Variability of DOC quantity and DOC quality as an indicator of DOC inputs to surface waters in a forested catchment

Oliver Lechtenfeld, Katharina Blaurock, Maria da Silva, Burkhard Beudert, Jan Fleckenstein, Stefan Peiffer, Benjamin Gilfedder, Luisa Hopp

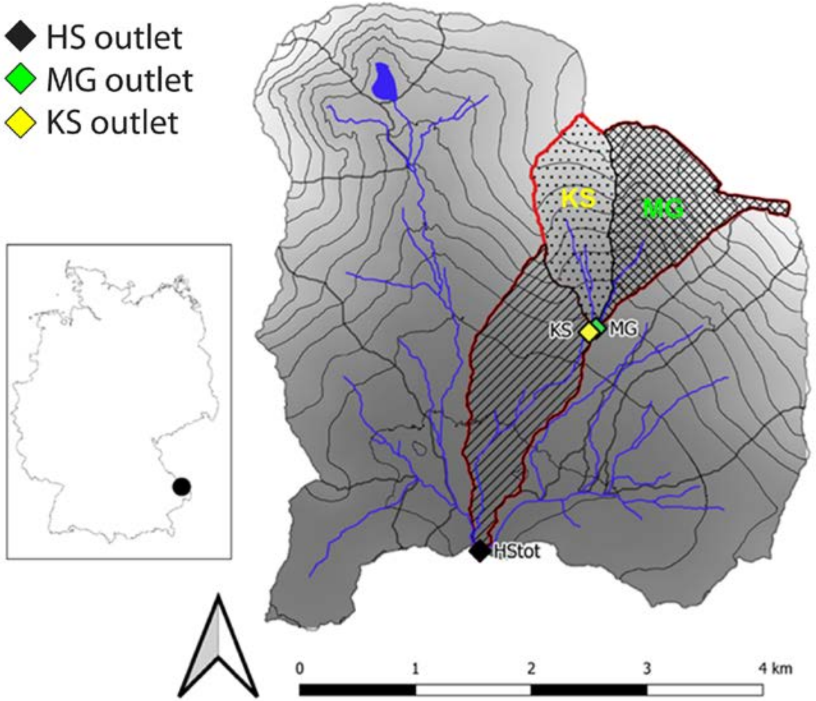
08.06.2023, Tharandt

Workshop: Terrestrische DOC-Einträge in Oberflächengewässer bewaldeter Einzugsgebiete

Outline

- Study area
  - Key features
  - Instrumentation
- Part I (DOC quantity) ← PhD work of Katharina Blaurock (UBT)
  - Event-based mobilization of DOC, as a function of topography and antecedent wetness conditions
- Part II (DOC quality) ← PhD work of Maria da Silva (UFZ)
  - Tracing DOC sources in-stream via high-resolution chemical fingerprinting
- Conclusion

Bavarian Forest National Park (BFNP) – Große Ohe

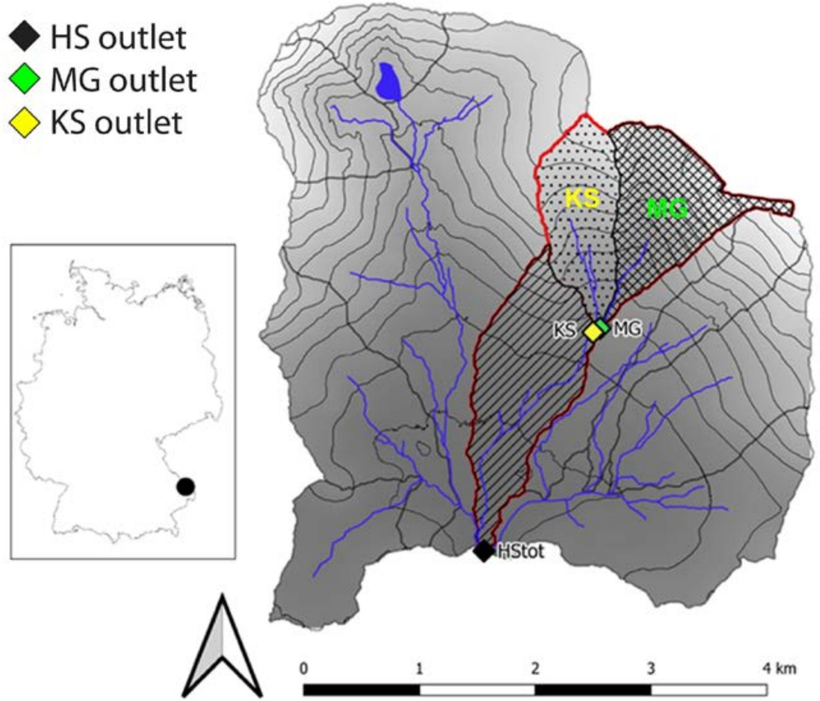


Catchment	Entire Hinterer Schachtenbach	Subcatchment Hinterer Schachtenbach (HS)	Subcatchment Markungsgraben (MG)
Area (km^2)	3.5	1.5	1.1
Elevation (m a.s.l.)	771–1355	771–1085	888–1355
Mean slope (°)	12.0	7.4	15.9
Soils (%)			
Cambisols	66	66	55
Podzols	15	0	34
Hydromorphic soils	17	34	5
Lithic Le			
Vegetatio			
Rejuvena			
Deciduou			
Conifero			
Mixed fo			
Other			

