Editor (Thom Bogaard)
Dear authors, it unfortunately took a while, but I am happy with the two excellent reviews you received. One reviewed for the second time, one referee looked at it for the first time. Both want to see elaboration on the justification of the methods to superimpose recession curves by shifting along time-axis as this is key to the proposed method. I really like the point brought up by referee 2 abut the single vs probabilistic MRC and the terminology and the analogue with FDC's. Please elaborate on that.
Response: We have addressed all the points listed by the referees and in doing so have addressed the two issues raised above.

In summary, it seems to me, the paper needs some more work, but that seems doable. Feel free to make the paper a bit longe then it is now, we can also change the MS type to regular paper.
Response: Thank you for your supportive comment. We have very carefully responded to the reviewers' comments, and in the process have added additional substantive content that we think justifies the MS type now being a regular paper. We have also revised and harmonised the formatting of all figures.

Both reviewers have queried the subjectivity involved in the manual superposition of individual recessions, and we believe these concerns arise from a misunderstanding of what we are illustrating. As such, we have made several changes to the paper to better describe and clarify what we have done. In brief here, it should be recognised that:

- the characterisation of aleatory uncertainty in the MRCs (i.e. the percentile curves) is undertaken using a form of correlation analysis, which is an objective analysis that is easily automated. The only subjective decision that needs to be made is the definition of the no-rain period used to identify recessions, the significance of which is readily assessed, and the bin sample size.
- the process of manual superposition is undertaken merely to illustrate how individual recessions may be mapped to different percentile curves, they are not used to derive the percentile curves; in essence, we are demonstrating that variations in recession behaviour from the "average" MRC curve can be readily interpreted as being due to natural variability in antecedent conditions.

We see that our attempt to illustrate how the results of the analysis can be visualised using individual recessions has been conflated with the method used to derive the percentile MRCs, and this is unfortunate. We have accordingly made changes to the paper to avoid this misunderstanding, as discussed below.

Anonymous Referee #1
Although the authors have answered many of my questions, the manuscript still requires thorough revision. Based on the authors' response, the following suggestions for revision are provided below.
Response: Thank you for again reviewing our draft manuscript.

(1) A comparison of the proposed methods with other methods is needed.
Response: We have added several sentences at the end of Section 1 Introduction to make our objective for writing the paper clearer and we quote "Thus, we hypothesise that there is a continuum of recession curves that can be represented by a single (average) Master Recession Curve, or by a family of exceedance percentile curves. This family of curves represents the natural variability (i.e. aleatory uncertainty) in antecedent hydroclimatic and heterogeneous storage conditions in unconfined aquifer/s supplying streamflow, which provides a quantitative framework for characterising observed differences in recession behaviour. Our paper addresses this hypothesis."

In the analysis, we have used the correlation method to estimate the Master recession Curves. We provide a literature review to support this decision. We do not see the need to explore alternative methods to estimate the MRCs. Our paper is not about estimating MRCs but rather about what an MRC represents.

(2) The authors stated that "the superimposition of an observed recession on an MRC plot was simply achieved by translating the observed recession data horizontally along x-axis". The main problem with this approach is that it is too subjective, which is why the -dQ/dt~Q method is more popular.

Response:

There are two points here. (1) the analysis is too subjective and (2) the popularity of -dQ/dt~Q method.

The method used to derive the percentile MRCs is objective and easily automated, and this fact should not be confused with how we illustrate the superposition of individual recessions on percentile MRCs. Our hypothesis is to show that the MRC represents a family of recessions (percentiles) rather than a single (average) curve as adopted in the current literature. To do this we showed that in our Figures 3, 4, 5 and S1, S2 and S3 the observed recessions, across four hydrologically diverse catchments, fitted the computed MRC curves closely for a range of percentiles. The exercise in superposition could have been automated, but we chose a simple manual approach as its purpose is merely to illustrate how individual recessions vary in response to antecedent conditions. We have provided additional text to expand on this point in Section 3.

