



Abstract Volume 17th Swiss Geoscience Meeting

Fribourg, 22nd + 23rd November 2019

12 Hydrology, Limnology and Hydrogeology

sc | nat 

Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
Académie des sciences naturelles

**UNI
FR**


UNIVERSITÉ DE FRIBOURG
UNIVERSITÄT FREIBURG

12. Hydrology, Limnology and Hydrogeology

Peter Molnar, Michael Doering, Tobias Jonas, Sandra Pool, Michael Sinreich, Sanja Hosi

Swiss Society for Hydrology and Limnology SGHL

Swiss Hydrological Commission CHy

Swiss Hydrogeological Society SGH

TALKS:

- 12.1 Arnoux M., Cochand F., Hunkeler D., Brunner B., Schaefli B., Jonas T.: Groundwater and discharge regime evolution with climate change in Alpine catchments
- 12.2 Beria H., Larsen J.R., Ceperley N.C., Michelin A., Schaefli B.: Increased snowpack ephemerality augments groundwater recharge in the mid-elevation belt of the Swiss Alps
- 12.3 Cochand F., Hunkeler D., Sinreich M., Brunner P.: Modelling recharge by precipitation at the Swiss scale
- 12.4 Doda T., Ramón C., Ulloa H., Wüest A., Bouffard D.: Density currents induced by differential cooling in a small temperate lake: seasonality in their occurrence and magnitude
- 12.5 Kiewiet L., Wicki A., van Meerveld H.J., Seibert J.: Explaining shallow groundwater concentrations with surface and bedrock topography, and soil and bedrock composition
- 12.6 Mastrotheodoros T., Pappas C., Molnar P., Burlando P., Manoli G., Fatichi S.: Dissecting the water tower of Europe: a high-resolution ecohydrological modelling of the European Alps
- 12.7 Mettra F., Blanckaert K., Lemmin U., Barry D.A.: Sediment connectivity in the Rhône Basin: from an isolated thunderstorm at Illgraben to a turbidity current in deep Lake Geneva
- 12.8 Michel A., Brauchli T., Wever N., Epting J., Lehning M., Huwald H.: Stream Temperature Evolution in Switzerland simulated with downscaled CH2018 Climate Change Scenarios
- 12.9 Perego R., Pera S., Bulgheroni M., Boaga J., Galgaro A.: Hydro/thermogeological state of the Maggia river delta: potential shallow geothermal energy implications
- 12.10 Weatherl R., Salgado M.H., Schirmer M.: Identifying sources and processes impacting groundwater recharge in the human environment
- 12.11 Wirth S.B., Bouffard D., Cojean A., Zopfi J.: Giant pockmarks in Lake Neuchatel, Switzerland: new multi-proxy evidence for lacustrine groundwater discharge

POSTERS:

- P 12.1 Botter M., Burlando P., Fatichi S.: Solute generation and C-Q relations: is solute input frequency or depth of solute generation the key-player?
- P 12.2 Brauchli T., Michel A., Lehning M., Schaefli B., Huwald H.: Stream temperature and discharge evolution over the last 50 years in Switzerland
- P 12.3 Cotte G., Vennemann T.: Does the Rhône River fertilise Lake Geneva ? (in the context of its re-oligotrophisation)
- P 12.4 Epting J., Huguenberger P.: Thermal potential of urban tunnel infrastructures in unconsolidated rock groundwater resources
- P 12.5 Scheidler S., Dresmann H., Huguenberger P., Epting J.: Geothermal use of an Alpine aquifer – Davos pilot study
- P 12.6 Etter S., Stobl B., Seibert J., Meerveld v.H.J. (Ilja): Accuracy of citizen science water level class observations
- P 12.7 Jeannin P.: KMC : a comparison of various models for assessing karst hydrology
- P 12.8 Li Z., Sun H., Zhang Y., Sibatov R.T.: Continuous time random walk model for non-uniform bed-load transport
- P 12.9 Peel M., Musy S., Popp A., Alvarez P.A., Purtschert R., Hunkeler D., Brunner P.: Getting the most out of environmental tracers in complex alluvial systems
- P 12.10 Peleg N., Molnar P.: Temperature effects on extreme rainfall modify catchment response
- P 12.11 Pool S., Frances F., Garcia-Prats A., Puertes C., Pulido-Velazquez M., Sanchis-Ibor C., Schirmer M., Yang H., Jimenez-Martinez J.: Modelling the effect of irrigation modernization on groundwater recharge
- P 12.12 Popp A.L., Pardo-Alvarez A., Schilling O.S., Musy S., Scheidegger A., Peel M., Purtschert R., Hunkeler D., Brunner P., Kipfer R.: Elucidating stream-groundwater interactions using real-time, in situ noble gas analysis and numerical modeling
- P 12.13 Saurwein D.: Towards decadal hydro-glaciological forecasts for the hydropower sector
- P 12.14 Tu L., Zander P., Szidat S., Vogel H., Grosjean M.: The influence of trophic history and lake mixing regime on long-term phosphorus fractions retention in sediments of deep, eutrophic lakes: a case study from Lake Burgäsch, Switzerland
- P 12.15 Wicki A., Stähli M., Hauck C., Lehmann P.: Soil hydrological monitoring for regional landslide early warning

