Simple Catchments and Where to Find Them:

The Storage-Discharge Relationship as a Proxy for Catchment Complexity

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Key Points

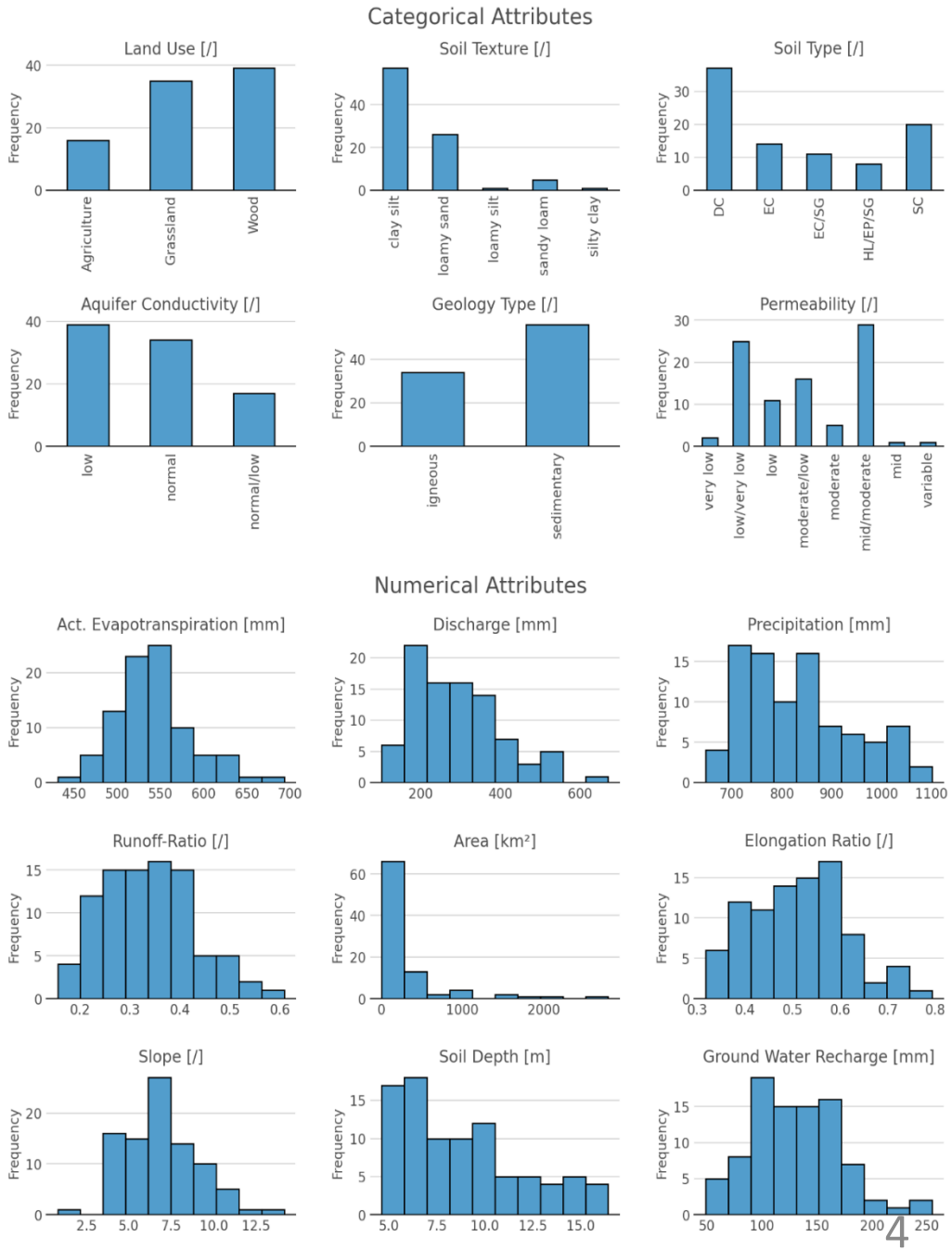
- Exponential storage-discharge relationships define simple catchments
- Simple catchments have a good permeability and can be found in regions of igneous geology, a clay-silt soil texture and tend to be oval.
- Large sample studies that cover small, but heterogenic area highlight the influence of catchment attributes apart from weather conditions.

