

## Authors Reply to the Short Comment by John Ding on "Are streamflow recession characteristics really characteristic?" by M. Stoelzle et al.

### 1. Introduction

The Discussion paper by Stoelzle, Stahl and Weiler (2012) represents a continuing fascination with analytical techniques of streamflow recession, the low end of flow regime. The purpose of this brief note is to bring to the attention of the hydrology community a forgotten technique buried in engineering archives.

Authors Reply: We thank Mr. Ding for this interesting comment and we will add a reference with the presented method in the introduction of the revised paper. It would be interesting to calculate recession parameters with the Ding-method and to compare the results with the 9 RAMs in our study. However, we think that our choice of approaches is adequate enough to illustrate the variability due to different estimations of recession parameters and to answer the question in the title of the paper. Further on, we have chosen approaches that applied both recession extractions procedures and a fitting model. Nevertheless we want to relate some statements by Mr. Ding to our results.

### 2. Power-transform method

For recession flow analysis, Brutsaert and Nieber (1977) pairs the first-order time difference and addition of the flow data,  $Q(t-1)-/+Q(t)$ . Prior to their work, the analysis was done using directly the raw data,  $Q(t)$ , usually plotted in log-scale on a semi-log paper (e.g. Roche, 1963).

Regarding the second part of Equation 4 of the Discussion paper: (4.2):  $Q(t) = \{Q_0^{1-b} - [1-b]at\}^{1/(1-b)}$ , if  $b \ll 1$ , By taking the power of  $(1-b)$  on both sides, this becomes: (4.2a):  $Q^{-(b-1)}(t) = Q_0^{-(b-1)} + (b-1)at$ ,

Note there exists a linear relation between the transformed flow value,  $Q^{-(b-1)}(t)$ , and the elapsed time  $t$  (e.g. Ding, 1966).

(Note: Between Pages 10572 and 10573 of the Discussion paper, some lines appear missing.)

Authors Reply: We cannot locate the mentioned missing lines in the sentence before Eq. 4.

### 3. Flow recession parameters

Regarding the interpretation of recession parameter  $b$ , this can be related back to the degree of nonlinearity  $N$  in a nonlinear storage-outflow relation,  $Q = (cS)^N$ , in which  $c$  is a scale parameter. Ding (1974) presents a similar, linearized recession equation as follows:

$$(4.2b): Q^{-(1-1/N)}(t) = Q^{-(1-1/N)}(0) + (N-1)ct,$$

Equating the powers of  $Q(t)$  in Eqs. 4.2a and 4.2b:  $-(b-1) = -(1-1/N)$ , one obtains:

$$b = 2 - 1/N.$$

Parameter  $b$  is thus a re-scaled nonlinearity of the watershed nonlinearity  $N$ .

Similarly, equating the two corresponding time-dependent terms yields  $a = Nc$ .

Since parameter  $N$  is now known to vary, for practical application, from 1 to 3 (e.g. Ding, 2011),  $b$  is thus expected to vary between 1 and 1.67.

In Figure 1, the three middle, vertical sub-plots using linear regression for model fitting show respectively the best-fitted  $b$  values of 1.48 (by Vogel), 1.69 (Brutsaert), and 1.46 (Kirchner). Brutsaert's  $b$ -value of 1.69 lies slightly above the upper (practical as opposed to theoretical) limit of 1.67. Both Vogel's and Kirchner's lie close to but below  $b = 1.5$ , which corresponds to an  $N$  value of 2.

Ding (1966) shows that an  $N$  of 2 characterizes in part the outflow hydrograph from a cross section of an unconfined aquifer. As the outflow from groundwater storage becomes the lateral inflow to the river, the type of water storage in a watershed and its contribution to the base flow of a stream shift, in a downstream direction, from that in aquifers to that in river reaches. Since the channel storage is characterized by an  $N$  value of 1.67 by Manning friction or 1.5 by Chezy, (e.g. Ding, 2011), this gives a corresponding  $b$  value of 1.4 or 1.33.

#### 4. Are streamflow recession characteristics really characteristic?

To respond to the provocative question, raised by the authors, which headlines the Discussion paper, the answer is to be a YES, as far as the recession (shape) parameter  $b$  is concerned. Results from the authors' numerical analysis, as shown in Figures 1 and 3, pairing the linear regression procedure, and the Vogel and Kroll, and the Kirchner data extraction procedures, as well as those from the writer's previous theoretical analysis, both indicate a narrow range of the re-scaled nonlinearity  $b$  from 1.4 to 1.5.

#### 5. An alternative

In contrast to the Brutsaert and Nieber, and two other similar RAMs (recession analysis methods) evaluated in the paper, the use of the power-transformed flow values in linear regression analysis offers an explicit (in the outflow) but indirect (in the computation) alternative for fitting recession parameters to the extracted recession data. The conventional log-transform method is a special case of the power-transform one in which the watershed nonlinearity (re-scaled or not) is unity, i.e. it being a linear storage system.

