RESEARCH GROUP

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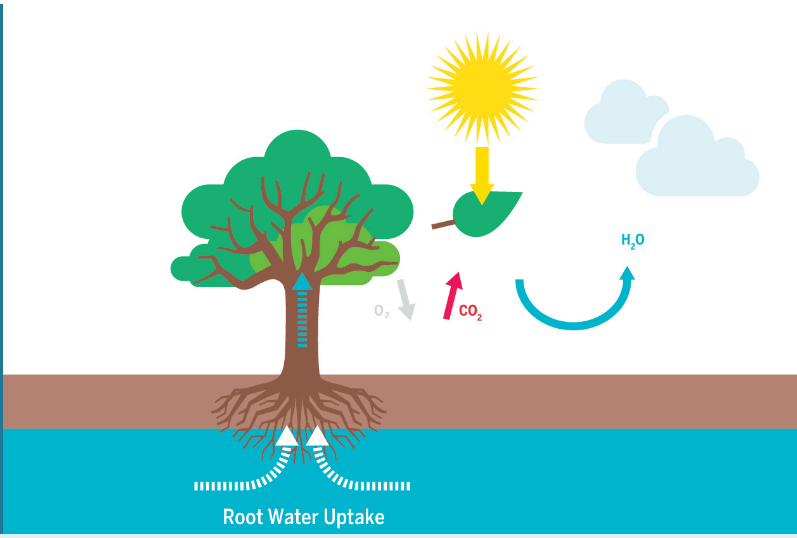
Catchment and Eco-hydrology



At the Catchment and Eco-hydrology (CAT) research group, we rely on a unique blend of experts in catchment hydrology, eco-hydrology, isotope hydrology, hydro-geochemistry, environmental chemistry, sediment transport and plant physiology for characterising the fluxes of water, matter and contaminant within and across the various compartments of the critical zone.
We collaborate with our colleagues from the AGRO and REMOTE groups for leveraging the full potential offered by new in-situ and remote sensing technologies (some of them developed in-house) – providing data with unprecedented spatial and temporal resolution, ultimately serving for the calibration and validation of newly designed forecasting and prediction tools of hydro- and agro-ecosystem responses to global change.

MAIN EXPERTISE FIELDS

Sensing and numerical process-based modelling of water, matter and contaminant fluxes within and across the various compartments of the critical zone, development of new environmental sampling and analytical protocols, with a focus on:

- Vegetation response to global change: experimental biophysics from micro-scale to whole plant scale; water cycle-vegetation feedbacks.
- Bedrock weathering, soil erosion and sediment transport: fine sediment fluxes, sources, composition and dynamics; origin and dynamics of nutrients and trace elements.
- Hydrological extremes: (flash-)flood and drought monitoring and forecasting tools.
- Water futures under change: surface and groundwater age dating; water resources response to global change. quantitative and qualitative assessment and management of water resources.
- Instrumental development: high-frequency sampling and monitoring systems; new water extraction systems; new geophysical tools for characterising groundwater resources.

RESEARCH CHALLENGES

Our activities are wired around fundamental and applied research questions:

- What factors control the fundamental eco-hydrological catchment functions of water, solutes and matter collection, storage, mixing and release?
- How resilient or vulnerable are catchments – and their fundamental eco-hydrological functions – towards global change?
- How can we overcome measurement limitations proper to an accelerating hydrological cycle and an inherent sheer endless spatial and temporal diversity in rainfall-runoff responses?
- How can we re-align the outstanding capacity to collect and create data with our (limited) ability to assimilate it (4Vs of big data), enhance our process understanding, and ultimately improve our predictive capacities?