12.1

Groundwater and discharge regime evolution with climate change in Alpine catchments

Marie Arnoux¹, Fabien Cochand¹, Daniel Hunkeler¹, Philip Brunner¹, Bettina Schaeffli² & Tobias Jonas³

¹*The Centre for Hydrogeology and Geothermics of University of Neuchâtel, University of Neuchâtel, Rue Emile-Argand 11, CH-2000 Neuchâtel (marie.arnoux@unine.ch)*

²*Institute of Earth Surface Dynamics, University of Lausanne, CH-1015 Lausanne*

³*Institute for Snow and Avalanche Research, Flüelastrasse 11, CH-7260 Davos Dorf*

The hydrology of alpine areas is highly sensitive to climate change, especially on a seasonal time scale. Recent studies suggest a general decrease in snow accumulation and a shift of snow-influenced discharge event towards earlier periods of the year. Depending on future scenarios, these snow-cover changes can be combined with warm and dry summers. The associated seasonal magnitude of discharge regime change is most likely influenced by groundwater storage. However, hydrogeological data are very limited in these areas, mainly because of the difficulty to develop monitoring networks in Alpine Terrain. The dynamics of alpine groundwater processes and their influence on catchment response to climate change remains therefore poorly understood. In fact, the role of groundwater is rarely considered explicitly in hydrological studies.

In order to highlight the influence of groundwater storage on discharge regime evolution with climate change, we run recent climate change scenarios for Switzerland (CH2018) with hydrological and hydrogeological models for several alpine catchments across Switzerland. The results provide insights on how groundwater and discharge dynamics are affected by climate change in alpine areas. Winter low flows will move toward summer low flows in the future. However, the intensity of summer low flows will be buffered by the dynamic groundwater storage in the catchments and therefore the combination of their unconsolidated aquifer units. These dynamics have implications for water management at larger scale which should be considered in the future, as only some alpine rivers will continue to sustain low flow periods in downstream valleys.

12.2

Increased snowpack ephemerality augments groundwater recharge in the mid-elevation belt of the Swiss Alps

Harsh Beria¹, Joshua R. Larsen^{2,3}, Natalie C. Ceperley¹, Anthony Michelin¹ & Bettina Schaeffli^{1,4}

¹*Institute of Earth Surface Dynamics (IDYST), University of Lausanne (UNIL), Switzerland (harsh.beria@unil.ch)*

²*School of Geography, Earth and Environmental Sciences, University of Birmingham, United Kingdom*

³*The Birmingham Institute of Forest Research (BIFoR), University of Birmingham, United Kingdom*

⁴*Now at, Institute of Geography, University of Bern*

A warming climate brings with it changes in the spatiotemporal distribution of precipitation with significant implications for water resources availability. Higher air temperatures, a direct consequence of global warming, will result in greater proportion of precipitation falling as liquid rain than as snow. Snowmelt has been previously shown to be more efficient at recharging groundwater aquifers than an equivalent amount of rainfall. Lower amount of future snowfall along with increased snow cover intermittency increases uncertainty in groundwater recharge patterns in mountainous parts of the world.

Using a combination of stable water isotopes and baseflow recession analysis based on streamflow measurements spread across 39 headwater catchments in Switzerland, we show that ephemeral snowpacks that accumulate and melt during winters contribute disproportionately more to groundwater recharge than seasonal snowpacks that accumulate during winters and melt over the ensuing spring and summer period. We also identify an elevational divide currently existing at 1500 m a.s.l. in Switzerland, separating catchments dominated by ephemeral and seasonal snowpacks. This divide will move higher up to around 2000 m a.s.l. with a 2.5°C increase in air temperature, resulting in higher groundwater recharge in catchments between 1500 – 2000 m a.s.l. The increased winter recharge will come at a cost of lower summer flows, making summer baseflow more dependent on summer rainfall, increasing the likelihood of mid-summer droughts. Our study has important implications for changes in water resources availability in the Swiss Alps that are likely transferable to other mountainous regions in the world.