Authors Reply (2.-5.): The comments of Mr. Ding refer to the fitted  $b$  values of the linear regression model in Figure 1 and summarized that the  $b$  is expected to vary between 1 and 1.67. We have calculated 80  $b$ -values for the linear regression model and actually 6% of these values are smaller than 1 and around 25% are larger than 1.67, thus around 30% of these  $b$ -values are not in the mentioned value range. We assume that this can be an issue of streamflow measurement precision or amount of excluded recession segments due to the proposed extraction procedure in each method (i.e. catchments with many, but always very short recessions) resulting in "imprecise" recession plots with an insufficient amount of points. Obviously the extraction procedures of VOG.reg, BRU.reg and KIR.reg are "too characteristic" and thus insert a bias into the linear regression model.

As in Table 1 listed the values of slope  $b$  among the linear regression model vary more than one would expect. The results suggested that a linear regression model and the derived  $b$  values highly depend on the recession extraction procedures. However, if derived recession slopes are really characteristic we would expect an more consistently ranking among the catchments (Fig. 1). Low to moderate Spearman's rho's indicate that the used RAMs (even with a linear regression model) lead to various, non-characteristic estimations of recession parameter  $b$ .

Table 1: Distribution of slopes for different extraction methods and model fitting by linear regression.

RAM	$b < 1$	$b > 1.67$	$1.4 < b < 1.5$
VOG.reg	10%	15%	20%
BRU.reg	5%	45%	25%
KIR.reg	5%	15%	15%

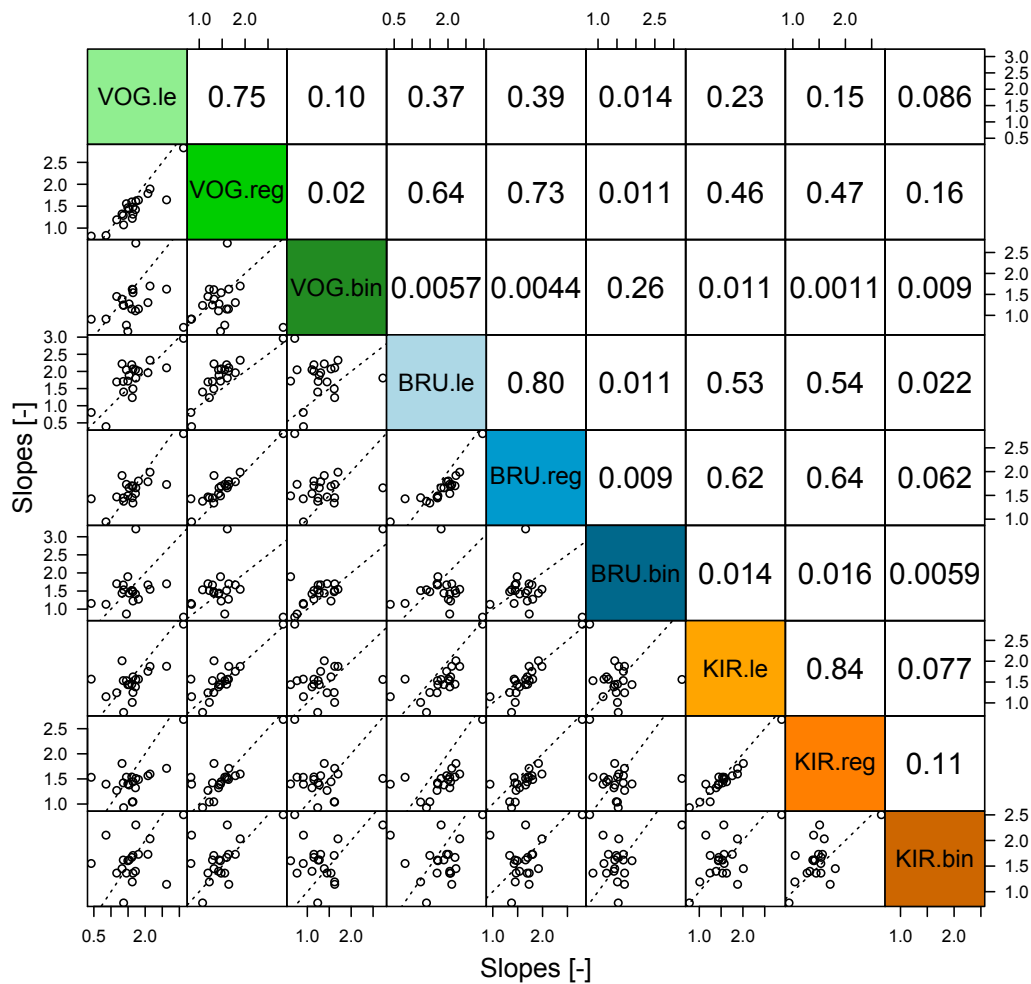


Fig 1.: Below diagonal: scatterplots for calculated slopes  $b$  from each combination of RAMs with the 1:1-line (dashed line), above diagonal: corresponding Spearman's rho.