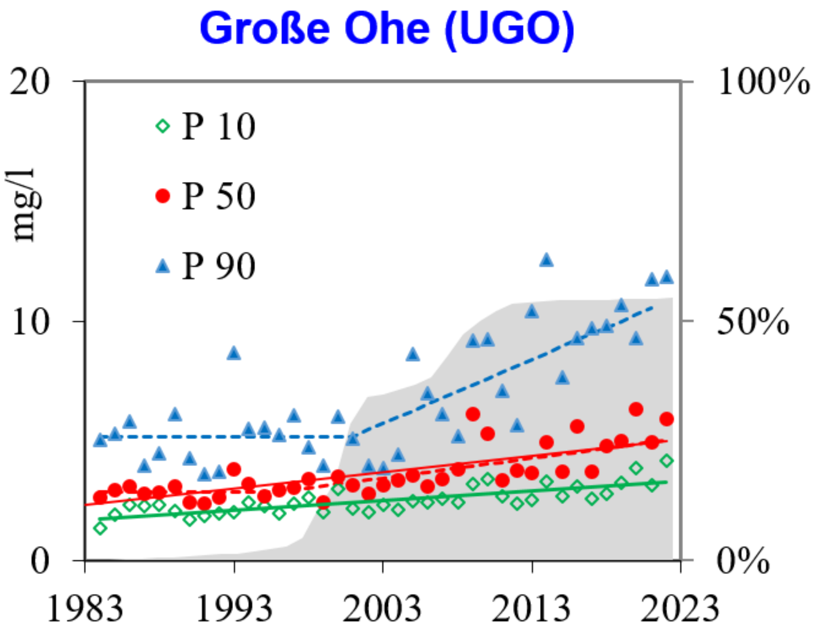
The catchment of the "Grohe Ohe" and the studied sub-catchments Markungsgraben (*MG*) and Hinterer Schachtenbach (HS). The Kaltenbrunner Seige (*KS*) also contributes to the HS.

Blaurock, K.; Beudert, B.; Gilfedder, B. S.; Fleckenstein, J. H.; Peiffer, S.; Hopp, L. Low hydrological connectivity after summer drought inhibits DOC export in a forested headwater catchment. *Hydrology and Earth System Sciences 2021, 25 (9), 5133-5151. DOI: 10.5194/hess-25-5133-2021.*

Long term DOC trends in the BFNP



The catchment of the “Grohe Ohe” and the studied sub-catchments Markungsgraben (MG) and Hinterer Schachtenbach (HS). The Kaltenbrunner Seige (KS) also contributes to the HS.



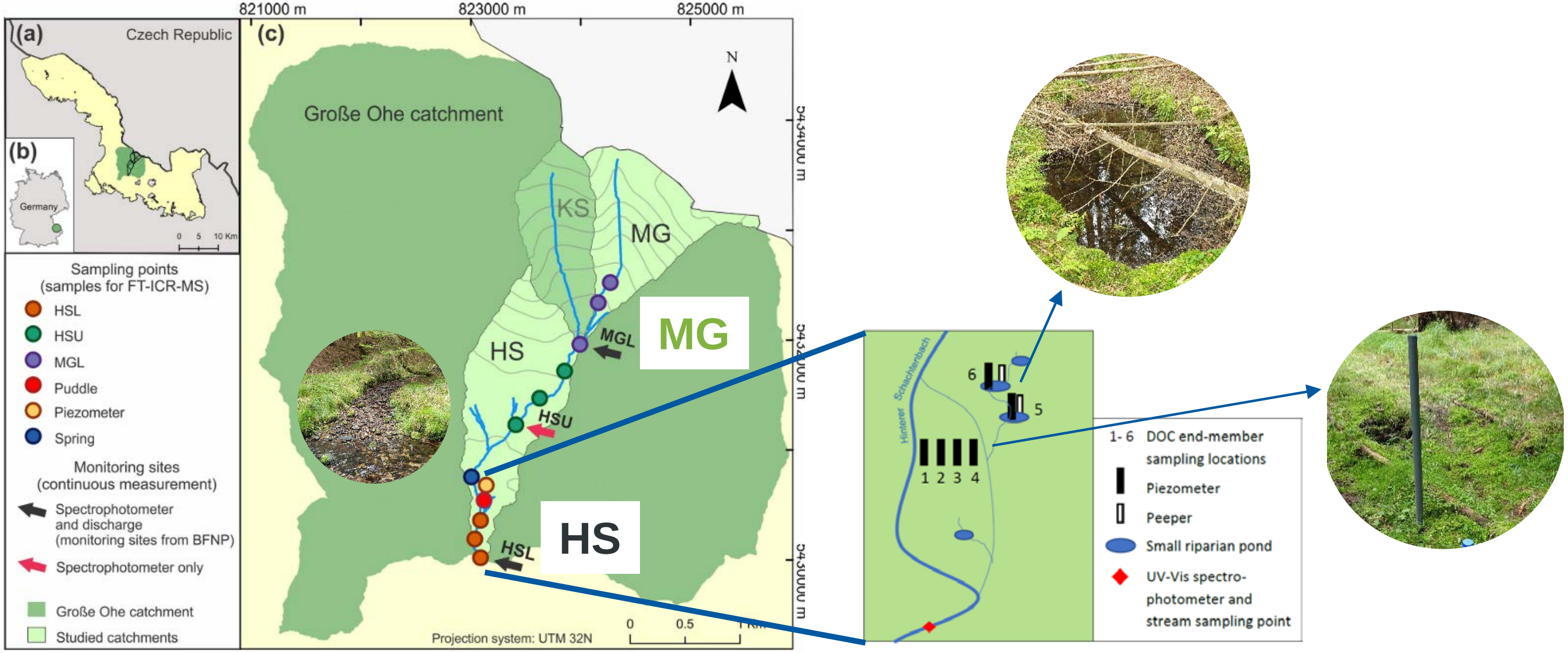
Trends in annual percentiles of DOC concentration in the “Große Ohe” river and percent of the catchment affected by deadwood (bark beetle). © Burkhard Beudert (BFNP)

Research questions

1. What are the mechanisms that drive DOC export in the BFNP?
2. How do steep vs flat catchment sections differ in their response to rain events?
3. Where does the DOC come from? I.e., what are the source areas for DOC?
4. What is the relative contribution of different catchment sections?

