https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

Rosalia: an experimental research site to study hydrological processes in a forest catchment

Josef Fürst[1], Hans Peter Nachtnebel[1], Josef Gasch[2], Reinhard Nolz[3], Michael Paul Stockinger[3], Christine Stumpp[3], Karsten Schulz[1]

[1]Institute for Hydrology and Water Management (HyWa), University of Natural Resources and Life Sciences Vienna (BOKU), Vienna, Austria.
[2]Forest Demonstration Centre, University of Natural Resources and Life Sciences Vienna (BOKU), Vienna, Austria.
[3]Institute for Soil Physics and Rural Water Management (SoPhy), University of Natural Resources and Life Sciences Vienna (BOKU), Vienna Austria.

Correspondence to: Josef Fürst (josef.fuerst@boku.ac.at)

Abstract.

Experimental watersheds have a long tradition as research sites in hydrology and have been used as far back as the late 19th and early 20th century. The University of Natural Resources and Life Sciences Vienna (BOKU) has been operating the experimental research forest site called “Rosalia” with an area of 950 ha since 1875 to support and facilitate research and education. Recently, BOKU researchers from various disciplines extended the “Rosalia” instrumentation towards a full ecological-hydrological experimental watershed. The overall objective is to implement a multi-scale, multi-disciplinary observation system that facilitates the study of water, energy and solute transport processes in the soil-plant-atmosphere continuum. This article describes the characteristics of the site, the recently installed monitoring network and its instrumentation, as well as the datasets. The network includes 4 discharge gauging stations, 7 rain-gauges, together with observation of air and water temperature, relative humidity and conductivity. In four profiles, soil water content and temperature are recorded in different depths. In 2019, additionally a program to collect isotopic data in precipitation and discharge was started. On one site, also Nitrate, TOC and turbidity are monitored. All data collected since 2015, including in total 56 high resolution time series data (10 min sampling interval), are provided to the scientific community on a publicly accessible repository. The datasets are available at https://doi.org/10.5281/zenodo.3997141 (Fürst et al., 2020).

1 Introduction

For many areas in environmental water management and decision-making, it is essential to understand hydrological processes and their dominant controls at different spatial and temporal scales. In order to investigate hydrological processes and their complex interactions with their environmental components, long-term measurements from interdisciplinary hydrological observatories are required (Schumann et al., 2010;Blöschl et al., 2016). Experimental watersheds have a long tradition as research sites in hydrology and have been used as far back as the late 19th and early 20th century (USGS Reynolds Creek, (Seyfried et al., 2018)). Given the long-term character of these datasets, global change impacts, such as climate, on the hydrological cycle can be investigated in those watersheds (Bogena et al., 2018).

Over decades, it has been realized that hydrology (and its related disciplines) cannot be treated in isolation; rather, hydrological processes that are driven by meteorological conditions are also strongly controlled by complex feedback mechanisms with biotic and abiotic systems. Therefore, experimental catchment sites have continuously transitioned into multidisciplinary research catchments, with the “Critical Zone Observatories” as a prominent example, initiated in 2007 by the U.S. National Science Foundation (Anderson et al., 2018).

Understanding processes from research based at single catchments is limited to the physio-geographic conditions at the particular location. In order to extend multi-disciplinary observation and modelling strategies to a wider spectrum of boundary conditions in a harmonized way, networks of interdisciplinary, hydrological observatories have been founded over the last

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

decades. International activities include the German "TERrestrial ENvironmental Observatory network" (TERENO; (Zacharias et al., 2011), the "International Network for Alpine Research Catchment Hydrology" (Bernhardt et al., 2015), the "US National Science Foundation's National Ecological Observatory Network" (NEON (Kampe et al., 2010)), and the "Euro-Mediterranean Network of Experimental and Representative Basins" (ERB) as part of UNESCO FRIEND (Flow Regimes from International Experimental and Network Data). In this framework, a recent report on the status and perspectives of hydrological research in small basins in Europe was published by Holzmann (2018).

These networks of observatories allow addressing a number of open research questions in hydrology as formulated most recently (Blöschl et al., 2019). The most challenging questions with regard to catchment hydrology relate to considering sub-grid variability when process understanding and model parameters are regionalized and applied to ungauged basins, as well as the derivation of flow paths and residence times of water and solutes in the subsurface at different scales; they both require concerted efforts on the part of the hydrological research community. While such networks of observatories exist, they need to be complemented in their instrumentation and observation capacities harmonizing temporal and spatial frequencies and by allowing to continuously monitor natural tracers such as ions, metals, and stable isotopes ratios such as $^{2}H/^{1}H$, $^{18}O/^{16}O$ or $^{15}N/^{14}O$ in precipitation, discharge and in the catchment subsurface system. The Plynlimon research catchment in the U.K. (Neal et al., 2011;Cosby and Emmett, 2020), or the Krycklan catchment study in Sweden (Laudon et al., 2013) are good examples of such catchments.

In order to better understand the structure and functioning of complex ecosystems and their long-term response to environmental, societal and economic pressures at different spatial scales and to contribute to the knowledge base informing policy and to the development of management options, the "Long Term Ecosystem Research" (LTER) initiative has been established as a global network (LTER Network Office, 2020). The LTER was initiated in 1980 in the U.S.A. with initially 6 catchments and has since then expanded to other continents and countries, comprising a wide range of ecosystem types, climates and pressures. The LTER has been further developed into "Long Term Socio-economic and Ecosystem Research" (LTSER) to address and emphasize the human dimension (Haberl et al., 2006). Only recently has the European Commission decided to establish the integrated "European Long-Term Ecosystem, critical zone and socio-ecological systems Research Infrastructure" (eLTER RI) as a "European Strategy Forum on Research Infrastructures" (ESFRI) (European Strategy Forum on Research Infrastructures, 2020).

The University of Natural Resources and Life Sciences in Vienna (BOKU) has a long tradition and experience in operating field experimental sites in different disciplines, often cross-cutting to assist research, to monitor environmental changes and climate impacts, to provide the ground for development of new monitoring techniques, and to train students in applied research. The experimental research forest site called "Rosalia" with an area of 950 ha was implemented in 1875 to support and facilitate research and education, mainly in forestry disciplines (Figure 1). Several forest dieback studies were carried out in the 1980s. The "Rosalia" became part of the Austrian LTER-CWN (Research Infrastructure for Carbon, Water and Nitrogen) initiative, when in 2013 a group of BOKU researchers from various disciplines extended the "Rosalia" instrumentation towards a full ecological-hydrological experimental watershed.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

