Interaction of climate, vegetation, and water age in catchments across scales and climate zones

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Abstract

Recent studies have demonstrated a direct relation between climate characteristics and vegetation in catchments. For example, plants appear to develop a root system that allows both optimal growth and resistance against region-specific droughts (Gao et al., 2014; Ho et al., 2005). As climatic conditions also affect the way catchments store and release water (i.e., the transit times), we expect a direct relation between vegetation and transit times. To test this hypothesis, we have established a dataset of water balance and stable water isotope data across more than 50 catchments in various climate zones, which will be further expanded over the course of the project. This dataset allows for determining root zone storage capacities and transit time metrics such as the young water fraction (Kirchner, 2016) across catchment scales and climate zones. We will present how transit time metrics vary as a function of root zone storage capacities and how this can be related to catchment and vegetation characteristics and climatic conditions. The results will help understand how changing vegetation cover due to climate and land use change might affect catchment water storage and release in future. We see a vast potential of isotope studies across diverse catchments. We are thus calling for a community effort to provide streamflow isotope data from previous work in a unified framework as a basis for further global analyses using stable water isotopes. Gao, H.; Hrachowitz, M.; Schymanski, S. J.; Fenicia, F.; Sriwongsitanon, N.; Savenije, H. H. G., Climate controls how ecosystems size the root zone storage capacity at catchment scale. Geophysical Research Letters 2014, 41, 7916–7923, doi:10.1002/2014GL061668. Ho, M. D.; Rosas, J. C.; Brown, K. M.; Lynch, J. P., Root architectural tradeoffs for water and phosphorus acquisition. Functional Plant Biology 2005, 32, (8), 737-748. Kirchner, J. W., Aggregation in environmental systems – Part 1: Seasonal tracer cycles quantify young water fractions, but not mean transit times, in spatially heterogeneous catchments. Hydrology and Earth System Sciences 2016, 20, (1), 279-297.

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Interaction of climate, vegetation, and water age in catchments across scales and climate zones

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1 Introduction

Recent studies have demonstrated a direct relation between climate characteristics and vegetation in catchments. For example, plants develop a root system that allows both optimal growth and resistance against region-specific droughts. As climatic conditions also affect the way catchments store and release water (i.e., the transit times), we are analysing **links between vegetation and transit times**. This may help us understand how changing vegetation might affect catchment water storage and release in future.

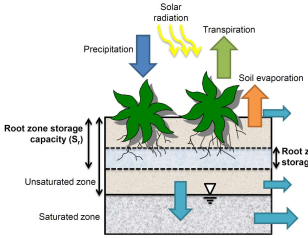
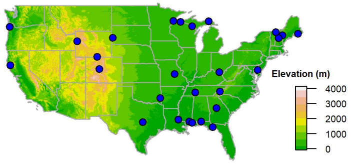


Fig. 1: Interactions between root zone storage and water storage and release.

How do **transit time metrics** vary as a function of plant-accessible water storage in the unsaturated root zone, i.e. **root zone storage capacities**?

2 Study catchments

a



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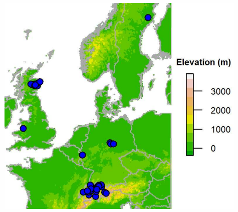

Fig. 2: Study catchments in the USA[1] (a) and Europe (b).

3 Methods

(1) DATA

- 67 catchments (0.385–8264.9 km^2)
- **Isotopes**: monthly $\delta^{18}O$ in precipitation (P) and streamflow (Q)
- **Water balance**: daily P, T (or PET) and Q data
- Where $\delta^{18}O$ in P not available: $\delta^{18}O_P$ amplitude map[2]

(2) YOUNG WATER FRACTIONS (F_{yw})

- Proportion of water ages below 2–3 months
- **Sine-wave regression** of $\delta^{18}O_P$ and $\delta^{18}O_Q$ → approximation by amplitudes A_Q and A_P:

$$F_{yw} = A_Q / A_P$$

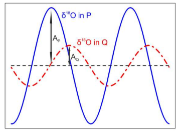

Fig. 3: Approximation of F_{yw} by A_Q and A_P.

(3) ROOT ZONE STORAGE CAPACITIES

- Annual maximum storage water deficits (S_R) derived from catchment evapotranspiration (E_t) and effective precipitation (P_e):

$$S_R = \max \int (E_t - P_e)dt$$

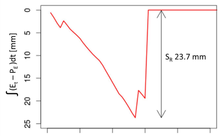

Fig. 4: S_R equals the cumulative difference between E_t and P_e (modified from [3]).

- Root zone storage capacity as S_R with **return period of 20 years**[4] ($S_{R,20}$) using the Gumbel extreme value distribution

4 Results

(1) YOUNG WATER, STORAGE CAPACITY & VEGETATION

- $S_{R,20}$ increases from heathland to broadleaf forests (Fig. 5a).
- F_{yw} increases from arable land to broadleaf forests (Fig. 5b).

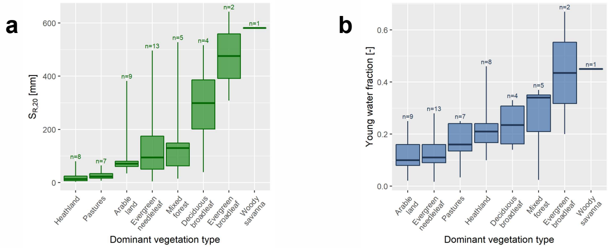

Fig. 5: Root zone storage capacity with return period of 20 years (a) and young water fraction (b) vs. dominant vegetation type in catchments.

(2) YOUNG WATER FRACTION vs. STORAGE CAPACITY

- $S_{R,20}$ in European catchments mostly below 100 mm
- Slight decrease in F_{yw} with increasing $S_{R,20}$ in UK and CH
- No clear overall relationship between F_{yw} and $S_{R,20}$

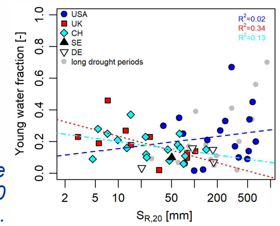

Fig. 6: Young water fractions vs. root zone storage capacities with return period of 20 years ($S_{R,20}$).

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5 Conclusions and Outlook

- **F_{yw} is slightly decreasing with increasing $S_{R,20}$** in European catchments, where $S_{R,20}$ mostly < 100 mm
- Catchments with large $S_{R,20}$ show large range of F_{yw} → decoupling between water storage by plants and runoff generation?
- Next: inclusion of catchments in New Zealand, Australia, Africa and South America

We need a unified framework to store and provide streamflow isotope data as a basis for further (global) analyses. Ideas on platforms, implementation, datasets? Let me know!

References

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