13 Hydrology and Hydrogeology

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Swiss Society for Hydrology and Limnology SGHL,
Swiss Hydrogeological Society SGH

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13.2 Blanc T., Peel M., Brennwald M., Kipfer R., Brunner P.: Novel approach for efficient injection of tracer gases into a flowing river

13.3 Brunner M. I., Voan Loon A. J., Stahl K.: Extreme and moderate streamflow droughts are governed by different hydro-meteorological processes

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13.1
Mountain springs and climate change

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In Alpine valleys, drinking water comes mainly from mountain springs. Alpine regions are particularly sensitive to climate change, especially to decreasing snowfall and increasing periods of drought. Therefore, it is necessary to determine how these water resources will evolve in order to anticipate possible shortages. Thus, several springs located in the Val de Bagnes in Valais, for which flow rate data are available, have been selected. Two approaches were then combined: (1) the calculation of drought resistance indicators and (2) the hydrological modelling of spring flows with the latest climate projections for Switzerland. The water quality of the springs was also taken into account. The results show the differences in the sensitivity of the spings and allow the identification of the strategic groundwater resources, less sensitives to temporary drought events. This analysis also highlights the importance of developing a measurement network now, which is essential for future projections to anticipate and adapt drinking water management in Alpine regions.

13.2
Novel approach for efficient injection of tracer gases into a flowing river

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Bank filtration contributes with 40 % to the drinking water production of Switzerland. The quality of this water might get altered under changing conditions, such as land use, climate change, or river renaturation works. It is, therefore, crucial for drinking water management to understand river water - groundwater interactions, and thus detect the associated dynamics.
Gas tracers have the potential to become informative tracers in this regard since they are invisible, non-toxic, and conservative. Furthermore, they are easy to handle and, since recent technology development of portable mass spectrometers, simple to measure directly and continuously on the field. They are therefore ideal tracers for groundwater, yet their application to surface water remains challenging, especially their injection into flowing river water. Such injection could be very interesting for gas tracer tests to study bank filtration. However, injecting gas into a river is inefficient and logistically and financially prohibitive for long duration and high river discharge rates. Thus, it undermines the efficient application of gas tracers in this context.

In this study, we present an approach to resolve these challenges and efficiently inject a high amount of gas into a flowing river. We use diffusive injection as it provides very high injection efficiency and we selected cheap and accessible material for our setup. To demonstrate the robustness of our method, we applied it in the Emme (canton Bern, Switzerland). We were able to supersaturate the river water for 35 days by one order of magnitude in comparison to the natural dissolved gas concentration. We monitored the dissolved gas concentration both in the river and in a well located close by, therefore obtaining precious time series of both water bodies. This data provides quantitative information on the infiltration dynamics and proves the hydraulic connection between the river and the well. Furthermore, such long and continuous time series represent ideal input and output functions for physically based numerical models to quantify mixing ratios and transit time distribution.

13.3
Extreme and moderate streamflow droughts are governed by different hydro-meteorological processes

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Streamflow droughts are generated by a variety of processes including rainfall deficits, a lack of snow accumulation, or high evapotranspiration. The importance of different drought generation processes may vary with event severity but to date it remains unclear how. To study the link between event severity and the importance of different hydro-meteorological drivers, we propose a formal classification scheme for streamflow droughts and apply it to a large sample of catchments in Europe. The scheme assigns events to one of eight drought types using information about drought seasonality, precipitation deficits, and snow availability. Our findings show that drought driver importance varies regionally, seasonally, and by event severity. More specifically, we show that rainfall-deficit droughts are the dominant drought type in western Europe, while northern Europe is most often affected by cold-snow-season droughts. Second, we show that rainfall-deficit and cold-snow-season droughts are important from autumn to spring, while snowmelt and wet-to-dry-season droughts are important in summer. Last, we demonstrate that moderate droughts are mainly driven by rainfall deficits, while severe events are predominantly driven by snowmelt deficits in colder climate zones including the Alps and by streamflow deficits transitioning from the wet to the dry season in warmer climate zones. This high importance of evapotranspiration and a lack of snowmelt for the development of severe droughts suggests that these high-impact events might undergo the strongest changes in a warming climate because of their close relationship to temperature. As a consequence, the Alps are expected to be one of the regions in Europe most affected by future changes in drought generation processes and related magnitudes.

13.4
Impacts of Climate Change on Swiss Alluvial Aquifers – Adaptation and Mitigation Measures using MAR and MSWR

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Artificial groundwater recharge and natural infiltration of surface waters are two factors determining water quantity and quality of alluvial aquifers. We evaluated a set of selected future climate scenarios to project future groundwater recharge and associated temperature imprint for three alluvial aquifers in the urban agglomeration of the city of Basel, Switzerland.
3D numerical groundwater flow and heat-transport modeling allowed quantifying and differentiating between natural and articifial groundwater recharge processes and thermal impacts. The influence of climate change on natural and artificial groundwater recharge processes could be distinguished. For aquifers where the infiltration of surface water is an important component in the groundwater balance, which is common to many alluvial aquifers, the effects of climate change will be influenced by changes in river flow and thermal regimes. As such, individual drinking water wells are exposed differently to the various components of groundwater recharge (Figure).

Our results show that seasonal shifts in natural groundwater recharge processes and adaptation strategies related to artificial groundwater recharge could be an important factor affecting groundwater resources in future. With increased groundwater recharge during high runoff periods in winter/spring, decreased groundwater temperatures can be expected (Epting et al. 2021). While increased artificial groundwater recharge in summer months, are likely to increase groundwater temperatures. In view of more frequent heatwaves and drought periods, our results highlight the importance of Managed Aquifer Recharge (MAR) and Managed Surface Water Recharge (MSWR) as useful tools for existing and future groundwater management.

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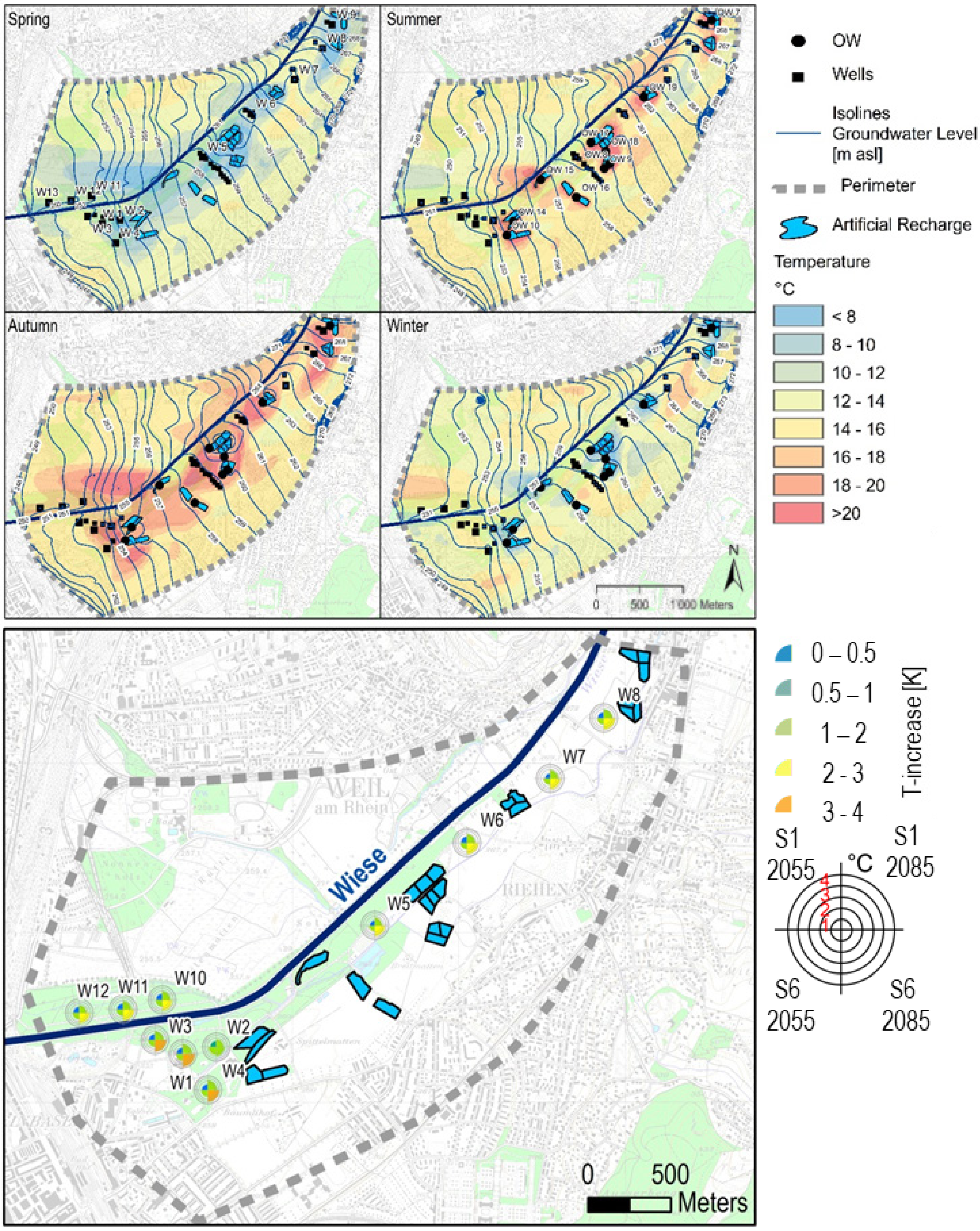

Figure: Above: Seasonal hydraulic and thermal groundwater regime 2018 for different seasons in the Lange Erlen case study area. Below: Temperature change for two climate scenarios (S1 and S6) for the years 2055 and 2085 compared to the reference state in 2000 of the drinking water wells in the Lange Erlen. Landeskarte© Bundesamt für Landestopografie.

13.5
Hydrochemical evolution of geothermal waters in the Geneva Basin

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Groundwaters circulating in Upper Mesozoic carbonates are of great interest for geothermal heat production and storage applications in Switzerland. This study aims at providing new insights and improve interpretations about the mineral-water reactions and the fluid-flow paths mechanisms across the Geneva Basin (GB), which is the most active region in Switzerland in terms of geothermal exploration and implementation projects. Data from previous studies are combined by new one by new ones collected from cold and hot springs and geothermal exploration wells in 2018 and 2020 in the framework of the *GEothermies* (www.geothermies.ch) program and HEATSTORE project (www.heatstore.eu).

Major ions, trace elements, and the isotopes of Oxygen, Hydrogen, Sulfur, Strontium, and Carbon have been analysed constraining the meteoric origin, the circulation path, residence time revealing how Mesozoic carbonate aquifers act as preferential host rocks for geothermal waters. The Jura Mountains and the Saleve Ridge are the main catchment areas and an evolution from a pure Ca-HCO_3 footprint for the cold springs, to a Na > Ca-HCO_3 and a Na-Cl compositions, is observed from the NW to the SW sectors of the Geneva area. The residence time is in the order of a few years for the cold springs and reaches up to 15–20,000 years for the deep wells GEo-01 and Thonex-01.

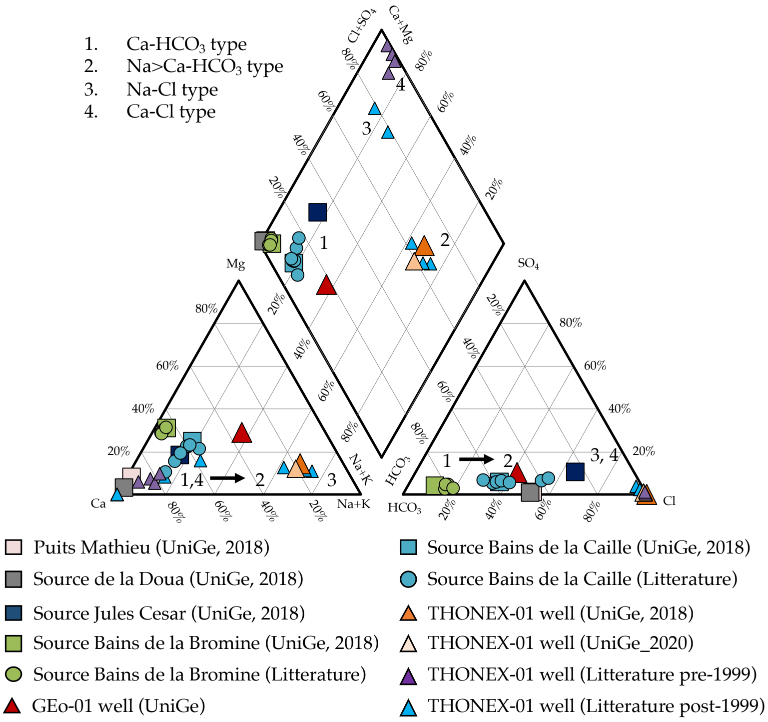

Figure 1. Piper diagram (Piper, 1944) for the groundwater types in the study area (modified from Guglielmetti et al., 2022).

