"New baseflow separation and recession analysis approaches for streamflow" by M. K. Stewart, Hydrol. Earth Syst. Sci. Discuss., 11, 7089–7131, 2014

Response to Anonymous Review #1

Note In the paper I used the term "baseflow fraction", but this will be called "baseflow index" or "BFI" here and in future paper revisions.

I appreciate the many helpful comments of Anonymous Referee #1.

Review General comments
"The author presented a new approach to separate baseflow from streamflow based on different flow components of total streamflow. It is stated that recession analysis can give very misleading results when only total streamflow is considered. The paper is surely in the scope of HESS and very interesting for the readership as a step forward to a more objective and process-based baseflow separation and recession analysis is made. However, I think the manuscript could be improved in several ways. Suggested improvements are: a) the link between the presented analysis and the published literature could be easily improved. At some points necessary references are missing (e.g. (5) in Section 8.3) or the cited papers are not the best choice. b) As a new method is proposed more guidance is needed how to apply the procedure (catchment types, streamflow data, time step). It should be clearly stated whether this method is focused on an event-based or not c) It is a long manuscript. I am not sure if all parts are essentially needed or at least a more comprehensive structure of the different section will improve the readability of the paper."

Reply Points a), b) and c) are noted, and will be worked on.

Review Specific comments
"1. It might be helpful to spend some more time to clearly describe the technical assumptions to apply this method. For example, it could be more precisely explained whether this is a recession event-specific analysis method (like master recession) or a continuous separation method for an entire streamflow series (like minima-method). Interestingly, the Author mentioned shortly in the discussion 8.2 that an analysis of total streamflow (without considering different components) is feasible during low flow, when quickflow in streamflow is very small. But the proposed method characterized early and late recession behavior. Later will typically occur during low flow; more clarity is needed here.
Section 8.1 nicely summarizes the features of the proposed method, but some guidance is needed to evaluate the relationship between response times of catchments and the required time step in data (hourly vs. daily data). In other words, is this approach applicable with daily streamflow data in larger catchments when the response characteristics of quickflow/baseflow are more or less unknown?"

Reply I will spend more time on describing the application of the method. The method in principle applies a digital filter (equations 6 and 7) to an entire streamflow series, based on constants determined by fitting baseflow plus a fast recession to a master streamflow recession curve (or to individual streamflow recession events during summer and winter). In the present case, the filter is applied to streamflow data for February and August 1996.

Separating the streamflow recession into its early and late parts is important, because whereas the early part is composed of varying amounts of both quickflow and baseflow, the late part is dominated by the baseflow only. So recession analysis of the late part of the streamflow recession is not misleading.

The time step in flow data should reflect the timing of the catchment responses, with hourly data more suitable for fast-responding catchments. However, the approach is applicable to both hourly or daily flow data, as the digital filter can be applied just as easily to hourly or daily data.

Review "2. As many papers using the –dQ/dt-Q-method, the Author cited the paper that has introduced this method (Brutsaert and Nieber, 1977). However, recession analysis is an on-going discussion in hydrology and from my point of view the discussion in section 3 has a lack of appropriate references (P7099L4- P7100L8). Several papers (Rupp and Selker, 2006; Biswal and Marani, 2010; McMillan *et al.*, 2011; Shaw and Riha, 2012) have discussed the shortcomings of the –dQ/dt-Q-method, which should be mentioned here as these analysis giving misleading results (P7100,L8)."

Reply Previously published shortcomings of the –dQ/dt vs Q method will be considered here.

Review "3. This is extensive and comprehensive manuscript, therefore a clear structure with distinctive sections is helpful to guide the reader through a) the recession analysis theory, b) the new baseflow separation method, c) the application in the study catchment and d) the justification of the proposed approach. The high number of different sections (1-9 each with different subsections) makes it somehow difficult to follow the argumentation of the Author. Perhaps it is worthwhile to consider a separate justification of the approach in one section and remove all isotope and transit time theory (e.g. 5, 7.4, 7.5, 8.4) from the first part of the paper? Another example is the mixed methods and results in section 7.1 (P7012/7013). One could argue that the calibration procedure (P7103,L1- P7104,L18) could for logical reasons be placed into the methods section above."

Reply I agree that removing the transit time theory (Section 5) and reducing Sections 7.4, 7.5, 8.4 will help by removing unnecessary complications. If I can make it work, I will include a new method description and justification section including part of Section 7.1 as suggested. However it may become more difficult to understand if Section 7.1 is split.

