Are hillslope characteristics drivers of subsurface flow variability?

Sophie Bachmair and Markus Weiler

UNI FREIBURG

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Introduction

Hillslope hydrological dynamics, particularly subsurface flow (SSF), are highly variable and complex. A solid understanding of hydrological dynamics and soil-vegetation-atmosphere interactions at the hillslope scale is necessary to predict runoff response for ungauged hillslopes. To gain better process knowledge we intercompared shallow water table dynamics of three adjacent, large-scale hillslopes with similar slope, aspect, curvature, geologic and pedologic properties but differences in vegetation cover. What are the controls driving subsurface flow dynamics? Can SSF variability within and among hillslopes be explained by measurable hillslope characteristics?

Methods

Determination of hillslope characteristics

Topography via GIS
- Slope, upslope contributing area, aspect, plan and profile curvature

Soil properties
- Well depth
- Ks (Horslev) via slug test
- Mean slope of quick and slow part of recession after slug injection

Vegetation
- Stemflow index
- Amount of trees in vicinity
- Event throughfall
- Canopy coverage via fish-eye-pictures

Determination of water table responses

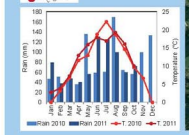
Different temporal scales
- Entire time series
- Seasonal scale
- Event scale

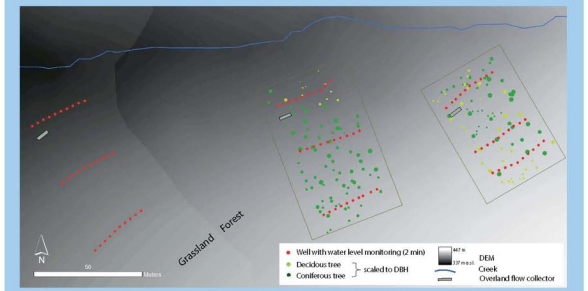
Different parameters, e.g.
- Area below water table normalized to well depth
- Percentage of time when water table > threshold
- Slope of water table rise (event scale)
- Lag time until water table rise (event scale)

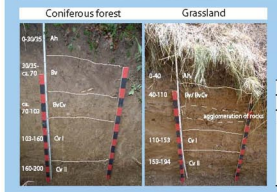
Multivariate statistical analysis

Study site and experimental set-up

GERMANY
47.957° N, 7.838° E
Zero-order catchment (0.21 km²)







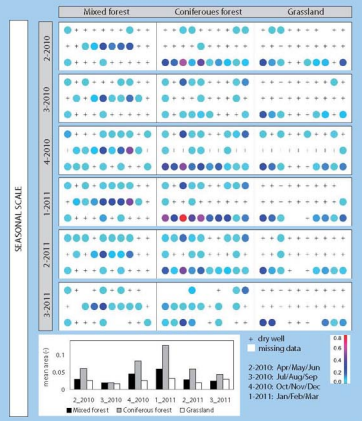
Soil type: Cambisol (WRB)
Parent material: periglacial drift cover over cristalline bedrock

Soil properties coniferous forest versus grassland

Horizon	Sand-Silt-Clay (%)		Bulk density (g/cm³)		Corg (%)	
	Con. F.	Grass	Con. F.	Grass	Con. F.	Grass
Ah	45-39-16	48-37-16	1.1	0.9	18.6	18.2
Bv	39-43-18	38-44-18	1.4	1.7	6.4	2.7
BvCv	44-42-14		1.8	1.7	1.5	2.7
Cv I	21-64-16	35-48-17	1.7	1.8	0.9	1.2
Cv II	44-46-11	62-29-9	1.8	1.7	0.7	0.8

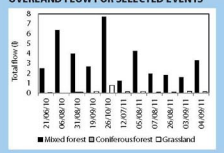
Hydrological dynamics versus hillslope characteristics

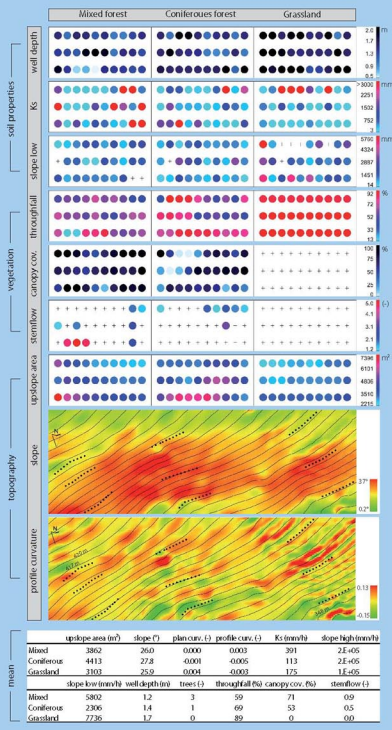
AREA BELOW WATER TABLE NORMALIZED TO WELL DEPTH



The water table response patterns reveal that the grassland hillslope wells are less often activated and the mean area of water table is also lower than at both forested hillslopes. This applies for all temporal scales.
Moreover, there are seasonal differences in water table response, which are best discernible at the event scale. During wet fall/winter/spring mostly the lower transect wells are activated. In summer also middle and upper transect wells respond but there is higher spatial variability.

