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Discussions

Interactive comment on "Stream flow recession patterns can help unravel the role of climate and humans in landscape co-evolution" *by* P. W. Bogaart et al.

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1 Note for the authors and editor

The following review was written by a student of the MSc programme Earth and Environment at Wageningen University. As part of the course Integrated Topics in Earth and Environment, students are asked to prepare a review of a scientific paper. The supervisor of this review process is Ryan Teuling. The manuscript by Bogaart et al. was one of the manuscripts that was selected for this exercise. The review is written as an official review in order to comply with the course guidelines, but it should be considered

by the authors as a regular comment which they can use to improve the manuscript. I hope that this comment will positively contribute to the review process and that it will help the authors to improve their manuscript for possible publication in HESS.

2 Introduction

Land cover change, both natural and anthropogenic, is suggested to be responsible for changing recession behaviour. Land cover change is characterized by system adaptation and change, towards more optimal ecohydrological conditions. This suggests that landscape co-evolution is at play; landscape characteristics are affected. For example, landscape characteristics that are possibly affected are area, sediment percentage and tree volume. More landscape characteristics are mentioned in Table 1 of Lyon et al. (2012). Co-evolution of landscapes is not to be seen on a short time scale. Spatial features do not change directly and may evolve differently in time depending on local or regional conditions. For example, land use changes may take several years to be reïňĆected on the corresponding soil properties (German, 2003; Runyan et al., 2012). Landscape co-evolution could happen through climate change and human activity. The goal of the paper is to determine regional patterns in river recession behaviour, taking into account correlations between soil, vegetation, humans and atmosphere as a measure of landscape co-evolution, and unravel the natural and anthropogenic controls establishing these patterns and changes. In other words, the study aims to show that landscape co-evolution occurs because of changes in climate and human activity through the use of stream flow recessions. The authors use recession behaviour as a tool to show how landscapes adapt to changes in recession, influenced by climate and humans.

3 Summary

This research was conducted in Sweden, because of strong gradients in climate, land cover and human habitation. Also, the discharge of many rivers in Sweden is being monitored daily and there have already been previous studies to build upon (Lyon et al., 2012). Changes in climate or human influences may lead to altered river discharge dynamics. Humans can affect discharge directly (through construction of dams/reservoirs, artificial drainage) and indirectly (through deforestation or other land use changes). Also humans influence the climate, leading to climate change, which will change discharge dynamics. Evapotranspiration has a significant effect on the shape of recession as well (Brutsaert, 1982). Human modifications to the natural system change the storage-discharge relationship and associated recession dynamics of catchments directly or through co-evolution of soil, vegetation, climate and landscape, which changes the annual evapotranspiration and discharge fluxes.

The analysis starts with the conservation of mass-equation:

$$dS/dt = P - E - Q \tag{1}$$

with S as the storage of water in a catchment and P, E and Q as respectively the rates of precipitation, evapotranspiration and discharge (Kirchner, 2008). A catchment receives input in the form of precipitation (P), which is either stored (S) or lost as evapotranspiration (E) or discharge (Q). By studying discharge recessions, using the powerlaw recession model, information on storage-discharge relationships can be obtained. The powerlaw model consists of the following formula:

$$-dQ/dt = aQ^b \tag{2}$$

Plotting the time derivative of stream flow (dQ/dt) against stream flow (Q) itself will make all of the individual recession hydrographs overlap. A and b are parameters depending on the amount of water stored in the aquifer (Troch et al., 2013) and are

obtained through fitting. This best fitted line provides information on storage and discharge. $1/a$ is the recession time scale and b determines the linearity of the plot (with a linear reservoir for b =1). The results show a general decrease in a and an increase in b over time, so slower recession (increased retention) and increasing non-linearity of Swedish catchments over the last 50 years. Each land cover class occupies a well-defined region in the a-b phase-space, which can be connected to mechanistic explanations based on hydraulic and hydrologic process laws. Several patterns and trends in the recession parameters results can be attributed to numerous natural and anthropogenic causes. For some of the cases though the independence to these drivers was verified. The paper contributes to existing literature as it provides more insight in how various natural and anthropogenic changes in land cover alter recession behaviour. Plenty of the papers in the references are either about discharge dynamics, recession behaviour and/or land use changes. In my opinion the aim of the paper is to make a coupling of the properties mentioned above to explain recession behaviour. The title presents landscape co-evolution as the variable that is being explained in the paper, while after reading the paper recession behaviour turns out to be explained, using land use changes as one of the explanatory variables.

4 Concerning points

4.1 Linearity of recession plots

Log-log recession plots such as in Figure 1 are often approximately linear, suggesting a power law relationship between discharge Q and the recession rate dQ/dt:

$$-dQ/dt = aQ^b \tag{3}$$

Here, b is the slope of the best fit line. However, the best fit is not necessarily linear. Even in logarithmic plots there may still be non-linearity. Linear relations like in the first graph of figure 8 of Kirchner (2009) are not always the case. For a linear relation, parameters a and b need to be constant. In this case non-linearity will result in different slopes at different ranges of discharge (Q). Looking at the upper graph in Figure 1 the best fit is a linear line. However you could choose for a non-linear line as the best fit too, with a larger slope b at low values of Q and slope b gradually decreasing with increasing Q. In this case, at different values of Q, the values of a and b are different as well, while these should have been assumed constant. So at different discharge ranges it is possible to have different recession behaviour.

In the paper it is presumed that the fitted line through the data cloud of Q vs. -dQ/dt is linear. Is it really a linear relation? If not, this assumption is false, and so are the conclusions drawn from this. To solve this problem, we have to assure that the fitting is independent of the distribution of (or range in) Q. One way of doing this is binning. Binning divides the graph in bins, resulting in multiple narrow ranges of Q. In each of these bins an average value of dQ/dt is taken at a certain Q. Then a line is fitted through these averaged values. This method makes sure that the parameters a and b are constant, making the graph solely dependent on Q.