Review "4. P7102, L2-15: Firstly, why is the catchment area not mentioned? This information might be interesting as the author referring to method by Hewlett and Hibbert (1967) who focused on recession behavior and recession analysis in "small watersheds". Is the proposed approach restricted to a certain catchment size? Secondly, the study also focuses on baseflow separation and recession analysis, therefore some information about the geology (perhaps in Fig. 3) might be interesting as recent studies argue that besides physiographic characteristics also geology is a valuable descriptor for baseflow generation processes (Bloomfield *et al.*, 2009; Stoelzle *et al.*, 2014). Thirdly, some information about the streamflow regime is needed to evaluate the differences between summer and winter events and their characteristic recession behaviour (e.g. is there significant influence of snow/snowmelt?)."

Reply GH1 catchment area is 218 ha. The proposed approach is not restricted to any particular catchment size. More information on the geology and streamflow regime of GH1 will be given.

Review "5. P7102, L14-15: What is suggested by the information of runoff accuracy? Is this 30- year-old estimation still valid? Information about the accuracy during low flow might be even more valuable to evaluate the magnitude of the separated baseflow component."

Reply The flow data is nearly 20 years old, so the quoted runoff accuracy is the relevant figure. There are problems with the low-flow measurements (e.g. staircase recessions in the lowest parts of the recessions) which are also very common in flow records of other catchments. This makes the GH1 catchment a typical case for application of the method, rather than a special case, but any flow record shortcomings should be kept in mind.

Review "6. P7014, L20-29: The discussion of the flow duration curves in Fig. 4e and 5e is very interesting. What are plausible processes for different FDC-patterns in the winter and summer? Already published references might be helpful for the reader to link recession behaviour with FDC analysis."

Reply I will explore these suggested approaches in the paper.

Review "7. At the end I wonder how reliable the results and implications of this paper are as only data from one catchment is used during the analysis. The author could at least inform the reader when specific recession behaviour of the study catchment and/or specific results not apparently valid in other catchments."

Reply I think the reviewer is asking if there are any results from the BRM analysis in the GH1 catchment which would not be valid in other catchments. Not that I know of. I have applied the BRM method to several catchments, and it has given varied but apparently valid results. I will soon be submitting a second paper on the use of the BRM method, applied to the Toenepi Catchment in Waikato, New Zealand.

Review Minor/technical comments:
1. P7091,L8: The author could add a reference to "Hortonian view of catchments" or explain shortly why this association is relevant for baseflow separation methods.

Reply The "Hortonian view of catchments" is a phrase from Beven (1991), who is already cited in the paper (P7091, L9). I will add quotation marks. The phrase refers to infiltration excess overland flow and implies a view of catchment runoff as being derived very much from overland and very near-surface sources.

Review 2. P7091,L10-12: The author should give references for the mentioned "recent modelling studies". What does "[…] ,although it may be embedded in later modelling calculations" exactly mean?

Reply For example Jakeman et al., 1990. It means that flow components from different reservoirs (e.g. with short and long mean residence times) are often simulated by catchment models thereby implicitly separating the hydrograph.

Review 3. P7092,L8-9: “[…] and based generally on the results of tracer hydrograph separations” This statement puzzles me as the author later stated that the BRM method can be applied using streamflow time series alone. I guess that tracer data justified the proposed method, however, this needs to be clarified.

Reply The bump of the BRM method is generally based on the results from tracer data (see references cited on P7095, L3-4). The BRM method can be applied using streamflow time series alone (once f and k are known) because it is a digital filter (Eqs. 6 & 7).

Review 4. P7092, L11-12: FDCs are for the first time mentioned here. The author could shortly comment on the purpose of applying the method to FDC. Perhaps a link to section 4 might be helpful here.

Reply I will add a sentence and a link to section 4 here.

Review 5. P7093, L13: “…has proven to be effective in many catchments,…” Reference(s) would be helpful to point out the effectiveness of such separations in application.

Reply This is just a linking sentence to improve readability, I’m not sure references are needed here, since the paper already has so many references.

Review 6. P7094, L1: Sloto and Crouse (1996) seems to be very arbitrary reference here. This report presented a tool to apply a baseflow separation based on a minima method, but other papers before have discussed the minima-method more detailed. The author should at least insert a “e.g.” here.

Reply Ok

Review 7. P7094,L16: “Other authors…” – references?

Reply Ok

Review 8. P7096,L11: Please link the “evidence” to the according section in this paper (section 7.4?)

Reply I will add the words “(given above)”. The evidence was given in the paragraph between P7094, L19 - P7095, L18.

Review 9. P7103,L22-23: Are the slope values really comparable?

Reply Yes, because they give similar BFIs.

Review 10. P79104,L6-7: “the line shown on the lower part of the streamflow points has a slope of 4” – Clarify which line is meant here.

Reply There is only one line through the (blue) streamflow points.

Review 11. P7106, L2: How many recessions with which length?

Reply There were 4 winter and 2 summer recessions as shown on the graph. These were the longest recessions without rainfall or snowfall during a three year period (Pearce et al. (1984).