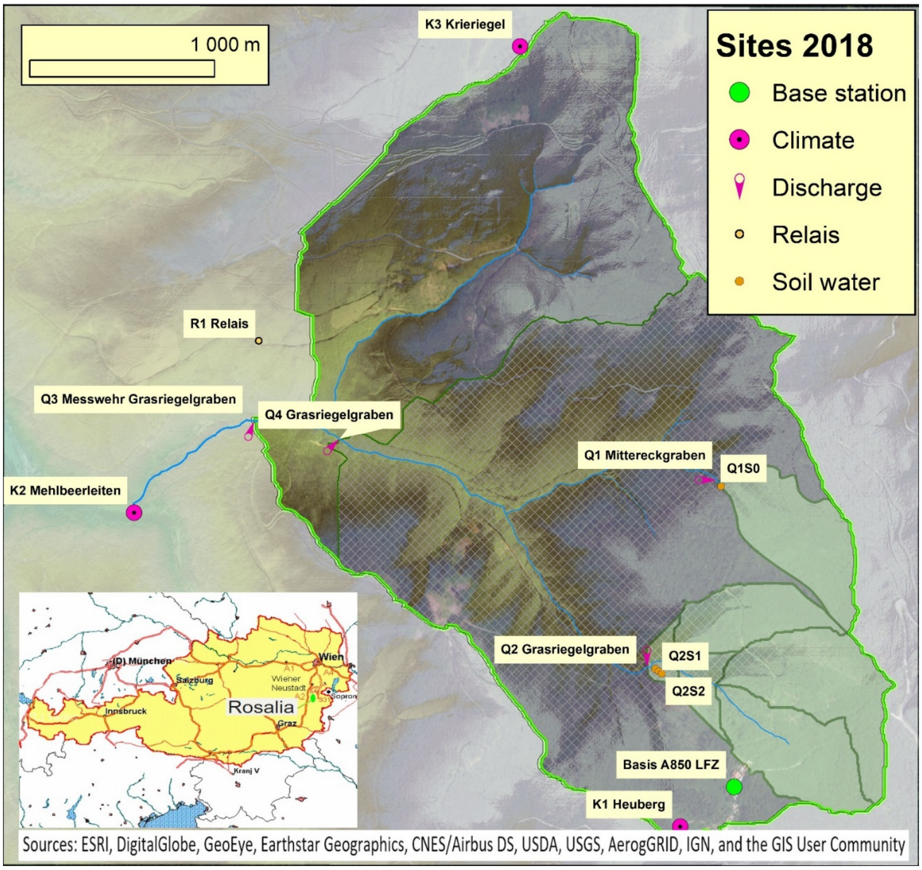

Figure 1: Overview map of the watersheds and the monitoring network.

The overall objective was and still is to implement a multi-scale, multi-disciplinary observation system that facilitates the study of water, energy and solute transport processes in the soil-plant-atmosphere continuum. A research emphasis is on bridging the gap between point related measurements and finding effective parameters to upscale the results to spatial units pertaining to the size corresponding to model flow and transport processes in forested watersheds. Distinctive features of the current "Rosalia" research monitoring setup are the continuous measurement of tracers in the precipitation and in the discharge of selected creeks within the catchment, which allows deriving travel time distributions for sub-catchments and investigating flow pathways in detail. Additionally, large-scale highly controlled experiments can be undertaken in the entire catchment outdoors, such as for example rain-sheltering part of the forest to simulate drought conditions that might be expected to occur under climate change conditions or, researching the ecosystem transitioning of the forest from its actual state into a pristine, unmanaged natural forest; or increasing the input of nitrogen into the system to simulate increased atmospheric N-deposition. The subsequent impacts on the forest ecosystem and its services (including water, energy and solute fluxes, species distribution, biomass, soil microbial activity and the release of greenhouse gases, amongst others), as well as mitigation and adaptation strategies are and will be investigated by the multidisciplinary team of researchers (Schwen et al., 2015;Leitner et al., 2017). These experiments are permissible due to research contracts with the Austrian Forestry Agency ("Österreichische Bundesforste"). While the selection process for specific experiments and their details have not yet been finalized, it is necessary in the meantime to guarantee a baseline data set of relevant boundary conditions, internal fluxes and states. The "Rosalia" has been collecting base-line data since 1972 to today.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

The specific objective of this article is to document the monitoring network and the recorded data and make them available to the scientific community. The article first introduces the "Rosalia" experimental research watershed along with its physio-geographical properties (section 2) and its observation and instrumentation network (section 3). In section 4 various data from different locations are shown and discussed, and section 5 introduces some application and process studies based on these data. The article closes with a reference to the data set (section 6) and a short summary (section 7).

2 Description of the watershed

The Rosalia Mountains (German: Rosaliengebirge) belong to the eastern foothills of the Alps on the state border between Lower Austria and Burgenland in Austria (LAT 47°42'N, LON 16°17' E). In the research watershed, the terrain height ranges from 320 to 725 m asl, and is characterised by steep slopes (96 percent of the area steeper than 10%, and 55 percent steeper than 30%).

Crystalline rocks are dominating, but coarse grain gneiss, sericitic schist, phyllite and dolomite are also encountered. In the years 1989-2018, annual precipitation was between 560 and 1100 mm (average 790 mm, standard deviation 128 mm), and mean annual air temperature was between 5.5 and 10 °C (average 8.2 °C, standard deviation 1.2 °C).

Frequently during summer, heavy convective storms occur, which often cause pluvial floods destroying forest access roads, culverts and other infrastructure (Figure 2).

Figure 2: Destructions of forest roads due to a storm on June 29, 2009 (Photo: J. Gasch)

The watershed is almost completely forested with typical tree species and forest types in Austria dominated by beech communities (Fagetum) and spruce-fir-beech forest communities (Abieti-Fagetum). Forest practice has been changed to promote uneven aged mixed species stands. The forest is at different development stages ranging from clear cut areas to mature forest stands.

The main benefits of Rosalia as a research site are:

1. The watershed is part of the demonstration forest of the BOKU, and therefore a large amount of watershed information already exists, including soil maps, high resolution DEM (digital elevation model), maps on forest growth and productivity, detailed topographic maps and more.
2. There is a well-established cooperation between BOKU and the owners of the forest, Austrian Forestry Agency ("Österreichische Bundesforste"), which facilitates even large scale experiments with a duration of several years.
3. Rosalia can be reached from Vienna within less than an hour, making maintenance cost-effective.
4. BOKU has an educational center right at the border of the watershed, with seminar rooms, basic laboratory facilities and accommodation for up to 40 persons. Resident staff at the educational center is able to assist in urgent situations like in case of a storm or power failure.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

3 Network of measurement sites

A network of stations has been set up to collect hydro-meteorological data: at 4 gauging stations, river discharge, water and air temperature, relative humidity and electrical conductivity of water are monitored. The locations were selected to cover nested sub-watersheds of 9, 27, 145 and 220 ha, respectively. At one of these sites (Q4, 145 ha), water quality (NO_3-N, TOC, turbidity) is monitored by a spectrometer probe. Here, also stream water samples are taken for analysing stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δ^2H).

Precipitation is measured by 7 rain gauges at different altitudes. At two of these locations, precipitation is additionally collected for the analysis of $\delta^{18}O$ and δ^2H.

At four locations, soil profiles were equipped with sensors measuring soil water content and soil temperature in four and three depths, respectively.

Figure 1 displays an overview map of the watershed and the network of stations, and Table 1 lists all the sites, the installed sensors and the observed variables.

Table 1: List of sites, sensors and variables (as of March 2020)

Site	**Sensors**	**Observed variables**
Q1 Mittereckgraben RTU A753	Conductivity and temperature sensor Ponsel C4E	Electrical conductivity Water temperature
	Rain gauge RG1 (Adcon tipping bucket)	10-min rain depth 0.2 mm events
	Air temperature and humidity sensor TR1 (Adcon)	Air temperature Relative humidity
	1-ft H-Flume with 2 ultrasonic distance sensors (Baumer)	Water level in H-Flume discharge
	Tipping bucket device 11	Small discharge
	4 HydraProbe soil sensors (Stevens)	Soil water content Soil temperature Electrical conductivity of soil water
Q2 Grasriegelgraben RTU A753 Q2S1 RTU A723 Q2S2 RTU A723 Soil water profiles	Conductivity and temperature sensor Ponsel C4E	Electrical conductivity Water temperature
	Rain gauge RG1 (tipping bucket)	10-min rain depth 0.2 mm events
	Air temperature and humidity sensor TR1	Air temperature Relative humidity
	1-ft H-Flume with 2 ultrasonic distance sensors	Water level in H-Flume discharge
	4 HydraProbe soil sensors	Soil water content Soil temperature Electrical conductivity of soil water
	3 HydraProbe soil sensors at Q2S1 und Q2S2	*Parameters see above*
	2 SM1 soil moisture and temperature sensors at Q2S1 and Q2S2	soil moisture and temperature at 4 depths
K1 Heuberg RTU A753	OTT Pluvio^2 L – Weighing Rain Gauge	10-min rain depth 0.1 mm events
	Air temperature and humidity sensor TR1	Air temperature Relative humidity
	Palmex - rain sampler	Precipitation isotopes ($\delta^{18}O$, δ^2H)
K2 Mehlbeerleiten RTU A753	OTT Pluvio^2 L – Weighing Rain Gauge	10-min rain depth 0.1 mm events
	Air temperature and humidity sensor TR1	Air temperature Relative humidity
K3 Krieriegel RTU A753	OTT Pluvio^2 L – Weighing Rain Gauge	10-min rain depth 0.1 mm events