Updated Abstract

Hydrological theory often assumes an exponential relationship between storage and discharge, but how often do we find such a behavior in real catchments? We analyze catchment attributes, discharge and weather conditions from 1992 to 2018 for 89 catchments in Hesse, Germany. All catchments have uniform weather conditions, but a wide range of catchment characteristics. We find that only a fraction of catchments follow a roughly exponential behavior in their storage-discharge relationship. Far more catchments are complex and depict irregular patterns with even extreme variation from one year to another. The large set of catchments with similar weather conditions reveals that physical attributes that drive catchment complexity are diverse and include permeability, conductivity, geology, soil and to a lesser extent also their shape. We conclude that generalization of runoff generation process is very difficult and has to consider the idiosyncrasies of unique catchments.

Methods: Database

- 89 Catchments in Hesse, Germany
- Discharge and Climate Data for 26 years (1992-2018)
- Hesse provides very diverse catchments in regard to their catchment attributes, while having similar climatic conditions
- All data and code used is available in an open repository: https://github.com/zutn/Simple-Catchments-Hesse

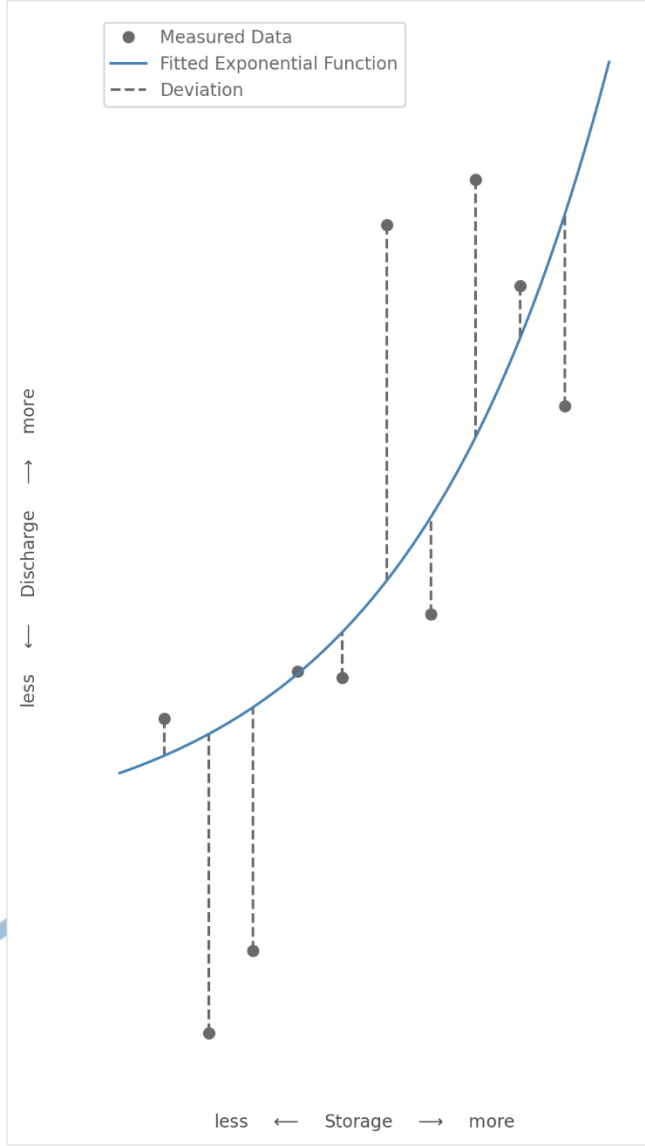


Methods: Annual Cumulative Storage

- Calculate daily storage change, by using the basic water balance equation:
  - $0 = P(t) - ET(t) - Q(t) - \Delta S(t)$
- Calculate annual cumulative storage relative to the state of the beginning of the year:
  - $\Delta S = \sum_{t=0}^{1y} P(t) - ET(t) - Q(t)$

