Towards a method to characterize groundwater dynamics during drought

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Motivation

Groundwater properties, as measures of storage, control the propagation of drought through the ecohydrogeological system as well as societies vulnerability to drought.

Many studies point to the importance of groundwater, and use terms like „slow“, „fast“, „flashy“ or „inert“ to describe groundwater properties that are thought to explain differences in system behaviour.

Can we go beyond this? Can we make these terms for system properties more specific, at best in the form of quantitative expressions? Can these expressions help analyse the impacts of droughts on goundwater systems in more detail?

Objective

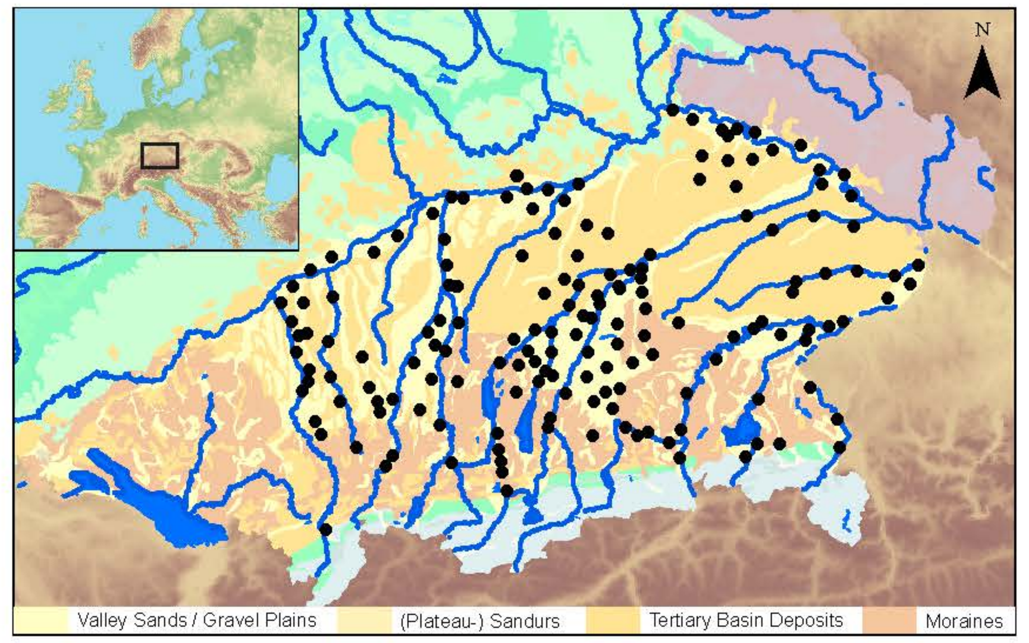
Finding methods to **quantify „groundwater dynamics“** in order to:

- characterize groundwater gauges and aquifers in a quantitative manner.
- better understand the vulnerability of groundwater systems to drought.

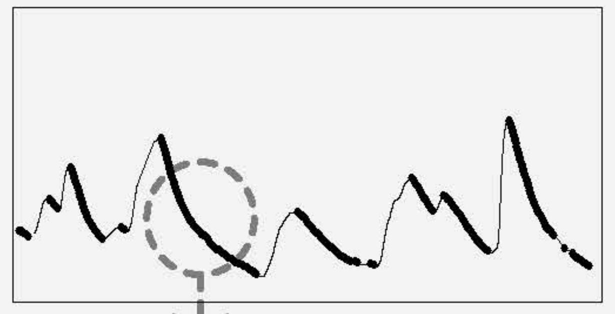
Study Area / Data

Southern German Molasse Basin: Shaped in pleistocene. Moraines in the south, incised tertiary deposits in the north, sand & gravel fillings along the rivers.

Data from 61 groundwater observation wells across the basin, various time series lengths (20-100 years). Selection criteria: located in molasse basin, near-natural sites, daily measurement frequency, largely continuous (few gaps).

