difference | -76.80 | -86.24 | -84.67 | -94.22 | -119.97 |