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"The role of small experimental catchments in education and research"

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ERB MEDAL LECTURE

Four Decades of Enjoyment with Mountain Hydrology

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Abstract

Austrian writer Stefan Zweig, notes in his book Decisive Moments in History, that while history usually flows like a slow stream, changing little for decades or even centuries, there are rare moments when a single event changes the world forever. In our lives, similar moments can determine our future path. One such moment brought me, a student of hydrogeology expecting to spend his professional life doing hydrogeological surveys and pumping tests (likely doing something else or operating its own consultancy business at present), – into the research of hydrological balance and processes in mountains, learning from many distinguished colleagues, and exploring new ideas.

I was fortunate to join a newly established hydrological research catchment from its very beginning – helping to build the measurement network in the beautiful Tatra mountains, conducting and evaluating observations, designing and performing my own experiments, thinking about the uncertainties influencing our conclusions and doubts that sometimes accompany academic work.

Although I did not need to think about the organisation and direction of our research in the very beginning, over time I concluded for myself that two intertwined aspects of the long-term research in mountains are important. The first is long-term, consistent monitoring of basic hydrological characteristics – catchment discharge, precipitation, air temperature, snow water equivalent and soil moisture. This is not a trivial task, but its successful completion (although it is never truly finished) provides the basis for detecting variations that can test our perceptions, theories or products. The second aspect involves short-term measurements focused on specific questions that can provide resources for the long-term monitoring and address emerging research themes. I would like to share a few reflections on both aspects and mention some findings that have surprised me (perhaps only me). They are related to stream-groundwater interactions, spatial distribution of precipitation, stream sampling frequency and more.

SESSION 1
Small Experimental Catchments as Platforms for Research and Education

The Magyaregregy Experimental Catchment as a Platform for Hydrological Research and Practical Training

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Abstract

Small experimental catchments play an important role in understanding hydrological processes, while they also provide unique opportunities for education and practical training. The upper catchment of the Völgységi Creek, located in the Eastern Mecsek Hills in Hungary, is a fast-responding and erosion-sensitive experimental catchment. The small streams typically flow in rocky channels, and intensive rainfall events can generate rapid flood waves. Due to its near-natural conditions and diverse topography, the catchment is well suited for hydrological and hydro-meteorological research.

The Lászlóffy Woldemár Hydrometric Station of the Faculty of Water Sciences, Ludovika University of Public Service, operates in the catchment and serves both research and educational purposes. Monitoring and scientific activities in the area had stopped for several decades, but they were restarted in 2017. Since 2019, a complex monitoring system has been gradually developed. The current monitoring network includes meteorological stations, stream gauge systems, soil moisture monitoring stations, and mobile field measurement equipment. Continuous field measurements provide the opportunity to investigate rainfall-runoff processes, soil moisture dynamics, and near-surface lateral water movement in detail.

The research infrastructure is strongly connected to university education. The hydrometric station regularly hosts hydrometry field practices, field courses, BSc and MSc thesis projects, and PhD research activities. Students actively participate in instrument installation, data collection, field measurements, and data processing. In this way, the experimental catchment functions as a living laboratory that supports practice-oriented engineering education.

The aim of the study is to demonstrate how a small experimental catchment can simultaneously support long-term hydrological research, model development, and the practical side of engineering education. Based on the experiences gained so far, small experimental catchments can play an important role in the education of future hydrologists and water engineers, while also contributing to a better understanding of extreme hydrological events.

Keywords: *experimental catchment, hydrological monitoring, field education, hydro-meteorological measurements, rainfall-runoff processes, engineering education*

Integrating Forest Hydrology Research and Field Education in the Hidegvíz Valley Experimental Catchment, Hungary

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Abstract

The Hidegvíz Valley research area maintained by the University of Sopron plays a significant role in Hungarian forest hydrology research and education. The experimental catchment provides an excellent field laboratory for investigating precipitation partitioning, runoff generation, forest water cycling, groundwater dynamics, and water quality under changing climatic conditions. Long-term hydrological observations in the valley support a better understanding of watershed processes and the ecological importance of water retention in forested landscapes.

Recent studies conducted at the site demonstrated that even temporary water retention interventions can substantially improve local water availability. Short-term retention measures resulted in rapid increases in streamflow and groundwater levels, creating more favourable conditions for riparian forest ecosystems during increasingly frequent summer drought periods. These findings highlight the potential of small-scale retention solutions as practical tools for climate adaptation and sustainable watershed management.

In addition to its scientific importance, the research area has a major educational function. It serves as a living outdoor classroom where university students, young researchers, and professionals can gain practical experience in field hydrology, environmental monitoring, and data interpretation under real-world conditions. Through the integration of research, education, and applied water-management practices, the Hidegvíz Valley research catchment represents a valuable model for sustainable forest watershed management and climate resilience.

Keywords: *experimental catchment, forest hydrology, water retention, outdoor classroom*
Acknowledgement: This work was supported by project EGF/392/2025 "Erdőállományok vízháztartása".

Hydrological Research and Student Education on the Medvednica Mountain (Croatia)

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Abstract

Medvednica mountain is situated on the northern edge of the city of Zagreb, Croatia's capital. It is a forested, geologically complex mountain whose relief is very much shaped by numerous small streams. Those streams have a torrential hydrological nature, with quick reactions to precipitation. Nevertheless, recent studies discovered that those streams are fed throughout the whole year by numerous springs. More than 900 springs were mapped on the southern half of the Medvednica mountain nature park. It was the first comprehensive research and spring mapping of this scale in this area, and one of the first in Croatia in general. Together with their location, spring discharge classes were determined for most of the springs and physico-chemical parameters were measured in situ. The research has shown great geomorphological and hydrological diversity, with springs of discharge under 1 L/s dominating the area. Measured electrical conductivity (EC) values witness the complex lithology of the area, but they also reflect anthropogenic influence on the water quality. The methods used in this research are presented to geography students during field classes. Furthermore, small catchments of the Medvednica mountain are used in field education because of their complex environment: the upper reaches of the streams are mostly in their natural state, while the lower, urban sections have been altered by human activity. For this reason, they are ideal for field education. Students in field excursions have the opportunity to learn about the hydrology of streams and springs, hydromorphology, geomorphology, as well as practical field measurement methods used in physical geography.

Keywords: *Medvednica mountain, hydrology, field education, springs*

Multi-criteria Assessment of the Benefits of Water Retention Techniques in Small Agricultural Catchments: An Inclusive Workflow to Maximise Relevance, Uptake and Educational Value

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Abstract

The OPTAIN (EU-horizon, www.optain.eu) project aimed to develop an innovative participatory workflow and decision support system to assess how the use of natural small water retention measures (NSWRM) benefits the long-term sustainability of agricultural production in small catchments in the context of a changing climate. The core of the workflow was a modelling framework using the SWAT+ hydro-biochemical model that was able to simulate water, sediment and nutrient fluxes within the catchment on land and in the various types of water bodies. The selection, sizing and placement options of simulated NSWRMs within the catchment was guided by the local multi-actor reference group (MARG), assuring that the process is inclusive and the options are practically applicable for farmers and supported by local policymakers. A multi-criteria system usable for education and decision support has been subsequently developed that helped simultaneously weigh and communicate the costs and benefits each of several thousand NSWRM placement variants in the catchment along the most important set of environmental and (socio-)economic indicators chosen by the local MARG. The outcome has been integrated into a web-based learning environment that is usable for education, dissemination and policy support. The workflow has been developed simultaneously on 14 case studies in 3 different biogeographical regions of Europe, assuring that the workflow is fully adaptable to local conditions elsewhere. In this presentation we use a Norwegian case study from the boreal region to demonstrate the overall workflow and to highlight selected aspects.

Keywords: *natural small water retention measures, SWAT+ model, agricultural catchment, multi-objective optimisation, environmental and economic indicators*

Testing Nature-Based Solutions in the Small Catchment of the Szilágyi Creek

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Abstract

The study site is located near Püspökszilágy, which is traversed by the Szilágyi Creek. Although typically characterised by low discharge, the stream has repeatedly caused flooding in the settlement during periods of intense rainfall. In response, the local community, under the leadership of the mayor, has implemented a range of interventions to mitigate recurring destructive mudflows. These include small-scale nature-based water retention measures (NSWRMs), such as a series of log dams and a lateral retention reservoir, among others.

The impacts of NSWRMs on the hydrological regime of a small catchment remain largely unexplored, making the site particularly suitable for detailed investigation, especially given its proximity to Budapest.

Within the framework of the ClimaPannonia HE project, MATE has initiated a comprehensive, multidisciplinary study addressing key aspects such as water quality, soil water retention, and microclimatic effects. The primary objective is to reduce existing knowledge gaps and uncertainties regarding the effectiveness of NSWRMs.

Numerous students from various disciplines have already joined the research in the frame of bachelor's and master's theses and student competitions. In the future, the site will also support practical education through field visits. The project further emphasises stakeholder engagement by organising training sessions and field trips. The catchment is a strong example of collaboration between local governance, research, and education.

Keywords: *NSWRM, nature-based solution, log dam, water regime, catchment*

The Kielstau Catchment as an Ecohydrological Living Laboratory: 20 Years of Research and Education

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Abstract

For the past 20 years, the Kielstau catchment in northern Germany has served as a living laboratory for ecohydrological research, education and training. Located in the young moraine landscape of northern Germany, the catchment is characterised by low relief, shallow groundwater, agricultural land use, artificial drainage, and hydromorphological modifications, providing a representative example of a managed lowland system. At Kiel University, the catchment is regularly used for workshops, excursions, student theses, PhD projects, and teaching activities, thereby linking field experience with process understanding. Hydrological records are available since 1985 and have been complemented by long-term water quality monitoring and targeted field campaigns since 2005. These long-term observations support scientific investigation and student training by enabling the analysis of hydrological, hydrochemical, and ecological dynamics across temporal and spatial scales and by providing a basis for hydrological and water quality modelling. Since 2010, the catchment has been recognised as a UNESCO ecohydrology reference site. The Kielstau therefore demonstrates how long-term experimental catchments can effectively connect monitoring, modelling, and empirical learning while strengthening knowledge transfer between universities, water management, and regional stakeholders.