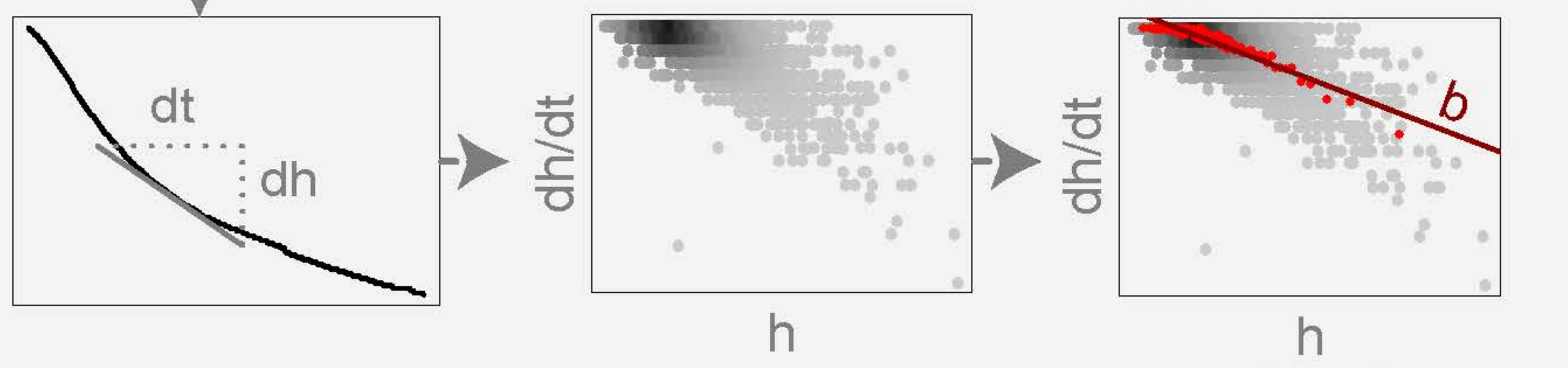


Methods



Recession Constant

Idea is based on the Kirchner (2009) method, which was developed in order to derive catchment (dynamic) storage from streamflow observations. We apply this approach to groundwater observations to get a measure of dynamics.



1) Take the recession limb of the hydrograph.

2) Calculate the slope dh/dt of every data point.

3) Plot the **hydrograph slope dh/dt against the head h** for every timestep t.

4) Create binned means (=red dots; mean over all 100 percentiles).

5) Fit linear model to binned means. Model slope b is **Recession Constant**.

Drought Characteristics (Fixed Threshold Level Method)

To test the Recession Constant with respect to drought behaviour, we compare it with simple drought characteristics, calculated with the threhsold level method:

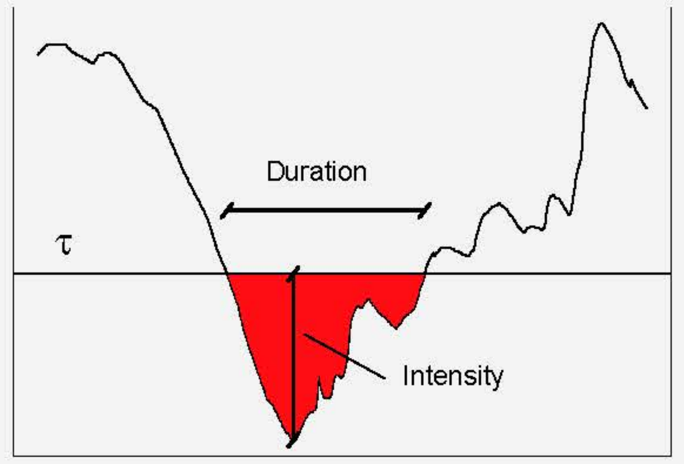
1) Quantile from cumulative empirical distribution of time series as threshold (here: 20% quantile).

2) Drought starts: when the hydrograph falls below the threshold.

3) Drought ends: when the hydrograph exceeds the threshold again.

4) Time in between is the drought **duration**.

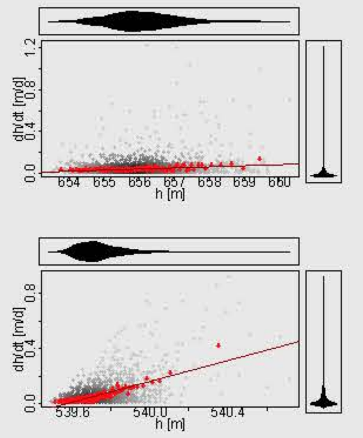
5) Maximum deviation from threshold during drought is the drought **intensity**.