Noble gases and hydrocarbons were also analysed. Noble gases reveal a meteoric origin without major inputs from deep sources. The Geo-01 hydrocabon composition does not fall within the pure microbial nor thermogenic gas fields and rather shows a mix between microbial and thermogenic gas (Do Couto et al., 2021). The stable isotopic carbon and hydrogen composition of methane reveals that the thermogenic gas is most likely originating from an early mature source-rock. At Thonex-01 methane si close to the thermogenic with potential source rock from the Permo-Carboniferous.

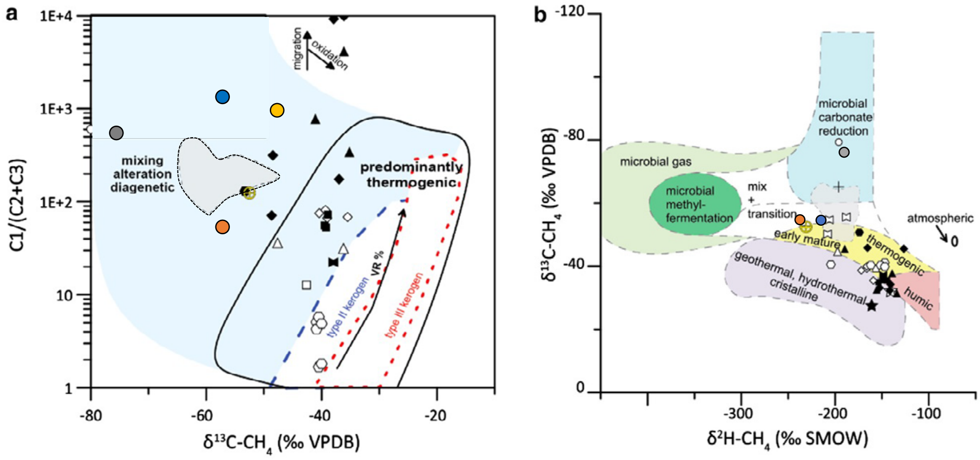

Figure 2. Modified “Bernard diagram” showing the methane carbon isotopic composition vs. dryness (modified after Bernard et al., 1976; Whiticar, 1999) showing the composite biogenic and thermogenic composition of the gas retrieved from Satigny (this study). b Interpretation of gas origin using stable carbon and hydrogen isotopic composition of methane according to Whiticar (1999). Data from this study combined to those retrieved from (Do Couto et al., 2021)

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13.6
Understanding the present and future state of groundwater in alpine headwater catchments using hydrogeophysics

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In Switzerland and many other regions of the world, alpine groundwater plays a vital buffering role, ensuring perennial streamflow down-gradient. Globally, human reliance on alpine groundwater resources is expected to increase while the reliability of the resource is expected to be severely impacted by climate change. Given the increasing importance and uncertainty of the resource, there is a glaring lack of data on the mountain groundwater. In order to understand the future seasonal dynamics of water resources in alpine regions as snow- and ice-cover changes, it is vital to have quantitative, spatially-resolved hydrogeological information. Non-invasive geophysical methods such as time-lapse gravimetry (TLG) and electrical resistivity tomography (ERT) are uniquely adapted to fill this knowledge gap.

TLG involves measurements of acceleration due to gravity, *g,* at one or more locations at multiple points in time. Using absolute-referenced mobile relative gravimeters, single survey accuracy in the few parts-per-billion range is achievable. Under certain conditions, one can readily resolve changes in groundwater storage on the order of 10 cm equivalent water column. While TLG is ideal for providing spatially-resolved information on seasonal and annual variations in groundwater storage, accurate quantitative use requires a more advanced approach than the simple Bouguer plate approximation (BPA) fixed conversion factor. A first step in this direction is the integration of topographic or hydrostratigraphic data into the analysis (Halloran, 2022) which allows for more accurate estimates of groundwater storage changes using Δg data (Figure 1).

Studies in the alpine headwater catchment *Tsalet* (Vallon de Réchy, Valais; Figure 1) have employed TLG (Arnoux et al. 2020) and ERT (Millwater, in prep.) in order to characterise and delineate the complex moraine, talus and colluvium superficial aquifers. The ERT measurements have enabled three-dimensional characterisation of these units and their integration into a hydrogeological model. This geophysics-informed numerical model is used to evaluate hypotheses on the the current groundwater dynamics as well as the response of the system to future climate-change impacts.

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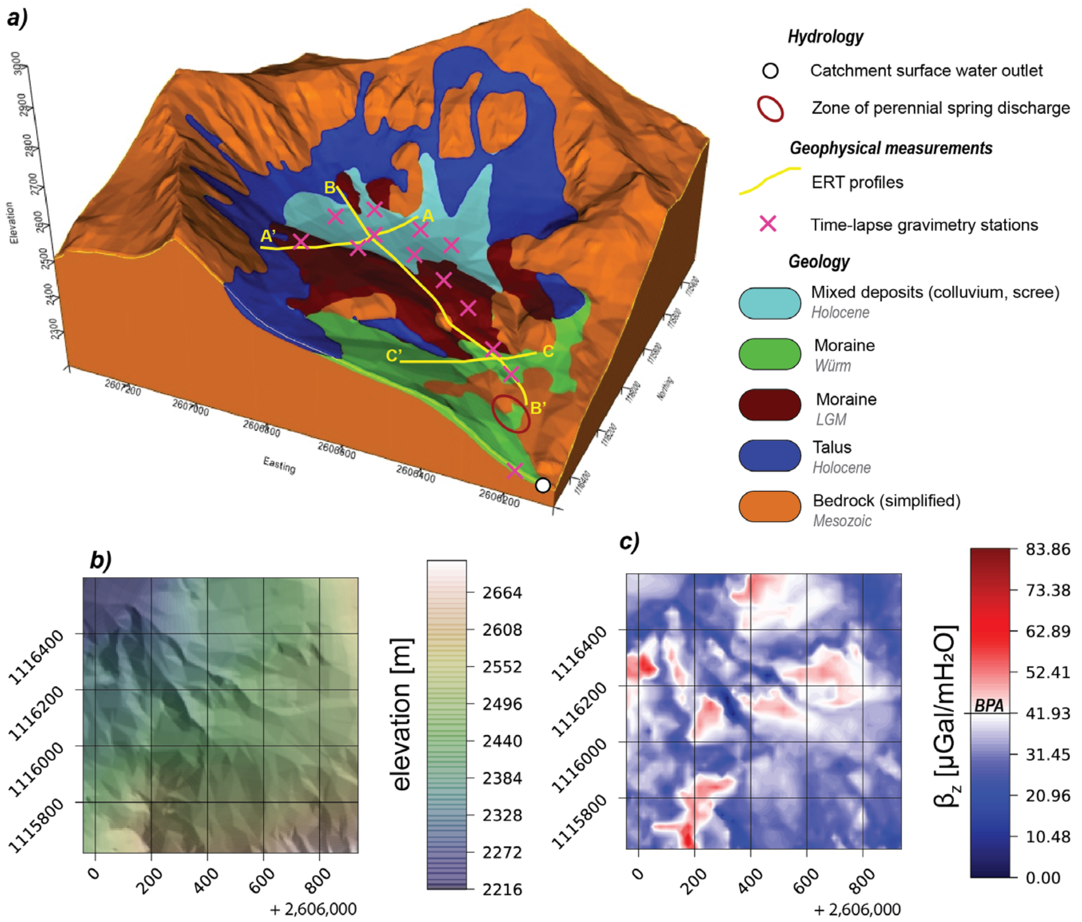

Figure 1. a) TLG and ERT survey locations in the *Tsalet* catchment (Vallon de Réchy) overlaid on a geological model. b) Topographic map of the lower catchment area. c) The corresponding topography-informed factor, β_z (Halloran, 2022), for conversion between changes in gravity and changes in groundwater storage. BPA = *Bouguer* plate approximation.

13.7
Consequences of intermittent ventilation on the energy balance of a karst system

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A karst massif is crossed by a network of fractures and conduits driving water and air from the atmosphere deep into the massif. These fluids exchange heat at the boundaries between rock, air and water. The thermal characteristic of the medium together with thermal processes including convection, evapo-condensation, radiation and conduction, concur to settle the caves' temperature. The thermal length, the distance at which the external temperature fluctuations are dulled, and the energy balance of the cave system depend on its geometry and the fluxes therein. Understanding what modifies these thermal characteristics is of interest e.g. for paleoclimatic studies on speleothems or low-enthalpy geothermal exploitation.
We equipped Longeaigue cave (Val-de-Travers, Jura mountains) with several sensors measuring airflow and temperatures along the main conduit network. The cave has a lower and upper entrance. It is mainly dry and is crossed by an intense airflow which complies with the chimney effect. The temperature oscillations observed throughout the cave are chiefly related to external temperature and airflow variations. Results from 8 monitoring stations reveal that more than 90% of the energy brought in by the air during ventilated periods is exchanged within the first tens of meters from the cave entrances. However, during periods of rainfall and snowmelt the cave can be flooded, interrupting temporarily this airflow several times per year. Our observations show that the transient nature of this airflow modifies the temperature signals in the cave. Here, we demonstrate that the intermittent aeraulic regime affects the cave energy balance in a differentiated way according to seasonal hydrological conditions. In the light of climate change, we anticipate a progressive shift toward summer ventilation phases enhancing the warming of the system.
On longer time scales, comparable changes in the cave geometry may impact on the interpretation of speleothem temperature-sensitive proxy records.

13.8
Predicting streamflow recession in alpine catchments: how does bedrock morphology control the dynamics?

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Global-scale models project that by 2050 about 1.5 billion people worldwide will be directly dependent on streamflow contributions from mountains (Viviroli et al., 2020). However, due to the difficulties of gathering relevant data at high elevations and the lack of fundamental physically-based understanding on the processes involved, the representation of the groundwater flow in alpine catchment- to regional-scale hydrological models is currently overlooked. It is often limited to a simplified homogeneous and shallow layer with effective hydraulic properties. This raises questions regarding the validity of such models to quantify the potential impacts of climate change, where subsurface heterogeneity is expected to play a major role in their short- to long- term regulation (Hartmann et al. 2017).

Based on a comprehensive analysis of hydrological, climatic, geological and geomorphological databases available in the Alps, we provide evidence that such simplification lead to inaccurate estimates of groundwater and streamflow dynamics involved at baseflow (Roques et al., 2021). The analysis allows the identification of key features of the landscape which might control this deviation, with particular attention to slope, drainage density, depth to bedrock, and lithology as the main drivers. We use numerical modelling to validate the main hypothesis identified from the regional- scale data analysis. We specifically explore the role of vertical heterogeneity of hillslopes on groundwater flow and streamflow recession discharge (Roques et al., 2022). We found that when hydraulic properties are vertically compartmentalized (Figure 1), streamflow recession behaviour may indeed strongly deviate from what is predicted by homogeneous groundwater theory. We further identify the hillslope configurations for which the homogeneous theory derived from the Boussinesq solution approximately hold and conversely for which it fails. By comparing the modelled streamflow recession discharge and the groundwater table dynamics, we identify the critical hydrogeological conditions responsible for the emergence of strong deviations.

Our results confirm the critical importance of accounting for structural configuration and heterogeneity of the subsurface in catchment- to regional-scale hydrological models. We conclude by summarizing the current knowledge of physical mechanisms that could lead to complex hydrological behavior in Alpine contexts, and discuss implications in defining modeling strategies for the Critical Zone community.