Keywords: *ecohydrology, monitoring, education, modelling, lowland*

On the Use of Tracers in Engineering Research and Teaching in Plots and Small Basins

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Abstract

This review examines the use of tracers in the research and engineering education, within the context of experimental plots and small basins. Tracers, including coloured, thermal, and fluorescent types, serve as essential tools for understanding hydrological processes and environmental impact studies. They allow both researchers and students to quantify key hydrological variables such as water flow velocity, residence time, infiltration rates, and the dynamics of pollutant transport. Furthermore, tracer experiments provide hands-on experience in transport phenomena, allowing students to bridge theoretical models with real-world behaviour. Several examples on the application of tracers in surface hydrology are presented. Using these tracers, it is possible to visualise flow paths, assess water quality variability, and analyse sediment transport, thereby improving characterisation of drainage basin processes. This review underscores the significance of using tracers and their implications for sustainable engineering practices and solutions.

Keywords: *drainage basins, hydrological processes, surface hydrology, hands-on experience*

SESSION 2
Hydrological and Hydrometeorological Extremes in Small Catchments

Discharge and Vegetation Responses to Drought in Selected Small Watersheds in Germany

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Abstract

The three consecutive years from 2018 to 2020, as well as 2022, were marked by severe droughts across large parts of Germany. The subsequent years were characterised by less extreme weather conditions, particularly in terms of precipitation.

This current study by the German working group "FRIEND-Water / ERB" analyses the dry years as well as the subsequent years with normal conditions and their impacts on selected small watersheds in near-natural landscapes in Germany. The analysis aims to examine hydrological processes at high temporal and spatial resolution and to evaluate the effect of watershed characteristics on drought response. This will contribute to our understanding of the hydrological impacts of droughts.

Preliminary results show severe low flows in the watersheds during the hydrological summer months in drought years. In subsequent years, however, varying regional and seasonal precipitation patterns lead to considerable spatial differences in discharge patterns. Additionally, the Normalized Difference Vegetation Index (NDVI) was calculated

based on remote sensing data and compared for different points of time for the selected catchments. The spatial representations show different levels of plant vitality, from which areas with stressed or even dead vegetation cover could be identified. These can provide indications of vegetation and ecosystem activity, which also depends on water availability.

Keywords: *drought impact, small catchments, discharge, NDVI*

The Role of Runoff Generation and Subsurface Stormflow in Extreme Flood Modelling of Alpine Catchments

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Abstract

On 30 August 2020, an extreme flood event occurred in the Oselitzenbach catchment (23.4 km², Austria), with a recorded peak discharge of 86 $m^3 s^{-1}$. Hourly precipitation data from the INCA nowcasting system indicate a maximum rainfall intensity of 44.8 mm h^{-1} and a cumulative precipitation of 307.6 mm over 87 hours, highlighting the relevance of antecedent moisture conditions. The event was reconstructed using the precipitation-runoff model ZEMOKOST, employing both historical and recent spatial field data, including runoff coefficient mappings derived from irrigation experiments and soil surveys. The catchment was subdivided into 78 subunits, with runoff generation and roughness parameters assigned from regional-scale interpretations. Subsurface stormflow was explicitly considered by assigning a uniform intermediate runoff share of 60%, differentiated by two subsurface flow velocity classes. The model was driven by uncorrected INCA precipitation data. Simulated and observed hydrographs show very good agreement, with Nash–Sutcliffe and Kling–Gupta efficiencies of 0.81 and a Spearman rank correlation of 0.92. Results demonstrate that spatially differentiated runoff coefficient interpretations, combined with a simplified representation of subsurface flow processes, allow robust flood modelling in alpine headwater catchments dominated by shallow, compacted soils and high runoff propensity.

Keywords: *Alpine flood modelling, runoff generation processes, subsurface stormflow*

Meteorological Drought Assessment of Antalya City Centre, Turkey

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Abstract

Drought is an important problem that affects water resources and natural balance, especially in regions with Mediterranean climate conditions. In this study, meteorological drought in the Antalya Basin was investigated using monthly precipitation data from two different observation stations.

One of the datasets belongs to Antalya Airport station covering a long period between 1959 and 2021, while the other station includes data between 2010 and 2021. The analyses were carried out using the DrinC programme and supported with Excel calculations. Monthly precipitation values were evaluated separately in order to understand seasonal changes.

The results show that precipitation is not evenly distributed throughout the year. Winter months have relatively high precipitation values, whereas summer months have very low or almost zero precipitation, which clearly indicates drought conditions. This situation shows that the basin is especially vulnerable during dry periods.

In addition, some differences were observed between the two stations, which indicate that drought conditions may change depending on location. The long-term data also helps to better understand how precipitation changes over time.

Overall, this study provides useful information for understanding drought in the Antalya Basin and can support future water management and planning studies.

Keywords: *Antalya Basin, climate variability, DrinC, drought, precipitation*

Disturbance of Water and Matter Budgets after Bark Beetle Attack at Lange Bramke, Harz Mountains, Germany

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Abstract

Effects of climate change and forest development on the hydrological regime and drought stress were analysed for the catchment of Lange Bramke, Harz Mountains, Germany. Forest stands at Lange Bramke were clearcut in 1948 and the complete catchment was reforested thereafter. Hydrological observations at Lange Bramke started immediately after the clearcut resulting in more than 75 year-long time series, which served for the analysis of possible climate change effects on discharge regime and on drought stress risk of the Norway spruce stands within the catchment. Runoff relative to precipitation decreased within the first four decades after reforestation, while evapotranspiration increased due to the growing water demand of the forest stands. Recently, bark beetle attacks after severe drought events killed more than 75% of the Norway spruce trees. As a consequence, interception and transpiration decreased drastically, while runoff increased substantially. Nitrate output from the catchment increased immediately after the dieback of the forest stands. The presentation emphasises the importance of long time series for the evaluation of the effects of forest development, climate change as well as disturbances on the hydrological regime and matter budgets of small catchments.

Keywords: *hydrological regime, forest development, drought stress, climate change, disturbance*

Landcover Mitigation of Flood Events in Wet and Dry Initial Conditions

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Abstract

With the Mediterranean region forecast to experience more intense rainfall, increasing the probability of more severe flood events, there is an urgent need to understand how land cover impacts floods in both wet and dry initial conditions. This is particularly important in the region's mountainous terrain, where most runoff is generated and strongly influenced by changes resulting from land abandonment and subsequent revegetation. Building upon research in headwater catchments (< 3 km^2) in Northern Spain, with 5 representative land covers: naturally forested, afforested, naturally revegetated, terraced, and degraded, we use empirical data to study the potential for nature-based flood mitigation. Our approach takes 3 representative years of data and parses them into wet and dry initial conditions, comparing peak flows, response time, and hydroclimatic factors for each catchment. Preliminary findings show that peak flows are higher across land covers under wet initial conditions compared to dry, especially in the naturally revegetated and afforested catchments. For both wet and dry, the terraced catchment has the lowest peak flows and the degraded the highest. The peak flows are determined by precipitation total, except for the terraces in dry conditions, although baseflow contributes significantly, except in the degraded. Rainfall intensity only impacts peak flows in the degraded catchment and influences the response time in both the revegetated and forested catchments. A further analysis is planned to build upon the current findings and delve deeper into the differences between each land cover type.

Keywords: *land cover, flood event, peak flow, monitored catchments, Mediterranean mountains*
Acknowledgement: This project has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 101178498 and the FORWARD Project (PID2024-161314OB-I00) funded by MICINN.

SESSION 3
Hydrological and Ecohydrological Monitoring in Small Catchments

Quantifying Local Forest Transpiration by Thermal Infrared Sensing

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Abstract

Remotely sensed canopy temperature is useful for measuring plant water status because transpiration strongly affects energy partitioning between sensible and latent heat. Thermal-infrared remote sensing is becoming a routine tool for drought monitoring from satellites, and it is also used for ground-based monitoring of, for example, crop irrigation needs. Despite strong correlation between leaf temperature and plant water status, fully realising the potential of thermal remote sensing for quantifying water budgets requires accounting for other environmental conditions, vegetation canopy structure, and physiological processes. We developed a simple technique to estimate leaf temperature based on leaf-scale physics and show that it is empirically strongly correlated with tree water use in a young beech forest in Luxembourg. Here, we show that leaf temperature can be combined with moderately simple local monitoring of meteorological conditions (temperature, humidity, wind speed, net radiation) to estimate transpiration at fine temporal scale. We compare our estimates to measurements of sap flux and soil moisture, and identify uncertainties and conditions under which the technique is most effective.

Keywords: *evaporation, sap flux, canopy temperature, leaf temperature*

Contemporary Hydrological Research and Monitoring in the Plitvice Lakes NP, Croatia

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Abstract

Plitvice Lakes NP, a UNESCO World Heritage Site, is located in Croatia in the mountainous region of the Dinaric Karst, where specific hydrological processes take place and significant anthropogenic pressure is evident due to intensive tourism development. Since 2019, a hydrological working group from the University of Zagreb, Faculty of Science, Department of Geography has intensified research in the area of Plitvice Lakes NP. Focus was on research of changes in discharge regimes of streams feeding the lake system as well as on the hydromorphological development and status of streams and lakes. In addition, since 2022, hydrological monitoring has been established on the Bijela Rijeka Stream, one of the main contributing streams of the whole system. The results of monitoring will be presented, as well as problems and plans for further development of the monitoring system. Changes in the discharge regime of streams reflect shorter and warmer winters with less snow and warmer summers with general lower low flows but also higher variability due to summer short intensive rain episodes. Results of our research are used for the management of this fragile and valuable environment.