This includes research on:

- water sources, flow paths and transit times, including the multimodality of stream TTDs, its origin, and its consequences for tracer hydrology and stream chemistry
- water quality and sediment characteristics, including sources, transport and toxicity of suspended sediments, emerging micropollutants, nutrients and trace metal concentrations
- soil-vegetation-atmosphere transfer of energy, gas, water and nutrients, including the identification of general physical constraints on vegetation-environment interactions that will help constrain our expectations about the future of water resources, food production and ecosystem services
- reconstruction of historical environmental conditions by using natural archives or proxy records for extending short, incomplete or low-quality datasets hindering the detection and mechanistic interpretation of climate change signals in environmental records
- new technologies and methodologies for overcoming limitations of conventional monitoring instruments and protocols, including field deployable prototypes for high-frequency or passive environmental sampling and laboratory prototypes for measuring stable isotope fractionation of O and H in water under harsh environmental conditions.

Application areas

- Global change & water – (flash-)flood and drought monitoring and forecasting tools; water resources response to global change; quantitative and qualitative assessment and management of water resources
- Global change, nutrient, carbon and water cycles – soil-biosphere-atmosphere interactions at multiple spatio-temporal scales under environmental and ecohydrological extremes; soil microbial controls over carbon and nutrient cycling in ecosystems
- Environmental monitoring – high-frequency sampling and monitoring systems; real-time adaptive environmental monitoring; passive samplers; water extraction systems; geophysical tools for characterising groundwater resources
- Soil erosion and sediment transport - fine sediment sources, composition and fluxes; origin and dynamics of nutrients and trace elements
- Space resources and exo-hydrology – observation and modelling of water ice sublimation and related isotope fractionation in a lunar environment (high vacuum and low temperature)

Main assets

We provide a one-stop-shop for integrated solutions to complex questions inherent to the anticipation of eco-hydrosystem responses to global change:

Water tracers for environmental assessments

- Dating of surface and ground water samples (tritium, C14, stable isotopes of O and H)
- Groundwater recharge and depletion, Groundwater fraction in river flow, Constraining of catchment water balances (e.g., electrical conductivity, major & trace ions, water temperature, radio- and stable isotopes, ground-based thermal IR)
- Exo-hydrology (e.g., observation and modelling of water ice sublimation and isotope fractionation under lunar environmental conditions)

Water and vegetation

- Plant water uptake & transport
- Shoot and root gas and nutrient exchange
- Leaf gas and energy exchange

Water quality and sediment characteristics

- Sources and toxicity of emerging micropollutants
- Nutrients and trace metal concentrations
- Origin and transport of suspended sediments

Hydrological analyses

- Precipitation (e.g., calculation of areal rainfall, Intensity-Duration-Frequency analysis)
- River flow (e.g., flow frequency, flood frequency, flood probabilities, flood prediction, low flow frequency)
- Hydrological proxy data series collection and analyses

Numerical modelling

- Rainfall-runoff modelling
- Eco-hydrological modelling
- Hydrogeological modelling
- Catchment transit time modelling

EQUIPMENT

For overcoming pressing technological limitations of conventional tools and protocols, we design, build and test field and laboratory prototypes, experimental set-ups and protocols – responding to demanding high-resolution and /or high-frequency sampling /sensing criteria. In addition, we rely on state-of-the-art field and laboratory infrastructures, including:

- Weierbach experimental catchment: operated in a long-term research perspective and focusing at CZ research (https://blogs.egu.eu/divisions/hs/2020/07/29/weierbach-catchment/).
- Water sampling: long-term grab sampling programs of surface & groundwater bodies, passive samplers, high-frequency event-based sampling of rainfall-runoff events with automatic sampling devices.
- Isotope laboratory: designing its own water extraction protocols (from soils, plants, regolith) and carrying out subsequent O and H stable isotope analyses with laser spectrometers.
- Geochemistry laboratory: offering environmental sample mineralization and preparation for the determination of nutrients and trace metal concentrations as well as Sr-Nd-Pb isotopic ratio quantifications.
- Sediment characterisation: turbidimeters, laboratory and field laser diffraction particle size analysers, sediment sampling devices, UV-VIS spectrometer probes and an underwater camera.
- Geophysics: IRIS Syscal Pro 120 all-in-one multi-node resistivity and induced polarization imaging system for environmental and engineering geophysical studies (e.g., 2D and 3D characterisation of subsurface geometry and properties).
- Numerical modelling tools: HydroGeoSphere, Coupled Water Balance and Vegetation Optimality Model, Catchment Travel Time Distributions