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

Q3 weir Grasriegelgraben RTU A723	Depth sensor Keller PR46X	Water level at weir discharge
	Rain gauge RG1 (tipping bucket)	10-min rain depth 0.2 mm events
	Air temperature and humidity sensor TR1	Air temperature Relative humidity
Q4 Grasriegelgraben RTU A753	2-ft H-Flume with 2 ultrasonic distance sensors (Baumer)	Water level in H-Flume discharge
	Rain gauge RG1 (tipping bucket)	10-min rain depth 0.2 mm events
	Air temperature and humidity sensor TR1	Air temperature Relative humidity
	S::can conductivity and temperature sensor condu:lyser	Electrical conductivity Water temperature
	S::can multi lyser spectrometer probe	TOC, NO_3-N, turbidity
	Palmex - rain sampler	Precipitation isotopes ($\delta^{18}O$, δ^2H)
	Teledyne ISCO full-size portable sampler 6712	River water isotopes ($\delta^{18}O$, δ^2H)

3.1 Data acquisition

Although the observed variables have different temporal characteristics, it was decided to record all *in-situ* measurements (except stable water isotope data) at synchronous 10-min-intervals in order to simplify data storage and organisation. For this purpose, a UHF radio telemetry network (ADCON telemetry by OTT Hydromet GmbH) was implemented enabling data transfer, data storage and data management in a web accessible Database Management System (DBMS). At each monitoring site, different sensors are connected to a remote telemetry unit (RTU). Within the network, several RTUs store and transmit data to a base station (located at the demonstration center building), and receive control commands from the base station. Apart from physically connecting the sensors to the RTU and providing power supply (solar or external), all setup, parameterisation, etc. is done remotely via a web interface to the base station. From the base station, data are transmitted to the DBMS addVANTAGE Pro via an internet link. Furthermore, data is stored redundantly for several days in the RTU, for several weeks in the base station and unlimited in the DBMS addVANTAGE Pro. The DBMS addVANTAGE Pro is the main interface for administrators, regular users and the public. It is ADCON's universal data visualization, processing and distribution platform. It is fully web-based, runs on a reliable PostgreSQL database engine, and is fully scalable from a single user version for 5 RTU's to servers with thousands of clients and thousands of RTU's. Stable water isotope data are not automatically uploaded to the DBMS but samples are collected on-site and picked up manually by university staff for further analysis in the laboratory. Precipitation samples are collected bi-weekly with totalisators with plans to refine the sampling interval to daily in 2020, while streamflow samples are collected as daily grab samples using an autosampler.

Monitoring of time series is complemented by terrestrial surveys of soil properties during field courses of students and geophysical explorations. Topographic information is available from various DEMs, including a 0.5 x 0.5m resolution LIDAR.

3.2 Description of sites

Discharge gauges

The hydrological sites for discharge measurements were selected with the objective to collect data for nested sub-catchments of different sizes. It was possible to find locations just at culverts of forest access roads, which has several advantages: (i) the sites are accessible by car, which is important for cost effective maintenance, (ii) they have a defined sub-catchment outlet, and (iii) the H-flume devices could be attached directly to culvert pipes, thus utilizing the road dams to catch even larger flows completely.

To measure discharge, H-flumes devices were selected because they cover a wide range of flow rates, and most sediments are flushed through due to their horizontal bottom. For sites Q1 and Q2 with a watershed size of 9 and 27 ha, respectively, the 1-

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

foot H-flumes can measure discharge from 0.02 up to 55 l/s, where the upper limit corresponds to an approximately 5-year flood discharge (at the 27 ha site). Site Q4, with a watershed of 145 ha, is equipped with a 2-foot H-flume (Figure 3). Water level at the H-flumes is measured by pairs of ultrasonic distance sensors. One of these sensors measures the depth to the water level and the second measures a fixed reference distance. With the ratio of known reference distance over measured distance, the depth to the water level is corrected for the dependency of sound velocity on air temperature and relative humidity. Although H-flumes are comparatively insensitive to the accumulation of sediments, we developed a compressed-air flushing system to keep the outflow section and the water level reference point free from sediments and debris.

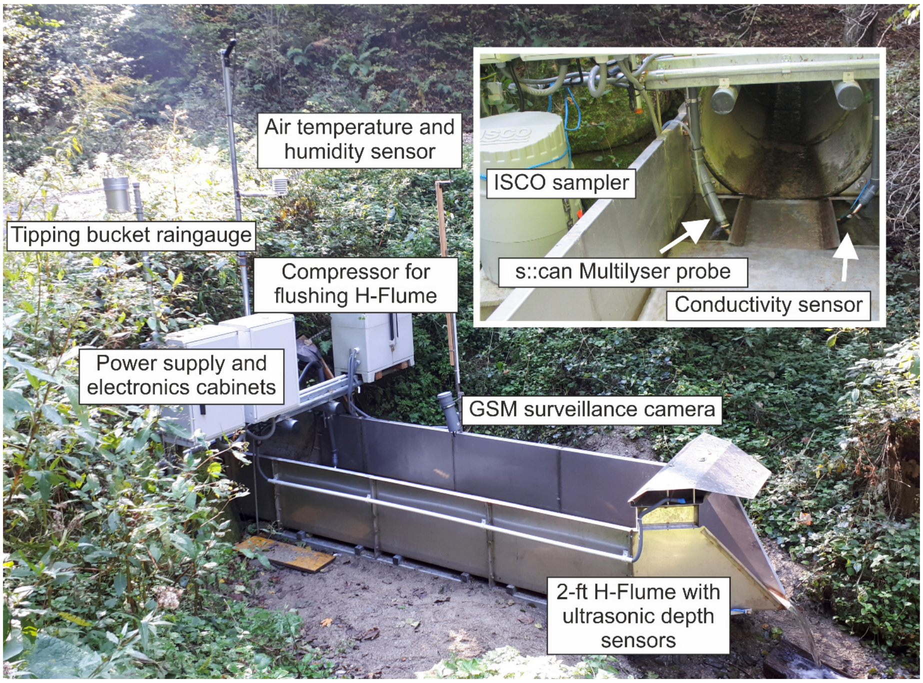

Figure 3: Gauging site Q4 with 2-Ft H-Flume, spectrometer device and auto-sampler

Site Q3 (223 ha) was already constructed in the 1980's, using a Thompson weir. Water level is measured by a capacitive pressure transmitter.

Sites Q1, Q2 and Q4 are additionally equipped with sensors for electrical conductivity, water temperature, air temperature and relative humidity. At sites Q1 and Q2, Ponsel C4E sensors (4 electrodes) were installed to measure water temperature and conductivity, because of their SDI-12 interface and low power consumption. They work electronically reliably, but it turned out that the measured conductivities are sensitive to minimal biofilms on the sensor, and there seem to be also some issues with achieving a stable reading after power-on or after cleaning. The collected data are trusted only to represent the relative dynamics of conductivity, e.g., due to dilution during a storm event, but absolute values should be taken with care. Currently, alternative sensors are tested to replace the C4E devices. At site Q4, a different type of sensor (s::can Condulyser ™) is used, which, after more than a year of operation, records reliable and stable data.