Keywords: *discharge regime, hydrological monitoring, Plitvice Lakes National Park, climate change*

Stream Temperature Seasonal Patterns in a Forested Mediterranean Catchment

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Abstract

Stream temperature (Ts) integrates complex interactions among rainfall inputs, subsurface flow pathways, and catchment physiography, making it a valuable tracer of runoff generation dynamics. In this study, we used Ts to analyse the hydrological response of the nested Re della Pietra catchment in Tuscany, Italy. We analysed 273 rainfall-runoff events at two stream sections, identified with an automatic procedure. Stream temperature hysteresis was quantified using the Hysteresis Index (HI), which describes loop direction (positive values indicate clockwise loops, negative values counterclockwise), and the Temperature Response Index (TRI), which captures the net warming (positive TRI) or cooling (negative TRI) of the stream from event start to peak discharge.

Preliminary results indicate that clockwise hysteresis dominates year-round at both sites, accounting for 77% of events at the headwater subcatchment (Lecciona) and 65% of events at the outlet (C4). This pattern, observed across all seasons, suggests rapid mobilisation of warm, shallow subsurface water at the onset of storm events, followed by progressive cooling as deeper groundwater and cooler runoff contributions become increasingly important along the falling limb. The clockwise signal was more pronounced in the upper part of the catchment than at the outlet (median HI = +0.24 at Lecciona. +0.17 at C4), indicating that downstream mixing among springs, tributaries, and groundwater progressively dampens the thermal signature of individual storm events. Furthermore, HI and TRI exhibited clear seasonal variability, with the strongest and most consistent clockwise signals occurring during the wet season (October–May), whereas responses became weaker and more variable during the dry season (June–September).

These findings highlight the potential of Ts as a high-frequency tracer for characterising runoff generation processes, water sources, and flow pathways in Mediterranean headwater catchments.

Keywords: *stream temperature hysteresis, forested headwater catchment, Mediterranean climate, hysteresis index, temperature response index, rainfall-runoff events*

Shifting Uncertainty in Discharge Measurements by Integration of Advanced Sensor Technology

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Abstract

To monitor nutrient losses from agricultural areas and their changes following governmental regulations and incentives, quasi-standardised water sampling at catchment outlets was established in the 1990s in Norway (JOVA), aligned with the Water Framework Directive. Catchment specific stage-discharge rating curves were developed to estimate discharge from water level measurements and to steer the discharge-proportional composite water sampling. Today, sensors to measure water velocity are established and used in combination with water level measurements to derive discharge directly, instead of indirect estimations. Although sensor-based approaches promise improved discharge estimation, uncertainty may shift from rating curves toward sensor technology. To test this, we 1. assessed the agreement of water level, velocity and discharge measurements of two different sensors in a catchment in Mid-Norway; and 2. compared discharge derived from an established rating curve with sensor-derived discharge measurements for a catchment in Southeastern Norway. The results of both approaches will be presented, and methodological uncertainties will be discussed.

Keywords: *runoff, long-term observation, next generation monitoring*

Zooming in on Catchment Processes: High-Resolution Sensors in Long-Term Monitoring

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Abstract

After more than 30 years of quasi-standardised monitoring of water quantity and quality of small agriculture-dominated catchments in Norway (JOVA), advanced sensor technology has been introduced increasingly. Introduced sensors provide temporally highly resolved runoff, turbidity, and nitrate measurements. Such measurements promise to give valuable insights into dominating processes in single runoff events of complex agro-hydrological catchments. To gain insights, a hysteresis analysis using runoff-concentration plots was applied to runoff, nitrate, and turbidity sensor measurements of multiple events during a three-month trial period in a catchment characterised by cold climate (Mid-Norway). Runoff-concentration relationships of single events were categorised with respect to their dominating pattern (clockwise, counterclockwise, eight-shaped, chaotic). The pattern can indicate the relevant flow and pollution pathways of an event. The results of this analysis will be presented and discussed in context with potentially explanatory driving processes.

Keywords: *drainage, surface runoff, erosion, leaching, nutrients*

Controls on Runoff Processes in Forested Catchments: A Global Perspective

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Abstract

Understanding the controls on runoff processes in forested catchments is critical for land, water and forest management. However, our current knowledge of their hydrological functioning largely derives from individual sites or limited interc1omparison studies, and a coherent global analysis of runoff processes is lacking.

In this work, I compiled a global database comprising data of 691 forested catchments extracted from 267 studies published between 1993 and 2024. I used this new dataset to identify the dominant climatic, hydrological, pedological, vegetational, and geological/geomorphological controls on runoff generation, streamflow response and streamflow prediction. I tested seven classic hypotheses in forest hydrology and an original one addressing the dominance of climate as an overarching control and its variability across humid and less humid regions.

Overall, the results highlight the interaction of multiple factors on runoff processes in forested catchments worldwide, particularly revealing the more important role played by geological/geomorphological, pedological, and hydrological factors in certain processes compared to climate, while the relative importance of vegetation increases under humid conditions. This global analysis provides new process-based insights, revises long-standing theories, and offers an empirical basis for advancing our understanding of catchment functioning and improving hydrological modelling in forested catchments across the globe.

Keywords: *streamflow magnitude, streamflow prediction, hydrological response, global scale*

The Beech and Spruce Transpiration Explored by a Combination of Sap Flow and Stable Isotopes

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Abstract

The transpiration of the two dominant Central European tree species, beech and spruce, plays an important role in the water cycle. Two approaches were used to study and compare the transpiration of these tree species. The first approach involved measuring tree sap flow, which revealed differences in the amount of water transpired. The second approach was to measure the isotopic composition of water in the tree sap, which revealed whether the water used for transpiration originated from summer or winter precipitation. On warm summer days, the transpiration of beech was more than two times higher than the transpiration of spruce. The water source for transpiration differed during the dry period at the end of June and became increasingly similar during the rainier part of the summer. This information is important not only to describe the actual water balance, but it can also be used to predict the expected impacts of climate change related to the rise of temperatures or the transition of forest species.

Keywords: *transpiration, beech, spruce, stable isotopes, sap flow*

Isotopic Insights into the Dynamics of Soil Water Pools along an Elevation Gradient

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Abstract

Recent intensive research on the soil-plant-atmosphere enables to trace water movement and plant responses at much finer spatial and temporal scales. However, the soil water dynamics is still not fully understood. This study aims to provide a comprehensive characterisation of the dynamics of distinct soil water pools – mobile versus tightly bound water – along an elevation gradient from lowland agricultural areas to upper mountain catchment in the Bohemian Forest (the Czech Republic). In contrast to conventional bulk water sampling, a key innovation of this study lies in the experimental design across the elevation gradient combined with a novel extraction method that selectively isolates tightly bound soil water for isotopic analysis. The results indicate a prolonged residence time of winter-derived soil water in lowland sites, in contrast to a rapid turnover at the highest elevation, where the winter water signal dissipates shortly after snowmelt. Distinct isotopic compositions among water pools – mobile versus tightly bound water – were particularly evident in lowland areas at the edges of the growing season, while tightly bound and bulk soil water exhibited, on average, only minor or no isotopic differences. In the context of the projected continued decline in snow cover at higher elevations in Central Europe, these findings are critical for improving predictions of soil water storage and, consequently, plant water availability under ongoing climate change.

Keywords: *hydropedology, isotope analysis, soil water dynamics, extraction, elevation gradient*

Next Generation of Long-Term Water Quality Monitoring Methods

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Abstract

Long-term monitoring of water quality in agriculture-dominated catchments is essential for the development and success control of environmental measures. In the 1990s, monitoring sites across Norway were established. There, water quality has been monitored continuously by flow-proportional composite sampling over 14-day periods, respectively. This approach relies on sound discharge measurements and appropriate settings for sampling frequency. Today, new monitoring devices such as nitrate sensors are available. They measure concentrations in situ, thereby avoiding interference from storage and transport, and with high temporal resolution, capturing short-term transport dynamics. This provides magnificent advantages and could replace sampling in the long-term. To prevent a bias in the time series, both monitoring approaches were compared for nitrate with +2 years of measurements at a catchment in Mid-Norway. The results showed good agreement within the measurement uncertainty of the laboratory analysis (±20%). However, during a 10-week period, there was a clear bias of about 1 mg N/L. It remained unclear which of the methods was more correct during this time due to their intrinsic measurement uncertainties. Overall, the measurements from both monitoring approaches were largely consistent and showed a similar degree in measurement uncertainty. However, nitrate sensors provide more information on transport dynamics which improves process understanding at catchment level.

Keywords: *nitrogen, nutrients, runoff, extreme events, JOVA*

Geostatistical and Deterministic Approaches to Throughfall Measurements

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Abstract

Throughfall (TF) dynamics in forested catchments are driven by a complex interplay of forest stand parameters, rainfall characteristics, and climatic forcing. However, the specific influence of hillslope topography and its associated stand characteristics on the spatio-temporal variability of TF remains poorly understood. This study aims to identify key TF predictors and evaluate their role in controlling TF spatial correlation at the hillslope scale.

The study was conducted on a forested north-facing hillslope (mean slope of 30°) within the 0.3 km² Lecciona catchment in the Tuscany Apennines, Central Italy. The site is dominated by pure stand of European beech trees (aged coppice), whose diameters decrease from the bottom to the top of the hillslope. TF was monitored from February 2024 to March 2025 using plastic collectors with an opening of 60 cm², manually emptied roughly after each rainfall event. The samplers were deployed on the Lecciona hillslope forming 18 squares of 10 × 10 m, for a total monitoring area of 1800 m². In each square, two TF collectors were randomly placed ("kernel" collectors) and in six squares a transect of four collectors was placed at increasing distances from each other (0.1 m, 0.4 m and 0.5 m). Furthermore, nine trees were selected for a radial transect of three collectors at and increasing distance from the tree stem (0.2 m, 0.6 m and 1.1 m). Within the experimental grid we determined the position of each sampler and trees with a total station. Gross precipitation was measured by a weather station placed at the top of the hillslope. We divided the entire observation period into leafed and leafless periods.