Selected publications

2021

- Exploring the regolith with electrical resistivity tomography in large-scale surveys: electrode spacing-related issues and possibility, Gourdol, L., Clément, R., Juilleret, J., Pfister, L., and Hissler, C. (2021). Hydrology and Earth System Sciences 25, 1785-1812.
- The Weierbach experimental catchment in Luxembourg: A decade of critical zone monitoring in a temperate forest - from hydrological investigations to ecohydrological perspectives, Hissler, C., Martínez-Carreras, N., Barnich, F., Gourdol, L., Iffly, J. F., Juilleret, J., Klaus, J., Pfister, L. (2021). Hydrological Processes. 35. e14140.
- A comparison of catchment travel times and storage deduced from deuterium and tritium tracers using StorAge Selection functions, Rodriguez, N. B., Pfister, L., Zehe, E., Klaus, J. (2021). Hydrology and Earth System Sciences 25, 401–428.

2020

- Saturated areas through the lens: 2. Spatio-temporal variability of streamflow generation and its relationship with surface saturation, Antonelli, M., Glaser, B., Teuling, A.J., Klaus, J., Pfister, L. (2020). Hydrological Processes 34, 1333-1349.
- Saturated areas through the lens: 1. Spatio-temporal variability of surface saturation documented through Thermal Infrared imagery, Antonelli, M., Glaser, B., Teuling, A.J., Klaus, J., Pfister, L. (2020). Hydrological Processes 34, 1310-1332.
- Organizing principles for vegetation dynamics, Franklin, O., Harrison, S.P., Dewar, R., ..., Schymanski, S., et al. (2020). Nature Plants 6, 444–453.
- Multimodal water age distributions and the challenge of complex hydrological landscapes, Rodriguez, N.B., Benettin, P., Klaus, J. (2020). Hydrological Processes 34, 2707-2724.
- Freshwater pearl mussels from northern Sweden serve as long-term, high-resolution stream water isotope recorders, Schöne, B. R., Meret, A. E., Baier, S. M., Fiebig, J., Esper, J., McDonnell, J., and Pfister, L. (2020). Hydrology and Earth System Sciences, 24, 673–696.
- Multi-tracer analysis to estimate the historical evolution of pollution in riverbed sediment of subtropical watershed, the lower course of the Piracicaba River, São Paulo, Brazil, Tomazini da Conceiçãoa F., Fernandes A.M., Lupinacci C.M., Menegário A.A., Hissler C., Moruzzi R.B. (2020). Science of the Total Environment, 743, 140730.

2019

- Catchment travel times from composite StorAge Selection functions representing the superposition of streamflow generation processes, Rodriguez, N.B., Klaus, J. (2019). Water Resources Research, 55, 9292-9314.
- How meaningful are plot scale observations and simulations of preferential flow for catchment models?, Glaser, B., Hopp, L., Jackisch, C., Klaus, J. (2019). Vadose Zone Journal, 18, 180146.
- Assessing the Catchment Storage Function through a Dual-Storage Concept, Carrer, G., Klaus, J., Pfister, L. (2019). Water Resources Research, 55, 476–494.
- Sediment transport modelling in riverine environments: on the importance of grain-size distribution, sediment density and suspended sediment concentrations at the upstream boundary, Lepesqueur, J., Hostache, R., Martinez-Carreras, N., Montargès-Pelletier, E., Hissler, C. (2019). Hydrology and Earth System Sciences, 23, 3901–3915.
- A global assessment of freshwater mollusk shell oxygen isotope signatures and their relation to precipitation and stream water, Pfister, L., Grave, C., Beisel, J. N., McDonnell, J. J. (2019). Scientific Reports, 9, 4312.