- We look at steep (upstream) and flat (downstream) sections of the same catchment
- We look at events and baseflow conditions
- We look at stream and soil (porewater)

Instrumentation and sampling period 2020 - 2023



Sampling locations in the Hinterer Schachtenbach (HS).

Detailed view of the riparian zone sampling locations in the lower section of the Hinterer Schachtenbach (HS).
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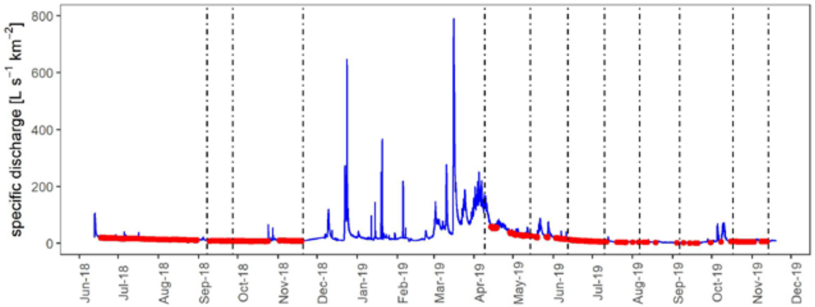
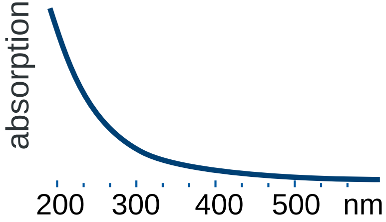
Instrumentation and sampling period 2020 - 2023

Discharge (Q)

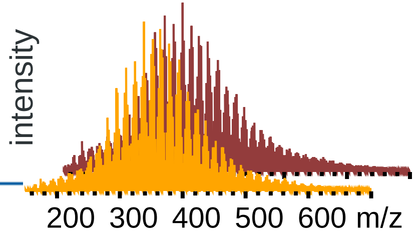


Spectrophotometer (spectro::lyser ®)



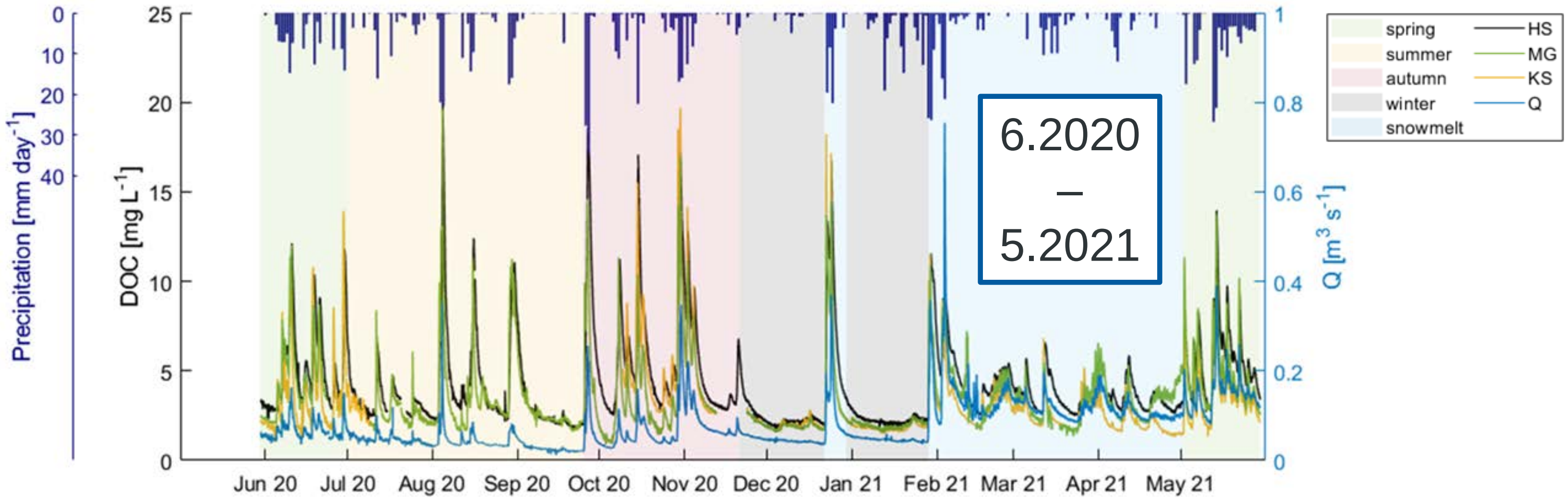
- High frequency, in-situ
- Estimation of DOC concentration
- Estimation of DOC quality (aromaticity)

Fourier-transform ion cyclotron resonance mass spectrometry (FT-ICR-MS)



- Chemical fingerprint of DOM
- Detailed tracing sources and processed
- Lab

Instrumentation and sampling period 2020 - 2023



In-stream DOC concentrations at outlets of Kaltenbrunner Seige (KS) and Markungsgraben (MG) sub-catchments and at outlet of Hinterer Schachtenbach (**HS**) catchment and discharge at HS (Q).