12.3

Modelling recharge by precipitation at the Swiss scale

Fabien Cochand¹, Daniel Hunkeler¹, Michael Sinreich² & Philip Brunner¹

¹The Centre for Hydrogeology and Geothermics of University of Neuchâtel (CHYN), rue Emile-Argand 11, CH-2000 Neuchâtel (fabien.cochand@unine.ch)

²Federal Office for the Environment FOEN, Hydrology Division, Hydrogeology Section, Papiermühlestr. 172, CH-3063 Ittigen

Groundwater recharge by precipitation is one of the key components of the groundwater water balance. It is therefore crucial to establish reliable estimations of recharge whenever a hydrogeological study is carried out. However, recharge is often roughly estimated or used as a calibration parameter to close the water balance. This study presents a novel methodology for estimating recharge for Switzerland at a fine resolution (125mx125m).

From a physical point of view, recharge occurs via infiltration of a fraction of precipitation through variably-saturated vertical flow. Infiltration is reduced by evapotranspiration (ET) processes through the soil before contributing to the saturated zone (the aquifer). These processes have been studied for a long time with lysimeters, and can be simulated using numerical simulators which couple the Richards and surface flow equations. We developed “Numerical lysimeters” to estimate recharge using HydroGeoSphere (HGS, Aquanty (2017)). The HGS model allows for the fully-coupled simulation of surface flow, subsurface variably-saturated flow and ET.

Figure 1a shows the conceptual model and the required data for simulating recharge. The soil is represented by a column on top of which a positive flux representing precipitation and a negative flux representing potential evapotranspiration (PET) are applied. The surface allows for the consideration of different surface properties and slopes that reflect land-use and topography. Different soil properties (such as hydraulic conductivity or van Genuchten parameters) and various ET are also considered to reproduce different unsaturated flow conditions, rainfall interception and ET processes. At the bottom of the column, a seepage boundary condition (BC) is set and the vertical flow reaching this BC is considered to represent groundwater recharge.

To employ the approach at a Swiss scale, major assumptions have to be made due to limited availability of data. Alpine regions are excluded because of the lack of data. To keep the computations trackable, Switzerland is divided in 267 areas, each being attributed to a set of climatic parameters (precipitation and temperature). The identification of these regions is based on statistics of the meteoswiss grid-data products (MeteoSwiss, 2013). For each identified area, daily rainfall and temperature (converted in PET) are extracted, again using grid-data products from the period 1999 - 2018. Subsequently, each climatic area is spatially discretized in 125x125m cells and a HGS lysimeter model is created for each cell. This resolution corresponds to the coarsest resolution of the available data, i.e. the soil properties data (FOAG, 2015). A total of 20'025 models were run and the results were post-processed to obtain daily, monthly or annual mean recharge rates (figure 1b) at the Swiss scale. Finally, model results are validated using lysimeter observations and other recharge estimation studies.

