Hydrol. Earth Syst. Sci. Discuss., 2, S255–S260, 2005
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European Geosciences Union


Hydrology and Earth System Sciences Discussions



# *Interactive comment on* "Using stable isotope tracers to identify hydrological flow paths, residence times and landscape controls in a mesoscale catchment" *by* P. Rodgers et al.

**P. Rodgers et al.**

Received and published: 8 June 2005

The thorough and perceptive comments from referee 1 are gratefully appreciated and have proved extremely useful in approaching the revision. The referee clearly put a great deal of time and effort into the review and this resulted in some very constructive suggestions. As a result, we have undertaken some re-analysis and have added further clarification and methodological justification, which have both addressed the referee's comments as well as hopefully improved the paper.

General comments:

1. A number of valid concerns were raised relating to the nature of the isotope input signature used in the study. These have been addressed as follows: i) Firstly, regarding the assumption of uniformity of precipitation isotopic input. Precipitation samples

were collected at approximately mean altitude (ca 300m) for the entire Feugh catchment so it was assumed that they represent a reasonable first approximation of inputs. Unfortunately resource restriction strictly limited our number of sample locations at the outset of the study. Although some altitudinal (and aspect) effects will undoubtedly influence the input over the catchment, this was not expected to significantly affect sub-catchment comparisons given that the topographic gradients are much less (only 70-776m) than more mountainous parts of Scotland. Thus the catchment does not usually have major snow pack accumulation during the winter. This expectation seemed to be confirmed by approximate tracer mass balance in terms of weighted mean concentrations (see below). ii) With respect to the approximation of past inputs in the study catchment this was always going to be limitation given that only a year's worth of data could be collected for the study. However, earlier studies from the nearby Allt a' Mharcaidh catchment confirm that the general d18O range and seasonal variations observed during the study year are broadly typical of those that can be expected. Moreover, by using the simple sine wave damping approach to residence time estimates we avoided the greater problems that would have ensued from using a convolution integral approach when antecedent information are unavailable. iii) Finally, the reviewer considers the most important issue to be the lack of consideration of the amount of precipitation becoming recharge. It is recognized that the original weighting of the input curves were potentially misleading and the reviewer points out that the mean d18O of the forced, upper estimate for annual precipitation indicates that isotopic mass balance is not achieved. We have now removed this artificially weighted input curve from the analysis and the data is now presented in a more straightforward, less ambiguous way. This shows that the weighted annual mean d18O for precipitation is actually very similar to the weighted mean from stream water at the catchment outfall at Heugh Head (-8.5L' volume weighted compared with -8.6L'). Thus the inputs sampled appear to be representative of the water reaching the stream

In a climate where precipitation is (on a global scale) relatively well distributed throughout the year and evaporation rates are relatively low (typically ca. 300m), seasonality



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of streamflow variation is relatively subdued. This was particularly the case during the study year which was wetter and cooler than average. Furthermore, most studies which have sought to weight precipitation inputs to account for recharge are primarily aimed at isolating the residence time of baseflows. This would be somewhat meaningless in a catchment where responsive surface/near surface hydrological pathways (with very short residence times) from peaty soils operate for much of the year, the concept of 'baseflow' is rendered as ambiguous at best. As is evident in Figure 2, the flows did not stabilise for any prolonged period. Thus as our streamflow samples included higher flow samples for fitting sine waves to give a more general, indicative estimate of MRT for the monitoring points during the study year. The primary aim of making the residence time estimated was to examine relative sub-catchment differences and internal catchment functioning at the mesoscale.

As Referee 2 points out in reference to the above methodological issues, they are considerations which are more critical in small-scale catchment studies but which become increasingly difficult to perform and interpret in larger, more complex catchments such as the mesoscale Feugh. At this scale, particularly in a generally investigative study such as this, it is therefore more sensible to retain a simplistic approach rather than obscure the data with potentially misleading methodologies based on potentially false assumptions that simply become self-fulfilling prophecies.