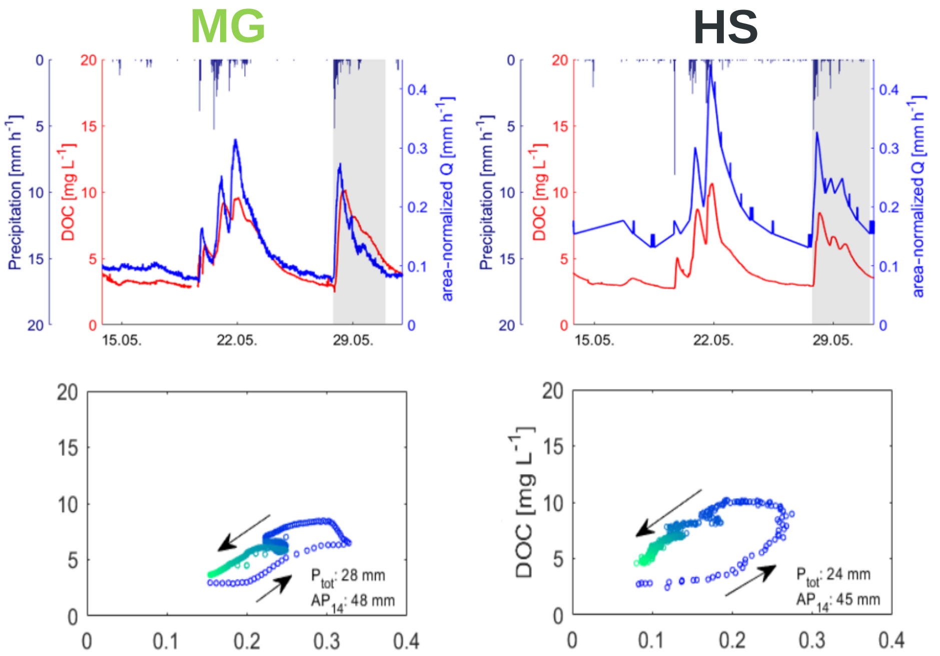
BioGeoOmics

Blaurock, K.; Beudert, B.; Gilfedder, B. S.; Fleckenstein, J. H.; Peiffer, S.; Hopp, L. Low hydrological connectivity after summer drought inhibits DOC export in a forested headwater catchment. *Hydrology and Earth System Sciences 2021, 25 (9), 5133-5151. DOI: 10.5194/hess-25-5133-2021.*

Impact of topography on Q-DOC relation and DOC export

Example event May 2019

- **MG**: narrow Q-DOC relation due to fast response of steep catchment section.
- **HS**: wider loops due to lag time until DOC source areas in flat catchment section are connected to stream.



DOC concentrations and area-normalized Q (top) starting 14 d prior to the event (gray area) in May 2019 at **HS** and **MG** and corresponding DOC–Q hysteresis during the events (bottom).

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Example event May 2019

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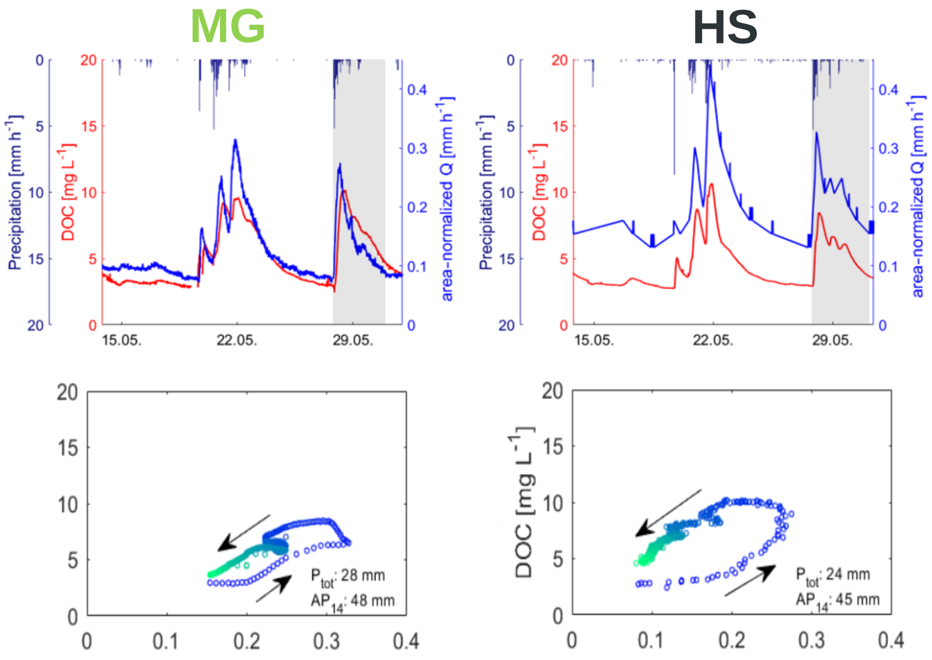
- **HS**: wider loops due to lag time until DOC source areas in flat catchment section are connected to stream.

→ “lag time” characteristic of “dominant source layer” concept (Ledesma et al 2018).