We used variograms to analyse spatial patterns in event TF. TF variograms were calculated using both robust and non-robust models, fitted to minimise the residual

sums of squares. To assess the temporal stability of TF, we calculated the Mean Relative Difference (MRD) and the Standard Deviation of the Relative Difference (SDRD), which were combined into the Index of Temporal Stability (ITS) to evaluate systematic bias and persistence in TF.

TF amount increased linearly with elevation in leafed and leafless periods, with a slightly higher slope for the leafless period. ITS analysis suggested that without leaves, the patterns of the TF ratio persist across the events, while the canopy cover in the leafed period acts as a filter that randomly redistributes water.

The relation between TF and stem distance showed that TF depends on distance to the closest stem, but only for the first meter does TF increase with distance from the stem. For longer distances, TF variability decreases and the relation with distance disappears. This is a combined effect of crown architecture and large branches in creating dripping points and/or dry points for TF.

The explorative variogram analysis indicated a median range (i.e. the distance beyond which data points are no longer spatially correlated) of 5 m for the leafless periods 2 m for the leafed period. This difference was caused by the effect of canopy cover in redistributing rain water. Furthermore, the analyses have shown that slope affects TF, independently of small-scale variation caused by redistribution of precipitation in the heterogenous canopy.

Keywords: *throughfall, spatial distribution, geostatistics, European beech, forested hillslope*

Satellite-Based Macrophyte Monitoring in Water Bodies as a Tool for Transboundary Catchment Assessment: Nemunas River Basin

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Abstract

Macrophytes are sensitive indicators of aquatic ecosystem condition. Their systematic monitoring in transboundary catchments remains constrained by the cost and labour-intensive traditional field assessments. This study presents a satellite-based macrophyte mapping algorithm developed for lakes and reservoirs, tested in the Nemunas River Basin, and transferable to comparable temperate lake environments.

The algorithm uses near-infrared reflectance thresholding of Sentinel-2 imagery, processed on Google Earth Engine, to classify lake surfaces into emergent, submerged and floating macrophytes, and open water. Classification relies on two seasonal NIR reflectance values, spring and summer, corresponding to key phenological stages of macrophyte development. A decision tree trained on unsupervised cluster labels from a single reference lake achieved an overall accuracy of 84.6% on independent drone-based field observations. It was applied to 173 lakes and reservoirs larger than 1 km² in the Nemunas River Basin over 2017–2024, producing the first spatially consistent macrophyte dataset for the full basin.

Results reveal a northeast-to-southwest gradient from submerged and floating macrophytes dominance in oligotrophic Baltic Upland lakes to emergent macrophytes dominance in southern agricultural reservoirs, driven by catchment land use rather than individual lake morphometry. A basin-wide tendency towards increasing submerged and floating coverage was identified in 55% of classified lakes. Ecologically consistent associations with spring temperature and precipitation confirm that the algorithm captures inter-annual variability.

Keywords: *macrophytes, remote sensing, aquatic vegetation*

Ecohydrological Monitoring as a Tool for Risk Analysis in a Small Urban-Rural Catchment – A Case Study of the Czechówka River

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Abstract

In areas with scarce surface water, any presence of it significantly increases the value of the landscape. Such areas include the Lublin Uplands and the region's largest city – Lublin (Eastern Poland). The scarce water network requires the identification and protection of existing river sections and catchment that have retained valuable aquatic environmental features. This is particularly challenging in rural-urban catchments where anthropogenic factors have repeatedly overlapped, creating a mosaic of varying terrestrial and aquatic environmental quality.

The aim of the study was to identify the main risks affecting the quantity and quality of waters in the Czechówka River, whose catchment of 79 km² is located in the upper part of the river in rural areas, and in the middle and lower parts within Lublin. Research was conducted at 10 monitoring points in 2025. The study covered hydrological, hydrochemical and biological (including microbiological) measurements of the waters in the Czechówka catchment. The ecohydrological monitoring employed comprised both field and laboratory observations.

The results confirm significant variability in water quality within the catchment, as well as a significant impact of land use on the water's chemical composition. Eutrophication, which is linked to the inflow of nutrients from urban and agricultural areas, proved to be a particularly significant problem. The increased concentrations of nitrogen and phosphorus contributed to the intensive phytoplankton growth. Despite the significant transformation of the river valley and the degradation of water quality, some sections

have preserved their retention and ecological functions. Spring areas, pond complexes and sections of the valley with valuable wetland plants play a particularly important role.

Keywords: *ecohydrological monitoring, river catchment, urban-rural catchment, water quantity and quality*

SESSION 4
Advances in Hydrological and Ecohydrological Modelling

Interpretable Symbolic Regression for River Water Level Prediction under Varying Hydrological Conditions

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Abstract

Reliable simulation of river water levels is essential for flood risk management, particularly in small catchments with rapid hydrological response. This study explores the application of Genetic Programming (GP)-based symbolic regression for modelling water level dynamics under varying hydrological conditions in the Fischbach catchment (Germany). High-frequency observations of rainfall and water level (5-minute resolution) from 2020 to 2024 were used to construct predictive models based on antecedent conditions and multi-scale rainfall accumulation.

To investigate model behaviour under intensified hydrological responses, subsets representing rapid stage increases were derived using threshold-based criteria. The analysis demonstrates that model performance is closely linked to the representation of hydrological conditions within the training dataset. Models calibrated on general conditions show limitations in capturing abrupt water level changes, whereas models trained on threshold-based high-response conditions demonstrate improved representation of peak dynamics.

Sensitivity analyses further reveal a shift in dominant predictors, with antecedent water levels governing baseline conditions and rainfall-related variables gaining importance during periods of rapid water level increase. The findings underline the importance

of data selection and regime representation in data-driven hydrological modelling. The proposed approach demonstrates the potential of interpretable symbolic models to support flood prediction and to enhance understanding of rainfall-runoff interactions in fast-responding catchments.

Keywords: *water level modelling, genetic programming, flood dynamics, symbolic regression, hydrological extremes*

Deriving Hydrological Signatures of Runoff Generation Mechanisms from Experimental Catchments Using Explainable AI

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Abstract

Hydrological signatures are widely used to characterise catchment behaviour, yet most existing signatures are empirically defined and lack a direct link to underlying runoff generation processes. This study aims to develop a new framework for defining process-relevant hydrological signatures based on attribution analysis using explainable deep learning. A number of experimental catchments with well-documented runoff generation mechanisms are compiled from previous studies. These catchments provide diverse hydro-climatic and landscape conditions and serve as a basis for exploring the relationship between rainfall-runoff responses and dominant runoff processes. Rainfall-runoff events are extracted at the event scale, and a Long Short-Term Memory (LSTM) model is employed to capture the nonlinear rainfall-runoff relationships. The Integral Gradients method is then used to quantify the contributions of key hydrological drivers, including rainfall amount, rainfall intensity, and antecedent wetness. Based on these attributions, this study proposes to define attribution-based hydrological signatures that explicitly describe how runoff responds to different controlling factors. The proposed signatures are expected to provide a more interpretable and process-relevant representation of runoff generation mechanisms compared to traditional empirical metrics. This ongoing work seeks to establish a new perspective on hydrological signature construction and to bridge data-driven modelling with process understanding, with potential applications in mechanism identification in catchments without well-documented runoff generation mechanisms.

Keywords: *hydrological signatures, runoff generation mechanisms, experimental catchments, explainable AI, rainfall-runoff processes*

Assessment of Event-Based Rainfall-Runoff Modelling Performance for Small and Ungauged Watersheds in the Upper Blue Nile Basin, Ethiopia

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Abstract

Ethiopia is characterised by a scarcity of observed rainfall and runoff data; consequently, even nowadays, the rational formula is commonly applied to estimate the design peak discharge. Hence, we would like to verify whether more advanced hydrological tools can be applied under such challenging conditions, and we provide an assessment of event-based approaches for estimating design hydrographs for small and ungauged basins. This is applied using the freeware software named EBA4SUB (Event-Based Approach for Small and Ungauged Basins). It is a classical approach, specifically tailored for ungauged conditions, that consists of selecting a design rainfall event based on the parameters of the Depth–Duration–Frequency (DDF) curves, estimating the rainfall excess, and transforming it into a direct hydrograph. Results seem promising; in particular, we verified that the Ethiopian small and ungauged watersheds can be modelled using advanced approaches that provide more complete design information for practitioners than the rational formula.

Keywords: *EBA4SUB, design hydrograph, rational formula*

SESSION 5
Erosion, Sediment Transport, and Landscape Processes

Rain Drop Size Distribution Linked to Soil Erosion in the Hydrological Open Air Laboratory, Austria

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Abstract

Identifying the key drivers of soil erosion in agricultural catchments is crucial for preventing land degradation. There is a lack of field studies on linking drop size distribution with suspended sediment load information in agricultural catchments. This study aims to explore how rainfall characteristics influence the suspended sediment load in the Hydrological Open Air Laboratory, a small agricultural catchment in Austria. The results show that the kinetic energy of rainfall and rainfall erosivity estimated by disdrometer and rain gauge data are comparable ($\rho = 0.93$ and 0.95, respectively). Winter rainfall events with small kinetic energy cause large total event suspended sediment load due to bare and saturated soils that reinforce surface runoff. In spring and summer, the average size and velocity of the drops are the largest and events with larger number of drops in the most frequent diameter class are associated with larger total event suspended sediment load.

In spring and summer, land management state and antecedent soil moisture conditions also impact erosion. The benefit of using disdrometer data is discussed.