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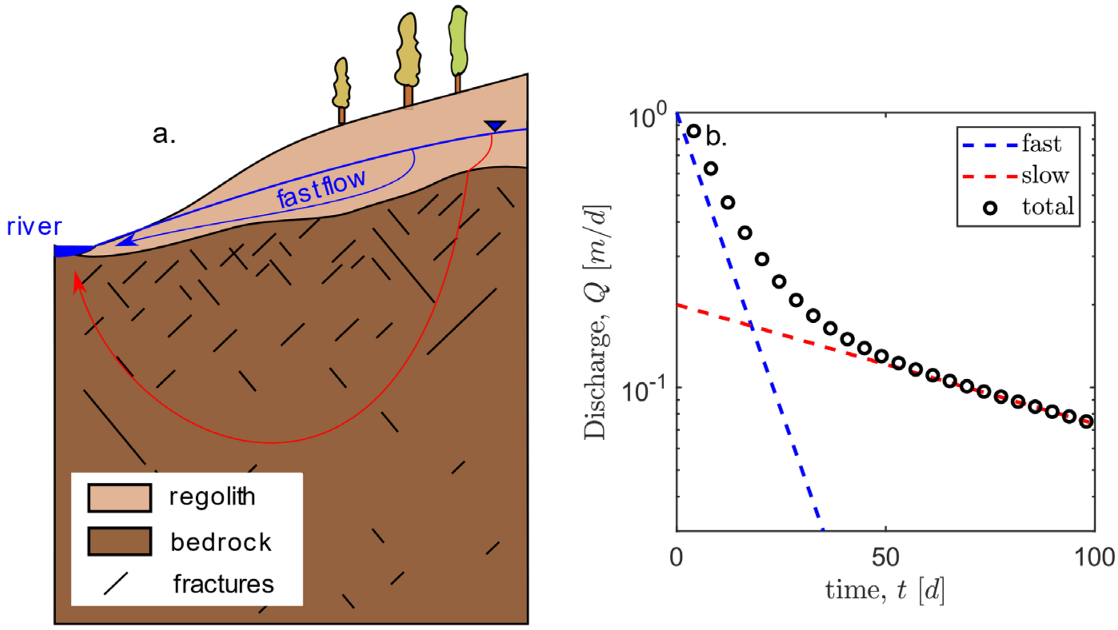

Figure 1. a. Conceptual model of a compartmentalized hillslope with groundwater flow distributed between fast flow within the shallow regolith/fractured aquifer and slow flow in the underlain bedrock; b. Theoretical streamflow behaviour considering two linear reservoirs (b=1) in parallel with fast (blue line,) and slow (red line,) drainage timescales. From Roques et al. (2022).

13.9
Buried paleo-channel detection with a groundwater model, tracer-based observations, and spatially varying, preferred anisotropy pilot point calibration

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Buried paleo-channels in alluvial sand and gravel (ASG) aquifers are typically highly conductive for groundwater flow and responsible for preferential flow paths that are capable of transporting contaminants faster than the surrounding sediments. However, it is notoriously difficult to detect and delineate such buried structures of increased hydraulic conductivity in ASG aquifers with the commonly used geophyiscal and modelling techniques. Consequently, these anisotropic and connected structures are rarely considered in the delineation of groundwater protection zones or the models used for groundwater management. To bridge this gap, we developed a new framework based on a combination of hydraulic and tracer-based measurements and the calibration of a fully coupled surface water-groundwater model against these observations using a novel inversion approach (Schilling et al., 2022). Tracer-based observations consist of radioactive tracers (e.g., ^{222}Rn, ^{37}Ar, $^{3}H/^{3}He$), which allow characterization of groundwater residence times, and of atmospheric noble gases, which allow tracking recently infiltrated river water in ASG aquifers. Groundwater modelling is carried out with the integrated surface-subsurface hydrological simulator HydroGeoSphere. Calibration is based on an innovative pilot point inversion that considers the spatially-varying directionality of the alluvial sediments and facilitates the identification of buried and connected structures. The proposed approach is more efficient compared to other existing methods for paleo-channel detection, as the complex and often poorly constrained geostatistical simulations that are used in other approaches are not needed. The applicability of the framework is demonstrated on a real-world drinking water wellfield of an ASG aquifer in the Emmental, Switzerland.

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13.10
GCOS project: Enhance snowfall estimates in existing Swiss precipitation products

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Snow is an important component of the water cycle in Switzerland, contributing approximately 40% of the runoff in Swiss rivers. Yet, precipitation datasets are often associated with considerable uncertainties, in particular in mountainous terrain. In Switzerland, most precipitation gauges have no wind shields and are thus prone to undercatch of snowfall, which can be considerable (several 10%). Unlike other countries, Switzerland does not have monitoring networks to automatically measure snow water equivalent (SWE). However, there are hundreds of stations to measure snow depth, many of which are co-located with precipitation gauges. In the absence of sufficient SWE data, we used a combination of precipitation and snow depth data along with snow modelling and data assimilation methods to determine biases in existing precipitation products. These methods were applied at both the level of individual stations and of gridded products. For RhiresD, the daily precipitation product of MeteoSwiss, we found a bias for snowfall of several 10%, as expected, but with regional and seasonal variations. The optimised precipitation product was provided to an energy-balance snow model. This made it possible to compare modelled and observed snow depth and to quantify the quality of the correction using cross-validation.

For providing spatial averages of snow depth values, one of the challenges to overcome is so-called preferential deposition of snow. In mountainous terrain, preferential deposition causes snow measurements at flat observation site to (normally) overrepresent regional snowfall. Today, airborne LiDAR datasets can provide spatially extensive high-resolution datasets of snow depth. We leveraged this new data source to close the gap between snow data from typical observations sites and regionally representative snowfall. The combined gridded precipitation product acknowledges both precipitation gauge undercatch and snowfall over-representation at flat observation sites. This spatial product was tested in the context of hydrological modelling in two ways. First, it was tested if the water balance can be better described compared to uncorrected data for non-glaciated and relatively undisturbed catchments. Second, simple conceptual hydrological models (including GR4J and HBV) were calibrated and validated for these catchments using both original and corrected precipitation input.

13.11

Changing patterns of heavy rainfall events across an urban area (Milan, Italy)

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Observations using remote sensing data reveal that urban areas affect the intensities and spatial structure of rainfall fields on small scales (i.e. at sub-hourly and sub-kilometer resolutions). However, since urban effects on rainfall have only been explored in a few cities and for a relatively short time, there is disagreement regarding the precise pattern of change (e.g. if cities act to enhance or reduce the area of storms) and the driving dynamic and thermodynamic forces behind it. As the hydrological response in urban areas is fast and highly sensitive to space-time rainfall variability, it is crucial to understand how urban areas change the spatial structure of rainfall to improve our abilities to nowcast rainfall and urban floods. We used weather radar data from MeteoSwiss (5 min and 1 km resolution) to analyze the spatial structure and intensity of heavy rainfall events that cross the city of Milan (Italy). We tracked these events over 7 years using a storm-tracking algorithm (from a Lagrangian perspective) and investigated the changes to the properties of the rainfall fields, such as their areal mean intensity, area, and areal rainfall, at varying distances relative to the city center. These radial distances were defined as either upwind or downwind using the storm's average direction of motion. We then evaluated composite storm properties at these different distances. Using an Eulerian perspective, we next explored how rainfall fields changed upwind and downwind of the city by considering fixed radar windows of 20 km by 20 km. At each window, we superimposed radar images that contained convective cells and centered them by their intensity peak. With the image composites, we examined changes in rainfall properties across windows. The results of the analysis from the two perspectives will be presented.

13.12
Changes in rainwater productivity across the rainfed agricultural areas in Ethiopia

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Water scarcity is one of the major constraints on agricultural productivity, particularly in moisture-limited regions. The intensifying atmospheric evaporative demand and changes in precipitation under the future climate are likely to modify the moisture availability and productivity in agroecosystems. We examined the spatio-temporal changes in aridity and water productivity (WP) in various climatic zones, from arid to hyper humid, under the present and future climates across the rainfed agriculture (RFA) regions of Ethiopia.

To do this, we (i) downscaled the future precipitation, air temperature, and shortwave radiation to a 5 km grid resolution. We considered multiple GCM projections under three shared socioeconomic pathways (SSPs) namely, SSP1-2.6, SSP2-4.5, and SSP5-8.5 for three future periods: 2020-2049, 2045-2074, and 2070-2099. As a reference to the present climate (1981-2010), we used the CHIRPS rainfall, a bias-corrected ERA5-Land (BCE5) 2-m air temperature, and ERA5-Land shortwave radiation; (ii) computed the reference evapotranspiration using the FAO Penman-Monteith and derived the aridity index; (iii) simulated the actual evapotranspiration using a daily bucket soil water balance model considering the spatial heterogeneity of the soil properties; and (iv) determined the main growing season (May-September) Evaporative Stress Indexes (ESI) as a proxy for WP, assuming an average crop yield response factor of the main cereal crops grown in Ethiopia.

The results show that the dominant climatic zones (sub-humid and humid) of the RFA regions will likely experience a minor or no change in aridity while the semi-arid areas will become wetter, for example by up to 30% under SSP5-8.5 by the end of the century. Under the present climate, the median rainfall WP (percent of the potential WP) during the growing season is about 45% in semi-arid, 65% in dry sub-humid, 77% in sub-humid, and 90% in humid climates. The projected WP shows an increase in the sub-humid and humid zones (by up to 8%) as well as in the semi-arid zones (up to 16%) under the three SSPs already in the next few decades. However, in the mid of the century, WP is likely to decrease by up to 4% in major parts of the sub-humid and humid zones under the three SSPs, and this change tends to spatially expand by the end of the century. The observed changes are the combined effects of the nearly consistent (but at a spatially explicit rate) increase in precipitation (for example up to 30% under SSP5-8.5 in the 2080s) and rising temperature (up to 5°C under SSP5-8.5 in the 2080s) over the RFA region.

13.13
Coupling a global glacier model to a global hydrological model prevents underestimation of glacier runoff

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Global hydrological models have become an increasingly valuable tool in the quantification of changing hydrological processes and their impact on the environment and society globally. However, glacier parameterization is often simplistic or non-existent in global hydrological models. By contrast, global glacier models do represent complex glacier dynamics and glacier evolution, and as such hold the promise of better resolving glacier runoff estimates. In this study, we test the hypothesis that coupling a global glacier model with a global hydrological model leads to a more realistic glacier representation and consequently improved runoff predictions in the global hydrological model. To this end, the Global Glacier Evolution Model (GloGEM) is coupled with the global hydrological model PCR-GLOBWB 2 using the eWaterCycle platform. For the period 2001-2012, the coupled model is evaluated against the uncoupled PCR-GLOBWB 2 in 25 large-scale (>50.000 km2) glacierized basins. The coupled model produces higher runoff estimates across all basins and throughout the melt season. In summer, the runoff differences range from 0.07% for weakly glacier-influenced basins to 252% for strongly glacier-influenced basins. The difference can primarily be explained by PCR-GLOBWB 2 not accounting for glacier flow and glacier mass loss, thereby causing an underestimation of glacier runoff. The coupled model performs better in reproducing basin runoff observations mostly in strongly glacier-influenced basins, which is where the coupling has the most impact. This study underlines the importance of glacier representation in global hydrological models and demonstrates the potential of coupling a global hydrological model with a global glacier model for better glacier representation and runoff predictions in glacierized basins.

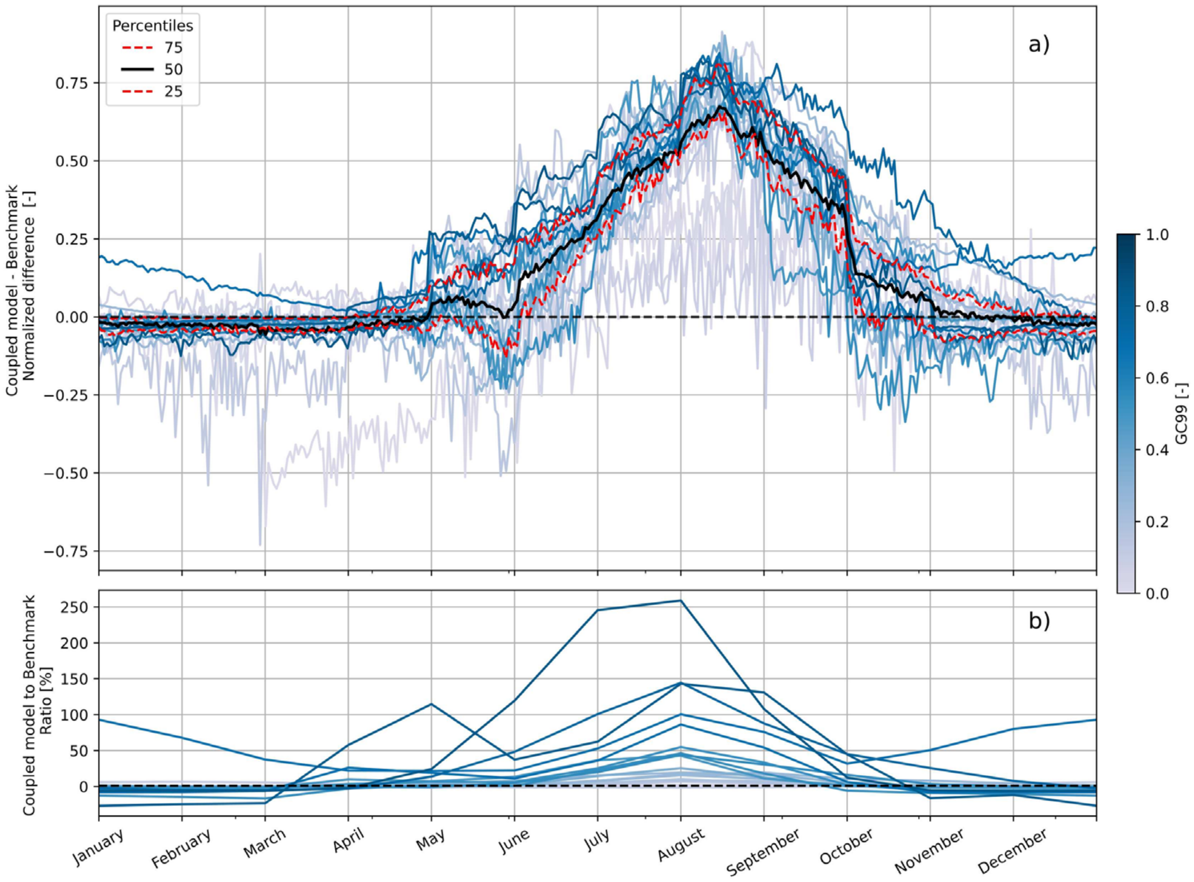

Figure 1. a) Mean normalized difference (ND) between the coupled model (PCR GLOBWB 2 & GloGEM) and the benchmark (only PCR-GLOBWB 2) for all 25 basins, showing that the coupled model produces higher runoff estimates throughout the melt season. The normalization is performed against the 99th percentile of the difference over the whole time range (2001-2012). The mean is computed for each calendar day over the same period. The solid black and dashed red lines represent the quartiles among the 25 basins. b) Ratio of the coupled model to the benchmark, averaged per month and over the period 2001-2012. The blue hue in both figures represents the 99th percentile of the routed GloGEM glacier runoff contribution to the coupled model runoff (GC99). The data of the three Southern Hemisphere basins are shifted six months forward in time to match the Northern Hemisphere months on the x-axis.