OVERLAND FLOW FOR SELECTED EVENTS





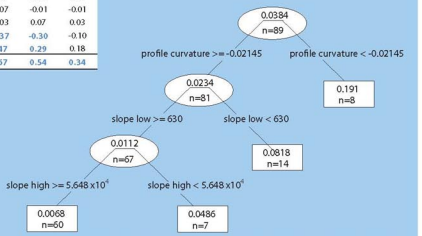
Results

Partial and multiple correlation coefficients for different seasons

Predictor variable	2-2010	3_2010	4-2010	1-2011	2-2011	3-2011
upslope area	0.06	-0.19	-0.03	0.05	-0.01	-0.09
slope	-0.32	-0.15	-0.30	-0.42	-0.23	-0.23
plan curvature	-0.14	-0.03	-0.17	-0.20	-0.21	-0.10
profil curvature	-0.09	-0.06	-0.12	-0.10	-0.11	-0.10
aspect	0.04	0.01	-0.02	0.11	-0.02	0.08
Ks	0.38	0.03	0.31	0.36	0.34	0.09
slope high	-0.19	-0.14	-0.28	-0.26	-0.17	0.03
slope low	-0.35	-0.16	-0.35	-0.39	-0.39	-0.21
well depth	0.18	0.27	0.14	0.21	0.27	0.27
amount trees	-0.36	0.01	-0.27	-0.35	-0.30	-0.03
throughfall	-0.04	0.06	0.07	0.06	0.10	0.03
canopy coverage	-0.06	0.03	-0.04	-0.07	-0.01	-0.01
stemflow	-0.03	0.04	0.00	-0.03	0.07	0.03
land use	-0.23	-0.18	-0.33	-0.37	-0.30	-0.10
transect	0.40	0.17	0.35	0.47	0.29	0.18
multiple R^2	0.56	0.22	0.53	0.67	0.54	0.34

The partial correlation between area below water table and one hillslope characteristic is generally low; highest values (r >= 0.3 indicated in blue) show the variables slope, Ks, slope low (slow part of recession after slug injection), amount of trees, land use type (forest/grassland), and transect (lower, middle, or upper hillslope transect). In summer (3-2010/3-2011) the strength of the linear relationship between water table response and mapped hillslope characteristics is lower than in fall/winter/spring.

Regression tree for season 2-2010



A regression tree explains the variation of a response variable by recursively splitting the data into more homogeneous groups based on combinations of explanatory variables. To construct the regression tree for spring 2010 the splitting variables profile curvature, slope low, and slope high (slow and fast part of recession after slug injection, respectively) are used. The first explanatory variable is profile curvature, which splits the water table response data (n=89, mean=0.038) into two more homogeneous subsets at the cutting point -0.0214: one group with larger area below water table (n=8; mean= 0.191), the other group with smaller area below water table (n=81; mean=0.023).

The other seasons are similar to 2-2010 in terms of nodes and splitting variables (soil properties and topography as main predictors).

Preliminary conclusions

- The observed spatio-temporal variability of water table response results from a complex set of interactions among hillslope characteristics. Soil properties and topography show the highest single explanatory power. Further statistical analyses will be conducted highlighting the role of vegetation.
- During summer (high intensity rainstorms, low antecedent wetness) the correlation between hillslope characteristics and water table response parameters is lower than during spring/fall/winter. This indicates that additional controls may be important under dry summer conditions (e.g. preferential flow features), which cannot be captured by the chosen characteristics.
- The grassland hillslope shows a lower frequency of well activation and a smaller area of water table despite higher rainfall input. Surface flow rates are generally very low and are negligible compared to the mixed forest hillslope. Differences among hillslopes thus likely go back to differences in other properties such as a higher amount of macropores and soil pipes at the grassland site.

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Studienstiftung des deutschen Volkes

Institute of Hydrology, Albert-Ludwigs-University of Freiburg, Germany
sophie.bachmair@hydrology.uni-freiburg.de www.hydro.uni-freiburg.de www.hillslope-experiments.de