Keywords: *rainfall, soil erosion, disdrometer*
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Variability of Suspended Sediment Transport Dynamics between Seasons and Flow Pathways in a Small Agricultural Catchment

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Abstract

Suspended sediment dynamics in small agricultural catchments were shaped by the interaction of overland and subsurface flow processes, yet no event-scale, flow pathway-specific comparisons of seasonal discharge (Q)-suspended sediment concentration (SSC) relationships within a single catchment exist. This study addresses this gap by analysing Q-SSC relationships during 18 overland flow events (2012–2022) using high temporal resolution (1-min), multi-station monitoring in the Hydrological Open Air Laboratory (HOAL), Lower Austria, across three different flow pathways: a partly tile-drained piped headwater inlet, an overland flow station, and the aggregated catchment outlet. Seasonal Q-SSC relationships were fitted for each station, and event-based coefficients were compared. Results revealed clear scale effects between flow pathways and strong seasonal contrasts. SSC was highest in overland flow, lowest at the partly tile-drained headwater inlet, and in-between at the aggregated catchment outlet. All flow pathways showed increased SSC magnitude and variability in the growing season. Event-scale Q-SSC coefficients showed no systematic seasonal variation for the partly tile-drained piped headwater inlet, while both the overland flow and aggregated catchment outlet showed higher intercepts and flatter slopes in the growing season. This pattern in the overland flow and aggregated outlet stations reflected higher baseline SSC during the growing season, while sediment transport was concentrated at higher discharges during the dormant season. Overall, our findings underscored that multi-station monitoring was essential for disentangling flow pathway-specific Q-SSC dynamics as typical single-outlet

measurements obscure flow pathway-specific dynamics critical for designing effective mitigation strategies in agricultural catchments.

Keywords: *discharge (Q)-suspended sediment concentration (SSC) relationship, seasonal variability, flow pathways, overland flow*

Effect of Surface Temperature and Rainfall Intensity on Sediment Yield in an Alpine Experimental Hillslope

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Abstract

Major natural hazards on steep mountain hillslopes intensify erosional processes and strongly affect the upper soil layer. Studies on sediment dynamics integrating the analysis of geomorphic changes based on high-resolution digital elevation models with surface temperature and rainfall intensity data remain scarce in Alpine areas, where freeze-thaw cycles strongly influence soil erosion. This study aims to: 1. assess multi-temporal geomorphic changes using high-resolution digital surface models on two avalanche-affected hillslope areas; 2. quantify the sediment collected at the base of the hillslope during two summer seasons; and 3. investigate the influence of meteorological forcing on the sediment yield. Reconstructed differences of digital surface models show that erosion volumes substantially exceed deposition. The resulting imbalance (> 45%) indicates significant soil loss at the monitoring site. Similarly, a total of 8,240 kg of soil was removed from Area 1 (910 m^2) during the sampling period. Sediment yield showed a significant positive correlation ($p < 0.05$) with land surface temperature (LST, $r = 0.67$), air temperature ($r = 0.69$), and rainfall intensity ($r = 0.62$). High LST coupled with intense summer rainfall increased sediment yield. Based on our results, we call for similar studies on other Alpine hillslopes to estimate erosion dynamics following extreme events and implement nature-based restoration of avalanche-affected grasslands.

Keywords: *sediment yield, Alpine hillslope, erosion, geomorphological changes, meteorological forcing*
Acknowledgement: This study was carried out within the Agritech National Research Center and received funding from the European Union Next-Generation EU (Piano Nazionale di Ripresa e Resilienza (PNRR) – Missione 4 Componente 2, Investimento 1.4–D.D. 1032 17/06/2022, CN00000022). This abstract reflects only the authors' views and opinions; neither the European Union nor the European Commission can be considered responsible for them.

Linking Forest Phenology and Hydrometeorological Controls: Spatiotemporal Sediment Dynamics in a Mediterranean Forested Catchment

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Abstract

Managing forested catchments requires a thorough understanding of suspended sediments, which are crucial to river morphology and the health of ecosystems. However, understanding transport dynamics in mountainous and forested terrain remains complex. This study analyses the spatiotemporal dynamics of sediments in the Re della Pietra experimental catchment (Tuscany, Italy), an area of 2 km² with a 700 m elevation gradient and a step-and-pool morphology. The methodology involved integrating high-frequency (5-minute) turbidity data, recorded by a high-definition turbidimeter, hydrometric level data, soil moisture data, and meteorological data recorded by a comprehensive weather station. Data recording started in December 2023 and is continuing. Optical turbidity data (FNU) were converted into sediment concentration (SSC, g/l) and total solid load (SSL, g). The analysis, conducted on an event-by-event basis, uses the HydroEvents software package for hydrograph separation. Temporal dynamics have been investigated through the hysteresis index. Preliminary results highlighted seasonal variations in transport regime, specifically in suspended sediment loads and in transport efficiency, between the growing and dormant seasons. Higher amounts of sediment were transported during the growing season. The hysteresis index did not show any significant variations between the growing and dormant seasons, indicating

that local or non-local sources of sediment were not associated with seasons. Future work will investigate the role of leaf cover and growing activity in influencing erosion and fine sediment transport dynamics, providing new insights into the resilience of Mediterranean forest catchments in the context of climate change.

Keywords: *suspended sediment, forested catchment, turbidity, erosion, geomorphology*

SESSION 6
General Research Topics on Catchments

Runoff Regulation in Small Lithuanian River Catchments: A Comparative Analysis Using Hydrological Indicators and GIS Data

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Abstract

This study analyses three small Lithuanian river catchments – Yslykis, Skroblus and Vilnia – using long-term daily discharge series and GIS-based information on relief, land use and soils. The aim was to assess whether differences in catchment structure are reflected in hydrological behaviour. For this purpose, the natural runoff regulation coefficient (ϕ), its interannual variability, the ratio of 7-day minimum discharge to annual mean discharge, and the proportion of zero-flow days were calculated. These indicators were evaluated together with mean slope, relief amplitude, land-use composition, and dominant soil texture groups. Clear differences emerged among the analysed catchments. The Skroblus catchment showed the most stable hydrological regime and the strongest runoff regulation (ϕ = 0.96; CV = 0.86%; 7Qmin/Qmean = 0.82; no zero-flow days recorded). The Vilnia catchment occupied an intermediate position (ϕ = 0.84; CV = 5.95%; 7Qmin/Qmean = 0.48). The Yslykis catchment stood out as the least regulated, characterised by high interannual variability, very limited low-flow support, and frequent no-flow periods (ϕ = 0.43; CV = 22.36%; 7Qmin/Qmean = 0.008; zero-flow days accounted for 18.5%). The identified hydrological differences generally correspond to the physical characteristics of the catchments: Skroblus is steeper and more forested, Vilnia has a mixed structure, while the Yslykis catchment is dominated by agricultural land. The results show that combining hydrological indicators with official GIS data can be useful for explaining runoff regulation in small river catchments.

Keywords: *small catchments, runoff regulation, GIS-based analysis, catchment characteristics*

Habitat Fragmentation in a Karst River: A Case Study of the Vrljika River (Southern Croatia)

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Abstract

This study presents the application of the modified MesoHABSIM methodology to assess habitat suitability for the endemic softmouth trout (Salmo obtusirostris) in the Vrljika River, a karst watercourse flowing through the enclosed Imotski-Bekija karst field in southern Croatia. The Vrljika River is a typical karst river flowing through the karst field, with high discharge variability, low gradient, historical flooding, and significant transformation due to human interventions. The research was conducted along a 7.5 km upstream river section significantly altered by four river barriers constructed primarily for agricultural irrigation. Field surveys were conducted during low summer flow conditions to capture the most ecohydraulically limiting habitat conditions. The entire study river section was surveyed using UAV technology, and the resulting orthomosaics served as the spatial basis for mapping hydromorphological units within a mobile GIS environment. Hydraulic parameters were collected using an ADCP mounted on an autonomous vessel equipped with an RTK positioning system, yielding more than 100,000 measurement points. The results indicate that a dominant proportion of habitat is unsuitable along the entire study river section (61.36%), while optimal habitat accounts for 32.85% and suitable habitat for only 5.79%. Particularly unfavourable conditions were observed in the two most upstream reaches, where the proportion of unsuitable habitat exceeds 80%, despite their proximity to the main spring Opačac. The analysis of limiting factors shows that substrate characteristics and reduced flow velocity are the primary drivers of habitat unsuitability. The findings clearly highlight the negative impact of river barriers on habitat fragmentation and the disruption of longitudinal connectivity. Future research will address the habitat dynamics of softmouth trout (Salmo obtusirostris) under varying hydrological conditions.

Keywords: *habitat fragmentation, river barriers, habitat suitability, karst, Vrljika River*

Partitioning Climatic Forcing and Land-Surface Filtering in Soil Moisture Dynamics

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Abstract

Predicting catchment response to environmental change requires decoupling climatic forcing (macro-scale soil water supply) from land-surface filtering (local soil water redistribution). We applied Windowed Spectrum Difference (WSD) analysis to quantify differences between two time series in their energy distribution across scales and time, focusing on the semi-oceanic Weierbach (Luxembourg) and the humid-Mediterranean Can Vila (Spain).

Intra-catchment results demonstrate that land-surface filtering is scale-specific. In the Weierbach catchment, Norway spruce smooths intense precipitation into multi-week soil moisture cycles (16–64 days) more effectively than deciduous beech or oak. Topographically, riparian zones preserve higher medium-scale variance than upslope positions, reflecting sustained moisture connectivity. In Can Vila, forest cover similarly mutes the high-frequency "noise" prevalent in pasture sites.

Inter-catchment comparisons reveal that at long periods (> 128 days), regional climatology overrides local filtering. Can Vila exhibits higher spectral power, driven by Mediterranean seasonality, compared to the buffered oceanic regime of Weierbach. Crucially, cross-site analysis shows both forest canopies provide a universal stabilising function regardless of climate. Identifying these "spectral fingerprints" offers a robust framework for predicting how land-cover transitions will alter catchment sensitivity to intensifying rainfall extremes.