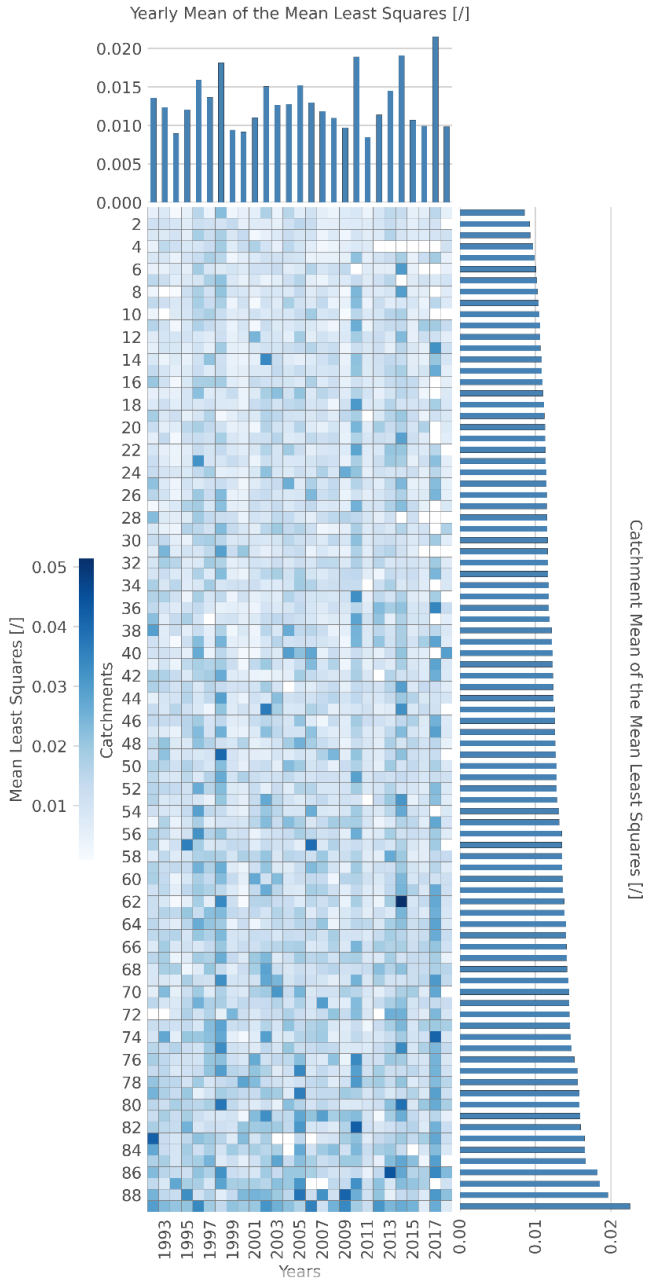
Methods: Complexity of the Storage-Discharge Relationship

- Evaluating the relationship between the annual cumulative storage and the discharge by testing how well it can fitted with an exponential function.
- For this we used the mean least square method:
  - The lower the combined residuals (deviations) are the simpler is the catchment.
  - Catchments in this study referred as simple therefore have an almost perfectly exponential storage-discharge relationship.