Rain gauges

Sites K1, K2 and K3 are equipped with weighing rain gauges OTT Pluvio². Antifreeze fluid is added during the frost period, so that continuous measurement is possible. At the discharge sites Q1 – Q4, tipping bucket rain gauges are installed. They require more maintenance, because the funnel is easily blocked by atmospheric deposition, and they do not work during frost. Records from November to April must therefore be carefully checked using air temperature records and by comparing the data

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

with the records from the weighing rain gauges. Also, in the forest, it was not possible to follow all the rules for proper placement of a rain gauge. Especially, it was unavoidable that obstructions (trees) are sometimes closer to the gauge than their height. Particularly the rain gauge at Q1 is directly affected by interception of the trees above. Two rain totalisators (Palmex Ltd., Croatia) were installed collecting precipitation samples for isotope analysis at the meteorological station K1 and discharge site Q4.

Soil water

Stevens® HydraProbe® soil sensors with SDI-12 communication protocol (Stevens Water Monitoring Systems, Inc., Portland, OR, USA) were installed to simultaneously measure soil moisture, temperature and salinity (Stevens, 2015). Based on the selected SDI-12 command, the sensors deliver a standard data packet of six variables, including three variables characterizing the dielectric properties of the soil and the resulting values of soil water content, temperature, and bulk electrical conductivity. In total, four soil profiles were equipped with HydraProbes. In two of the profiles, the sensors were installed at depths of 10, 20, 40 and 60 cm below surface (Figure 4); in the others, the sensors were installed at 10, 20, and 40 cm depth. Soil profile Q1S0 is located approx. 20 m upslope of gauge Q1. Soil profiles Q2S0, Q2S1 and Q2S2 form a transect up the slope line at 16, 30 and 45 m distance from Q2. This design supports a cross section of soil water parameters measured along the slope line.

Figure 4: HydraProbe sensors installed at site Q2S0

Water quality

Since 2018, the water quality parameters NO_3-N, TOC, and turbidity are monitored by a spectrometer probe S::can Multilyser at site Q4. Starting in June 2019, a Teledyne ISCO full-size portable autosampler with a capacity of 24 1-litre bottles (model no: 6712) was installed at the same site to collect daily water samples for laboratory analysis of the stable oxygen and hydrogen isotopes of river water ($\delta^{18}O$, $\delta^{2}H$). The auto-sampler for collecting the river water samples needs a constant power supply to operate. A daily sampling interval with 500 ml of water per day was chosen for the long-term monitoring to cover long-term changes in base flow and daily snapshot information in case of events. The amount of water ensures a statistically sound sample size. On the one hand the sampling interval is short enough to enable the investigation of runoff events, and on the other hand it is long enough that the autosampler can be left in the field for 24 days without maintenance. The suction tube leading from the H-flume to the ISCO autosampler is occasionally affected by frost. The frozen water inside the tube then prevents the autosampler pump from collecting water samples. Since the installation of the system, this has happened only rarely (less than 20 days), and we plan on further measures to mitigate freezing issues that arise from small amounts of residual water in the tube that the pump cannot fully flush out.

Close to the auto-sampler open precipitation samples are collected bi-weekly with a totalisator station (Palmex Ltd., Croatia) which is suitable for isotope sampling (Gröning et al. 2012). The collected precipitation thus did not undergo canopy-induced changes of the isotopic value which have the potential to influence the results of hydrologic models (Stockinger et al., 2015). Additionally, a Palmex totalisator station was installed at K1 to also consider elevation effects on isotope ratios.

$\delta^{18}O$ and δ^2H are analysed using laser spectroscopy (Picarro L 2140-i, Picarro Inc., Santa Clara, CA, USA). A calibration with laboratory reference material calibrated against the Vienna Standard Mean Ocean Water and Standard Light Antarctic Precipitation scale was used. All values are given in delta notation, and precision of the instrument (1σ) was better than 0.1‰ and 0.5‰ for $\delta^{18}O$ and δ^2H.

4 Data

All time series data are recorded, stored and routinely visualized by addVANTAGE Pro. For intensive analysis, data are regularly exported into the frequently used and freely available time series management system HEC DSS and the management software HEC DSSVue (Hydrologic Engineering Center, 2010). HEC DSSVue has powerful visualisation features and provides a convenient graphical editor for the time series. Editing is important, because the raw data have to be cleaned from obvious artefacts, such as spikes generated during maintenance, occasional obstructions of flumes during storms and similar disturbances. Nonetheless, raw data will always remain available in the database. Edited data are clearly marked by a label. For even more flexible and automated processing, the HEC DSS database is also converted into a simple SQLite database (Hipp et al., 2019), which provides efficient and simple access from a variety of software tools, including Python and R (Müller et al., 2018).

Implementation of the instruments started in spring 2015. First time series at sites Q1 and Q2 started recording in May 2015. Until September 2015, also rain gauges K1 and K2, soil water profiles Q1S0 and Q2S0, and stream gauge Q3 were added and delivering data. Soil water profiles Q2S1 and Q2S2 were added in April 2016, rain gauge K3 and stream gauge Q4 in summer 2018. For the majority of data, more than four years of records are currently available (summer 2020).

4.1 Discharge data

Discharge is characterised by its wide range. At Q3 (watershed outlet at 223 ha), low flows in summer and fall can be less than 3 l/s, while peak flows of more than 500 l/s have occurred already twice since 2015. Specific discharge is typically between 1 and 2 l/(s km²) during low to medium flow and goes up to 30 l/(s km²) during peak flows (calculated from daily means).

Figure 5 illustrates the available discharge series. In the hydrographs for the time period 2018 to 2019, increased baseflows in spring and early summer are evident, as well as sharp peaks after rainfall events. The zoomed-in hydrographs July/August 2018 (Figure 6) illustrate characteristic diurnal fluctuations of discharge during no-rain periods in the vegetation period (see section Applications for more details). It should be noted that up to now, the H-Flumes never froze, recording reliable data also during winter, while the stilling basin at weir Q3 develops an ice cover during longer periods of freezing temperatures and in consequence, water level and discharge measurements are corrupted for short time periods.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