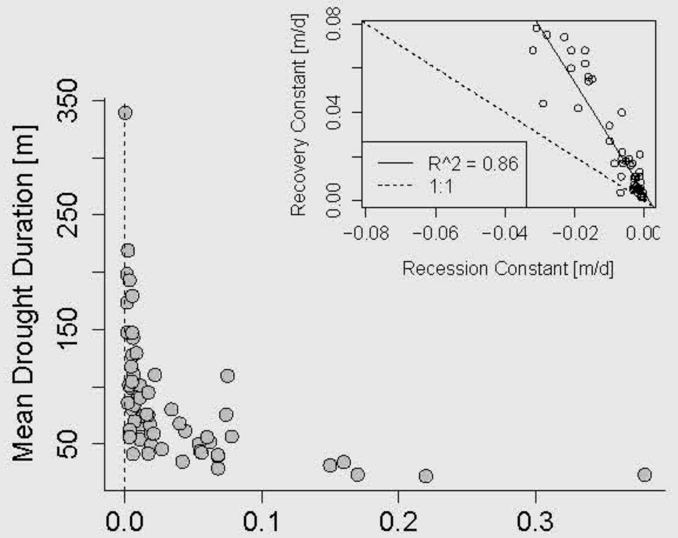


Recovery Constant

We can use this approach to calculate the Recovery Constant, simply by taking rising limb of hydrograph instead of falling limb.

Strong relationship between Recession- and Recovery Constant.