Keywords: *soil moisture dynamics, windowed spectrum difference, catchment filtering, scale-dependency*

The Impact of Climate Change on the Flow Regime of a Small River in Peri-Pannonian Croatia – The Example of the Bregana Stream

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Abstract

The Bregana stream is the 16.5 km long right tributary of the Sava River on the border of Croatia and Slovenia. There are two hydrological stations on the Bregana stream and one more on its main tributary, the Breganica stream. The Bregana stream drainage basin is mostly hilly and mountainous, sparsely populated, wooded, and humid, with a relatively developed stream network. The annual discharge change and the characteristics of the discharge regimes were analysed on the three hydrological stations between 1981 and 2020. No trend was recognised in mean annual discharges, but all three stations recorded a slight increase in annual minima discharges and a more pronounced increase in annual maxima discharges. Moreover, some notable changes occurred in the discharge regime in the research area. Summer decline is observed on the Bregana stream, and will probably continue given the predicted further warming and increase in evapotranspiration in almost all of Croatia. The results are expected considering the general reduction of average flows in summer found in previous hydrological research on main rivers in the Croatian part of the Danube basin and at most stations in Slovenia. Despite the changes in the annual course of mean monthly discharges, the discharge regime still corresponds to the peri-Pannonian pluvial-nival regime type, because the main characteristics of the annual course have remained preserved.

Keywords: *discharge regime, Bregana stream, hydrology, hydrogeography, Croatia*

SESSION 7
Field Experiments, Unexpected Behaviours and Lessons Learned

Quantifying Subsurface Flow Paths Using Experimental In Situ Methods in a Forested Site

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Abstract

To quantify groundwater recharge in a forested catchment, the partitioning of subsurface flow into its lateral and vertical components was undertaken by combining tracer and geophysical methods in the Rosalia Research and Training Forest of BOKU University.

To characterise infiltration processes, a dye tracer experiment with Brilliant Blue was conducted on a 1 m² subplot accompanied by 3D continual geophysical monitoring using electrical resistivity tomography (ERT). Dye coverage and flow type (matrix or macropore flow) were quantified using image processing. ERT monitoring gained further information on infiltration dynamics, while preferential flow pathways were identified from Brilliant Blue staining patterns. In the 0–8 cm soil depth, matrix flow dominated; whereas macropore flow was prevalent below 8 cm.

Additionally, tracer tests with Sulforhodamine G were performed to evaluate downhill lateral flow over a 40 m transect; however, no tracer signal was detected, suggesting predominantly vertical flow, or complex longer lateral flow paths. Follow-up experiments are being conducted at shorter spatial scales. A 4 m² subplot upslope of a purpose-built

flow collector was irrigated to capture lateral subsurface flow within the upper 40 cm of soil. Tracer applications are used to estimate flow travel times and assess macropore connectivity. Geophysical measurements over a larger area will delineate spatial variations in hydraulic properties, with tracer tests used to calibrate the petrophysical models.

The integration of multiple methods provides a robust framework for in situ characterisation of subsurface flow and its partitioning into lateral and vertical components.

Keywords: *lateral flow, groundwater, tracer, hydrogeophysics, ERT*

Testing the Perceptual Model of Runoff Generation Processes in the Ressi Experimental Catchment with New Data

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Abstract

Perceptual models describe runoff generation processes under different hydrological conditions. They are often based on a combination of hydrometric data and tracer data. However, they are rarely verified with the introduction of new measurements or tracers.

In this study, we use hydrometric and tracer data (stable isotopes of hydrogen and oxygen, major ions, and electrical conductivity) collected in the Ressi catchment, a 2-ha watershed in the Italian pre-Alps, to test the existing perceptual model based on previous hydrometric measurements and isotope data for selected events. The existing perceptual model of our earlier study describes that runoff during small events is mainly generated from the riparian zone, while hillslopes contribute the majority of water during larger events, thereby highlighting the role of precipitation and antecedent conditions on hillslope-riparian zone-stream connectivity. To test the perceptual model, we investigated concentration-discharge (C-Q) relations for 20 rainfall-runoff events between September 2015 and August 2018, and related these to event characteristics, e.g. rainfall event size, intensity, and antecedent moisture conditions, and metrics computed for the dry period preceding the rainfall-runoff events, e.g. duration, mean temperature. Our results show that event characteristics alone cannot account for the variability in C-Q relations, and that the flushing of nitrate, potassium, and chloride must be caused by other processes (e.g. leaching from the dry canopy, flushing from the dry streambed). We thereby highlight the usefulness of revisiting and refining existing perceptual models with new data.

Keywords: *concentration-discharge relation, major ions, hypothesis testing, runoff generation processes, stream length*

Importance of Near-Surface Runoff for Stormflow in a Small Swiss Pre-Alpine Catchment

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Abstract

Near-surface flow pathways, which include overland flow, biomat flow and lateral subsurface flow through the topsoil (i.e. topsoil interflow), provide fast transport routes for water and solutes from the hillslopes to the streams. To improve our understanding of these runoff processes and their importance for water and solute transport in humid, well-vegetated catchments, we installed 14 small (3 × 1 m), trenched runoff plots across the Studibach catchment, a small headwater catchment underlain by gleysols in the Swiss pre-Alps. We measured overland flow and topsoil interflow and streamflow dynamics and sampled precipitation, overland flow, topsoil interflow, soil water, groundwater, and stream water during rainfall events.

The results of these field measurements show that overland flow and topsoil interflow are chemically and isotopically similar and a mixture or rainfall and soil water (or groundwater). The similar signature of these flow pathways and the observed rapid infiltration of overland flow and exfiltration of soil water from macropores (especially roots and mouse borrows) a few meters further downhill, suggest that overland flow and topsoil interflow pathways are highly connected.

The results furthermore show that overland flow, topsoil interflow, and streamflow respond quickly to rainfall events. Peak overland flow and topsoil interflow occur before or at the same time as peak streamflow. Stream chemistry starts to change when near-surface runoff starts at the plots and changes from a baseflow (groundwater) signature to the signature of the near-surface flow pathways. Together these results show that near-surface runoff is likely the main runoff generation mechanism that causes the rapid increase in streamflow in pre-Alpine streams during rainfall events.

Keywords: *runoff generation, preferential flow, runoff plots, isotopes, hydrochemistry*

POSTER SESSION

Accuracy of VIIRS Snow Cover Mapping at Regional and Catchment Scale

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Abstract

The MODIS (Moderate Resolution Imaging Spectroradiometer) snow product has long been one of the most important sources of remote sensing data on snow cover at the global scale. In the near future, these data are expected to be replaced by observations from the VIIRS (Visible Infrared Imaging Radiometer Suite) sensor, which is located on the Suomi NPP and NOAA-20 satellites. One of the main advantages of VIIRS data compared to MODIS is higher image quality (375 m spatial resolution) and improved radiometric accuracy, allowing more precise distinction between snow, clouds, and other surface types. When transitioning from MODIS to VIIRS, it is essential to ensure the continuity of time series, as MODIS provided data for more than two decades. Therefore, a reliable and accurate evaluation of the new product is important for its use in future hydrological applications.

We have evaluated mapping accuracy of the VIIRS snow product at both regional and catchment scales. At the regional scale, data from 631 climate stations across Austria were used. At the catchment scale, the Jalovecký Creek catchment (northern Slovakia, area 22 km^2) provided the snow cover data from extensive snow course measurements (2012–2020) carried out at several open and forested sites. Snow detection in the VIIRS product relies on the Normalized Difference Snow Index (NDSI), which requires a threshold (TNDSI) to distinguish snow-covered from snow-free land. The optimal NDSI threshold (OTNDSI) was determined by detailed sensitivity analysis testing 100 TNDSI values (1–100, step 1) using daily snow depth observations from climate stations and snow courses. The overall accuracy (OA) of VIIRS snow cover was then assessed based

on the OTNDSI. Evaluations of OTNDSI and OA were performed for all stations and snow profiles, as well as for subsets representing different physiographic and land cover conditions.

Classification accuracy at 631 Austrian stations ranged from 52.3% to 99.3% (median 92.5%). The NDSI thresholds decreased with elevation and varied seasonally, with month- and elevation-based thresholds performing closest to the optimal. The elevation-based thresholds improved regional snow mapping by 1.5% at 900–1,200 m and 3.1% above 1,200 m. At the catchment scale, VIIRS achieved accuracy 71.5–95.9% at the open site and 58.1–93.7% in the forest.

Keywords: *remote sensing, NDSI threshold, snow cover, validation*
Acknowledgement: This work was supported by the grants from the Slovak Academy of Sciences (project VEGA No. 2/0019/23) and Slovak Research and Development Agency (projects No. APVV-23-0332 and VV-MVP-24-0208), and project Water4All/2023/1128.C/REACTION.

Bridging Research and Education through Small Experimental Catchments: The HydRoData Summer School

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Abstract

The integration of field-based data, obtained from experimental catchments and plots, is fundamental to advancing both research and higher education in the field of hydrology. This paper highlights the HydRoData summer school, organised in Ljubljana, Slovenia, as an initiative by the UNESCO Chair on Water-related Disaster Risk Reduction (University of Ljubljana, Faculty of Civil and Geodetic Engineering). The programme for this summer school has been designed to demonstrate how consideration of real-world environmental monitoring can directly enhance the learning experience. By working with rainfall, throughfall, soil moisture, runoff, and turbidity data obtained at dedicated research sites, such as the experimental plot in an urban park and small torrential experimental catchments, participants gain insight into the methodologies employed in measurement and data collection. In this way they are able to bridge the gap between theoretical models and the complex dynamics of hydrometeorological processes and drivers, antecedent soil moisture conditions, runoff formation, and sediment transport.