We acknowledge dQ/dt~Q method by Brutsaert and Nieber (1977) to estimate hydraulic properties of an unconfined aquifer is a popular method. We are very familiar with the Brutsaert and Nieber (1977) method as we have compared results for four streams (worldwide) using Brutsaert and Nieber (1977) procedure with a method based on the maximum recession constant, a key property of an MRC, in McMahon and Nathan (2025). In that paper we concluded that:

“The modified procedure [McMahon and Nathan] to estimate hydraulic parameters is parsimonious in that it uses a time-based rather than a time-derivative-based analysis and, consequently, does not require recession-slope plots to estimate coefficients a1 and a3. Because it is anchored by a master recession curve, which is specified in terms of non-exceedance cumulative frequency (aleatory uncertainty), individual recessions do not need to be considered, but average behaviour can be characterised to be representative of different climatic conditions.”

In the Brutsaert and Nieber (1977) procedure, the estimation of a1 and a3 is based the elimination of a portion of the sample, which is a subjective decision that is still not resolved. In contrast, the correlation method used in our paper involves no subjectivity other than to decide how rain-free periods are defined and the sample size of the bins.

Accordingly, we are in truth somewhat mystified about the popularity of the BN77 approach given the relative advantages of the maximum recession constant approach based on the correlation method in terms of its degree of parsimony, objectivity, and ease of computation. However, that said, we see no need to amend our current manuscript as we are focussed on an interpretation of the MRC that avoids the need to rely on simplistic averaging of recession behaviour. In concept this interpretation could be made using a variety of different methods, but we happen to choose the correlation method for its simplicity and (objective) ease of computation. The issue of manual superposition is an illustrative device that is not relied upon for derivation of the percentile MRCs.

Brutsaert W, Nieber JL. Regionalized drought flow hydrographs from a mature glaciated plateau. Water Resour. Res., 13, 637–643, https://doi:7W0132, 1977.
McMahon TA, Nathan RJ. Estimating hydraulic properties and residence times of unconfined aquifers. J. Hydrol., 654, 132861, 2025.

(3) Furthermore, analyzing the individual observed recession data in Fig. 2 is a better way to reasonably determine the percentiles of the recession segments.
Response: Our hypothesis is that the percentile curves represent natural variability in antecedent conditions governing recession behaviour. As such, it would not be expected that information on an individual recession could be used to parameterise the aleatory uncertainty involved. As far as we are aware, no one has described the MRC in probabilistic terms to account for natural variability, despite the fact that a number of authors have identified the limitations of relying on a single “averaged” curve. We reference four studies in our manuscript (Kienzle (2006), Fiorotto and Caroni (2013), Yang et al. (2019), and Gao et al. (2023)) that deal with multiple MRCs but none consider the hypothesis of a continuum of recessions nor how to estimate representative MRCs. These four references are in the original manuscript.

(4) The reasons for the natural variability should be quantitatively analyzed in the real catchments considering that the distribution of recessions “is the result of antecedent hydroclimatic conditions and heterogenous storage conditions in the unconfined aquifer/s feeding the streamflow" stated in the abstract.
Response:
We do not believe that there is any difficulty in accepting that natural variability governs streamflow recessions (indeed that it governs all aspects of hydroclimatology). Our contribution with this paper is merely to recognise its influence and to come up with a means to characterise it. Our hypothesis is that its dominant source is due to antecedent conditions, but in this sense we are not making assumptions that differ materially to those involved in any form of hydrologic frequency analysis. We do not need to study the physical dynamics of rainfall events to undertake a frequency analysis of rainfall occurrence, nor do we need to undertake a physical study of phreatic aquifer units to estimate the non-exceedance probability of low flow sequences. We do agree with the reviewer that physical reasoning supported by the study of “real” catchments can lead to valuable hydrologic insights, but such understanding will not alter the empirical evidence afforded by the statistical characterisation of natural variability. Our focus is on the latter, not the former. We trust that the changes made to the paper in response to other points raised will obviate the need to provide evidence for the physical reasons leading to this variability.