Results and Discussion:
Complexity of the storage-discharge relationship

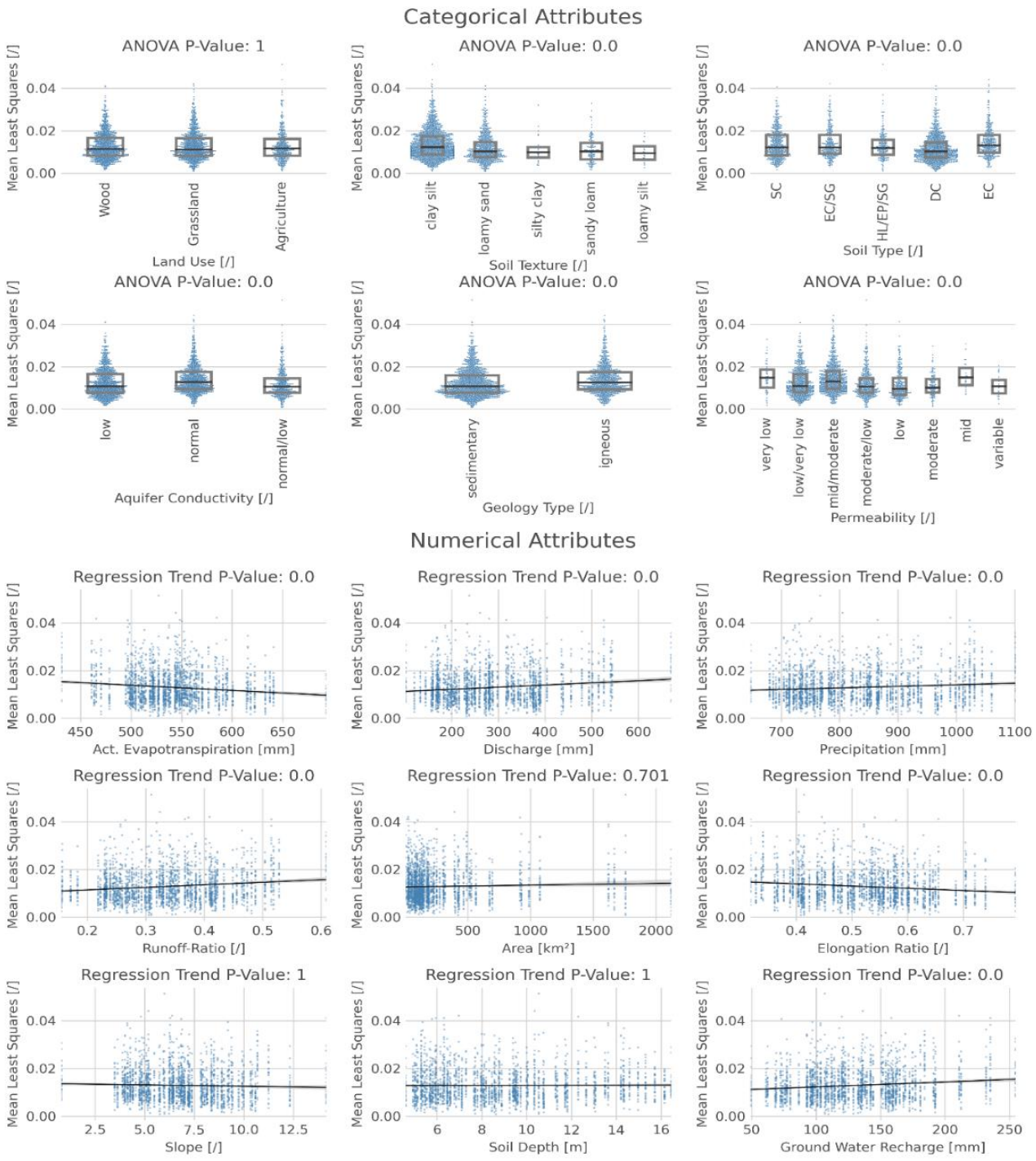
- Wide range of catchment complexity
- Varies by year for most catchments
- Low complexity catchments are, e.g. #1 – 5
- High complexity catchments, e.g. # 86 – 89 still have some years with low complexity
- Year and Catchment have similar influence on behavior
- Complexity correlates with standardized precipitation index (- 0.21) and the maximum amount of rain in one month (0.34)
- Results might be influenced by inter-year hysteresis processes



Heatmap of the mean sum of the least squares (measure of catchment complexity) for the 89 catchments of the Hesse data set, separated by years. Darker colors indicate higher complexity. Bar charts depict the mean values for the rows and columns.

Results and Discussion: Differences in catchment attributes between simple and complex catchments