The increasing global interest in this field-based approach is reflected in the growing international reach of HydRoData. Between 2023 and 2025, the summer school maintained a steady capacity with 26, 24 and 25 participants, respectively, while the number of applicants consistently exceeded available slots; by more than threefold in 2025. A wide institutional and national background of the participants further underscores the impact of HydRoData, more specifically, participants were of 21 and 16 different nationalities in 2023 and 2024–2025, respectively, coming from 19, 21 and 22 universities worldwide across the three years. Additionally, the participants' background, level of study, and knowledge of R programming differed. This wide audience confirms the essential role of data obtained in the field, i.e. in the experimental catchments and plots that serve as "living laboratories", indispensable for fostering international academic exchange and advancing expertise in modern hydrology.

The programme combines field work (data collection), exploring existing hydrological databases, and hands-on data analysis in R – connecting the full data workflow from source to insight. The 4th HydRoData summer school will be held between 31 August and 4 September 2026. The summer school is primarily dedicated to PhD students; however, Post-docs and Master's students are also welcome to apply.

Keywords: *HydRoData, summer school, hydrological modelling, field measurements, R software*

Analysis of the Effect of Tire Wear Particle (TWP) Size on Surface Runoff Transport at Laboratory Scale

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Abstract

Tire wear particles (TWPs) constitute a significant portion of microplastic pollution in urban aquatic environments. This study isolated and investigated the impact of TWP size on transport dynamics driven by surface runoff. Laboratory flume experiments assessed the transport of three TWP size ranges: small (0.85–2 mm), medium (2–4 mm), and large (4–6 mm). These were tested on both smooth and rough beds, arranged in three distinct spatial distributions: homogeneously distributed along the flume's length, concentrated within a 2 m section at the centre, and concentrated within a 0.2 m section at the flume's centre), all under the same flow conditions.

The results indicate that particle size is a determining factor in mobilisation and retention rates. On smooth pavements, smaller particles are entrained into the flow more quickly, reaching their transport peak earlier than larger particles, with overall retention remaining low (< 12%) across all sizes. The influence of particle size becomes more pronounced on rough pavements, where large particles (4–6 mm) exhibited up to 30% retention within surface imperfections when distributed homogeneously.

In conclusion, the likelihood of continuous transport to water bodies is inversely proportional to TWP size.

Keywords: *microplastics, water pollution, roughness pavement, urban drainage systems*

Evaluation of Grassed Waterways in a Small Austrian Catchment through Hydrodynamic Modelling

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Abstract

Grassed waterways (GWWs) are a nature-based solution in agricultural catchments to reduce surface runoff and soil erosion. Engineering practice concerns itself with the lumped impact of grassed waterways on the outflow hydrographs and sediment load, whereas a significant body of literature has studied the internal behaviour of water and sediment in GWWs to describe their impact on hydrological processes. This study uses a hydrodynamic modelling approach to estimate the impacts of GWWs in the Hydrological Open Air Laboratory (HOAL), a small (66 ha), densely instrumented, and tile-drained agricultural headwater catchment located in Lower Austria. At the beginning of 2023, the GWWs were installed in along the thalwegs of the catchment's agricultural hillslopes. By identifying events of interest before and after the installation of the GWWs and calibrating a coupled surface-subsurface HydroGeoSphere (HGS) model before and after, we aim to estimate the impact of the GWWs on the flow regimes in the HOAL in trapping sediment and retaining water in the landscape. This study aims to explore different scenarios regarding initial, antecedent and land use conditions to improve our understanding of GWW behaviour.

Keywords: *waterways, hydrodynamic modelling, HydroGeoSphere*

3D Representation of Drainage Basins for Engineering Education: Integration of GIS and 3D Printing

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Abstract

Understanding drainage basin systems is challenging due to the abstract nature of the concepts and the limitations of traditional 2D teaching methods. Key elements such as slope, watershed divides, drainage networks, and runoff direction are better understood through three-dimensional representations. This study explores the integration of geoinformation technologies with the production of physical 3D models of the Covões stream and Mondego river basins (Portugal), using altimetric data.

The workflow begins with remote sensing data acquisition and processing within a GIS environment. A Digital Terrain Model is derived from the Advanced Land Observing Satellite (ALOS) World 3D product, ensuring adequate spatial resolution; ALOS is dedicated to collecting panchromatic stereo and tri-stereo imagery at 2.5 m resolution with a swath width of 35 km. Data are clipped to watershed boundaries using QGIS with the OpenTopography plugin. The 3D to Stereolithography (STL) plugin converts raster data into a triangular mesh, enabling adjustments in vertical scale, exaggeration and resolution. The resulting STL file is then sliced and 3D printed to create a scaled physical model.

From a pedagogical perspective, these models enhance visual and tactile learning, improving the understanding of hydrogeomorphological processes and bringing students closer to real-world conditions. They also support communication with stakeholders, facilitating engagement and awareness in water management contexts.

Keywords: *digital terrain modelling, remote sensing, tactile learning, science communication*
Acknowledgement: This work was supported by Fundação para a Ciência e a Tecnologia (FCT), Portugal, under project CURE-NbS (Water4All/0002/2024). The first author was funded by CNPq, Brazil, Programa Especial de Cooperação Internacional/PECI (200818/2025-2).

SIMWE-Based Hydrogeomorphological Simulation of a Semi-Arid Watershed in Northeastern Brazil (Paraíba)

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Abstract

The hydrogeomorphological modelling approach SIMWE (Simulated Water Erosion) is a physically based, spatially distributed model developed in the 1990s by Lubos Mitas, Helena Mitasova and Jaroslav Hofierka to overcome limitations of empirical methods. Based on the Monte Carlo method and particle–field duality, it solves equations of surface runoff and sediment transport. SIMWE is implemented in the GRASS GIS environment through the modules r.sim.water and r.sim.sediment.

This study focuses on a watershed located in the semi-arid region of northeastern Brazil (Paraíba), an area prone to degradation, exacerbated by soil and water management practices and by increased hydrological variability, partly attributed to climate change. A high-resolution terrain model (1 m), derived from Unmanned Aerial Vehicle (UAV) data, supports the simulation of hydrological and sediment dynamics. The experiment simulates discrete rainfall events to map flow pathways and identify critical zones of erosion and sediment deposition. Preliminary results suggest that SIMWE is a robust tool for understanding watershed hydrogeomorphological dynamics. Model outputs will be validated against field observations to ensure consistency with real conditions. The results are expected to support conservation measures and climate adaptation strategies.

Keywords: *water erosion, soil and water conservation, remote sensing, UAV*
Acknowledgement: The first author was funded by CNPq, Brazil, Programa Especial de Cooperação Internacional/PECI (200818/2025-2). The work was also supported by MARE and ARNET (respectively, UID/04292/2025, https://doi.org/10.54499/UID/04292/2025; and LA/P/0069/2020, https://doi.org/10.54499/LA/P/0069/2020), Portugal.

Impact of Land Use Changes on the Chemical Properties of Sandy Soils in the Brazilian Semi-Arid Region

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Abstract

Land use changes alter soil chemical properties, directly affecting soil sustainability and long-term productivity. This study evaluated soil chemical properties under different land uses in the Brazilian semi-arid region (Pernambuco): Caatinga, dryland grain, dryland forage, dryland fruit, and irrigated agriculture. Soil samples were analysed for pH, electrical conductivity (EC), exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), available phosphorus (P), total nitrogen (N), and soil organic carbon (SOC). Acidic pH, despite semi-arid conditions, can be explained by the sandy texture of the soils (> 75% sand), which has low capacity to retain basic cations. Results show that EC was significantly higher in irrigated agriculture, though below 4 dS m^{-1}. SOC was higher in dryland forage, dryland fruit, and Caatinga, and lower in dryland grain. N showed a similar pattern as SOC. Irrigated systems presented intermediate SOC and N values. P was higher in the soil surface layer under irrigation, while K^{+}, Ca^{2+} and Mg^{2+} did not differ significantly among land uses. Thus, this study reveals that, in the study area, changes in land use alter soil chemical properties. Systems subject to frequent soil disturbance and the use of agricultural production inputs exhibited higher pH and EC, along with lower SOC and N levels. In contrast, less disturbed systems favoured SOC and N conservation, highlighting the importance of sustainable management practices for long-term soil productivity.

Keywords: *land use change, soil sustainability, soil nutrients, rainfed agriculture, drylands*

Thermal Tracing Approach for Detecting Water Loss Sink Points in Shallow Flooded Areas

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Abstract

Detecting water loss due to sink points in shallow flooded areas is important for improving water management and understanding flow processes in small agricultural and urban systems. This study investigates the use of a thermal tracer combined with infrared thermography to detect sink points under controlled laboratory conditions. Experiments were carried out in a 2 × 2 m² soil flume, where sink points with different permeabilities were artificially created to simulate various water loss conditions. A heated water tracer was continuously applied to generate temperature gradients, and thermal images were analysed to track the movement of the tracer plume over time. Sink locations were determined by identifying the stabilisation of the tracer's leading edge, indicating drainage into the sink point. The method successfully detected sink points in most scenarios, demonstrating its potential as a visual and non-intrusive technique. However, the results also reveal that detection performance is influenced by the interaction between tracer discharge and sink characteristics, with some conditions leading to rapid thermal diffusion and reduced accuracy. These findings highlight both the applicability and limitations of thermal tracing in controlled soil flume experiments for detecting water loss sink points and provide useful insights for future applications in real flooded environments.