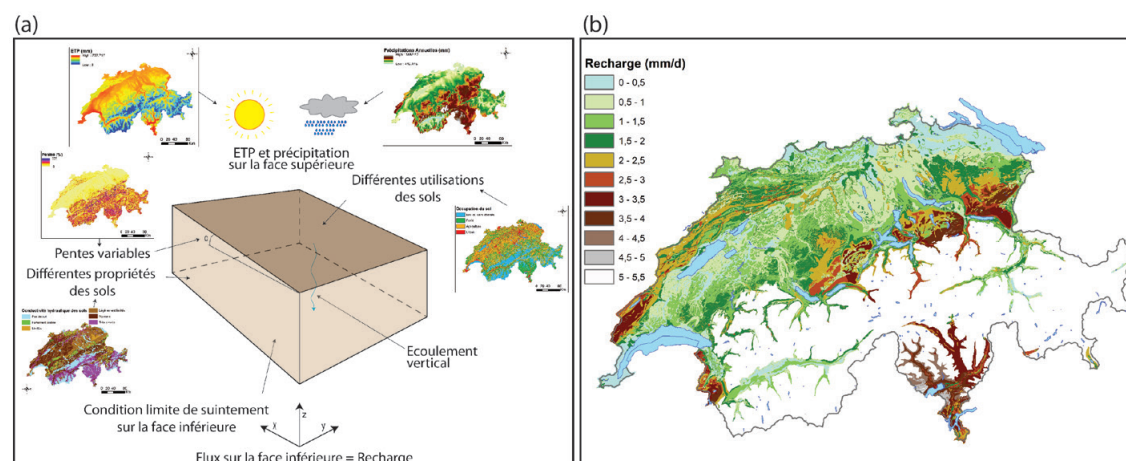


Figure 1: a) Numerical lysimeter using HGS and b) simulated annual mean recharge

REFERENCES

- Aquanty: HydroGeoSphere, a three-dimensional numerical model describing fully- integrated subsurface and surface flow and solute transport. Waterloo, ON, Canada., 2017.
 FOAG: Digital soil suitability map of Switzerland - Permeability, Federal Office for Agriculture (FOAG), 2015.
 MeteoSwiss: MeteoSwiss Grid-Data Products, Federal Office of Meteorology and Climatology MeteoSwiss, 2013.

12.4

Density currents induced by differential cooling in a small temperate lake: seasonality in their occurrence and magnitude

Tomy Doda^{1,2}, Cintia Ramón¹, Hugo N. Ulloa², Alfred Wüest^{1,2} & Damien Bouffard¹

¹Eawag, Swiss Federal Institute of Aquatic Science and Technology, Surface Waters - Research and Management, Seestrasse 79, CH-6047 Kastanienbaum (tomy.doda@eawag.ch)

²Physics of Aquatic Systems Laboratory, École Polytechnique Fédérale de Lausanne, Station 2, CH-1015 Lausanne

Differential cooling occurs in the littoral region of lakes, during calm and cold nights in summer and continuously in fall/winter. For uniform heat loss over the lake surface, shallower regions cool faster than deeper regions leading to horizontal density gradients. Nearshore waters become negatively buoyant and start to plunge creating a cold downslope density current that can reach the pelagic zone (Monismith et al. 1990).

This cross-shore flow, also referred to as “thermal siphon”, has the potential to transport biogeochemical constituents offshore and deeper into the water column (James & Barko 1991; MacIntyre & Melack 1995; Brothers et al. 2017). However, its significance for the lake ecosystem remains unknown. Thermal siphon has been observed in the field during specific cooling events (e.g., Monismith et al. 1990; James & Barko 1991; Fer et al. 2002), but never monitored over long time series where potential variability might be identified. The driving conditions of the flow are expected to change over time but their effects on the occurrence and magnitude of the density current are unclear.

To fill these gaps, we collected temperature and velocity data over several months in Rotsee, a small (0.5 km²) eutrophic lake located near Lucerne (Switzerland). The lake has an elongated shape and is well protected from wind, making it a potential site to observe thermal siphons.

Two vertical moorings, both composed of a chain of thermistors and an upward-looking Acoustic Doppler Current Profiler (ADCP), were deployed in the littoral region (mooring MT, 4 m depth) and the pelagic region (mooring MB, 16 m depth). They measured temperature and velocity over the entire water column from March to November 2019, providing information on the background stratification (MB) and the occurrence of thermal siphon (MT).

In addition, several short-term campaigns were performed during the fall period in 2018 and 2019 to increase the spatial and temporal resolution of the measurements. They consisted of three additional moorings M1-M3 and cross-shore transects of CTD (Conductivity-Temperature-Depth) profiles.

Finally, meteorological forcing was obtained from a weather station close to the lake shore.

Our observations reveal that thermal siphon is characterized by both short-term (~hours) and long-term (~days) temporal variability.

In fall, differential cooling leads to horizontal temperature gradients on the order of 10⁻³ °C/m (Figure 1) and produces a thermal siphon during both day and night. The cold density current is roughly 1-2 m thick, can reach a speed of 3 cm/s (Figure 2), and creates a microstratification close to the sediment of around 0.2 °C over approximately 2 m (Figure 1). As expected, periods of higher flow match periods of stronger microstratification (Figure 2).

In spring/summer, thermal siphon can occur during periods of low wind and strong night-time cooling. Inertial effects make it persist well after the end of the cooling period, often until the middle of the day. Its occurrence is clearly dependent on several factors, including surface cooling, low wind intensity and strong background stratification.