P 13.1
Implementation of Sewer Network Structures into Numerical Heat Transport Models via an Adaptive Surrogate Approach

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According to projections of the United Nations, more than two thirds of the world's population will live in urban regions by the mid of the current century. Rapid urbanization is associated with negative impacts on urban groundwater availability, with deteriorating factors for both quantity and quality. Adequate management strategies are required to increase the resilience of cities and their ecosystems. Sophisticated numerical models, designed for simulating the water flow as well as solute and heat transport processes in the subsurface, are powerful and established tools supporting decision making and planning and, hence, the sustainable use of subsurface resources.

Besides quantifying the water volumes available for abstraction, understanding the current thermal state of the subsurface and groundwater resources, as well as potential changes in the light of ongoing climate change and urbanization, is essential. Models designed for this very specific task should include at least all major objects (e.g., underground car parks, tunnels, sewer networks) which thermally contribute to groundwater heat regimes. For instance, heat exchange between the subsurface and sewer systems (the latter conducting comparably warm, untreated wastewaters from households and industry to treatment plants) may significantly contribute to the so-called subsurface urban heat island effect as especially observed in densely populated areas, and should, therefore, be addressed in groundwater management models.

However, fully 3-D implementations of all subsurface objects, especially of sewer networks with hundreds of kilometers of pipes, are typically out of question when applying such numerical models, since it would be associated with large computational demands (due to local refinements of model meshes) and, most likely, with increasing numerical instabilities of such simulations.

To overcome this limitation, the focus of our current research is to evaluate the suitability of an adaptive surrogate method as illustrated in Figure 1. Our method is based on quantitatively transferring the expected thermal exchange rates between, for instance, sewer pipes and their surrounding area in a simplified form to the elements of an existing model mesh. For this, the thermal interactions to be implemented are numerically investigated at multiple levels of complexity (e.g., multiple pipe sizes and shapes), and at multiple scales.

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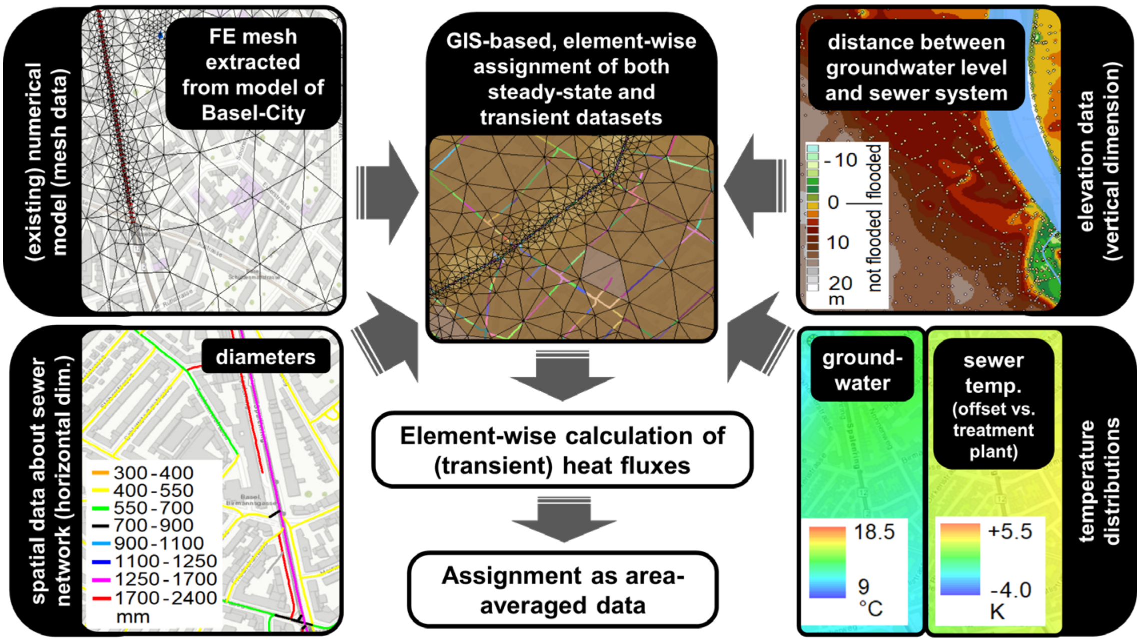

FIGURE 1: Concept of the adaptive surrogate approach (example: sewer networks) using both steady-state (e.g., pipe locations and shapes) and transient datasets (e.g., temperature distributions and distance to groundwater level).

P 13.2
Hybrid Forecasting of Sub-seasonal Streamflow and Lake Level in Switzerland

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Hybrid forecasting – a system that combines a dynamical/conceptual model with a machine learning (ML) model. Such a setup is able to benefit from the statistical power of ML while maintaining the understanding of physical processes from the traditional model. As many sectors in Switzerland depend heavily on water resources, e.g., hydropower, navigation and transportation, agriculture, and tourism, the objective of this study is to investigate the potential of such a hybrid setup to predict streamflow and lake level at a monthly forecast horizon to provide decision-makers with early information on water availability for better management.

In this study, we set up a hybrid forecasting system combing the conceptual hydrological model PREVAH with the Gaussian Process. We are able to demonstrate that the deployed hybrid forecasting system is able to provide sub-seasonal forecasts of streamflow and lake level for Swiss basins with descent skill for up to 3 weeks. Uncertainty of the hydro-meteorological prediction chain is accounted for by using 51 hydrological ensemble members and the ML uncertainty is accounted for by performing numerous randomizations. We also investigate different predictability drivers by considering input features such as initial conditions, European weather regime forecasts, and a hydropower proxy. Informed ML models with additional input features achieve better performance than those obtained using hydrological model outputs only, but the selection of features plays a crucial role.

This study shines a light on the use of hybrid forecasting for sub-seasonal prediction to provide useful information for medium- to long-term planning from an integrated risk management perspective.

P 13.3
Analysis of the Swiss groundwater monitoring network using Pastas models and groundwater signatures

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A good understanding of observed groundwater dynamics is of paramount importance for the sustainable use and management of groundwater resources. In this study, we analyzed groundwater level data from 29 boreholes in the Swiss groundwater monitoring network (NAQUA) operated by the FOEN (Collenteur et al., under review). To better understand the observed dynamics, the groundwater level time series were modelled using Pastas models (Collenteur et al., 2019), a lumped-parameter groundwater model with physically based impulse response functions. Additionally, the relationships between groundwater signatures, physiographic and climatic controls, and the calibrated model parameters were explored. The modeling results showed that most of the groundwater time series could be modelled with high accuracy using precipitation, potential evaporation, temperature, and often river stages as explanatory stresses. For some wells, there are indications that human interventions (e.g., pumping) may have influenced the groundwater levels. The influence of snow processes (snow storage and release as snowmelt) appears to impact only a few wells at higher altitudes, while most groundwater level data could be modelled well without taking snow processses into account. The resulting models can be used to select monitoring wells that are relatively free from anthropogenic influences and represent naturally occuring fluctuations. The analysis of the relationship between groundwater signatures, physiographic and climatic controls, and the calibrated model parameters revealed that strong correlations exist. We will argue that such relationships can be exploited to support the different phases of the modeling process, and provide examples of how this can be done.

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P 13.4
Geothermal Modeling - Interrelated Evaluation of Measured Temperature Data from Borehole Heat Exchangers and Heat Transport in the Geological Subsurface

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Knowledge of the thermal properties of the geologic subsurface and heat transport processes is crucial for future geothermal well planning. We hypothesize great potential in the analysis of subsurface thermal anomalies, especially in connection with the consideration of geological structures derived from a 3D model of the Basel area (Dresmann et al., 2013) and the development of a thermal hydraulic model (THM) using FEFLOW©. In addition to the thermal properties of the various geologic units and the geothermal heat gradient, the THM also takes into account the regional topographic groundwater flow regime.

The pilot study area is located in Binningen, south of the city of Basel. The results of the THM are compared with high-resolution temperature measurements performed in 21 borehole heat exchangers (BHE) and discussed in relation to the lithological and heat properties as well as heat transport processes. Preliminary modeling results show that the thermal regime can be modeled accurately and that simulated and measured temperature data are in reasonable agreement. In a next step the developed methodology will be transferred to further regions in Northwestern Switzerland and additional BHE temperature profiles analyzed. The goal is to characterize thermal anomalies in relation to the groundwater flow and thermal regime, water occurrences and the specific geologic-stratigraphic settings.

Acknowlegements: We thank the Office for Environmental Protection and Energy Basel-Landschaft AUE BL for providing the BHE temperature data in the context of the MSc thesis of Elina Roth.

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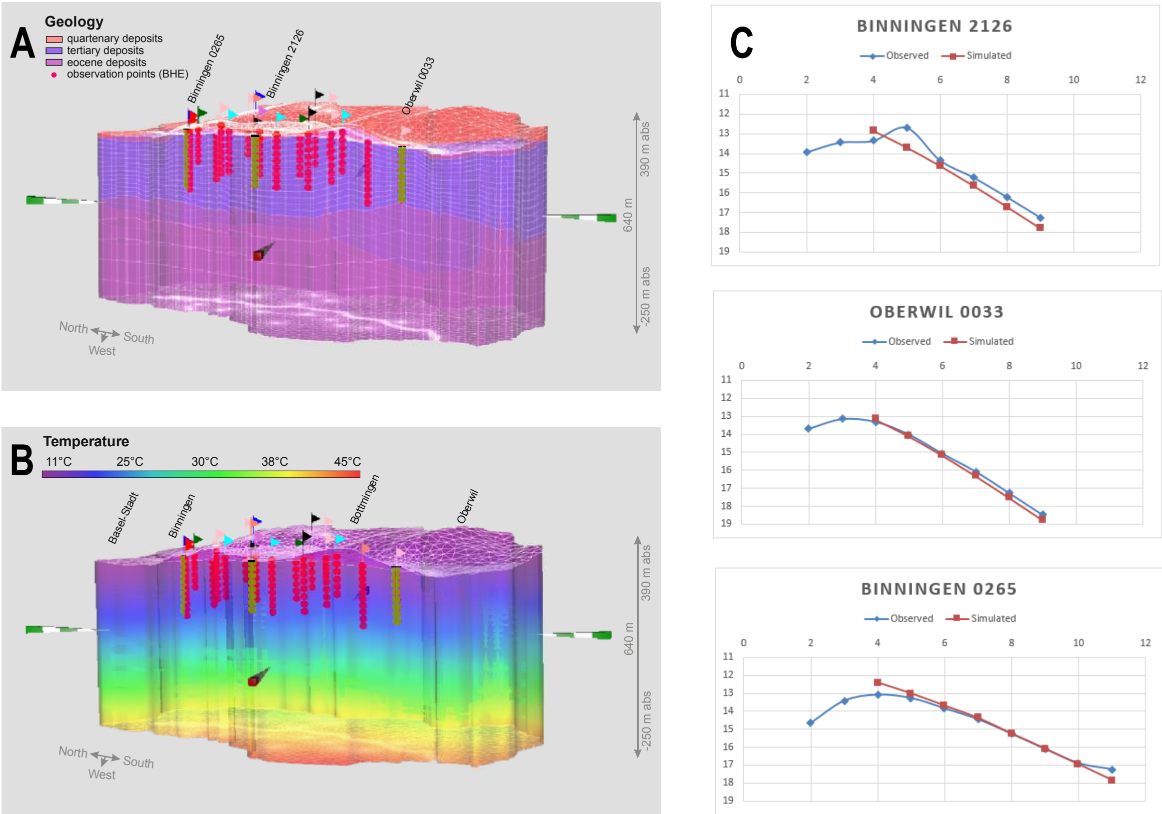

Figure: A – Geology; B – THM Model with simulated temperature distribution; C: Selection of measured and simulated BHE temperature data

P 13.5
From droughts to floods – analysing transitions under different hydro-climatic conditions

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Drought-flood transitions greatly challenge water management and the development of adaption measures to extreme events. These transitions can occur rapidly but may also take many months or years and are often studied using climate instead of streamflow data – neglecting the role of surface processes. The time between one extreme event and the next one may depend on climate and catchment characteristics including topography, soil types and water use. However, it is yet unclear how drought-flood transition times vary regionally in dependence of climate characteristics, flow processes, and water storage.