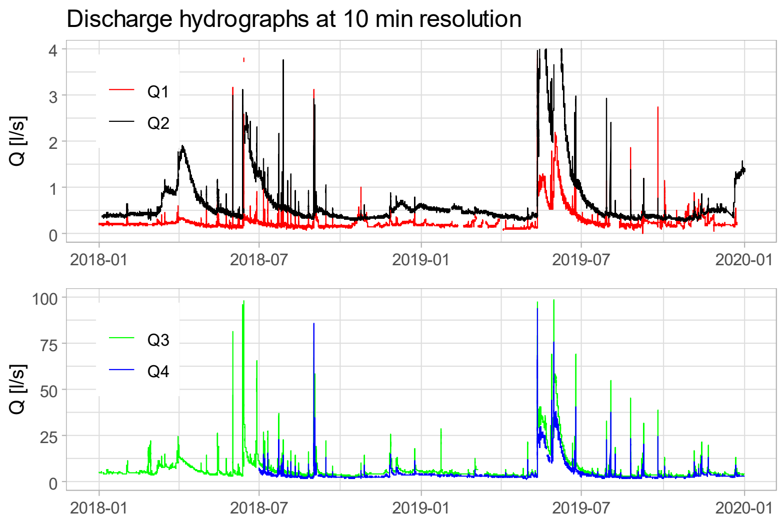

Figure 5: Discharge hydrographs

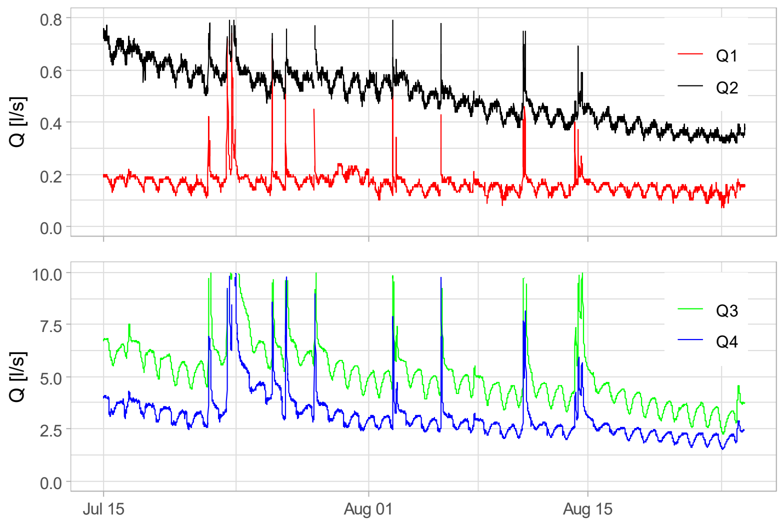

Figure 6: Diurnal fluctuations of flow for July/August 2018

4.2 Precipitation

The three weighing rain gauges provided gap-free records since the time of installation up to now, with a resolution of 0.1 mm. The four tipping bucket rain gauges could not provide complete, gap-free records, but the occasional malfunction is recognizable by comparison with the weighing gauges. For most rainfall events, consistent and plausible data were acquired by up to 7 rain gauges in total, providing a high-resolution rainfall pattern for a small area of 220 ha, and being spread over different altitudes from 320 to 700 m asl (Figure 7).

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

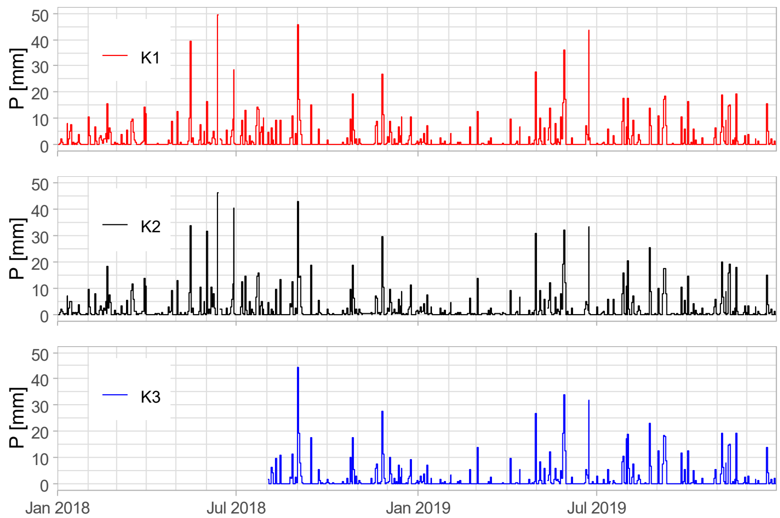

Figure 7: Daily rainfall at the weighing rain gauges

265 ## 4.3 Soil water data

With, in total, 14 HydraProbe sensors installed, and each measuring six variables, 84 soil water related time series at 10 min resolution are recorded, resulting in a large volume of data. Apart from an initial power supply problem at Q2S2, these sensors worked without any problem or data loss and required no maintenance. Figure 8 illustrates aggregated data of daily rainfall together with daily soil water content in 4 depths at profile Q2S0. It is important to mention that the installation of the sensors requires digging a trench, which causes a considerable local disturbance of the soil. Despite of careful refilling, local infiltration paths could be influenced, and data do not necessarily reflect natural conditions for some time after installation. Deeper probes, for example, sometimes reacted faster to rainfall than those close to the surface, because of preferential flow paths along the walls of the trench or along the cables (Figure 9). Due to consolidation, this effect generally vanished after the first few months, but can still occasionally occur due to opening of wormholes or other macropores or due to naturally occurring inhomogeneous infiltration patterns.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Open Access Earth System Science Data Discussions

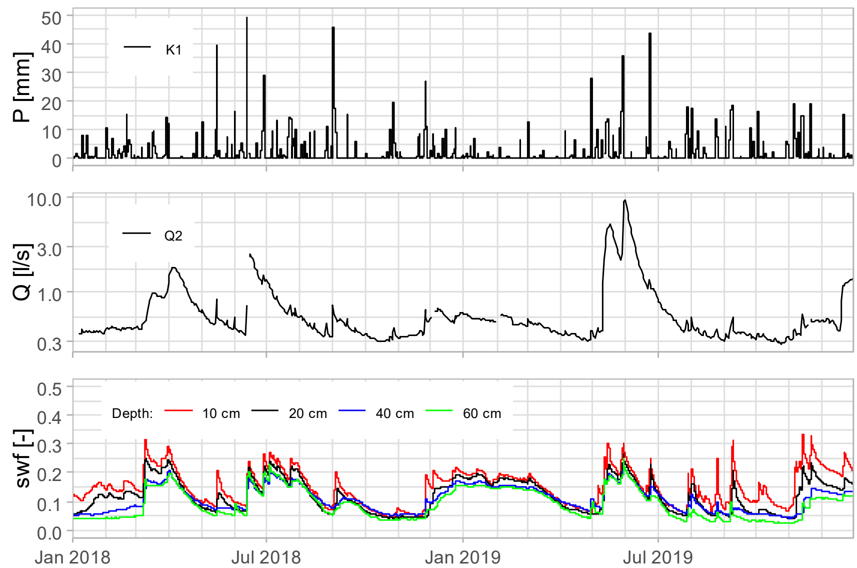

Figure 8: Daily soil water content (swf) and corresponding daily rainfall and log(discharge) at site Q2S0

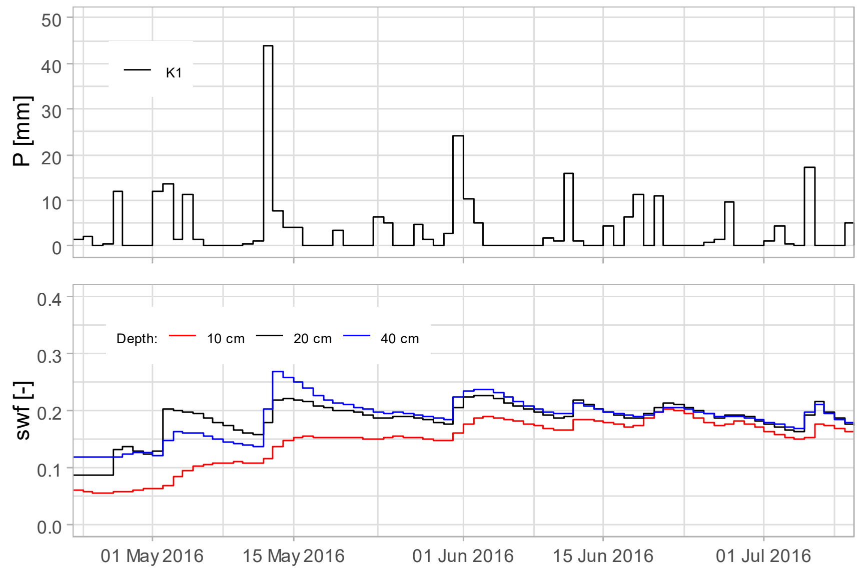

Figure 9: Detail of daily soil water content (swf) at site Q2S1: deeper sensors react faster to rainfall on May 12, 2016

4.4 Electrical conductivity and temperature of runoff

At the discharge sites Q1, Q2 and Q4, water temperature and electrical conductivity are measured. Due to risk of damage due to frost, the sensors have been removed during the frost period December to March at sites Q1 and Q2. Conductivity records at sites Q1 and Q2 may also be influenced by the sensor problems described above. Regular conductivity measurements with a portable device revealed that the conductivity of baseflow is stable at sites Q1 and Q2 (typically approx. 120 µS/cm), so that the recorded conductivity series are still informative for the separation of baseflow and direct runoff events, despite conductivity offsets in the records.