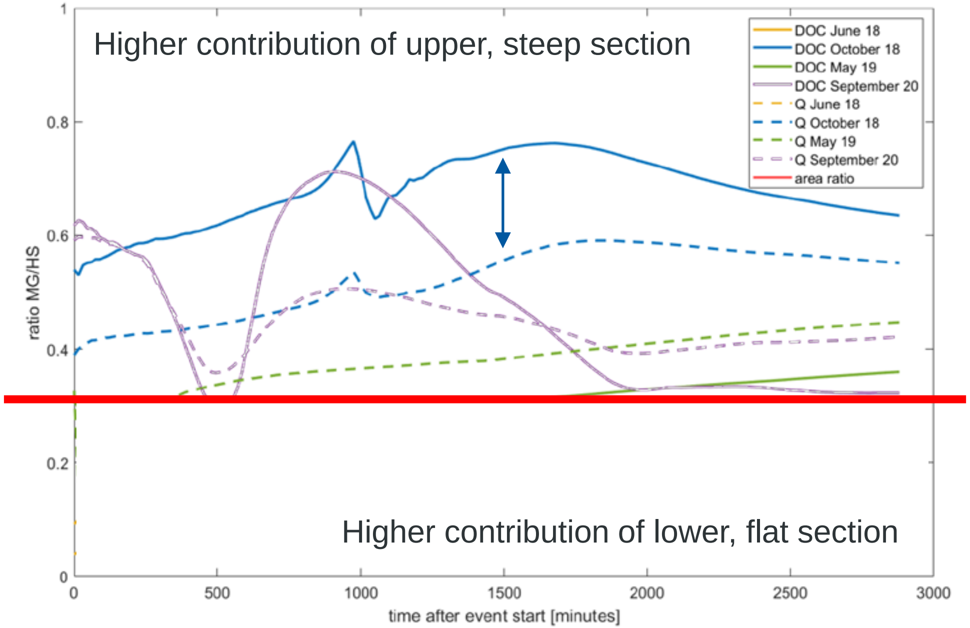


DOC concentrations and area-normalized Q (top) starting 14 d prior to the event (gray area) in May 2019 at **HS** and **MG** and corresponding DOC–Q hysteresis during the events (bottom).

Effect of antecedent conditions

- Response of (sub-)catchments depends on topographical position and antecedent wetness.
- Dry preconditions (Oct 18, Sept 20): MG contributes disproportionately more to DOC and Q.

  → faster response of steep sections, flat riparian zones must "reconnect" first (i.e., GW level rises first, then export possible)



Ratio of cumulative Q (dashed lines) and DOC load (solid lines) between MG sub-catchment and entire **HS** during the four selected events. The red line indicates the expected ratio by area (0.31).

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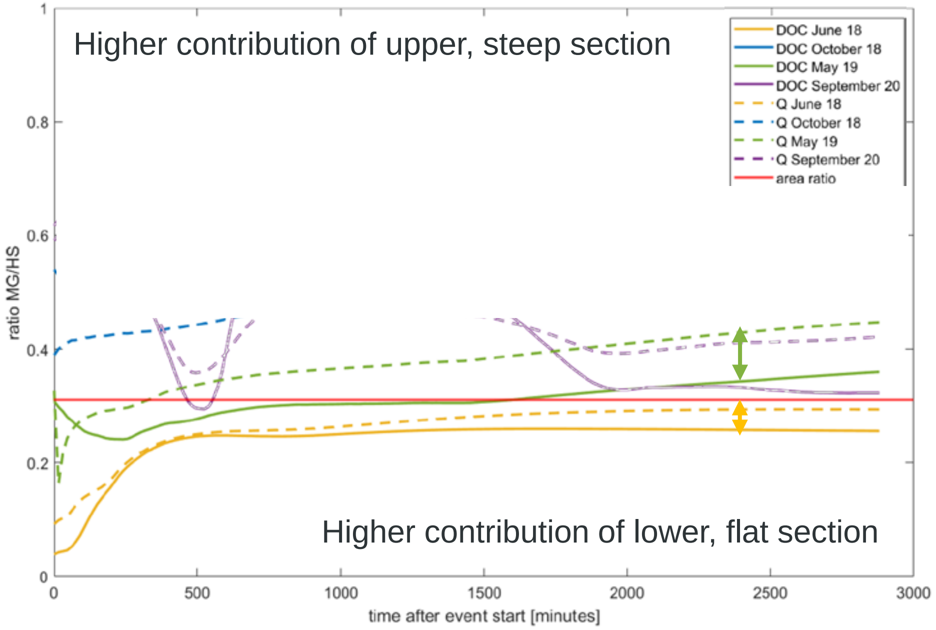
Effect of antecedent conditions

- Response of (sub-)catchments depends on topographical position and antecedent wetness.
- Wet preconditions (June 18, May 19): lower section of HS generate disproportionally more Q and DOC.

  → high GW level, “ready to export”.
- Even more pronounced for DOC than Q

  → DOC rich source areas connect.



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Lessons learned

- Topographical position and antecedent wetness control establishment of hydrological connectivity and DOC export behavior.

  How does it look exactly?

The impact of microtopography

- Shallow areas characterized by wider riparian zones with distinct micro-topography.
- Explains time lag:
  - o filling of ponds,
  - o connection of ponds to each other,
  - o surface runoff to stream
- Also observed in Rappbode catchment (Werner et al 2021)

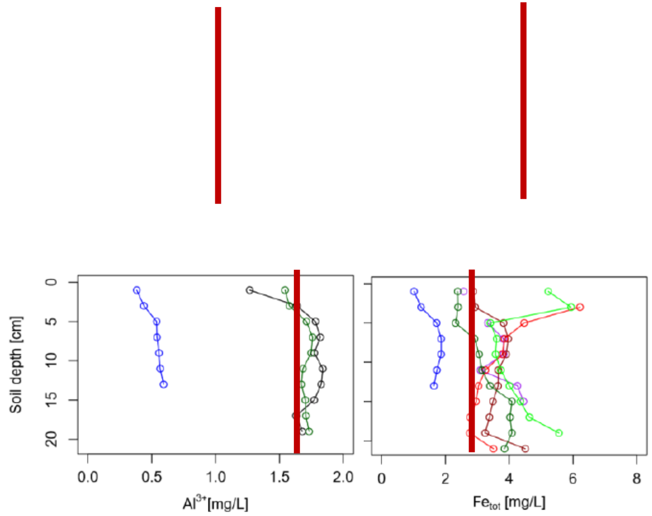
Filling and draining of ponds. Photos taken with a time lapse camera (a) before the event, (b) during the rising limb of the hydrograph, (c) at the maximum water level, and (d) at the lowest water level before the start of the next event.