In this study, we analyse how drought-flood transition times vary across different hydro-climates. Using the example of the contiguous United States, we investigate the relationship between the characteristics of droughts and subsequent floods. We analyse the durations of drought-to-flood transitions and the streamflow evolution during transition periods. Then, we link these properties to catchment and climate characteristics such as snow dominance and the degree of streamflow regulation. In doing so, we differentiate between different drought and transition seasonalities.

This analysis quantifies the time of occurrence and likelihood of (rapid) drought-flood transitions in different hydro-climatic regions. Such quantification is important because flood preparedness is often low during drought events, which potentially increases the severity of flood impacts.

P 13.6
Coupling a large-scale glacier and hydrological model – Towards a better representation of mountain water resources in global assessments

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In high mountain areas, glaciers are an important part of the hydrological cycle and contribute significantly to runoff in the summer months. Due to climate change, the annual runoff volumes originating from glaciers are undergoing significant change, making it essential to consider glacial melt in hydrological models when we want to model future hydrological changes realistically, especially with regard to mountain water resources. On a catchment scale, routines are available for incorporating glaciers. On a global scale, however, glaciers have been largely neglected so far. This is an important limitation of large-scale hydrological models often used for global climate change impact studies.

We present a framework to couple the global glacier model OGGM (Open Global Glacier Model) and the hydrological model CWatM (Community Water Model) on 5arcmin resolution globally. For both models the source code is openly available. This framework facilitates an explicit inclusion of glacier runoff in large-scale hydrological modelling through dynamic modelling of glaciers and allows research into the hydrological importance of changing glaciers. Specifically, we evaluate how the inclusion of glaciers changes the amount and seasonality of simulated runoff in a large-scale hydrological model in the past and the future. Using selected major river basins in Europe and North America as study areas, benefits, challenges and limitations of the coupling are pointed out.

The large-scale glacio-hydrological modelling framework will be openly available to facilitate further research and the inclusion of glaciers in future large-scale hydrological studies. It can potentially also be used with other global hydrological models.

P 13.7
Agricultural adaptations to increasing drought extremes and their feedbacks on catchment hydrology

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Climate is changing. In the future, summer and autumn streamflow is expected to decrease at low elevations in Switzerland and water availability is expected to play an increasingly critical role for agricultural production (BAFU 2021; Holzkämper 2020). To prevent drought-related yield losses, farmers may increase irrigation intensities and extend irrigated areas. Ongoing climatic changes and the anthropogenic responses to those changes may pose the risk of increasing water use conflicts (Klein et al. 2013; Zarrineh et al. 2020; Holzkämper et al. 2020). Solutions to stabilize agricultural production in the face of increasing drought frequencies, while minimizing the dependency on supplement irrigation will be crucial to reduce such risks. Possible solutions include planting deeper-rooted crops or varieties, mulching, or organic soil amendments to increase soil water retention. These measures also have direct impacts on key soil physical properties (i.e. hydraulic conductivity and thus infiltration capacity, and retention capacity) with consequences for runoff formation, evapotranspiration and groundwater recharge at the local scale. Because hydrologic responses at the catchment scale are highly dependent on such processes at the local scale, adjustments in agricultural management can have significant impacts on the hydrologic cycle and thus on the availability of water resources (and their quality). Depending on which adaptation measures farmers choose, hydrologic extremes (low and peak flows) may be exacerbated or, with the appropriate measures, mitigated. The potential benefits to be achieved through a large-scale implementation of measures to increase agricultural water use efficiency in Switzerland have not been quantified so far and may vary depending on climate projection and projection horizon.

We address this gap on the basis of a coupled modelling study exploring crucial interconnections between climate, soil hydrology, plant growth and catchment hydrology. The study will be conducted in the Broye catchment in the southwestern part of the Swiss Plateau (Figure 1). The study region is a focus area for agricultural production, has good coverage of hydrological data (Michel et al. 2020), and is known to be increasingly affected by water scarcity (Zarrineh et al. 2020). Water withdrawals for irrigation from the river have already been restricted or prohibited in past drought years and are likely to face increasing limitations in future drought years (Figure 1). Management adaptations increasing the water use efficiency are urgently needed to maintain agricultural productivity in the region. In this presentation, we present the conceptual framework of an integrated regional modelling study to address these issues. The approach builds on the agrohydrological model SWAP-WOFOST to determine current and future irrigation demands in the catchment depending on current and potentially adapted crop and soil management (e.g. adapted varieties and crops, mulching, cover-cropping or organic amendments). Different agricultural management scenarios will be evaluated in terms of achievable increases in agricultural water use efficiency. In addition to the benefits of mitigating drought-induced yield losses, we will also evaluate the hydrologic response to these measures at the catchment scale in terms of mitigating hydrologic extremes (low flows and peak flows) today and under future climate change. For this purpose, we will couple SWAP-WOFOST with the meso-scale hydrological model (mHM). By involving different research disciplines and actors (from agronomy, hydrology and climate modelling), we implement a holistic approach, which will allow to identify synergistic strategies for adaptation management in the region.

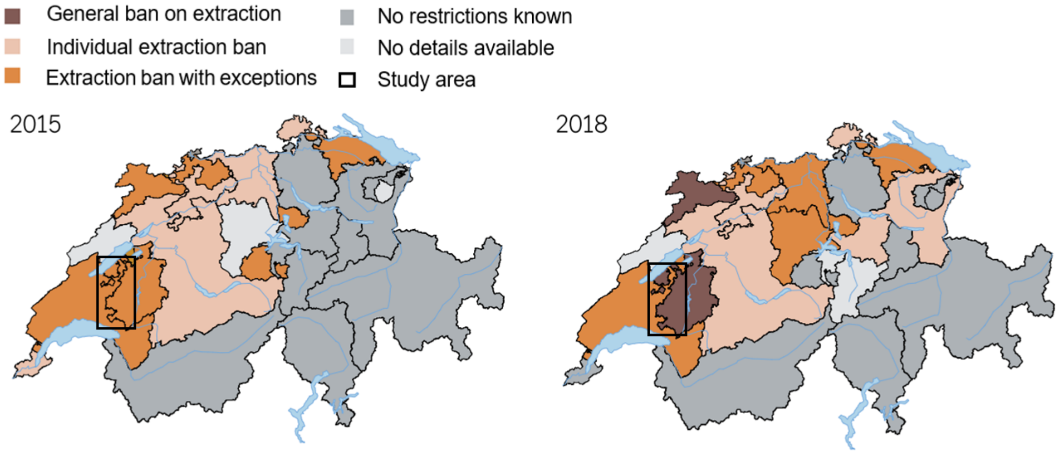

Figure 1. Restriction on water withdrawals for irrigation during the dry summers of 2015 and 2018 (adapted from BAFU 2021).

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P 13.8
Climate change impacts on the debris-flow activity in a high-alpine catchment

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Debris flows are surging mixtures of water and sediments and can threaten humans and infrastructure. In alpine catchments, debris flows are often triggered by high runoff events as a response to intense rainfall, snowmelt, or a combination thereof. Therefore, debris-flow triggering is expected to be sensitive to predicted changes in temperature and precipitation in course of climate change. Quantifying these changes is, however, challenging. While changes in temperature are relatively certain, future precipitation characteristics have lower signal-to-noise ratios (e.g., Hirschberg et al., 2021). Furthermore, how such changes influence the seasonal snowpack is not trivial. For example, snowmelt is predicted to start earlier in the year, but at lower rates (Musselman et al., 2017). Quantifying changes in debris-flow triggering runoff events in high-alpine catchments therefore requires to study the complex interactions of changes in precipitation, temperature and the snowpack.

Our study focuses on the Grabengufer and the gully below (Fig. 1a). Grabengufer is a rock glacier above the municipality of Randa (Valais). The rock glacier front regularly delivers mobile sediments to the gully (1900 m a.s.l.), where debris flows are frequently triggered after rain and/or snowmelt. We use ALPINE3D, which is a spatially distributed version of the multi-layer snowmodel SNOWPACK (Lehning et al., 2002), to simulate the snowpack evolution and runoff in the Grabengufer basin. Due to the small size and the steepness of the basin, the discharge can be simplified as the snowmelt and liquid precipitation in each pixel and in each timestep (Fig. 1b). A debris-flow record consisting of 34 events between 1985 and 2016 allows for calibrating a debris-flow triggering discharge threshold. Meteorological data is available from MeteoSwiss and surrounding IMIS stations. Finally, we plan to use the AWE-GEN stochastic weather generator (Fatichi et al., 2011) and the CH2018 climate scenarios to study changes in debris-flow triggering discharge at hourly resolution. Although we cannot address the full complexity of such geomorphic systems leading to debris-flow triggering (e.g., rock-glacier dynamics), we study changes in extreme discharge, which is a key variable for future debris-flow hazards, by coupling state-of-the-art models. Furthermore, the studied basin is representative of high-alpine debris-flow torrents and the methods and results will be useful for researchers and authorities interested in climate change impacts on alpine mass movements.

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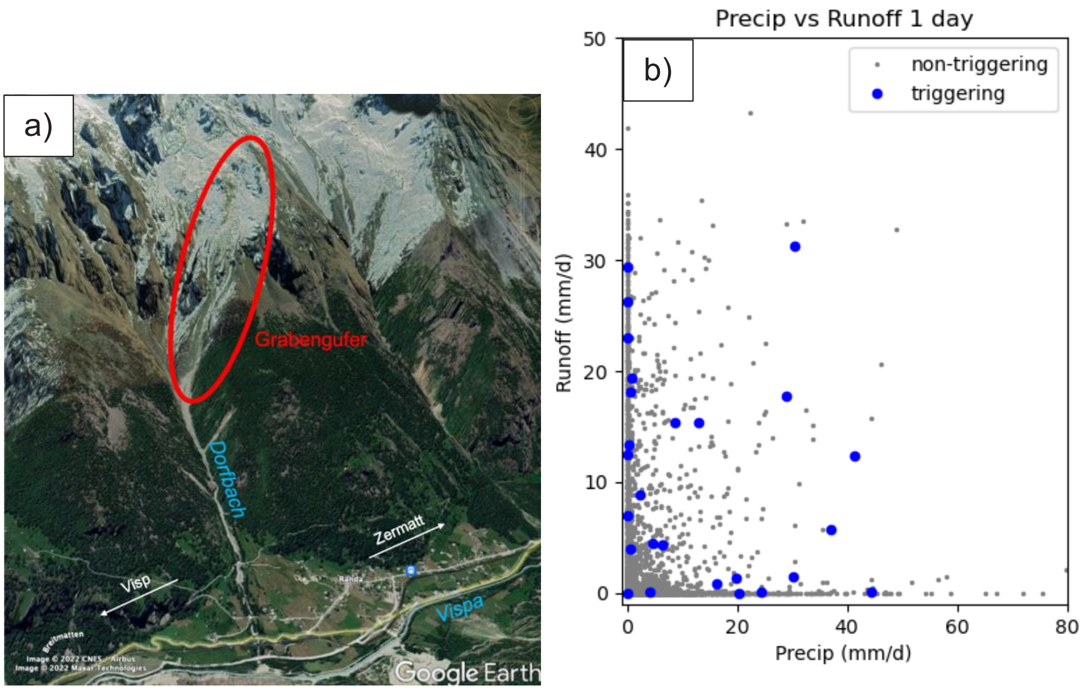

Figure 1. (a) Debris flows initiated at the bottom of the Grabengufer gully, flow into the Drofbach, and can potentially cause backwater effects in the Vispa. (b) Preliminary results from ALPINE3D showing that many debris flows are caused by intense rainfall, runoff from the snowpack, or both.