2. The use of the term 'mixing' has been clarified, and the paper now states clearly that mixing in terms of catchment waters of different residence times is purely conceptual. Nonetheless it was felt important to retain this idea of conceptual mixing given the discussion within the framework of end-member mixing and the relative influence of different hydrological sources/flow paths.

3. The reviewer was keen that the revised manuscript should consider the issue of model selection in more detail. Further justification has therefore been added to the text. However, it was not felt necessary to extend the analysis to include the use of the exponential piston-flow model as suggested by the reviewer. The exponential model

was considered most appropriate in this study given that it is best suited to catchments with generally short residence times and where overland flow is significant, and yet can still be applied at the annual time scale. Most importantly, the EPM model requires parameterisation of an additional dispersion coefficient that was deemed to add further unnecessary uncertainty given considerable inherent uncertainty and sensitivity in the input isotope signature used in any simple residence time model. These arguments are presented in the revised manuscript.

4. The organization of the paper has been improved in conjunction with both referee's comments. The former "Results" section is now "Results and discussion", and the former "Discussion" is now "Conclusions and implications".

5. Influence of catchment characteristics: This section has been added to and more focus has been given to it in the introduction. The significance of these aspects of the paper has been emphasized as requested.

Specific comments:

1. Snowmelt isotopic composition was not sampled directly because there was no significant snow pack accumulation during the study year. The isotopic composition of the snow that did fall in the catchment was instead integrated in with the weekly bulk precipitation sample when melted. Comparison of weighted means for precipitation and Heugh Head suggest that mass balance was more-or-less maintained, implying any melt effect was not major.

2. The effects of heather moorland burning and the possible presence of resulting hydrophobic soil layers was is a significant issue in the hydrology of upland Scotland. However, its significance is mostly restricted to events at the end of prolonged dry periods which were not evident in the study year.

3. Sample collection was dependent on the annual flow regime, i.e. the data presented represents a random sample of flows across the year with no attempt to target specific

flows or account for seasonal differences (which in any event were reasonably modest in 2001-2002). The implications of this in terms of the steady state model assumptions are recognized but are counter-balanced by the particularly wet summer experienced during the study year, as well as the general modest seasonality in terms of evapotranspiration normally experienced in this area of Scotland. Thus by fitting sine curves through the data points and the averaging that results, given the sample frequency, is assumed to at least approximate a steady state for application of the exponential model in a way that allows sub-catchment differences to be assessed.

The referee's comment on the related problem of different averaging periods of precipitation versus stream samples has now been addressed by using the volume weighted weekly-sampled precipitation data for fitting the sine curve. Thus concerns relating to the potential bias to storm event in stream water isotopic composition in the MRT calculations are largely unfounded. The sine-wave regression modeling method effectively averages out this week-to-week storm variability. Thus, the same sine-wave modeling applied to flow-weighted monthly stream water produced very similar modeled amplitudes (e.g. 0.37 cf. 0.35L' for Heugh Head), and therefore MRT estimates. The authors feel that this further highlights one of the advantages of the modeling method adopted, in that it effectively provides an averaged estimate over the annual time scale rather than being biased by the very short residence times associated with storm events.

4. Text was changed.

5. Bliss (1970) reference added cf. DeWalle et al., (1997).

6. Text was changed.

7. Reference added as suggested as well as further justification for only using the exponential model rather than the alternatives suggested.

8. Mean precipitation d18O has now been weighted by volume as suggested. This allows proper comparison with mean stream water d18O and shows them to be relatively

close to achieving isotopic balance without recharge being considered.

9. Figures 3 and 4 have been switched as suggested.

10. Text was changed.

11. The weighting of the precipitation model has now been simplified and the only precipitation model used is the monthly volume-weighted mean.

12. The effect of elevation differences in explaining the more damped stream water isotopic signatures for the Aven and Powlair sub-catchments is not considered to be significant given the relative modest altitude gradients in the Feugh catchment as a whole, and that the mean altitude of these catchments are closely comparable with those observed at similar scales (Charr and Bogendreip) in the Water of Dye sub-basin.

13. The groupings of responsive and freely draining soils have been described more clearly in the text.

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Interactive comment on Hydrology and Earth System Sciences Discussions, 2, 1, 2005.