Keywords: *infrared thermography, laboratory experiments, flooded environments*

Influence of Hydroclimatic Characteristics on the Ecosystem Services of a Small Forested Mountain Catchment

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Abstract

Except their role in regulating runoff in the downstream areas, forested headwater catchments provide a number of other ecosystem services. Many of them depend on hydroclimatic characteristics such as precipitation, air temperature, snow depth and snow cover duration. Our study evaluated the impact of hydroclimatic characteristics on the survival conditions of roe deer (Capreolus capreolus) in the Jalovecký Creek catchment (the Western Tatra Mountains, northern Slovakia). The Winter Severity Index (WSI) based on the minimum daily air temperature and the average daily snow depth was used to characterise the severity of winters (November to April) 2023, 2024 and 2025 at a site located in the forest (altitude 1,000 m a. s. l.) and two other sites located near the upper forest boundary (altitudes 1,400 and 1,420 m a. s. l.). The results showed that all three winters were too severe for the roe deer at higher altitudes while moderate conditions were found at the lower altitude in winter 2025. The results suggest that WSI can be a suitable indicator of the ecosystem service related to lifecycle maintenance.

Keywords: *winter severity index, snow depth, air temperature, roe deer*
Acknowledgement: The study was supported by project Water4All/2023/1128.C/REACTION and the VEGA Grant Agency No. 2/0019/23.

Runoff Thresholds as State-Dependent Connectivity Transitions: A Global Synthesis across Diverse Catchments

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Abstract

Runoff threshold behaviour is widely observed in event-based hydrology, yet its interpretation remains inconsistent across climates and catchments. We present a global synthesis of storm-runoff thresholds from experimental catchments, focusing on threshold indicators, dominant runoff mechanisms, their shifts with increasing wetness, and recurring soil-geology controls. Across diverse environments, antecedent and within-event state variables, such as soil moisture, catchment storage and groundwater level, explain nonlinear runoff responses better than rainfall metrics alone, indicating that thresholds are mainly state dependent but rainfall triggered. With increasing wetness, runoff generation commonly shifts from infiltration-excess to saturation-excess overland flow, and then to subsurface or groundwater-dominated pathways. Recurrent combinations of soil depth, texture, permeability contrasts, lithology and geological structure form transferable structural fingerprints that regulate connectivity development and threshold behaviour. We therefore interpret runoff thresholds as hydrologic connectivity transitions within structurally constrained landscapes rather than fixed rainfall exceedances, providing a basis for cross-catchment comparison and improved representation of nonlinear runoff response in hydrological models.

Keywords: *runoff thresholds, hydrologic connectivity, soil-geology controls, nonlinear runoff response*

Hydroclimatic Extremes in the Western Tatra Mountains

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Abstract

Hydroclimatic (meteorological and hydrological) conditions in the Western Tatra Mountains, northern Slovakia are not characterised by severe extremes. However, wetter–drier and warmer–colder periods can be identified over decades. They can influence freshwater ecosystem services provided by forested mountain headwater catchments. We analysed precipitation, air temperature, catchment discharge and snow water equivalent in the Jalovecký Creek catchment (area 22 km^2, mean altitude 1,500 m) to identify such periods in hydrological years 1991–2020. Daily data showed that the number of days without precipitation was gradually decreasing from 225 in 1991 to 151 in 2020. Long periods (at least 14 days) without precipitation were observed especially in years 1991–1993, but the longest dry period started at the end of October 2011 and lasted 33 days. The highest number of days with heavy precipitation was observed in 2010. The longest hot periods occurred in August 1992 and July–August 2015 while the coldest period was observed in January to March 2005. Although the highest number of days with extremely high discharge was observed in 2010, the highest daily discharge was measured in May 2014. On the other hand, extremely small discharges occurred only in years 1996, 2006 and 2017. The highest snow water equivalent (SWE) at 1,500 m a. s. l. was observed in April 2000 (773 mm). Substantially smaller maxima were measured there in other winters. At lower altitudes (1,100 m a. s. l.), the SWE measured at the end of March 2019 (548 mm) was almost as high as in 2000 (553 mm). The winters of 2010 and 2011 had extremely small SWE maxima (170 and 184 mm) even at 1,500 m a. s. l. Compound extreme events have not been observed in the catchment.

Keywords: *Carpathian Mountains, headwater catchments, extreme events*
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Plant Cover Controls on Hydrological Behaviour during Wet and Dry Periods

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Abstract

The Mediterranean region is recognised as a hotspot for climate change, with rising temperatures and increasing frequency of extreme events such as droughts and intense rainfalls. Over the 20th century, Mediterranean mountains, which are the main water sources for the lowlands, have undergone widespread agricultural land abandonment and subsequent vegetation expansion, with significant consequences for runoff generation. Given the projected increase in the frequency of extreme weather events (dry and wet), this study examines how dry and wet periods influence the hydrological response under representative and contrasting vegetation covers. We used long-term climatological and hydrological data from four monitored small headwater catchments in the Central Pyrenees, including a natural forest, two abandoned areas (revegetated and afforested), and a degraded area. The Standardised Precipitation and Evapotranspiration Index (SPEI) was calculated to classify dry and wet conditions (SPEI ± 0.84). Our analysis shows 1. significant differences in hydrological behaviour between dry and wet years at both annual and seasonal scales; 2. a precipitation threshold across all catchments, with runoff coefficients exceeding 0.30 during wet years and fall below 0.20 during dry years (except in the degraded catchment); 3. the memory effect of prolonged droughts and a longer recovery period from dry conditions in the forested and revegetated catchments. This study highlights the importance of long-term data from experimental sites for understanding hydrological dynamics and monitoring the impact of climate change in Mediterranean mountains and water resources.

Keywords: *Mediterranean Mountains, monitored catchments, land cover changes, droughts, SPEI*
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Quantifying Rainfall Interception across Different Urban Tree Species and Its Effects on Soil Water Dynamics

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Abstract

Vegetation plays a critical role in regulating soil water dynamics in urban environments by influencing rainfall partitioning and subsurface hydrological processes. This study quantifies the interception capacity of urban trees and evaluates how differences in effective rainfall beneath canopies control components of the soil water balance. Interception was estimated from measured throughfall, while soil water fluxes, including transpiration, soil evaporation, storage, and deep percolation, were simulated using the HYDRUS-1D model. Model inputs include gross rainfall or effective rainfall (throughfall for under-tree soils), soil volumetric water content (VWC), potential evapotranspiration (PET), and soil hydraulic parameters.

Field measurements were conducted in an urban park in Ljubljana, Slovenia, from 2023 to 2025. The experimental plot includes various tree species, such as deciduous species – birch (Betula pendula) and maple (Acer negundo), and evergreen – black pine (Pinus nigra), white pine (Pinus strobus) and yew (Taxus baccata). A tipping-bucket rain gauge was installed in the open area to measure gross rainfall. Throughfall beneath the birch and pine canopies was measured using V-shaped steel trough collectors equipped with tipping-bucket flow gauges. Throughfall under other tree types was monitored using the same equipment to record open-area rainfall, but positioned under tree canopies. VWC at multiple depths (16–20, 51–54 and 74–76 cm) was continuously monitored at 5-minute intervals using TEROS-10 sensor probes in open areas.

Soil hydraulic parameters were obtained using inverse modelling in HYDRUS-1D with VWC data, assuming a three-layer soil profile (loam – loam – silt loam) to 100 cm. Model calibration, based on comparisons between simulated and observed VWC from March to October 2023, yielded NSE values of 0.81 and 0.73 at the 16–20 and 51–54 cm

observation depths, respectively. The validation period (March–July 2024) produced NSE values of 0.74 and 0.64, respectively. The calibrated model was then used to simulate soil water balance components for March–October 2025 under species-specific throughfall inputs. Results indicate that interception varies among tree species, generating distinct effective rainfall regimes and significantly influencing soil water dynamics. This indicates strong coupling between canopy processes and subsurface hydrology.

Keywords: *urban trees, rainfall interception, soil water dynamics, HYDRUS-1D, ecohydrology*
Acknowledgement: The work was supported through the PhD grant of the first author, which is financially supported by the Slovenian Research and Innovation Agency (ARIS). This study is also part of ongoing research programme P2-0180.

Hydrological Processes Revealed by Young Water Fraction from $\delta^{18}O$ Seasonality in a Mediterranean Forested Catchment

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Abstract

The young water fraction (Fyw), derived from the seasonality of stable oxygen isotope ($\delta^{18}O$), serves as a crucial indicator for elucidating hydrological processes at the catchment scale. However, the spatial distribution patterns and controlling mechanisms of Fyw in mountain forested catchments remain poorly understood.

In this study, we analysed a 2 km² forested catchment underlain by sandstone with a Mediterranean climate in the Apennines (Central Italy) to investigate the Fyw and associated hydrological processes from precipitation to soil, spring, and stream waters. We found that the different waters within the catchment consistently reflected the sinusoidal seasonal pattern of precipitation $\delta^{18}O$. Along the flow path from precipitation to deep soil (40–60 cm), spring, and stream waters, the seasonal amplitude of $\delta^{18}O$ gradually diminished, whereas electrical conductivity gradually increased, consistently indicating increasing flow path lengths within the catchment.

Following precipitation inputs, Fyw in deep soil water at both the hilltop and footslope decreased substantially, from 1 to 47%–55%. Subsequently, Fyw in groundwater along different flow paths was further reduced to varying extents: in the spring near the catchment divide (SP1), Fyw declined to 41%, whereas in the downstream groundwater near the stream water section C0 (SP0), it decreased to 11%. Notably, when downstream groundwater entered the surface stream network at C0 and flowed through C2, C3 and ultimately to the catchment outlet at C4, Fyw remained relatively stable (11%–15%), showing no significant further decline.

Our results highlight that in mountain forested catchments, soil and groundwater reservoirs play a dominant control over Fyw in different water compartments, with the soil reservoir reducing Fyw by 45% and the groundwater reservoir by 44%. Overall, Fyw exhibits a tendency to stabilise along the continuum from downstream groundwater to the stream. This study enhances our understanding of Fyw dynamics in Mediterranean forested catchments and provides a scientific basis for elucidating hydrological processes at the catchment scale.

Keywords: *$\delta^{18}O$ seasonality, young water fraction, soil water, groundwater, Mediterranean forested catchments*

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