P 13.9
Modeling River hydro-morphological responses to Land Use Land Cover Change in Tropical Regions: the case of Sebeya catchment, Rwanda.

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The tropics have experienced the fastest rate of Land Use Land Cover Change (LULCC) largely driven by demographic and socio-economic growth. Furthermore, climate change will likely intensify these changes due to global warming and increased frequency of extreme events. These changes have diverse effects on watershed and river hydro-morphological processes through alterations of the rainfall and runoff patterns, which translate into changes in the water balance components. Sebeya catchment in the domain of Western Province of Rwanda, is prone to flooding, associated with erosive processes, and mass movements. This is a result of the catchment geologic formation, steep topography, and the loss of forest cover on fragile soils, coupled with the increased prevalence of extreme rainfall events. This tropical catchment has a long history of deforestation, including the tremendous decline of Gishwati Forest, whose area decreased from 2,800 ha in 1980s to 600 ha in 2000s. The catchment forest cover has been converted to open land use for farming, pasture, and mining activities. These uncovered steep mountains with heavy rainfall, result in high water flow and flooding mainly at the downstream. Over the past thirty years, hundreds of people in the catchment have been displaced, while infrastructure and crops have been damaged yearly. Additionally, Sebeya River channels are subjected to morphological changes, due to high sedimentation which exacerbates during floods, as well as riverbank erosion.

Understanding the watershed hydro-morphological responses to the changes in climate and LULC –especially in tropical regions where rainy seasons are followed by dry seasons— is vital for effective land and water resources management, in the face of future changes. The objective of this study, therefore, is to quantify the catchment LULCC in the last three decades and predict future scenarios, using remote sensing data and LULC model. Furthermore, a hydrologic model is used to simulate and forecast the associated changes in hydro-morphological and flood frequency.

P 13.10
What can pore-scale optical measurements do?

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Despite progress in recent years, it is still a challenging task to understand the fundamental behaviour of fluid flow and transport at the pore scale, because pore-scale processes are often difficult to capture due to the opacity of porous media.
In this presentation, we show our recent pore-scale optical measurements on fluid flow and solute/heat transport.

In a 3D-printed fractured porous medium, we measure pore-scale fluid velocities using both Magnetic Resonance Imaging (MRI) and Particle Image Velocimetry (PIV) techniques and analyse the stress jump and velocity slip coefficients at fracture-matrix interfaces. In addition to fluid flow quantifications, we use laser-induced fluorescence (LIF) techniques to quantify a pulse-like injection of fluorescent dye into the same fractured porous medium and to understand the role of permeability heterogeneity on solute transport. We also capture the development of the thermal plume and the corresponding fluid velocities using combined PIV and two-colour LIF methods when a heat flux is introduced into porous media.

We also use PIV-measured fluid velocities to characterize the evolution of fluid flow paths in a single, self-affine fracture with rough walls, as the fracture undergoes shear displacement. Moreover, we capture both drainage and imbibition processes when immiscible dual-phase flows are injected into the same fracture, which experienced shear displacements. These experiments enable us to delineate the effect of fracture aperture heterogeneity on fracture fluid flow, induced by shear displacement. We extend our measurements on fluid flow and solute transport to a bifurcating fracture to quantify the distribution of fluid and solute mass at fracture intersections.

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P 13.11
CH-GNet – Swiss Groundwater Network

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There is a need for continuous competence building, expert support and a facilitated exchange between research and stakeholders in Switzerland to assess hydrogeological issues and challenges under the pressure of new developments. For this purpose, the CH-GNet was created.

The aims of the CH-GNet are to coordinate and promote practice-oriented research. Developed tools and gained information from the scientific community are to be made visible and transferred from science into practice. Scientific facts are to be compiled and strongly practice-oriented research is to be achieved by noticed groundwater-relevant problems as well as possible (voluntary) solutions. Together with the advisory board, the CH-GNet is setting concrete thematic priorities and is determining fundamental strategic directions.

Purely scientific facts are to be worked out for the respective topics and political statements are to be avoided. By bundling practice-relevant research results and making them visible, through organized workshops and the development of documents, help promoting continuous competence building, and a smooth exchange of information, the CH-GNet wants to support the cooperation of various interest groups and represent a source of information. In the present poster examples of the CH-GNet activities are shown

Figure 1. Swiss Groundwater Network. More Information can be found on our webpage https://www.swissgroundwaternetwork.ch/

P 13.12
Global Potential Groundwater Recharge Response to Climate Variability

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Periodic climate patterns such as climate teleconnections can have distinct effects on groundwater, and the ability to predict groundwater fluctuations in space and time is critically important for sustainable water resource management. However, the periodic controls on groundwater resources remain unconsidered in most studies. Teleconnections between global-scale climate oscillations and groundwater are poorly understood because the relationship between subsurface properties and surface infiltration can be highly nonlinear. Understanding of teleconnections is further hampered because many groundwater records are incomplete and groundwater levels are also anthropogenically influenced. Existing studies that have looked at how climate teleconnections control groundwater are based on a limited number of point measurements. Therefore, the spatial distribution of the teleconnections remains mostly unknown.

Here, based on an analytical solution derived from Richards' equation, we present a global assessment of when and where climate teleconnections are expected to propagate in groundwater levels. We model the response to idealized recharge oscillations below the root zone from five different global recharge model sources with periods that range from .monthly to decadal years. The largest periods are idealized representations of global-scale climate variability such as Pacific-North American Oscillation (PNA), North Atlantic Oscillation (NAO), El Niño/Southern Oscillation (ENSO), and Pacific Decadal Oscillation (PDO)

Our global-scale assessment reveals why in some regions periodic infiltration fluxes caused by climate variability remain absent in groundwater level fluctuations, whereas in other regions they result in more dynamic groundwater levels. We explore to what extent groundwater resources are sensitive to climate variability and may help forecast long-term groundwater levels.

P 13.13
Preserving the temperature-scaling of high intensity precipitation for a more realistic projection of sub-daily extreme events

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According to the Clausius-Clapeyron (CC) relation, the water holding capacity of the atmosphere increases by about 7% for each °C of increase in air temperature. It has been widely observed at multiple regions and climates that there is a scaling of the most intense events on record with the near surface air temperature at rates that resemble that of the CC. Convection Permitting Models – dynamical models designed to model the very intense, short-duration convective rain cells that typically occur under warm conditions– have further confirmed this phenomenon and project it to intensify under future climate scenarios.

Stochastic weather generators (WG) are models typically parameterized based on observations and used to simulate large ensembles of plausible high-resolution time series that preserve the correlations and cross-correlations found in climate. This allows practitioners to carry out more robust extreme value analysis, to quantify the internal climate variability of variables of interest, and, when forced to follow the signals emanating from climate models, they provide unique insight into the impacts of warming climate at small scales. Combined with the outputs of dynamical climate models, it is possible to carry out these analyses under any assumed climate trajectory.

The two-dimensional Advanced Weather Generator AWE-GEN-2d (Peleg et al., 2017), as one of the few of its kind, is an ideal to generate the distributed and high resolution climate variables necessary to project the impacts over complex topography (Moraga et al., 2021). In this work, we further improve the model by incorporating an explicit dependency of storm properties with temperature, with the goal of simulating the CC scaling of intense events, while preserving all the other cross-correlations built into the model. In doing so, we find a balance between the expected intensification of extremes with rising temperatures and the overall precipitation trends projected by conventional climate models, thus generating a more realistic dataset that represents the changes to small-scale extreme events.

Using the example of a mountainous catchment in the Swiss Alps, we use the new AWE-GEN-2d-CC to generate large ensembles of present and end-of-century climate time series following the outputs of multiple climate models. These ensembles are consequently used as inputs to a physically-based hydrological model, Topkapi-ETH, that allows us to explore the effects of climate change on hydrometeorological extremes at the sub-kilometer and hourly scale .

The simulations show how incorporating the temperature dependence in the model reveal that extreme precipitation events will increase under future climate scenarios, especially for short durations and relatively small return periods, whereas the change is less noticeable for rarer events (e.g. T > 100 years). This has a clear impact on the hydrological response of small catchments, as the annual maximum hourly and daily flows are projected to increase rather than decrease or remain constant, as projected using the previous model version (Moraga et al., 2021). These results highlight the importance of accounting for the temperature-intensity relationship when analyzing the impacts of climate change on extreme events, particularly for small or highly heterogeneous catchments that are particularly sensitive to short and intense events.

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P 13.14
Results of hydrogeological investigations in the framework of Nagra's deep borehole program

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In the framework of the Swiss Sectoral Plan for Deep Geological Repositories, Nagra carried out a comprehensive exploration campaign to characterize the remaining three potential siting areas Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) in northern Switzerland. Hydrogeological investigations at representative borehole locations contribute to the site comparison and to evaluate long-term safety of a repository for radioactive waste. The investigations focused on the host rock Opalinus Clay, its confining units and the regional aquifers above and below these low permeability units.

The hydrogeological survey comprised of in-situ tests as well as lab investigations of drill cores. In situ tests included fluid logging, hydraulic packer testing and groundwater sampling. Vertical hydraulic head distribution is also investigated in selected boreholes by means of long-term monitoring systems. Off-site lab investigations included measurement of matrix permeability and porewater investigations as evidence for transport processes.

The conducted investigations allowed to refine the knowledge from earlier investigations:

- In the siting areas NL and ZNO, the Malm aquifer is typically covered by several hundreds of meters of Molasse sediments. Fluid loggings conducted in the thick limestone unit of the «Felsenkalke» / «Massenkalk» and Villigen Fm. combined with FMI (Formation Micro Imager) of the boreholes provide an improved understanding of the nature and occurrence of water conducting features in this regional aquifer. In some areas, highly enriched stable isotope compositions and other isotope tracers in deep groundwaters evidence fossil components and low flow dynamics.
- The observed hydraulic properties of the Hauptrogenstein aquifer in the Bözberg area (JO) can be linked to the facies transition from the clay mineral-rich Klingnau Fm. in the east to the Hauptrogenstein carbonate platform in the west.
- Several local-scale aquifers were observed in the uppermost Keuper in association with different Members of the heterogeneous Klettgau Fm. The dolomitic Seebi Mb. in ZNO was found to constitute of an aquifer at least at the scale of the siting area. In NL, groundwater flow is locally occurring in association with fluviatile deposits within the Ergolz Mb. In JO, available data suggest that water is flowing in the porous and fractured dolostones of the Gansingen Mb. When present, the aquifers of the Klettgau Fm. represent the closest release pathway from the host rock.
- The investigations provide further evidence that the Muschelkalk is the dominant deep regional aquifer in Northern Switzerland. Comparably high hydraulic conductivities throughout the sites along with hydrochemical data support a well-connected regional flow system.
- Hydraulic packer tests in Opalinus Clay complement earlier datasets, notably from previous deep boreholes in Northern Switzerland and investigations in the Mont Terri Underground lab. Hydraulic conductivities are typically below 1×10^{-13} m/s and vary within a narrow range. Also, none of the test results suggests that fractures constitute discrete flow paths.
- Hydraulic packer tests in the confining units show generally low hydraulic conductivities typically varying between 5×10^{-12} and 1×10^{-14} m/s. Rare higher values are restricted to test intervals with fractures in thick sections with low clay mineral contents. Tests on drill-core samples allow to correlate matrix hydraulic properties with mineralogical composition and therewith to evaluate the role of individual lithofacies.

Acknowledgements: We acknowledge numerous contributions to the investigations by Nagra staff as well as by third party companies.