2018

- Technical note: Mapping surface saturation dynamics with thermal infrared imagery, Glaser, B., Antonelli, M., Chini, M., Pfister, L., Klaus, J. (2018). . Hydrology and Earth System Sciences, 22, 5987-6003.
- Inter-laboratory comparison of cryogenic water extraction systems for stable isotope analysis of soil water, Orlowski N., Breuer L., Angeli N., Boeckx P., Brumbt C., Cook C., Dubbert M., Dyckmans J., Gallagher B., Gralher B., Herbstritt B., Hervé-Fernández P., Hissler C., Koeniger P., Legout A., Macdonald C.J., Oyarzún C., Redelstein R., Seidler C., Siegwolf R., Stumpp C., Thomsen S., Weiler M., Werner C., McDonnell J.J. (2018). Hydrology and Earth System Sciences, 22, 3619-3637.
- Freshwater pearl mussels as a stream water stable isotope recorder, Pfister L., Thielen F., Deloule E., Valle N., Lentzen E., Grave C., Beisel J.-N., McDonnell, J.J. (2018). Ecohydrology, 11.

2017

- Genesis and evolution of regoliths: evidence from trace and major elements and Sr-Nd-Pb-U radiogenic isotopes, Moragues-Quiroga, C., Juilleret, J., Gourdol, L., Pelt, E., Perrone, T., Aubert, A., Morvan, G., Legout, A., Stille, P., Hissler, C. (2017). Catena, 149, 185-198.
- Framing and testing hypotheses in hydrology: theory and practice, Pfister, L., Kirchner, J. W. (2017). Water Resources Research, 53.
- Bedrock geology controls on catchment storage, mixing and release: a comparative analysis of 16 nested catchments, Pfister, L., Martínez-Carreras, N., Hissler, C., Klaus, J., Stewart, M. K., McDonnell, J. J. (2017). Hydrological Processes, 31.
- Technical note: An experimental set-up to measure latent and sensible heat fluxes from (artificial) plant leaves, Schymanski, S. J., Breitenstein, D., and Or, D.: Hydrology and Earth System Sciences, 21, 3377–3400.

Partenaires

- Administration de la gestion de l'eau – Ministère de l'Environnement, du Climat et du Développement durable
- Administration de l'environnement – Ministère de l'Environnement, du Climat et du Développement durable
- Administration des services techniques de l'agriculture – Ministère de l'Agriculture, de la Viticulture et du Développement rural
- Ville de Luxembourg – Service des eaux
- OHB Blue Horizon Sarl
- University of Luxembourg – Faculty of Science, Technology and Medicine
- Karlsruher Institut für Technologie – Institut für Wasser und Gewässerentwicklung, IWG/KIT
- Universität Mainz – Institut für Geowissenschaften
- University of Birmingham – School of Geography, Earth and Environmental Sciences
- INRAE – Unité de recherche Biogéochimie des Ecosystèmes Forestiers
- Université de Strasbourg – Laboratoire d'Hydrologie et de Géochimie de Strasbourg
- Université de Lorraine – Laboratoire Interdisciplinaire des Ecosystèmes Continentaux
- Wageningen University – Department of Environmental Sciences, Hydrology and Quantitative Water Management
- TU Delft – Civil Engineering and Geosciences, Water management department
- TU Vienna – Institute of hydraulic engineering and water resources management
- University of Saskatchewan – Global Institute for Water Security, School of Environment and Sustainability
- School of Renewable Natural Resources, Forest and Wetland Ecohydrology Lab (Louisiana State University)
- Swiss Federal Institute for Forest Snow and Landscape Research WSL
- Forschungszentrum Jülich
- Eidgenössische Technische Hochschule Zürich, ETHZ – Department of Environmental Systems Science
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