Werner, B. J.; Lechtenfeld, O. J.; Musolff, A.; de Rooij, G. H.; Yang, J.; Gründling, R.; Werban, U.; Fleckenstein, J. H. Small-scale topography explains patterns and dynamics of dissolved organic carbon exports from the riparian zone of a temperate, forested catchment. Hydrology and Earth System Sciences 2021, 25 (12), 6067-6086. DOI: 10.5194/hess-25-6067-2021.

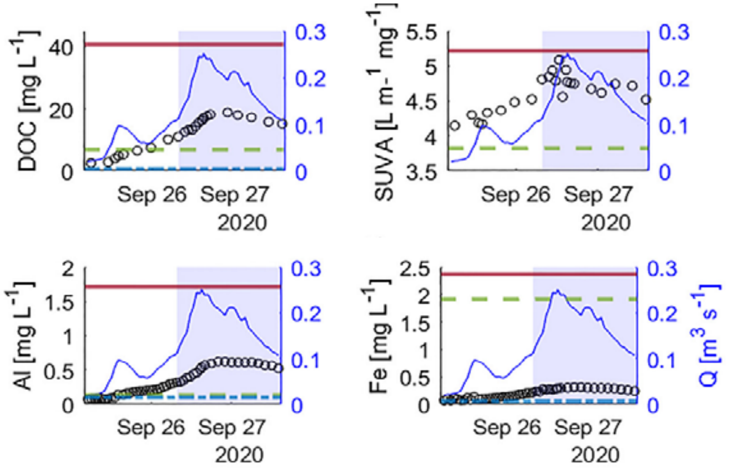
The impact of microtopography

- DOC concentration and quality during events approach pond water values

  → ponds are hotspots of DOC accumulation and release DOC into streams during events



Chemical composition of soil water in the upper 20 cm of a pond sampled between June and Oct 20. © Phil Gartner, Master Thesis UBT



Discharge (blue) and DOC concentration and aromaticity (SUVA), Al and Fe (black circles) of the stream during the event in September 2020. Mean values in the piezometers located in the forest soil (green dashed line) and the ponds (red line).

Blaurock, K.; Garthen, P.; da Silva, M. P.; Beudert, B.; Gilfedder, B. S.; Fleckenstein, J. H.; Peiffer, S.; Lechtenfeld, O. J.; Hopp, L. Riparian Microtopography Affects Event-Driven Stream DOC Concentrations and DOM Quality in a Forested Headwater Catchment. Journal of Geophysical Research: Biogeosciences 2022, 127 (12), e2022JG006831. DOI: 10.1029/2022jg006831.

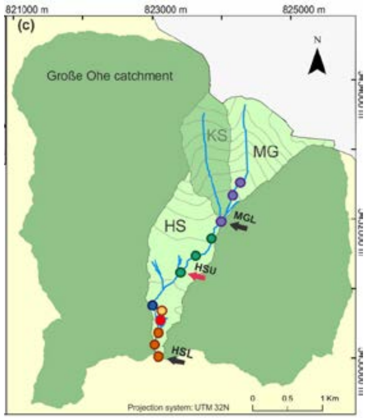
Lessons learned

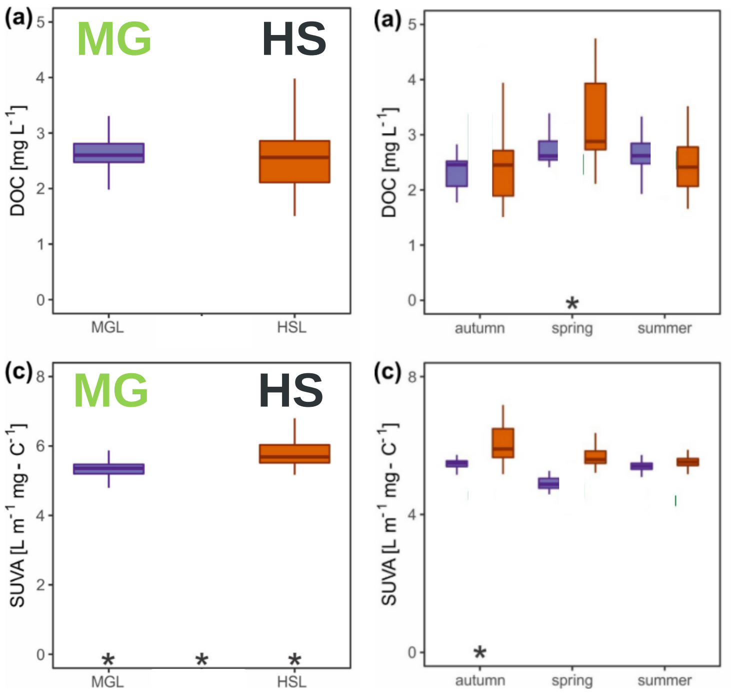
- Topographical position and antecedent wetness control establishment of hydrological connectivity and DOC export behavior
- Riparian zone microtopography (ponds) is a source area for in-stream DOC

Can we differentiate in-stream DOC sources based on its quality?