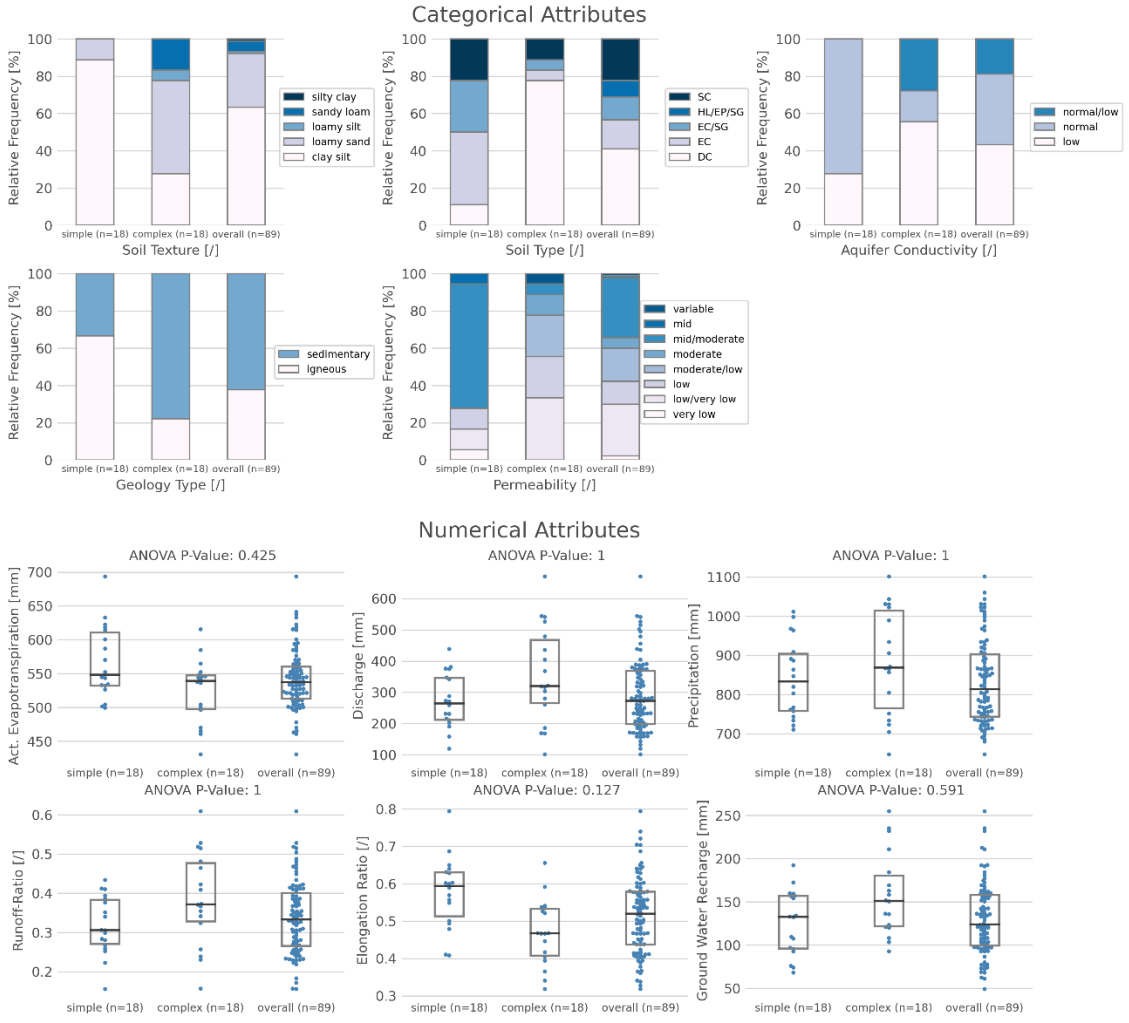
- Analysis which catchment attributes show a significant trend over the whole dataset
- Eliminates land use, area, slope and soil depth from further analysis.



Differences and trends in the mean least squares for the categorical (top six panels) and numerical (bottom nine panels) catchment attributes for all years of all catchments. The p-values for the categorical attributes indicates if there is a significant differences between the categories. The p-values for the numerical attributes indicate if the trend between the mean least squares and the attribute is significant. In the categorical attributes the black line is the median and grey lines show the interquartile range. Soil type abbreviations: DC = Dystric Cambisol, EC = Eutric Cambisol, SC = Spodic Cambisol, SG = Stagnic Gleysol, HP = Haplic Luvisol, EP = Eutric Podzuluvisol.

Results and Discussion: Differences in catchment attributes between simple and complex catchments

- Last step, only looking at the most simple and complex 20 % of catchments to remove influences of climate.
- Shows clear differences:
  - Simple catchments: Normal aquifer conductivity and permeability, regions with igneous geology, clay silt soil texture, wide range of soil types.
  - Complex catchments: Low aquifer conductivity and permeability, regions with sedimentary geology, loamy sand soil texture, dystric cambisols.
- Study highlights what kind of catchment attributes are important when we have a large sample of catchments that all have similar weather conditions.
- Both climate and catchment attributes are important, but on different scales.



Differences in the categorical (top five panels) and numerical (bottom six panels) catchment attributes between simple and complex catchments and the overall data set. Only those attributes are shown that have a significant trend over the whole data set. Simple and complex refers to the 20 % of the catchments (n = 18), which have the lowest/highest catchment mean sum of the mean least squares considered. The p-values on top of the box plots for the numerical attributes indicate significant differences between the simple, complex and all catchments. Black line is the median and grey lines show the interquartile range. Soil type abbreviations: DC = Dystric Cambisol, EC = Eutric Cambisol, SC = Spodic Cambisol, SG = Stagnic Gleysol, HP = Haplic Luvisol, EP = Eutric Podzuluvisol.

Further information:

- Currently under review in Water Resources Research
- Similar research:
  - https://www.hydrol-earth-syst-sci.net/24/1081/2020/hess-24-1081-2020.html
- Research Gate:
  - https://www.researchgate.net/profile/Florian_Jehn
- If you have any questions, feel free to contact me at:
  - florian.u.jehn@umwelt.uni-giessen.de
- Thank you for your time!

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