

Authors Reply to the Anonymous Referee Comment #2 on "Are streamflow recession characteristics really characteristic?" by M. Stoelzle et al.

Review Overview: The authors make the point that investigators have used a variety of techniques to estimate recession parameters in the recession model $dQ/dt = aQ^b$. Even within these techniques, a variety of ways of censoring the data have been applied. The authors estimate recession parameters use 9 ways (3 estimation methods by 3 censoring methods) and show that a wide range of parameter values results. They recommend a multi-method estimation approach for further studies, where appropriate.

The results merit publishing, but the manuscript needs some attention. In particular, more discussion of how the different objectives of the original investigators (and the methods they, in response, subsequently developed) would seem to explain much of the variability in results.

We thank the Anonymous Referee #2 for the thoughtful comments and the helpful suggestions on our manuscript. Please see below for our detailed answers and suggested revisions (in blue).

Comments:

1. Title: I appreciate the desire to have a title that grabs attention, but this title is not very informative of the content. Recession parameter estimation methods are compared that were devised towards different ends, so to what extent do the authors truly address this question?

Authors Reply: We agree with the reviewer that each recession parameter estimation method was built on a certain perceptual model. However, all methods are still highly subjective, since the methodology to extract recessions and the method to fit the recession model cannot be compared with an unbiased estimation. On the other side, hydrologists continuously use these methods to compare catchments or extract characteristic information from the discharge data. With our paper we wanted to provide evidence, that the methods are actually not so characteristic as often being assumed based on the perceptual model (or the "physical basis" behind). As we could show in the paper (e.g. Figure 1) the methods results of the methods are inconsistent and therefore we should be allowed to ask the question *"Are streamflow recession characteristics really characteristic?"*

2. Abstract: The abstract would be more informative if the type of RAMS were briefly given. For one, they are all variations on the $dQ/dt - Q$ method. This at least could be said.

Authors Reply: As $-dQ/dt - Q$ is a widely used paraphrase for the presented recession analysis methods we will add a $-dQ/dt - Q$ term in the revised abstract.

3. p. 10566, line 9: Units of "a" should be $[L]^{(1-b)} [T]^{(2-b)}$

Authors Reply: The units of parameter a will be changed accordingly.

4. p. 10571, Section 2.1: While it was easy to recall what le, reg, and bin refer to as I read the paper, it was a challenge to remember all the details of BRU, VOG and KIR, even after more than one reading. It would be very helpful if the long paragraph on page 10571 were summarized in a table so important differences in the methods could be easily seen by the reader.

Authors Reply: An additional table (see below) will be added to the revised manuscript to illustrate the principal differences of the three recession extraction procedures.

Table 1. Main criteria of recession extraction procedures.

Recession extraction procedure	Criterion	Minimum recession length [days]	Excluding exterior parts of recession segment	Excluding recession segments depending on anomalous streamflow decline
VOG	Decreasing 3-day moving average	10	first 30%	> 30%
BRU	$dQ/dt < 0$	6-7(*)	first 3-4 days, last 2 days	$dQ(t_i)/dt > dQ(t_{i+1})/dt$
KIR	$dQ/dt < 0$	1	-	-

** Recessions have a minimum length of 6-7 days, because at least one "recession day" should remain after excluding non-recession parts.*

5. p. 10572, Section 2.2: Because Q appears in both sides of the linear regression equation, both the dependent and independent variable contain errors. For this reason, use of orthogonal regression, or total least squares regression, has been used by some to estimate "b" (e.g., Brutseart and Lopez 1998). Moreover, the regression is not being used to predict y from x , but to estimate "b", so the choice of which variable (dQ/dt or Q) to use as the dependent and independent variable is arbitrary. Use of standard linear regression may be resulting in an underestimate of the underlying value of "b". The authors should comment on this.

Authors Reply: We followed the method proposed by Vogel and Kroll (1992) with a linear regression equation. We will add the suggested reference to the revised paper and will comment on the different methods that can be used to estimate b .

6. p. 10572, lines 8-10: Have the authors found another study where quantile regression was used to estimate the lower envelope? If not, the authors could state that this is a novel application of the quantile regression technique to dQ/dt - Q analysis.

Authors Reply: As mentioned in the discussion paper some authors used the lower envelope method with different amount of points below this line. However, we haven't found a more precise description of the lower envelope technique, thus we decided to use quantile regression (p. 10572, line 7-10). We will also mention that this approach is a novel application of the quantile regression.

7. p. 10574, line 8: Reporting the range of values of "a" here has no meaning since they all have different units (which are a function of b). I would leave it out here, and leave out "a" out of Figure 3 and report only the recession time and storage depletion estimates. Same for page 10582, lines 27-30.

Authors Reply: We agree with the referee and will change the revised manuscript accordingly.

8. p. 10577, line 25-27: "The intercept can be seen as an estimator of the storage volume whereas derived slopes are more related to the rate and dynamic of storage depletion". For one, a groundwater theory-based examination of "a" (e.g. BN77) shows the intercept to be a function of a rate term and storage, so, in that context, the above sentence is incorrect. For another, it is not clear to me what the authors mean by "dynamic of storage depletion". Moreover, some have also shown the slope to be a function of spatial heterogeneity in aquifer parameters (e.g. Rupp and Selker 2005; Harman et al. 2009).

Authors Reply: We agree with the referee and will rewrite this paragraph in the new manuscript.

Citations: There are several instances where citations could be improved by change, elimination, or addition:

9. p. 10566, lines 10-11: BN77 introduced this. That one citation is sufficient. No need to cite all four references.