Baseflow DOC quality along the stream section

- Small effect of topography visible in DOC quality data: DOC in HS(L) more aromatic (plant derived) and varies more.
- But: No pronounced seasonal variation.





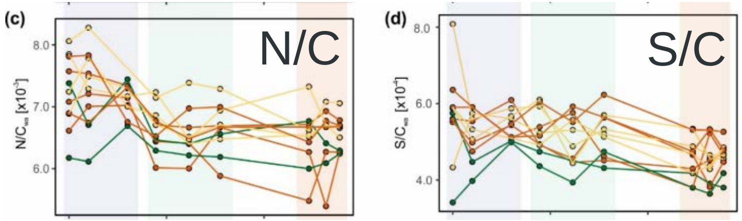
Spectrophotometer data recorded at baseflow conditions during the study period for dissolved organic carbon (DOC) concentration, and specific ultraviolet absorbance (SUVA).

Silva, M. P.; Blaurock, K.; Beudert, B.; Fleckenstein, J. H.; Hopp, L.; Peiffer, S.; Reemtsma, T.; Lechtenfeld, O. J. Delineating Source Contributions to Stream Dissolved Organic Matter Composition Under Baseflow Conditions in Forested Headwater Catchments. Journal of Geophysical Research: Biogeosciences 2021, 126 (8), e2021JG006425. DOI: 10.1029/2021jg006425.

Baseflow DOC quality along the stream section

- Upper section of catchment contributes more microbial (N-,S-rich) organic material.

  → Indicative of “reworked” organic matter from deeper soil layers.



Longitudinal profile of relative N- and S- content of organic matter calculated from the commonly found DOM compounds between samples of the same zone and colored according to the calendar season.

High resolution chemical fingerprinting:
More dimension allow for higher sensitivity and specificity

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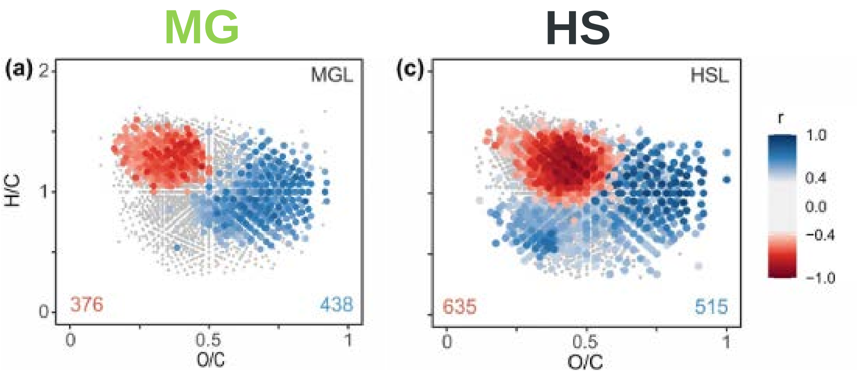
Contribution of DOC sources by chemical fingerprinting

Already under baseflow, different DOM contributions can be discerned:

- aromatic DOM increases with increasing DOC concentrations, aliphatic DOM decreases.

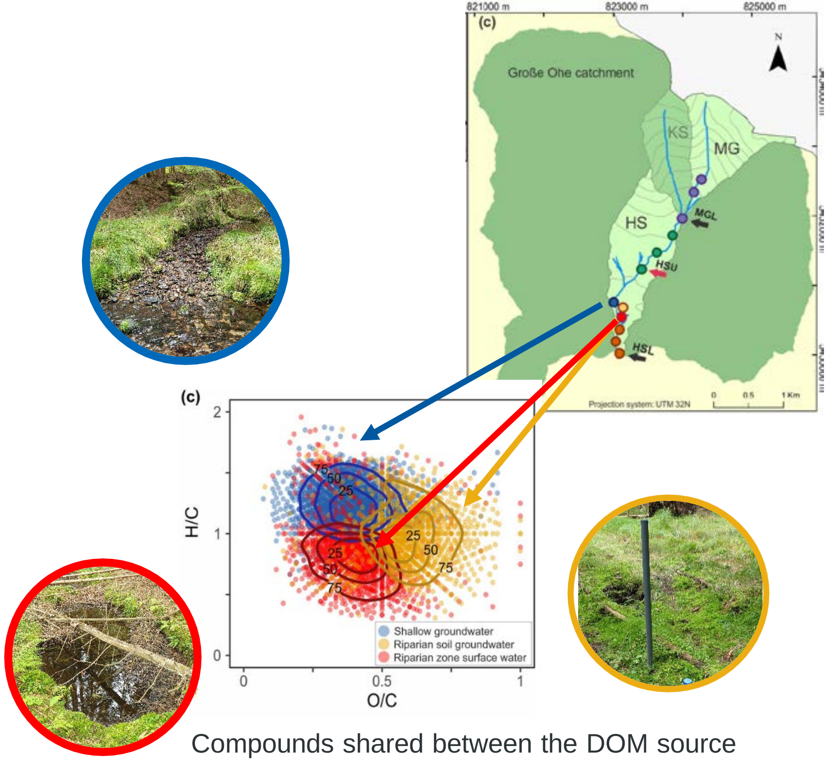


DOM compounds in Markungsgraben (**MG**) and Hinterer Schachtenbach (**HS**) color coded according to the correlation coefficient of abundance with dissolved organic carbon (DOC) concentration.

Contribution of DOC sources by chemical fingerprinting

Already under baseflow, different DOM contributions can be discerned:

- aromatic, CHO-rich DOM increases with increasing DOC concentrations, aliphatic DOM decreases.
  - o Aliphatic DOM attributed to (shallow) groundwater
  - o Aromatic DOM attributed to riparian soil water and riparian surface water.