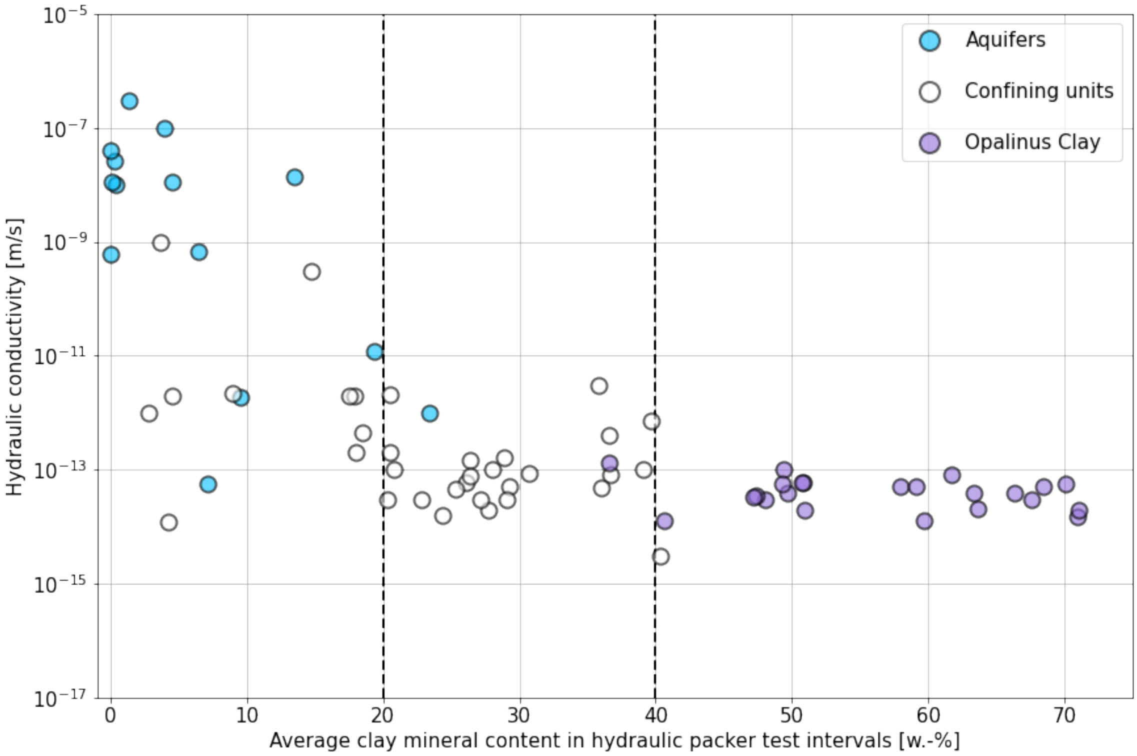

Figure 1. Hydraulic conductivities from hydraulic packer tests in function of the average clay content in test intervals (average clay content of the 5 m clay-poorest layer in test intervals considered).

P 13.15
Morphological evolution of the Rhone River in the Martigny bend

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INTRODUCTION
Extreme events and altered river discharges related to climate change are expected to become more frequent and more pronounced in the coming years, leading to new challenges for existing infrastructure (Berga, 2016). Sustainable water management is therefore a principal matter to ensure safety of waterways. In this framework, the correction of the Martigny bend is a priority measure of the 3rd Rhone River correction in Switzerland, which aims at increasing the flood protection in the region while ensuring sustainable conditions for the Rhone River (Arborino and Jordan, 2014). The project foresees widening the bed of the river to the regime width and lowering the bed in the bend. A numerical model is built to represent the priority measure, in order to evaluate the impact of the project on sediment transport capacity and the morphological evolution in the long term.

METHODOLOGY
Numerical simulations are run using BASEMENT v.2.8 software (Vetsch et al., 2020). The model represents a 4870 m long segment of the Rhone River, including the Martigny bend, and the confluence with the Dranse River and the Trient River. The analysis type is transient analysis (2D modeling) considering multiphase flow.
The model uses shallow water equations (SWE) and the Meyer-Peter & Müller formulation adapted for multiple grain size classes by Hunziker (MPM-H) to predict flow features sediment transport respectively.
A mesh sensitivity analysis is performed, and parameters, such as roughness, grain size distribution and critical shear stress are defined. The validity of the numerical model is assessed comparing the results with a physical model. The morpho-dynamic behavior is analyzed using a steady-flow simulation for a 10- years return period flood over a 15-days duration.

RESULTS
Figure 1 shows the evolution of the morphology at the upstream part of the model and indicates a deposition zone in the widening with an advancing sediment front close to the bend. The Dranse is bringing a greater concentration of sediments. These sediments are transported and deposited in the Rhone and create a second deposition zone with advancing front. At the upstream part of the Dranse River, a deposition and erosion dynamic leads to the formation of a preferential channel.
The grain size evolution presented in Figure 2 indicates that there is a grain size sorting and that the deposits are composed of finer sediments than the bed bottom grain size, both in the widening and at the confluence of the Rhone. The areas with the highest d_{50} (200 mm) correspond to non-erodible zones.

Figure 1 Bed variation of the Rhone River after 15 days

Figure 2 Diameter d_{50} of the Rhone River granulometry after 15 days

CONCLUSION

A numerical model of the priority measure of the 3rd Rhone River correction is built to assess the impact of the project on the sediment transport capacity and the morphological evolution in long term. Results indicate that the river reach is dynamic. Erosion and deposition zones are identified and highlight that a preferential channel is established. In addition, sediment grain size sorting is observed on the river reach.

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P 13.16
Regional-Scale Thermal Hydraulic Modeling for Preliminary Geothermal Potential Assessment – A Theoretical Approach using the example of Riehen

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Based on the approach of Tóth et al. (2020), we demonstrate how conceptual, generalized, and simplified Thermal Hydraulic Models (THM) can be used to simulate groundwater flow and heat transport and to support the identification of potential areas for the planned new medium-depth geothermal wells in the municipality of Riehen, Northwestern Switzerland. Regional-scale 2D THM were developed using COMSOL© based on geological section interpretations followed by an assessment of the influence of geological structures as well as the sensitivity of hydraulic and thermal parameters and boundary conditions. Preliminary modeling results show that the thermal regime can be modelled relatively accurately and reproduces measured temperature data (Figure). Furthermore, the most sensitive geologic units and parameters could be identified, which are faults (k-value and aperture) and aquitard (k-value, thermal conductivity) whereas the hydraulic parameters of aquifers have been recognized as not very sensitive.

The next step would be to use the gained experience and to update our existing high-resolution regional 3D geologic model, augment it with the recorded 3D seismic data, and develop a 3D THM. Information on 3D geothermal potential and groundwater flow regime would allow optimization of the location of production and injection wells for an efficient long-term use and to address groundwater protection issues already in the exploratory phase.

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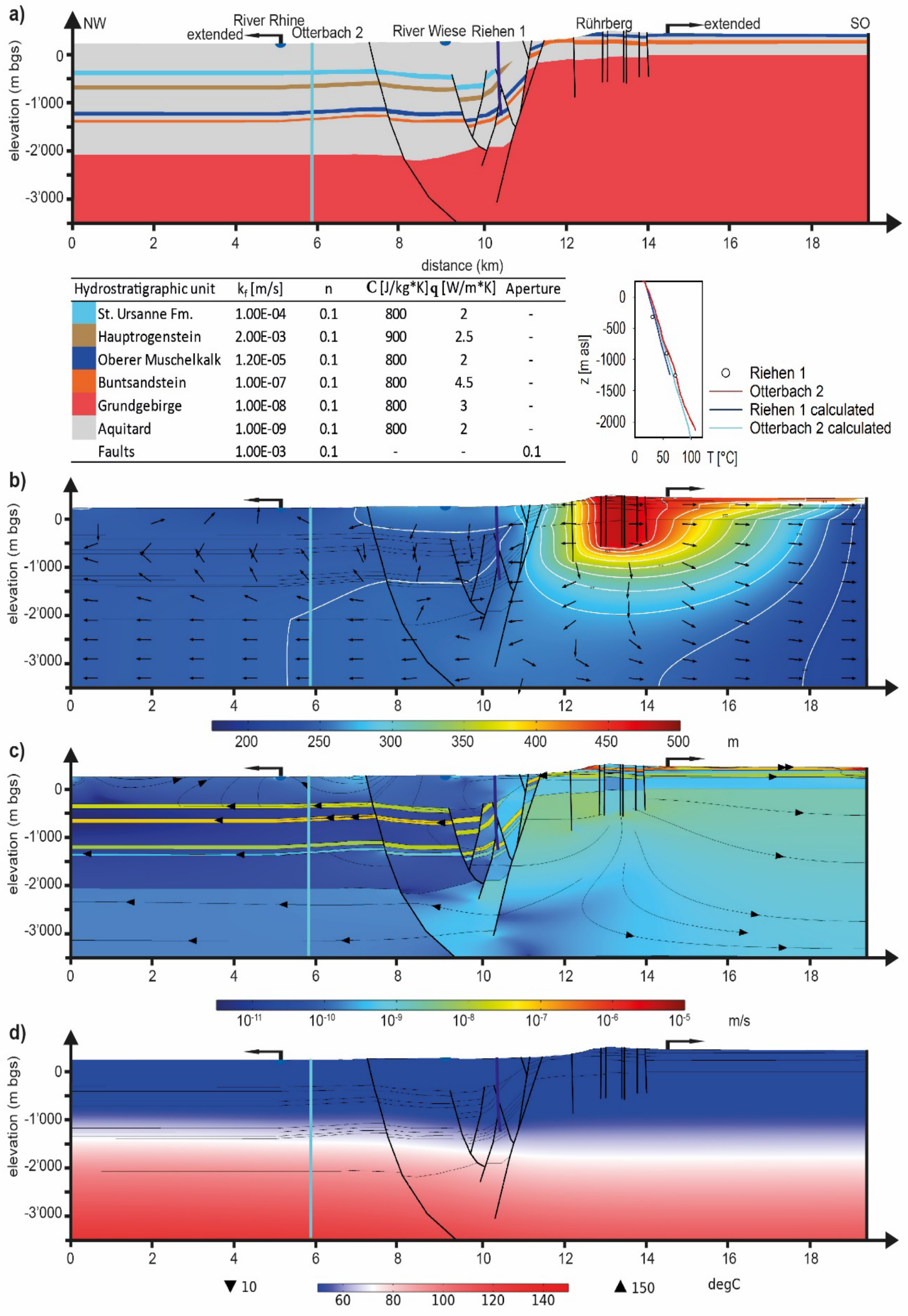

Hydrostratigraphic unit	k_f [m/s]	n	C [J/kg*K]	q [W/m*K]	Aperture
St. Ursanne Fm.	1.00E-04	0.1	800	2	-
Hauptrogenstein	2.00E-03	0.1	900	2.5	-
Oberer Muschelkalk	1.20E-05	0.1	800	2	-
Buntsandstein	1.00E-07	0.1	800	4.5	-
Grundgebirge	1.00E-08	0.1	800	3	-
Aquitard	1.00E-09	0.1	800	2	-
Faults	1.00E-03	0.1	-	-	0.1

Figure: Regional-scale 2D THM: a) geologic profile extended on both sides to avoid boundary effects; b) simulated groundwater flow and thermal regime showing the hydraulic head and uniform Darcy velocity vector field; c) Darcy velocity magnitude with characteristic streamlines; d) simulated temperature field. The graph shows the measured and calculated vertical temperature profiles from the deep borehole Otterbach 2 in Basel and the existing geothermal well Riehen 1.

P 13.17
Pedotransfer functions for soil hydraulic properties of Swiss forest soils

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Soil hydraulic properties (SHPs) are required to quantify water availability for water uptake by roots and to assess drought stress in forest trees from prolonged dry periods due to climate change. The measurement of SHPs is time consuming and requires complex instrumentation. An often-used alternative to measurements is the application of pedotransfer functions (PTFs) for estimating SHPs. PTFs are mathematical rules linking more easily obtainable soil information (e.g., soil texture, organic carbon content, pH, or cation-exchange capacity) with SHPs. Many of the available PTFs (for example, 'Rosetta', Schaap et al. 2001) were trained mainly on samples collected for arable land and therefore miss the effects of forest-specific soil formation processes (perennial vegetation, deep root systems, and high litter input alter the SHPs). These shortcomings can be avoided by building a PTF including soil samples from forests (Wessolek et al. 2009) or training it exclusively with forest soil samples as was done for southern Germany (Puhlmann and Wilpert 2011). However, as shown in Figure 1, none of the tested PTFs could successfully predict the water retention and hydraulic conductivity curve of Swiss forest soils that were described in Richard and Lüscher (1978, 1981, 1983 ,1987). Consequently, we built a new PTF for Swiss forest soils using two statistical methods: linear regression and random forest. The new PTF was validated using soil samples collected from another study in Valais (Walthert et al. 2021). The new PTF will be applied to estimate transpiration rates of forests in an ongoing research project.