10. p. 10566, line 15: No need to cite Kirchner (2009) here. BN77 had already plotted the curves on log-log scale, obviously because the values spanned orders of magnitude.

11. p. 10566, lines 20-23: Suggest rewriting to something like "Rainfall data can be used to exclude streamflow recession during periods with precipitation". No need for 4 citations here. BN77 would be sufficient, as they used rainfall data to filter streamflow data.

12. p. 10566, line 27: Inappropriate citation of BN77. They included data starting at first 5 days after rainfall, not 5 days after first declining of streamflow.

13. p. 10567, lines 10-14: I understand the point is to demonstrate that many cutoffs have been used, but I would just say they range from 2 days (e.g., Mendoza...) up to 10 days (Vogel. . .) and leave out the rest of the citations.

Authors Reply to 9. – 13.: The suggestions are very helpful improvements. The mentioned citations will be revised.

14. p. 10567, lines 1-14: Rupp et al. (2009) used yet another method to censor the data through longitudinal observations of streamflow.

Authors Reply: In the mentioned paragraph we want to highlight two points with reference to different recession extraction procedures: Very often procedures remove a certain amount of streamflow values at the beginning of every recession and assume a minimum recession length. The suggested paper by Rupp et. al (2009) is in the scope of the mentioned ranges as in this study a minimum recession length of 4 days was used and the first 2 days of recession were eliminated. We will add the suggested reference in the revised paper. Please note, that scatter reduction in dQ/dt -Q-plots that is also applied in Rupp et al. (2009) is discussed on p. 10579, line 27 – p. 10580, line 10 with reference to Rupp & Selker (2006a).

15. p. 10568, line 2: Citation of Rupp and Selker (2006a) is unnecessary here. Rupp and Selker (2006a) describe a different explanation for an upper envelope (numerical artifact). Another physical explanation of the upper envelope is given Wang (2011) who explains it as bedrock seepage.

16. p. 10568, line 14-15: Parlange et al. (2001) do not consider a "linear" model.

Authors Reply: Original sentence: "For example, binning was used by Parlange et al. (2001) to illustrate the sensitivity of the linear model's parameterization to the choice of lower compared to upper envelopes." We will rewrite this sentence in the revised manuscript: "For example, binning was used by Parlange et al. (2001) to illustrate that due to method-specific model fittings a bias in model parameterization need to be considered".

17. p. 10569, line 22: Aksoy and Wittenberg (2011) is not an appropriate citation here. They only have two catchments, so they could not really do an analysis of recession characteristics against other catchment characteristics. I suggest replacing this citation (e.g., Krakauer and Temimi 2011).

18. p. 10569, lines 1-8: It has been applied also to a lowland plain with a deep aquifer (Rupp et al. 2009).

19. p. 10569, line 10: Did Dewandel et al (2003) apply the dQ/dt -Q method? Would a more appropriate reference be Troch et al. (1993)?

20. p. 10573, line 7-9: This sentence and these citations are not necessary.

Authors Reply: We will reduce the number of citations here, but at least one reference might be useful for one or two readers to associate different solutions of Eq. (3).

21. p. 10578, lines 14-16: Excessive citations. I would remove a couple that do not add anything new.

Authors Reply: We cannot find the mentioned citations on this page.

22. p. 10579, lines 27+: Another source of bias is the use of time averaged values instead of instantaneous values; the latter is what the method strictly assumes (e.g. Rupp and Woods 2009).

Authors Reply: Only daily streamflow data is available. However, we discuss a possibility to reduce the scatter in recession plots when using daily instead of instantaneous streamflow data (p. 10579, line 27 – p. 10580, line 10).

23. p. 10581, lines 19-20: The authors cite Brutsaert and Lopez (1998) as an example of a study of temporal variability in aquifer response. I do not believe this paper dealt with this topic. The authors should find a more appropriate study to cite.

Authors Reply: This is a justified argument by the referee. We will rewrite this sentence in the revised manuscript. Brutsaert and Lopez (1998) discussed the cause of short-time effects in prolonged recession periods and assumed as Zecharias and Brutsaert (1998a) did before that various short-time effects like stormflow from the farthest parts of a catchments can contribute to the downstream outlet as a lagged signal, thereby distorting the late-time storage-outflow behavior (p. 10579, lines 9-11).

24. p. 10582, lines 8-10: Eng and Milly (2007) assume $b = 1$, so they are an inappropriate citation on the topic of “b” versus catchment area.

Autors Reply: Eng and Milly (2007) have given a set (cf. Table 1) of basin attributes' types in the cited paper that were used in 11 previous low flow regression studies. In all mentioned studies catchment area was found as a significant predictor to estimate low-flow characteristics with regional regression models. Accordingly, we will refer directly to the mentioned Table.

Minor edits:

p. 10568, line 29: Missing a word between “(1977)” and “good”?

Authors Reply: We will rewrite the complete sentence to make it more clear that a) a variety of RAMs exists and b) these different RAMs were applied to most diverse catchment types with different catchment characteristics.

p. 10577, line 19: “Flattening” could be replaced with a more precise term. I assume the authors mean a reduction in slope?

p. 10568, line 1: Comma after “envelopes”.

p. 10568, line 26: I would remove the word “successfully”. That’s a subjective judgment and its unnecessary here.

p. 10580, line 9: Remove “successfully”.

Authors Reply: These 4 suggestions and "minor edits" will be changed accordingly.