Compounds shared between the DOM source samples colored according to the source in which the compound showed the highest abundance.

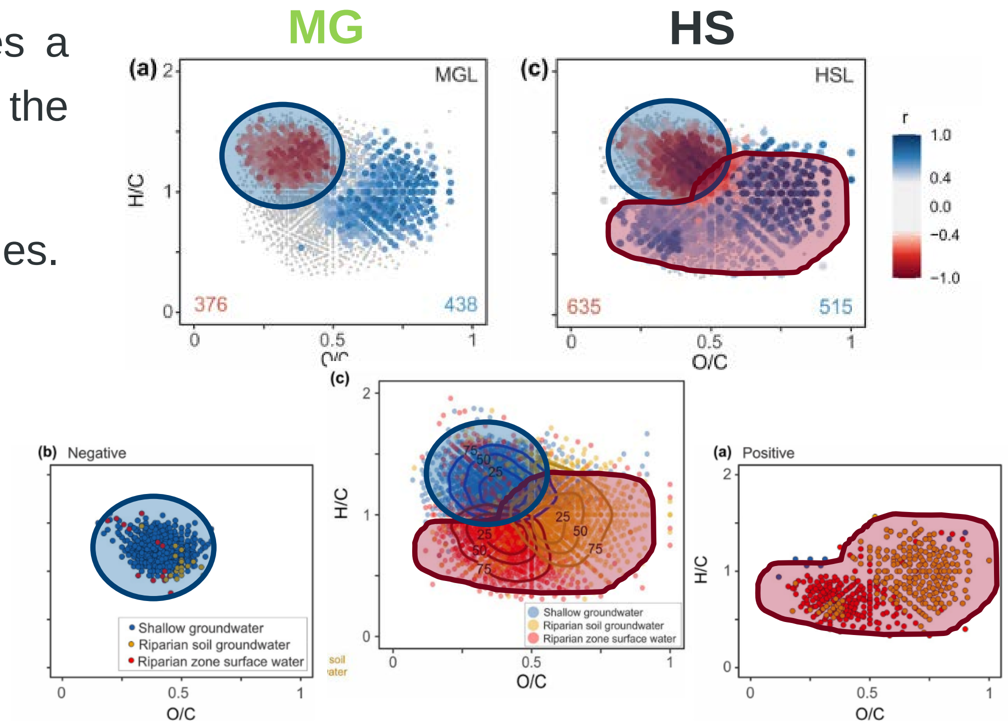
Silva, M. P.; Blaurock, K.; Beudert, B.; Fleckenstein, J. H.; Hopp, L.; Peiffer, S.; Reemtsma, T.; Lechtenfeld, O. J. Delineating Source Contributions to Stream Dissolved Organic Matter Composition Under Baseflow Conditions in Forested Headwater Catchments. Journal of Geophysical Research: Biogeosciences 2021, 126 (8), e2021JG006425. DOI: 10.1029/2021jg006425.

Contribution of DOC sources by chemical fingerprinting

Flat section (**HS**) of catchment contributes a unique DOM signature not observed in the upper section (**MG**). This signature

→ reflects aromatic DOM from riparian zones.

→ is positively correlated to DOC concentration.



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Lessons learned

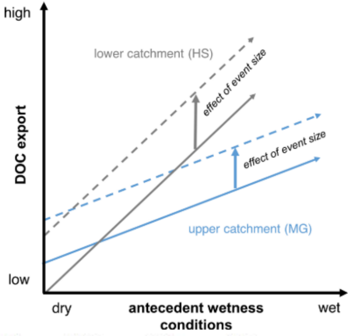
- Topographical position and antecedent wetness control establishment of hydrological connectivity and DOC export behavior
- Riparian zone microtopography (ponds) is a source area for in-stream DOC
- Combination of stream and soil water DOC quality can further resolve DOC source material and potential sources.
- Chemical fingerprinting supports conclusions from DOC quality with unique source signatures detectable in stream water DOM.

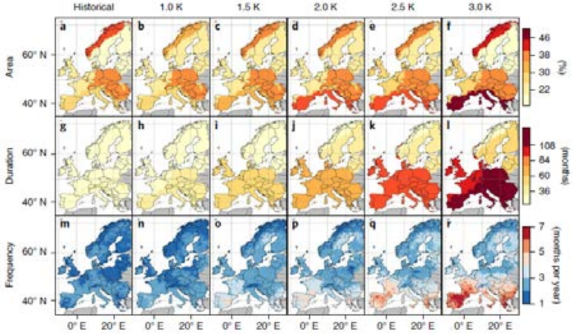
Conclusions

- Riparian zones are contributors to stream DOC with high concentrations and specific DOM quality.

- The connection and thus importance of the riparian zones depends on the wetness state and event size.

- Changes in drought and storm events frequency and duration may shift the importance of the contributing DOC source zones.





L. Samaniego, S. Thober, R. Kumar, N. Wanders, O. Rakovec, M. Pan, M. Zink, J. Sheffield, E. F. Wood, and **A. Marx** (2018): Anthropogenic warming exacerbates European soil moisture droughts. Nature Climate Change.
Blaurock, K.; Garthen, P.; da Silva, M. P.; Beudert, B.; Gilfedder, B. S.; Fleckenstein, J. H.; Peiffer, S.; Lechtenfeld, O. J.; Hopp, L. Riparian Microtopography Affects Event-Driven Stream DOC Concentrations and DOM Quality in a Forested Headwater Catchment. Journal of Geophysical Research: Biogeosciences 2022, 127 (12),

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