Review 12. P7107,L9: What does “mm (over the catchment area)” mean?

Reply It means that depth of water over the entire area of the catchment

Review 13. P7110, L16-19 Please give references for misinterpretation in previous studies (or some examples what kind of misinterpretation was done in the past).

Reply I have given the general reason for possible misinterpretations caused by applying recession analysis to the early parts of streamflow recessions in Section 8.2 (i.e. that the streamflow is composed of two components and analysis yields mixed information not characteristic of either component). Applying recession analysis to the late parts of streamflow recessions, on the other hand, should not cause problems. Figs. 4d and 5d give graphic examples of how the slopes of lines through the streamflow points on recession plots are misleading because of the mixing of the two components (the slopes are about 4 and not representative of the characteristics of reservoirs in the catchment). Catchments in which baseflow supplies much of the annual flow (i.e. catchments with high long-term BFIs) are particularly likely to give misleading information when recession analysis is applied to the early parts of streamflow recessions. These cases are shown by high slopes in recession plots. References to previous studies where misinterpretation is likely are given in Section 8.2 (in the paragraph from P7110, L20 – P7111, L2).

Review 14. P7110,L20: Kirchner (2009).

Reply Ok

Review 15. P7111,L2: Please characterize “misleading information”

Reply See reply to 13. above.

Review 16. P7111, L22: Should be Stoelzle et al. (2013)

Reply Ok

Review 17. P7113, L12: Is only a graphically separation of early and late recession behaviour possible?

Reply Early and late recession behaviours can be separated when baseflow separation has been made.

Review 18. P7113, L14-22: SW-GW-interaction is a long time neglected field in hydrology, perhaps it is worthwhile to add some more information how the proposed method can help to improve the understanding of SW-GW-interaction (e.g. Barthel, 2014)

Reply I think this is a very good point and will add sentences based on the Barthel (2014) paper.

Review 19. P7114, L22-23: What is the (relevant) information in this sentence?

Reply The sentence will be removed.

Review Figures
Figure 1:
The schematic relationship between streamflow and baseflow is very interesting. Is the quickflow here the streamflow minus baseflow or total streamflow? It might be helpful to show all three components (streamflow, quickflow, baseflow) and/or multiple examples (three different recessions over time, each with separated quickflow and baseflow). Furthermore it seems valuable to show the reader schematically the Hewlett and Hibbert (1967) approach in this figure, which is introduced before P7094L6-16).

Reply Quickflow is the area between the streamflow and the baseflow curves, and the baseflow is the area under the baseflow curve. I would like to keep this figure as simple as possible, but will expand the caption to clarify any possible confusion over the quickflow.

Review Figure 4-6:
My expectation was a separate analysis of baseflow and quickflow. It is somehow confusing that sometimes streamflow with quickflow is compared, sometimes (also in the manuscript) baseflow with quickflow. For me it is not always clear whether streamflow is total streamflow or quickflow component. What is the dashed, vertical line in Figure 4c, 5c, 7c? In Figure 4 the bold font-style (f) should be removed.

Reply Streamflow always means total streamflow, quickflow is always the quickflow component only and baseflow is always the baseflow component only. The relationship between them is defined by Eq. 1. The BRM baseflow was problematic to plot on the recession plots, because its method of calculation (i.e. the ‘bump’ and the ‘rise’) cause distortion during the early part of the recession (this is illustrated by the dashed part of the baseflow curve in Fig. 7c). During the late part of the streamflow recession, the streamflow is composed of baseflow only and so represents the baseflow, but the low-flow accuracy is insufficient to reveal much detail in this area in Figs. 4c and 5c. However, Fig. 7c (for an idealised case) shows how the baseflow plots on the recession plot.

Review Figure 7:
(a) What are the numbers (4) and (2) here? The number of analyzed recessions?

Reply The number of winter recessions analysed was 4 and the number of summer recessions analysed was 2.

References

Barthel R. 2014. HESS Opinions ‘Integration of groundwater and surface water research: an interdisciplinary problem?’. *Hydrology and Earth System Sciences* **18**: 2615–2628. DOI: 10.5194/hess-18-2615-2014.

Beven, K. J.: Hydrograph separation? In Proceedings of the BHS 3rd National Hydrology Symposium, Southampton, 1991.

Jakeman AJ, Littlewood IG, Whitehead PG. 1990. Computation of the instantaneous unit hydrograph and identifiable component flows with application to two small upland catchments. Journal of Hydrology 117, 275-300.

Pearce, A. J., Rowe, L. K. and O'Loughlin, C. L.: Hydrology of mid-altitude tussock grasslands, upper Waipori catchment, Otago: II Water balance, flow duration and storm runoff, J. Hydrol. (NZ), 23, 60-72, 1984.