4.5 Isotopic data

The stable isotopes of water as an environmental tracer have found versatile use in catchment science in, e.g., estimating water transit times (McGuire and McDonnell, 2006) or hydrograph separation studies (Klaus and McDonnell, 2013). They are a powerful tool, complementing the hydrometeorological network of the Rosalia and thus data acquisition was started in 2019. At discharge site Q4 river and precipitation samples are collected since June and October 2019 (Figure 10). To date, the precipitation data have been collected as bi-weekly bulk samples and are compared to the daily river water grab samples. Although even bi-weekly precipitation samples cover some of the seasonal isotope variability in precipitation, an automatic daily precipitation isotope sampler will be installed in 2020 allowing for daily analyses of runoff processes in future. Still, comparison of precipitation with river isotope values already shows the response of the discharge to the precipitation input tracer signal (Figure 10). Furthermore, while not visible in precipitation samples (yet) due to the shorter time series, the seasonal variation of isotopes in river water is obvious with larger values in summer and lower values in winter months. This seasonality originated from contributions of precipitation to discharge, and isotope ratios in precipitation seasonally vary due to changes in temperature, sources of vapour for cloud-formation and different rain-out histories. There are some preliminary indications of different flow paths like baseflow (relatively stable isotope values around -10.2 ‰), interflow (moderate increases or decreases in isotopes, for example at the beginning of August 2019) and faster flow (sharp peaks) suggesting dynamic runoff processes and transit times in Rosalia which will be analysed in future.

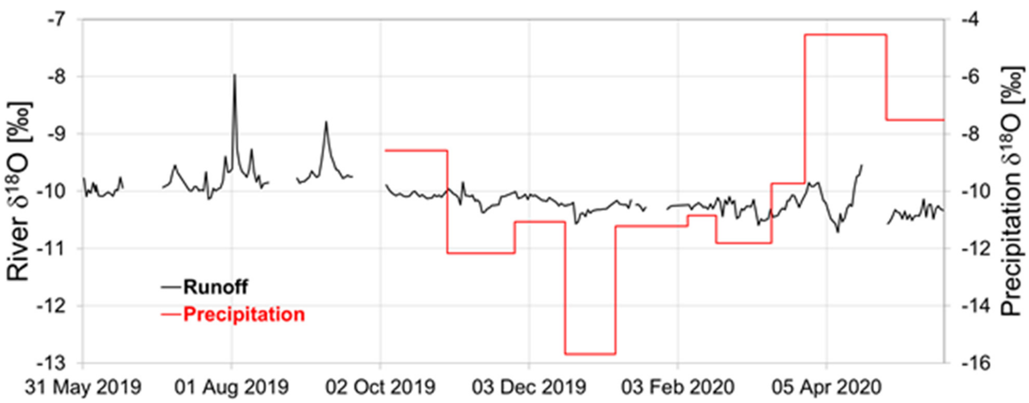

Figure 10: Precipitation and river isotopes at site Q4

4.6 Spatial data

Data interpretation is complemented by a comprehensive amount of spatial data characterising the site. DEMs at various resolutions are available, including a 10x10 m DEM, and two LIDAR based DEMs at 1x1 and 0.5x0.5 m. From these DEMs, the watershed divides and the drainage network have been derived in GIS. Additionally, a ground survey has been performed for the main creeks in 2018. These data are available in shapefile format.

5 Applications

The collected data are suitable to study processes of water flow and transport in small forested watersheds. Two examples are briefly described below.

5.1 Baseflow separation

As a first application of discharge and conductivity data, a simple two end-member mixing model was developed for the separation of baseflow and direct runoff (Lott and Stewart, 2016). Figure 11 illustrates the relationship between rainfall,

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

discharge and electrical conductivity. Because rainwater has a much smaller electrical conductivity than baseflow, direct runoff immediately after a rainfall event dilutes the stream discharge by mixing highly conductive baseflow and less conductive direct runoff. This effect is clearly visible in the time series, where the conductivity curve is almost a mirror of the discharge hydrograph. It is obvious, that high resolution electrical conductivity data can be utilized to separate baseflow and study concentration times of runoff. In future, end-member mixing or –splitting will be complemented by isotope data.

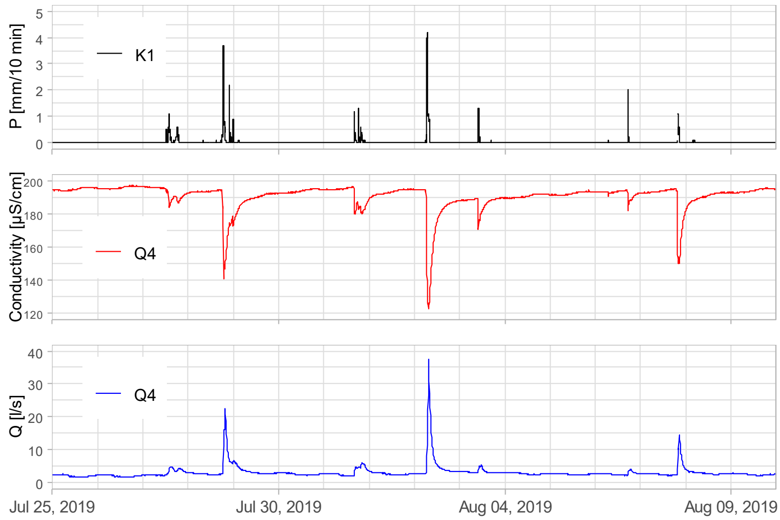

Figure 11: Synoptic display of rainfall, discharge and electrical conductivity at Q4

5.2 Diurnal fluctuations of baseflow

An interesting phenomenon is observed in no-rain periods during the vegetation period: daily fluctuations of discharge, with peaks at 8 a.m. up to 40% higher than the minimum at 5 p.m., occur consistently at all 4 sites (Figure 6). Obviously, this must be an effect of the transpiration of the forest. These diurnal fluctuations are not observed from late autumn to early spring.

A first analysis of this phenomenon was performed for the sub-watershed at gauge Q2, with a watershed area of 27 ha. Simple rule-of-thumb considerations reveal that a typical hourly transpiration rate of 1 mm/h (peak rate early afternoon) is equivalent to a flux of approx. 75 l/s, while a typical daily range of discharge at Q2 during a no-rain period in July/August 2018 is only 0.05 – 0.08 l/s – only a fraction of the daily cycle of evapotranspiration flux of the whole watershed. We therefore concluded that not the whole watershed, but only direct root water uptake in the immediate vicinity of the creeks (< 5 m) can generate these fluctuations. All other locations outside the immediate vicinity have far longer travel times (days to months) through the unsaturated zone to the streams. Local fluctuations in bottom flux at points in the watershed with varying lengths of the flow paths would also level out by superposition due to different travel times from the location to the creek. These daily cycles of evapotranspiration can therefore not be visible in the discharge of the creek. Of course, transpiration gradually reduces soil water storage and therefore the baseflow.