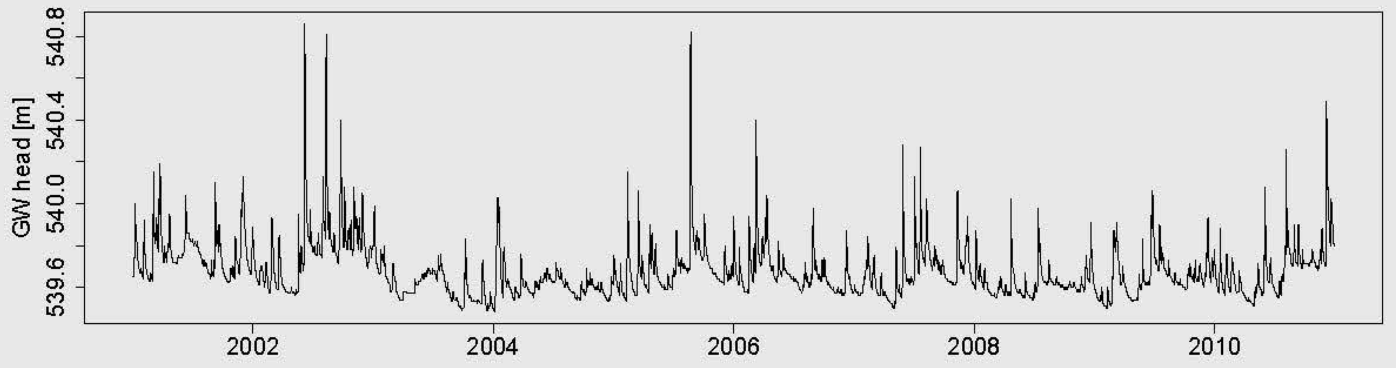




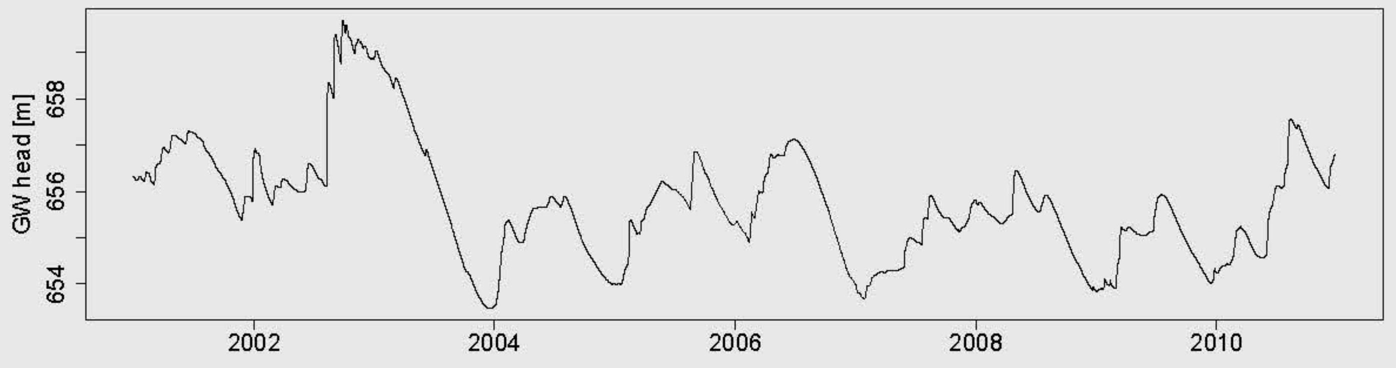
Same pattern in relationship between Recovery Constant and Drought Characteristics as with Recession Constant (just mirrored).