4.2 Mismatch title and paper content

In the discussion there is hardly any linkage between the recession parameters a and b and landscape co-evolution. It is mentioned whether recession behaviour of catchments is dependent or independent on variables like temperature, precipitation, stream flow and evapotranspiration. Also values of parameters a and b for various situations are provided, but what these values exactly tell us about landscape co-evolution remains unclear. The final product of the paper seems to be how strong a variable (f.e. temperature, precipitation, evapotranspiration) is related to recession behaviour. Further explanation of the strength of these relationships and its impact on landscapes is absent. What is even precisely the author's definition of landscape co-evolution? This

does not evidently come forward from reading the paper. The main focus seems to be on that changes in climate, landscapes and land use are used to explain recession. The title suggests differently: it should explain how humans and climate affect landscape characteristics through the use of recession behaviour. In the conclusion it is mentioned that the relative positions of most of the land cover types in the a-b phase-space are strongly linked to relative positions in a similar "water and energy efficiency" phase-space plot, suggesting that land use, water retention characteristics and energy partitioning are strongly interrelated, and possibly the result of co-evolution of the landscape. Again, co-evolution of landscapes is used to explain recession, instead of the other way around. Rephrasing the title differently would already solve part of these problems. Adjusting the title in such a way that it becomes clear that stream flow recession patterns are to be explained by human activity, climate change and landscape co-evolution.

4.3 Leaving out degenerated hydrographs

Continuous stream flow records were analysed to select individual recession events. There are several methods (lower envelope fitting, linear regression, binning) to extract these individual recession events from the stream flow records (Brutsaert, 2008; Vogel and Kroll, 1992; Kirchner, 2009). Once extracted, there are two types of hydrographs: informative and degenerated hydrographs. These are to be distinguished on the basis of the uncertainty in the regression process. The degenerated hydrographs yield unreliable estimates of recession parameters a and b. It is however possible to recover them, but this is not done because of the number of catchments. Reliable recession analysis is not always possible because of anthropogenic controls of stream flow (like dams), so these degenerated hydrographs seem to be (partially) the result of human influences. By leaving out degenerated hydrographs you possibly leave out those catchments with a strong human influence on recession behaviour (i.e. resulting in non-powerlaw behaviour), while judging from the title the role of human activity on landscape co-evolution through recession behaviour is one of the main topics of this paper. Human impact is possibly not completely left out of analysis by not using degenerated hydrographs, but at least for a large portion. Using both informative and recovered degenerated hydrographs might yield different results and therefore may result in different conclusions.

4.4 Lower envelope

According to Rupp Selker (2005) the data of the lower envelope of a hydrograph, plotted as $log(-dQ/dt)$ against $log(Q)$, are specifically those data points without contributions of overland flow, interflow or channel storage. Evapotranspiration affects both the intercept a and the slope b of the hydrograph (Szilagyi et al., 2007). The lower envelope of the data cloud has been taken to minimize the influence of evapotranspiration. By doing this, the contributions of other factors (besides Q) to the hydrograph are minimized. Not taking the lower envelope would result in much larger values, caused by evapotranspiration. Using this lower envelope method does however have some drawbacks. Now that the effect of evapotranspiration is minimized, any conclusions drawn on evapotranspiration will be less reliable. Increased evapotranspiration leads to desiccation of the landscape and increases the available water storage capacity of the soil, resulting in lower and less discharge peaks. It is reasonable to take the lower envelope of a hydrograph, as it decreases the influence of evapotranspiration and parameters a and b are less affected, as mentioned in Szilagyi et al. However, taking the lower envelope yields less importance of evapotranspiration on the hydrograph, thus it is more difficult to say anything about the influence of evapotranspiration on water storage and related discharge dynamics and about the link between evapotranspiration and the recession parameters that were obtained from the hydrograph. It becomes even more unreliable because it is unclear how the lower envelope is defined. Which data points are used for determination of the lower envelope? Did they take the lower 10 percent of the data cloud to determine the lower envelope? Or was it the lower 25 percent?

5 Recommendations

- Assure that the best fit in the powerlaw model is linear. If non-linear, a possible solution to receive a linear fit is binning. In this situation, parameters a and b can be assumed to be constant.
- Title adjustment: Human activity, climate change and landscape co-evolution can be used to explain stream flow recession patterns (or something slightly different).
- If the authors want the title to remain the same, it should be clearly indicated what the recession parameters mean to landscape co-evolution. Some examples would already clarify a lot and make these obtained recession parameters more concrete.
- Discuss that degenerated hydrographs should have been used to include the impact of humans on recession behaviour. Recovering degenerated hydrographs seems in this case to be a time-consuming process. Indicate in the discussion that the study could have included recovering degenerated hydrographs if more time would have been available, so that catchments with significant human influence on recession behaviour could have been included in this study.
- Specify how the lower envelope is defined. In other words: which part of the data cloud was used as lower envelope? If this is known, it becomes possible to tell to which extent evapotranspiration is of importance to recession behaviour (if of importance at all).

6 Remarks/Errors

Page 9868, line 24: two times “catchment” → delete one “catchment”.

Page 9872, line 13: two times “the” → remove one of these.

Page 9874, line 22: . . . < 0.1 mm day-22 → mm day-1.

Page 9883, line 11: . . . 97 catchments (34

Page 9884, line 3: two times “lead” → only one “lead”.

Page 9890, line 9: “. . . is expected to be result in . . .” → “. . . is expected to result in . . .”.

Page 9893, line 14: possible → possibly.

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