Anonymous Referee #2
This technical note develops a procedure for constructing probabilistic master recession curves (MRCs) to account for variable antecedent conditions and heterogeneous aquifer characteristics in the catchment, and analyses observed recessions in this context. The introduction of aleatory uncertainty in constructing MRCs is certainly welcome, and therefore I find this technical note relevant for the hydrological community. In my opinion, there are few issues that should be resolved before final acceptance of the note, in addition to minor comments listed below.
Response: Thank you for your support.

1. After constructing probabilistic MRCs, the authors superimposed observed recessions on the MRCs by shifting them (manually) along the time axis until they matched one of the five MRCs. In this way they obtained many allocated and several unallocated observed recessions. It is hard to understand why the observed recessions have to lie on one of the five MRCs. Each recession is a result of unique catchment conditions

and it is more likely that they should be allocated to an MRC for some very specific percentile (e.g., 37%) rather than the five ones used to present a family of MRCs. This procedure in the paper should therefore be better justified, as well as the need to compute NSE and correlation coefficients to support allocation to one of the five MRCs. The idea of allocating observed recessions to five discrete conditions also reflects the discussion about the seasonal variations (how the observed seasonal recessions group on specific MRCs).
Response: We agree each MRC is a unique representation of catchment conditions, and that there is an infinite continuum of percentile curves that could be presented (subject only to the limitations of sample size). If one looks closely at the plots, it is clear that if we had, for example, ten computed MRCs (say, 10%, 20%, …, 90%'iles) some of the observed recessions would move to an adjacent MRC and match the computed MRCs slightly better. Certainly, if we had chosen only three MRCs, many of the observed recessions would not have matched the computed MRCs. We adopt five MRCs to cover the range of conditions as these percentiles can be robustly estimated from the available sample sizes, and we believe this number is sufficient to illustrate our hypothesis. We have added text to Section 3 to make this point more clearly.

2. I believe that the authors could be more precise with the terminology when stating that they "hypothesize that the MRC is a continuum rather than a single average curve", and in similar sentences. In my opinion, there is natural variability in recession in general, while an MRC represents aggregated information from all recessions. Historically, MRC is an average curve, while in this paper recessions are aggregated into several MRCs in probabilistic terms after statistical treatment. An analogue of this is probabilistic representation of flow duration curves vs. the average flow duration curve (Vogel & Fennessey, 1994). Therefore, I think that it would be more precise to say that there is a continuum of recession curves, while their representation by an MRC could be either with a single (average) curve or with a family of percentile curves.
Response: Thank you for this clarity. We have modified the text to reflect your discussion. See the end of the Introduction, Section 2.1, and in the Conclusions.

3. The paper conveys relatively well the idea of introducing this aleatory uncertainty into the analysis, and I also like the part that shows that epistemic uncertainty is smaller than aleatory one. However, the paper still fails to provide wider context for researchers and practitioners and explain what are the benefits from constructing probabilistic MRCs using the described procedure. Since the percentile MRCs could also be constructed using other approaches than the correlation method, it would be useful to provide some kind of recommendations for future works. This can be done by amending the Conclusion section with a sentence or two.
Response: Thank you for this comment. We have added an additional paragraph to Section 4.1. We are reluctant to add a comment that our approach can be used with methods other than the correlation procedure without further detailed analysis.

Minor comments
• Consider not using "preceding climate" ((L9, L122, L317) for antecedent wetness/moisture catchment conditions, as these are a consequence of weather conditions, while the climate is defined as the average weather conditions over a long period of time.
Response: Thank you for this comment. We agree that climate is "… the long-term manifestation of weather" (Lo, 1992). Many unconfined aquifers have residence time of many months so we do not see it necessary to adopt the term 'weather' in the place of 'climate'. At L9, we use the term "antecedent hydroclimatic … conditions" which is not

inappropriate. At L122, we have added a phrase "…and weather conditions…". At L317, we have added a phrase "…and local weather…".