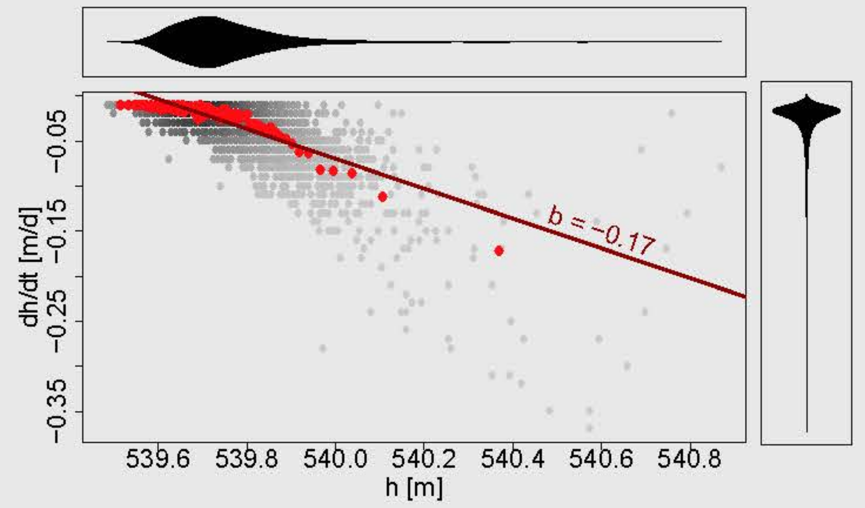
Results - Recession Constant

Example 1: **Fast Responding Gauge**



Example 2: **Slow Responding Gauge**

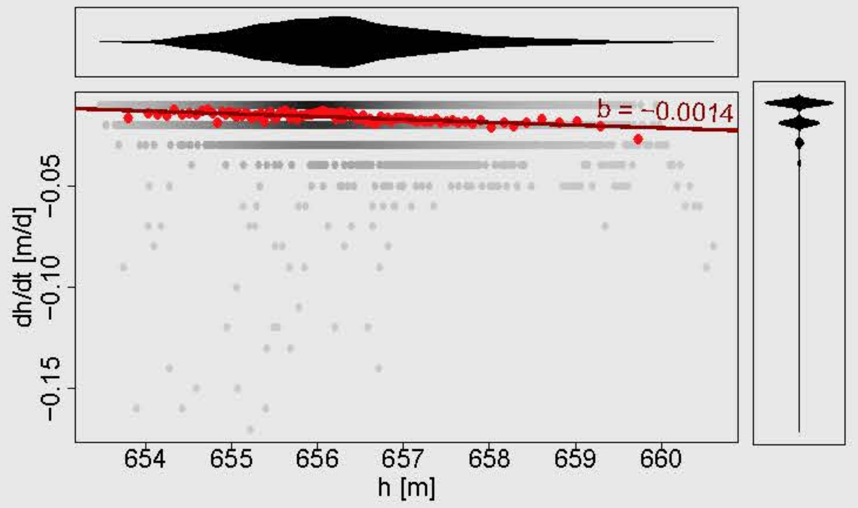




Two examples

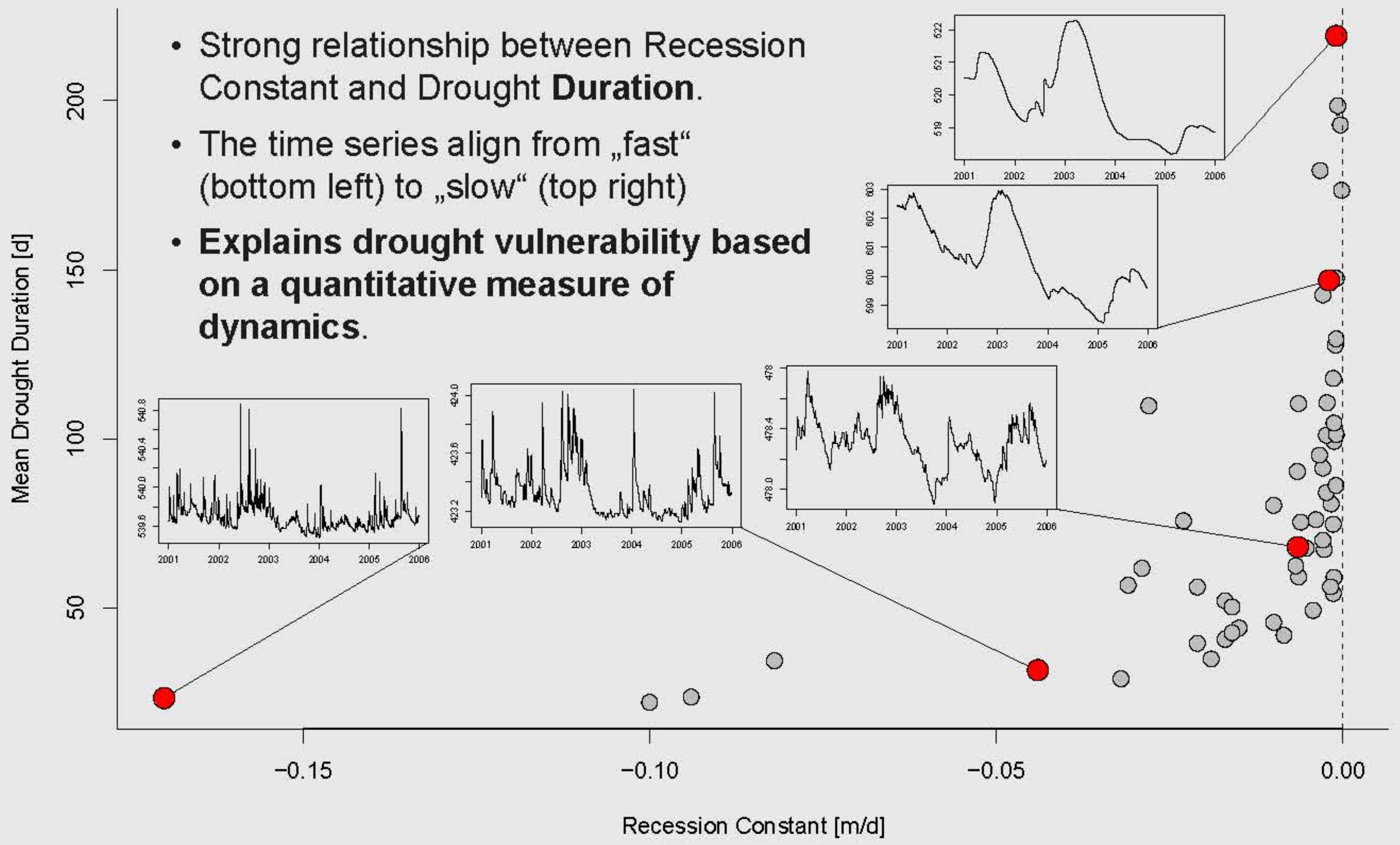
The recession plots (left + right) show a distinctly different pattern: steep for the „fast“ gauge (left), nearly horizontal for the „slow“ gauge. This is reflected by the slope of the linear model: the average recession per day is lower for fast gauges. Therefore, a lower recession constant equals faster response.