A schematic simulation experiment using HYDRUS1D (Simunek et al., 2005) was carried out to test the plausibility of this hypothesis. We assumed a saturated sandy loam soil of 60 cm depth, and a bottom boundary condition of constant water content. This boundary condition provides unlimited supply of water to the roots. The meteorological inputs radiation and temperature were generated by HYDRUS1D, based on the geographical position and day of the year. The length of the creek is approximately 1000 m. With a strip of 5 m land to the left and the right, a contributing area of 1 ha is represented. The resulting baseflow computed by HYDRUS 1D is presented in Figure 12. Computed and observed baseflow match surprisingly well. Also, the timing and shape of the hydrographs are matching well. These observations are currently analysed in all sub-watersheds using meteorological input data observed at the site as well as soil moisture data.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

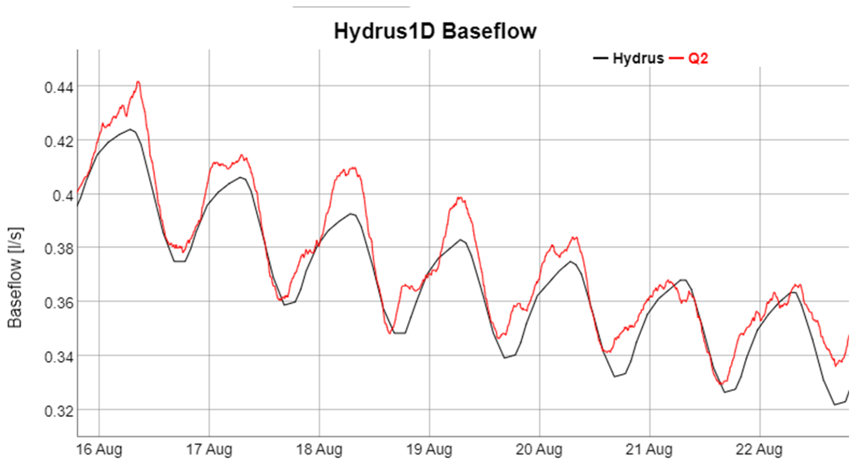

Figure 12: Comparison of observed and simulated baseflow

6 Data availability

All time series data have been cleaned from the most obvious errors and artefacts and stored in an easily useable database. Additionally, some auxiliary spatial datasets are made available: a 10 x 10m DEM, shapefiles of the watershed divides and the surface waterbodies, and a shapefile of the monitoring sites.

The data described above are available at https://doi.org/10.5281/zenodo.3997141 (Fürst et al., 2020). This repository consists of a SQLite database file with all the high resolution time series data, an MS Excel sheet with the isotopic data and the spatial datasets. Usage of the data is described by a comprehensive HTML file (generated by an also included R Markdown document), which includes a full technical description of the data, including R code chunks to read and visualise them. All data are visualised in the HTML document, so that a good impression of the characteristics of the data can be gained by just reading this document.

7 Summary

The data represent an effort to measure components of the energy and water cycle in a forested catchment in the Eastern Austrian Alps. The period of record for some components starts in 2015. Making the data available to the research and applied hydrology communities has two main objectives. First, it is intended to inform decision-makers in the Rosalia forest. The record is an important source of baseline data that can be used to assess the effect of disturbances, such as clear-cuts and changing forestry on hydrological processes. Second, these data are provided to allow others to also investigate hydrological processes, medium-term patterns and potential changes in this type of watershed. Measurements use consistent methods to ensure comparability within the research catchment. The data have proven fit for the purpose of supporting hydrological and hydro-meteorological process research.

Author contributions.

J. Fürst was involved in field work to collect the data discussed here, including selection and installation of the instruments, processing, quality assurance and quality control. H. P. Nachtnebel and K. Schulz are responsible for strategic decisions and funding. J. Gasch provided advice on site selection and provided some of the spatial data. R. Nolz was responsible for the selection and installation of soil sensors. M. Stockinger and C. Stumpp set up the isotope measurement network and maintain it. All authors contributed to writing the manuscript.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Competing interests.

The authors declare that they have no conflict of interest. Names of products and companies are only mentioned for better understanding and traceability; none of the authors is in a dependency to any of the mentioned companies

Acknowledgements.

Over the years, several people have contributed to implementation of the Rosalia test site, to operation of the instruments, data collection and deserve recognition. These include Wisam Almohamed, Matthias Bernhardt, Laurin Bonell, Reinhard Burgholzer, Roman Eque, Heinz Fassl, Martin Hackl, Mathew Herrnegger, Freddy Kratzert, Thomas Lehner, Martin Lichtblau, Johann Karner, Philipp Proksch, Andreas Schwen, Wolfgang Sokol, Gabriel Stecher, Johannes Wesemann.

References

Anderson, S. P., Bales, R. C., and Duffy, C. J.: Critical Zone Observatories: Building a network to advance interdisciplinary study of Earth surface processes, Mineralogical Magazine, 72, 7-10, 10.1180/minmag.2008.072.1.7, 2018.

Bernhardt, M., Schulz, K., and Pomeroy, J. W.: The International Network for Alpine Research Catchment Hydrology: A new GEWEX crosscutting Project, Hydrologie und Wasserbewirtschaftung, 59, 190-191, 2015.

Blöschl, G., Blaschke, A. P., Broer, M., Bucher, C., Carr, G., Chen, X., Eder, A., Exner-Kittridge, M., Farnleitner, A., Flores-Orozco, A., Haas, P., Hogan, P., Kazemi Amiri, A., Oismüller, M., Parajka, J., Silasari, R., Stadler, P., Strauss, P., Vreugdenhil, M., Wagner, W., and Zessner, M.: The Hydrological Open Air Laboratory (HOAL) in Petzenkirchen: a hypothesis-driven observatory, Hydrol. Earth Syst. Sci., 20, 227-255, 10.5194/hess-20-227-2016, 2016.