Lo S-s, 1992. Glossary of Hydrology. Water Resources Publications, Littleton, CO, USA

• L69: "structure approach" should be "structured approach"?
Response: Corrected.

• L106-108: Repetition of what was said in L31-34.
Response: We have deleted L106-108 and expanded L32 and L25.

• L138-142: This paragraph mentions the maximum recession constant as an important parameter associated with MRC. However, it does not provide any explanation why is this parameter important.
Response: In the paragraph we list four important uses with supporting references. We have added two sentences describing K_{max} and refer to its application in Section 4 of the revised manuscript.

• L144-149: Limited availability of "pure" recessions is understandable and I do not see why the authors describe and discuss the content of a figure from another paper. If the point of this paragraph is to underline the problem of having equal daily discharges in two consecutive days, maybe it is worth mentioning that this may be a result of coarser measurement resolution and not only of the physical processes in the catchment. Maybe it would also be appropriate to explain how these equal discharges were treated in the proposed methodology.
Response: We have deleted the reference to the Yeh and Huang (2019) paper. Step 1 (L155) in our manuscript addresses the question of equal daily discharges. The recession constant $K_j = Q_j/Q_{j-1}$ must be in range $0 < K_j < 1$.

• L158: "using constant bin sizes varying between 50 and 200 items" is not precise. Is the bin size constant in terms of constant discharge intervals or constant number of items? Also, Figure 2 shows bin intervals not covering the whole range of observed daily flows. How was the range of discharges selected for binning?
Response: Thank you. As requested, we have extended the bin intervals in Figure 2 to cover the whole range.

Our preference is to adopt a bin size of 200 which permits the statistics (mean, median and percentiles from 10% to 90%) of the K_j and Q_j values to be estimated with confidence. 200 is adopted so long as there are sufficient bins to determine which bins hold the maximum value of each statistic. Again, this is a subjective decision in which we adopt a minimum of five bins. For our analysis of Northern Arthur, the catchment with the least number of daily non-zero discharges, we adopted a bin size of 75 which yielded 6 bins. Item 2 in Section 2.1 has been amended to reflect this discussion.

• Captions of Figures 3, S1, S2, S3: "modelled recessions" may imply that the recessions come from simulations with a hydrological model, so it should be replaced by something else (computed or similar).
Response: We have replaced "modelled" with 'computed' in the captions.

• L257-266 and Figure 5: It is not instantly clear that MRCs in two plots in Figure 5 are the same MRCs, while the observed recessions are separated for wet and dry seasons, so this should somehow be clarified. Text in the figure caption, "Comparison of seasonal daily MRCs" adds to this confusion.

Response: Thank you. In the caption we have deleted the words “seasonal” and “modelled” but added “computed” in the first line of the caption and added a second sentence that states that both sets of computed MRCs are based on the same available data.

• L291-297: This paragraph discusses seasonal variation of recessions for Gibbo River in Figure 4. I think it would be beneficial to discuss this also for the other three streams, or at least for Northern Arthur River with the seasonal recessions in Figure 5. For example, observed recessions during the wet season for Northern Arthur River are also plotted on 25% to 90% MRCs, but for the dry season the conclusion is not the same for the two rivers.
Response: We have created a new Section 4.2 Seasonality, where we have brought together both paragraphs that deal with seasonality and added a third paragraph that describes an additional analysis in which we show that the maximum recession constant, which represents the slope (and, therefore, aleatory uncertainty) of the MRCs, is strongly correlated with antecedent monthly rainfalls (of duration 1, 3, 5, 7and 11 months). This additional analysis supports our hypothesis that MRCs are the result of varying antecedent climate and weather conditions and are represented by a continuum of MRCs rather than a single average MRC. Seasonality of the Northern Arthur catchment is included in this new section.

Reference

Vogel, R. M., & Fennessey, N. M. (1994). Flow-Duration Curves. I: New Interpretation and Confidence Intervals. Journal of Water Resources Planning and Management, 120(4), 485–504.