Challenge: ~10-20% of the gauges in the dataset have a non-linear recession in the curve of binned means (red dots). Those are mostly the fast responding ones, as the left example.



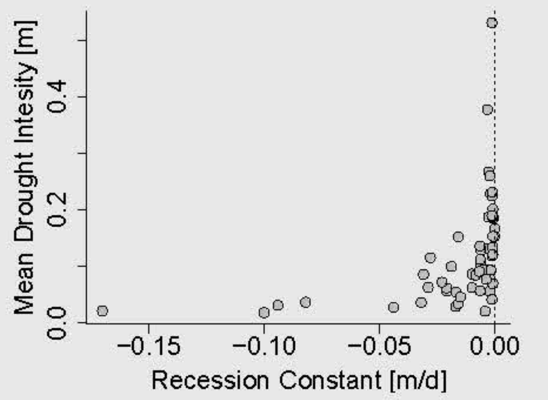
Relationship between Recession Constant and Drought Characteristics

- Strong relationship between Recession Constant and Drought **Duration**.
- The time series align from „fast“ (bottom left) to „slow“ (top right)
- **Explains drought vulnerability based on a quantitative measure of dynamics.**

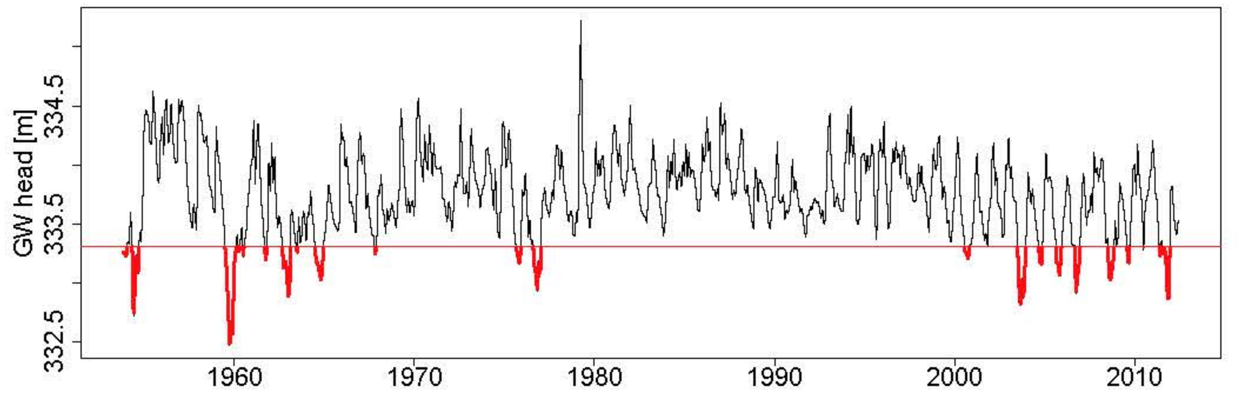


Good explanatory power of the Recession Constant concerning Drought Duration. But how about Drought **Intensity**?

→ Similar pattern but relationship is less explicit; Counter-intuitive: higher Recession Constant should result in steadier decline in drought periods and therefore a more explicit relationship.



Discussion



The Recession Constant captures one aspect of the dynamics. However there are **other aspects of dynamics** that can't be covered. E.g. the presence of (multi-)decadal cyclic patterns that make it hard to detect droughts with any threshold approach (graph above). Another aspect is the responsiveness to precipitation. Further methods need to be developed in order to grasp the groundwater dynamics in a multitude of facets.

Conclusion

- The Recession Constant is a suitable approach to quantify at least one aspect of the groundwater dynamics.
- Further aspects of dynamics are potentially quantifyable with different approaches.
- The Recovery Constant has some potential as well.
- Application & testing in different environments needed.

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Citations: Kirchner, J. W. (2009), Catchments as simple dynamical systems: Catchment characterization, rainfall-runoff modeling and doing hydrology backward, Water Resour. Res., 45.