Blöschl, G., Bierkens, M. F. P., Chambel, A., Cudennec, C., Destouni, G., Fiori, A., Kirchner, J. W., McDonnell, J. J., Savenije, H. H. G., Sivapalan, M., Stumpp, C., Toth, E., Volpi, E., Carr, G., Lupton, C., Salinas, J., Széles, B., Viglione, A., Aksoy, H., Allen, S. T., Amin, A., Andréassian, V., Arheimer, B., Aryal, S. K., Baker, V., Bardsley, E., Barendrecht, M. H., Bartosova, A., Batelaan, O., Berghuijs, W. R., Beven, K., Blume, T., Bogaard, T., Borges de Amorim, P., Böttcher, M. E., Boulet, G., Breinl, K., Brilly, M., Brocca, L., Buytaert, W., Castellarin, A., Castelletti, A., Chen, X., Chen, Y., Chen, Y., Chifflard, P., Claps, P., Clark, M. P., Collins, A. L., Croke, B., Dathe, A., David, P. C., de Barros, F. P. J., de Rooij, G., Di Baldassarre, G., Driscoll, J. M., Duethmann, D., Dwivedi, R., Eris, E., Farmer, W. H., Feiccabrino, J., Ferguson, G., Ferrari, E., Ferraris, S., Fersch, B., Finger, D., Foglia, L., Fowler, K., Gartsman, B., Gascoin, S., Gaume, E., Gelfan, A., Geris, J., Gharari, S., Gleeson, T., Glendell, M., Gonzalez Bevacqua, A., González-Dugo, M. P., Grimaldi, S., Gupta, A. B., Guse, B., Han, D., Hannah, D., Harpold, A., Haun, S., Heal, K., Helfricht, K., Herrnegger, M., Hipsey, M., Hlaváčiková, H., Hohmann, C., Holko, L., Hopkinson, C., Hrachowitz, M., Illangasekare, T. H., Inam, A., Innocente, C., Istanbulluoglu, E., Jarihani, B., Kalantari, Z., Kalvans, A., Khanal, S., Khatami, S., Kiesel, J., Kirkby, M., Knoben, W., Kochanek, K., Kohnová, S., Kolechkina, A., Krause, S., Kreamer, D., Kreibich, H., Kunstmann, H., Lange, H., Liberato, M. L. R., Lindquist, E., Link, T., Liu, J., Loucks, D. P., Luce, C., Mahé, G., Makarieva, O., Malard, J., Mashtayeva, S., Maskey, S., Mas-Pla, J., Mavrova-Guirguinova, M., Mazzoleni, M., Mernild, S., Misstear, B. D., Montanari, A., Müller-Thomy, H., Nabizadeh, A., Nardi, F., Neale, C., Nesterova, N., Nurtaev, B., Odongo, V. O., Panda, S., Pande, S., Pang, Z., Papacharalampous, G., Perrin, C., Pfister, L., Pimentel, R., Polo, M. J., Post, D., Prieto Sierra, C., Ramos, M.-H., Renner, M., Reynolds, J. E., Ridolfi, E., Rigon, R., Riva, M., Robertson, D. E., Rosso, R., Roy, T., Sá, J. H. M., Salvadori, G., Sandells, M., Schaefli, B., Schumann, A., Scolobig, A., Seibert, J., Servat, E., Shafiei, M., Sharma, A., Sidibe, M., Sidle, R. C., Skaugen, T., Smith, H., Spiessl, S. M., Stein, L., Steinsland, I., Strasser, U., Su, B., Szolgay, J., Tarboton, D., Tauro, F., Thirel, G., Tian, F., Tong, R., Tussupova, K., Tyralis, H., Uijlenhoet, R., van Beek, R., van der Ent, R. J., van der Ploeg, M., Van Loon, A. F., van Meerveld, I., van Nooijen, R., van Oel, P. R., Vidal, J.-P., von Freyberg, J., Vorogushyn, S., Wachniew, P., Wade, A. J., Ward, P., Westerberg, I. K., White, C., Wood, E. F., Woods, R., Xu, Z., Yilmaz, K. K., and Zhang, Y.: Twenty-three unsolved problems in hydrology (UPH) – a community perspective, Hydrological Sciences Journal, 64, 1141-1158, 10.1080/02626667.2019.1620507, 2019.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

Bogena, H. R., White, T., Bour, O., Li, X., and Jensen, K. H.: Toward Better Understanding of Terrestrial Processes through Long-Term Hydrological Observatories, Vadose Zone J., 17, 1-10, 10.2136/vzj2018.10.0194, 2018.

Plynlimon Experimental Catchments: https://www.ceh.ac.uk/our-science/projects/plynlimon-experimental-catchments, access: 2020/05/28, 2020.

Roadmap & Strategy Report on Research Infrastructures: http://roadmap2018.esfri.eu/media/1066/esfri-roadmap-2018.pdf, access: 2020/05/28, 2020.

Fürst, J., Nachtnebel, H. P., Gasch, J., Nolz, R., Stockinger, M. P., Stumpp, C., and Schulz, K.: Rosalia: an experimental research site to study hydrological processes in a forest catchment - data repository, Zenodo, https://doi.org/10.5281/zenodo.3997141, 2020.

Haberl, H., Winiwarter, V., Andersson, K., Ayres, R. U., Boone, C., Castillo, A., Cunfer, G., Fischer-Kowalski, M., Freudenburg, W. R., Furman, E., Kaufmann, R., Krausmann, F., Langthaler, E., Lotze-Campen, H., Mirtl, M., Redman, C. L., Reenberg, A., Wardell, A., Warr, B., and Zechmeister, H.: From LTER to LTSER: Conceptualizing the Socioeconomic Dimension of Long-term Socioecological Research, Ecology and Society, 11, 10.5751/ES-01786-110213, 2006.

Holzmann, H.: Status and perspectives of hydrological research in small basins in Europe, Geographical Research Letters, 44, 601-614, 10.18172/cig.3406, 2018.

Kampe, T., Johnson, B., Kuester, M., and Keller, M.: NEON: the first continental-scale ecological observatory with airborne remote sensing of vegetation canopy biochemistry and structure, Journal of Applied Remote Sensing, 4, 043510, 2010.

Laudon, H., Taberman, I., Ågren, A., Futter, M., Ottosson-Löfvenius, M., and Bishop, K.: The Krycklan Catchment Study—A flagship infrastructure for hydrology, biogeochemistry, and climate research in the boreal landscape, Water Resources Research, 49, 7154-7158, 10.1002/wrcr.20520, 2013.

Leitner, S., Minixhofer, P., Inselsbacher, E., Keiblinger, K. M., Zimmermann, M., and Zechmeister-Boltenstern, S.: Short-term soil mineral and organic nitrogen fluxes during moderate and severe drying–rewetting events, Applied Soil Ecology, 114, 28-33, https://doi.org/10.1016/j.apsoil.2017.02.014, 2017.

Lott, D. A., and Stewart, M. T.: Base flow separation: A comparison of analytical and mass balance methods, Journal of Hydrology, 535, 525-533, http://dx.doi.org/10.1016/j.jhydrol.2016.01.063, 2016.

LTER History: https://lternet.edu/network-organization/lter-a-history/, access: 2020/05/28, 2020.

Neal, C., Reynolds, B., Norris, D., Kirchner, J. W., Neal, M., Rowland, P., Wickham, H., Harman, S., Armstrong, L., Sleep, D., Lawlor, A., Woods, C., Williams, B., Fry, M., Newton, G., and Wright, D.: Three decades of water quality measurements from the Upper Severn experimental catchments at Plynlimon, Wales: an openly accessible data resource for research, modelling, environmental management and education, Hydrological Processes, 25, 3818-3830, 10.1002/hyp.8191, 2011.

Schumann, S., Schmalz, B., Meesenburg, H., and Schröder, U.: Status and Perspectives of Hydrology in Small Basins - Results and recommendations of the International Workshop in Goslar-Hahnenklee, Germany, 2009 and Inventory of Small Hydrological Research Basins, German National Committee for the International Hydrological Programme (IHP) of UNESCO and the Hydrology and Water Resources Programme (HWRP) of WMO KoblenzIHP/HWRP-Berichte, Heft 10, 71, 2010.

Schwen, A., Zimmermann, M., Leitner, S., and Woche, S. K.: Soil Water Repellency and its Impact on Hydraulic Characteristics in a Beech Forest under Simulated Climate Change, Vadose Zone J., 14, vzj2015.2006.0089, 10.2136/vzj2015.06.0089, 2015.

Seyfried, M., Lohse, K., Marks, D., Flerchinger, G., Pierson, F., and Holbrook, W. S.: Reynolds Creek Experimental Watershed and Critical Zone Observatory, Vadose Zone J., 17, 180129, 10.2136/vzj2018.07.0129, 2018.

Simunek, J., Van Genuchten, M. T., and Sejna, M.: The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media, University of California-Riverside, 240, 2005.

Zacharias, S., Bogena, H., Samaniego, L., Mauder, M., Fuß, R., Pütz, T., Frenzel, M., Schwank, M., Baessler, C., Butterbach-Bahl, K., Bens, O., Borg, E., Brauer, A., Dietrich, P., Hajnsek, I., Helle, G., Kiese, R., Kunstmann, H., Klotz, S., Munch, J.

https://doi.org/10.5194/essd-2020-254
Preprint. Discussion started: 26 November 2020

C., Papen, H., Priesack, E., Schmid, H. P., Steinbrecher, R., Rosenbaum, U., Teutsch, G., and Vereecken, H.: A Network of Terrestrial Environmental Observatories in Germany, Vadose Zone J., 10, 955-973, 10.2136/vzj2010.0139, 2011.