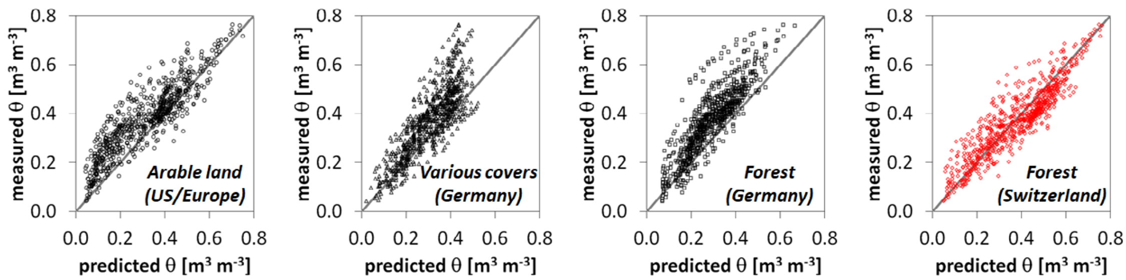

Figure 1. Comparison of water contents measured in Swiss forest soils (73 soil samples from 0 to 345 cm soil depth) with predictions using PTFs from the literature (black) and the new PTF (red). Each symbol denotes a water content measured at a specific matric potential. All previous PTFs underestimate the measured values (above 1:1 line).

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P 13.18
An ensemble based data assimilation framework for an integrated hydrological model: development and examples

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Ensemble-based data assimilation combines prior information from numerical model simulations with real-world observations to obtain the best estimates of model states (e.g. hydraulic heads) and even the parameters (e.g. hydraulic conductivity). In hydrological modeling, through assimilating tracers such as noble gases, the real-time operational simulation of water quantity, as well as quality, can be achieved. This can open, for instance, new windows for model-based operation of drinking water production. In this study, we developed a data assimilation framework for an integrated hydrological model. The Parallel Data Assimilation Framework (PDAF, http://pdaf.awi.de), which is a software environment for ensemble data assimilation has been coupled to the physically based hydrological model HydroGeoSphere for surface water – groundwater simulation. Multiple types of observations such as piezometric heads, streamflow, and tracer concentrations can be assimilated together. Both the model states and the parameters can be separately or jointly updated by the assimilation algorithm. Numerical experiments based on a Swiss drinking water wellfield are carried out for both the flow and transport simulations. One or multiple types of observations are assimilated. These observations include piezometric heads and noble gas concentrations such as ^{222}Rn, ^{37}Ar, and ^{4}He. The results are evaluated by comparing the estimated model variables with independent observation data between the assimilation runs and the free run where no data assimilation is conducted.

P 13.19
Impact of gold mining storage tailings on groundwaters and surface waters: the case of Hiré (southern Ivory coast)

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Abstract
The development of the mining industry in Bonikro, started in 2007, was seen as an economic opportunity for the locality of Hiré. The expansion of artisanal gold mining led to the industrial mining event in the area. This so called “mining boom”, while generating huge amounts of capital, is putting an enormous pressure on both agricultural activities and the preservation of the environment, in particular water resources. In order to contribute to the safeguarding of water resources of this region, this research project was initiated.

It aims in modelling the impact of these mining activities on the water resources of the sites exploited in the Hiré region. As a first step, the description of the hydrogeological system of the area will be done. To achieve this, a conceptual model of the site was developed and used to identify the flows of water. Based on this description, a simplified model will be implemented under Feflow code to predict the flow direction of groundwater. Therefore, this modelling requires need accurate data such as topography, geology, rainfall, temperature, evaporation, water chemistry, boundary conditions, pumping rate, hydrological regime, faults, etc. However, for reasons of data confidentiality and difficulty of access to the industrial mining site, data acquisition for such a project is often difficult. Thus, hypotheses were formulated and data from the literature were used to overcome this difficulty. In addition, the results of a model require validation by field data. The first results of the modelling will be presented on the poster.

Key words: Bonikro, Hiré, gold mining activities, heavy metals pollution, ground and surface water quality

General context
The locality of Hiré is located 45 km from Divo in the South Bandama region of Côte d›Ivoire. The mining activity, formerly practised by gold panners in alluvial and eluvial zones (Gaston, 1913; Chauveau, 1978), was taken over in 1920 in a semi-industrial manner by the colonists, thus putting an end to gold panning (Kouadio, 2008). From then on, the local population turned to the agricultural sector, which flourished before the cocoa crisis of the 1980s. This led to a shift in the economic model towards industrial mining in 2007, using a leaching process that produces a high recovery of gold (Haque, 1992), from the Bonikro gold deposits before spreading to the rest of the Hiré locality. Thus, mining generates large quantities of toxic waste, which must be properly managed to avoid impacting ecosystems ARIA, (2008) and AGC, (2015).
An analysis of investigations conducted (Bamba, 2012; Yapi et al., 2014; and ADHP, 2019) in surface and groundwater in Hiré ville and in the vicinity of the Bonikro mining site have shown the presence of cyanide, mercury, and TMEs at levels above the WHO limit values for drinking and irrigation water. In 2020, the Konan studies revealed the occurrence of new skin diseases in the Bonikro area. However, no study in Hiré has formally demonstrated a causal link between the presence of the mine and these new diseases.

As in Japan, causal links were established for Minamata disease (1950) due to mercury poisoning (Gillet, 2018). Moreover, Zhang et al, (2012), have shown that excess lead and cadmium can cause health effects (arthralgia, osteomalacia). It is therefore time to address the issues of the impact of mining on the environment and on the people living in the vicinity of the industrial mines in Hiré. To achieve this goal, it would be necessary to combine remote sensing and hydrogeological modelling to understand the hydrodynamic functioning of groundwater in the Hiré city in a context of environmental transformation.

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P 13.20
HYDROpot_integegral: a tool to simultaneously assess hydropower potential and ecological potential

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Low greenhouse gas emissions make hydropower a so-called climate-friendly electricity source. In Switzerland, hydropower is the most important electricity source, accounting for about 60% of total electricity production. However, the 1700 hydropower plants in Switzerland also alter river hydrology, habitats and connectivity, leading to biodiversity loss and ecosystem degradation. This leads to a conflict between the goals of the energy transition aiming for a climate-friendly energy production and the goal of natural conservation aiming for a reducion of negative impacts on freshwater ecosystems. A spatial explicit strategic assessment for hydropower localisation that compares environmental impact with hydropower production potential is crucial to reduce such conflics. The tool HYDROpot_integral is based on 70 geospatial datasets that are used to quantify for each river segment both the hydropower potential and the ecosystem potential (respecting sustaining, cultural and providing ecosystem functions). HYDROpot_integral has been compiled for Switzerland and is freely accessible. In this study we show the potential of the tool and compare the current state with the potential impacts of a 20% increase of hydropower power production for the Kander catchment. The findings of the study contribute to adress the challenges of the cumulative effects of hydropower and explore how to account for the longitudinal connectivity to better implement these effects in HYDROpot_integral.

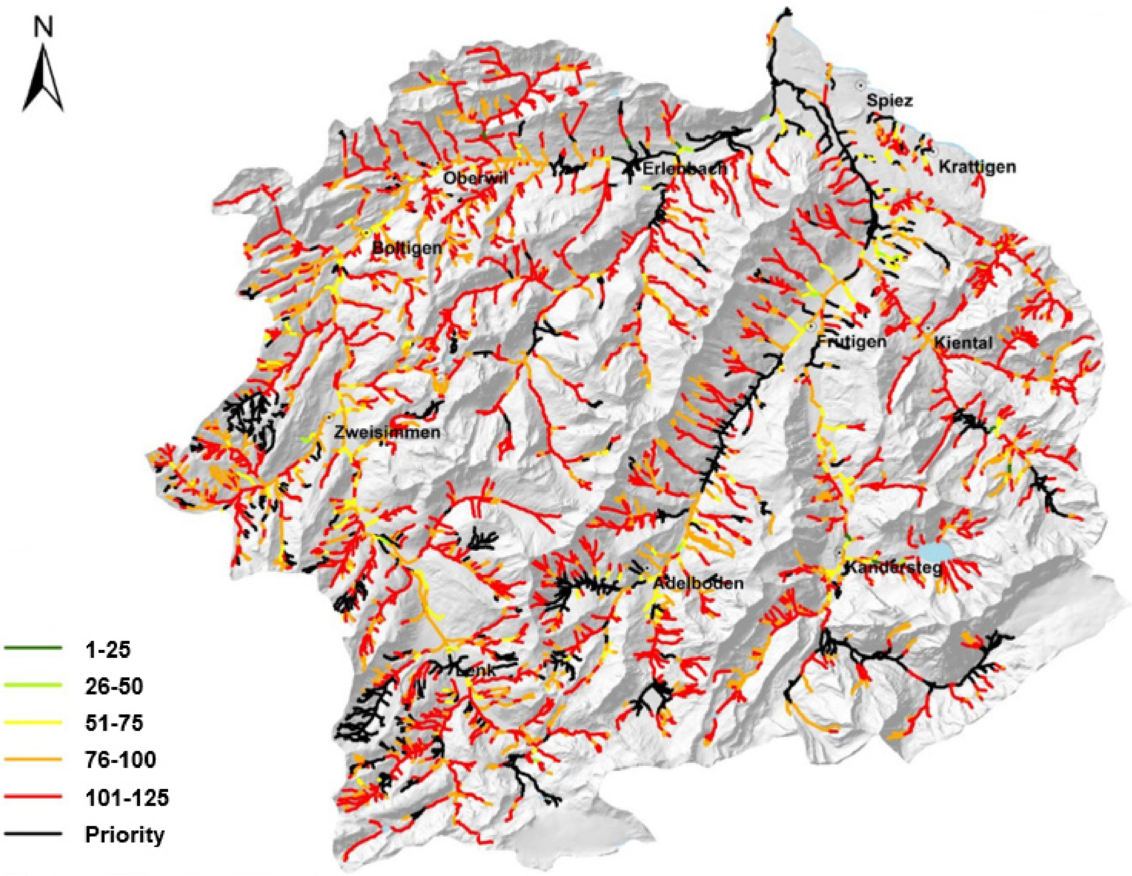

Figure 1. Quantification of sustaining, cultural and providing ecosystem functions in the Kander catchments (BE). Rank 1 is most suitable for hydropower production at minimum cost in terms of ecological and cultural ecosystem functions; rank 125 indicates the highest ecological and cultural ecosystem functions and the lowest economic functions and is therefore most suitable for protection; the Priority reaches (black) exclude use by law.

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P 13.21
Hydrological modelling with real and synthetic snow cover data assimilation

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To study long-term changes in the hydrology of snow-fed catchments, there is a need for long-term time series of snow cover data. Satellite imagery and climate reanalysis can both be used to quantify past snow cover, but they lack in baseline period length and spatial resolution respectively. In this study we apply a similarity-based method to generate synthetic high-resolution daily snow cover maps, and consequently combine these maps with hydrological model outputs in a data assimilation framework. The results are benchmarked against a case without synthetic snow cover forcing and a case with only observed snow cover maps. The study is performed on the Thur-Jonschwil sub-catchment in Eastern Switzerland, a meso-scale catchment covering a wide elevation range and experiencing different degrees of snow intermittency. With the currently implemented Direct Insertion data assimilation, the streamflow simulation performance slightly deteriorates but the SWE estimates improve significantly. To further explore the robustness of the methodology and the validity of these findings we will consider other data assimilation algorithms and hydrological models in the near future.

P 13.22
Multiple-point Geostatistics-based spatial downscaling of heavy precipitation

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High-resolution precipitation data in space and time is critical for many hydrometeorological, ecological, and environmental applications. At regional scales, gridded precipitation data are often obtained through remote sensing. However, their spatial resolution is often too coarse (i.e. 10^1 km) and requires to be downscaled to a finer resolution (i.e. 10^0 km). We demonstrate how the Multiple-point Geostatistics (MPS) framework can be used to downscale the CMORPH precipitation product from 8 km to 1 km resolution. We take the city of Beijing as a case study, with a specific focus on extreme precipitation events during 1998 - 2009. The high-resolution CMAPS dataset (1 km, hourly), available for the period 2015 - 2020, is used as a source of training images in the MPS framework. Three ground stations with hourly rainfall observation from 1950 to 2012 were used for validation. The study shows that: (i) After quantile-correcting the CMORPH data based on the CMAPS data, its exceedance probabilities at the three stations are closer to that of upscaled CMAPS and observations, which helps improve the search for training images in the MPS model; (ii) Structural similarity indexes higher than 0.8 are found for 100% (summer), 94% (autumn), and 97% (spring) of the downscaled precipitation fields, meaning that the downscaled precipitation preserves the spatial structures well, especially for summer extreme precipitations; (iii) After an adjustment of the intensities of the downscaled precipitation field using a scaling law with a spatial coefficient of variation factor, the 25 - 75% quantile values (low-precipitation intensities) agree with that of ground station observations, while the 90 - 99% quantile values (high-precipitation intensities) agree with the expected intensification due to the changes in spatial scales expected from the theoretical rainfall areal reduction factor. The results indicate that the downscaled precipitation field obtained from the MPS model preserves the precipitation spatial structure well and adequately estimates the intensities, especially for heavy precipitation. The proposed downscaled approaches can be applied to other precipitation datasets and in other regions.