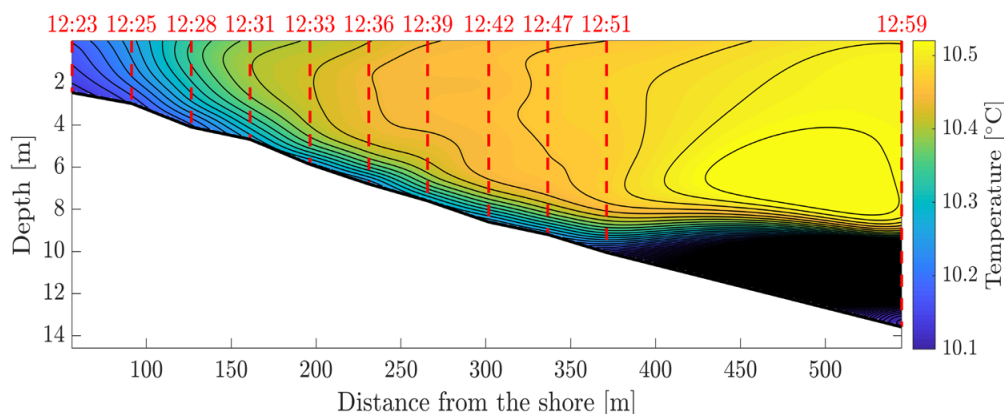


Figure 1. Interpolated cross-shore transect of temperature measured in Rotsee on November 20, 2018. The red dashed lines show the location of the 11 CTD profiles from which temperature was interpolated. Time is indicated in red for each profile and 0.02°C isotherms are represented by black lines.

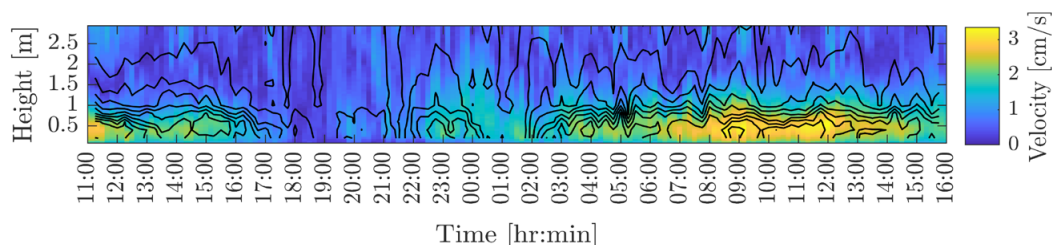


Figure 2. Velocity magnitude (norm) measured at M2 (6 m depth) over the first three meters above the bottom on November 20-21, 2018. The black lines represent the 0.03°C isotherms from temperature differences relative to the surface.

REFERENCES

- Brothers, S., Kazanjian, G., Köhler, J., Scharfenberger, U., & Hilt, S. 2017: Convective mixing and high littoral production established systematic errors in the diel oxygen curves of a shallow, eutrophic lake. *Limnology and Oceanography: Methods*, 15 (5), 429–435.
- Fer, I., Lemmin, U., & Thorpe, S. 2002: Winter cascading of cold water in Lake Geneva. *Journal of Geophysical Research: Oceans*, 107(C6), 3060.
- James, W. F., & Barko, J. W. 1991: Estimation of phosphorus exchange between littoral and pelagic zones during nighttime convective circulation. *Limnology and Oceanography*, 36 (1), 179–187.
- MacIntyre, S., & Melack, J. M. 1995: Vertical and horizontal transport in lakes: linking littoral, benthic, and pelagic habitats. *Journal of the North American Benthological Society*, 14 (4), 599–615.

12.5

Explaining shallow groundwater concentrations with surface and bedrock topography, and soil and bedrock composition

Leonie Kiewiet¹, Adrian Wicki², Ilja van Meerveld¹, Jan Seibert^{1,3}

¹Department of Geography, University of Zurich, Winterthurerstr. 190, 8057 Zurich (leonie.kiewiet@geo.uzh.ch)

²Swiss Federal Research Institute WSL, Mountain Hydrology and Mass Movements, Zürcherstrasse 111, CH-8903 Birmensdorf

³Swedish University of Agricultural Sciences, Department of Aquatic Sciences and Assessment, Uppsala, Sweden

Concentrations of major- and trace elements in shallow groundwater depend on the composition and reactivity of the material and contact time. Topography influences the hydraulic gradient and, thus the flow velocity and chemistry. We investigated the importance of surface and bedrock topography, as well as soil and bedrock chemistry to describe shallow groundwater chemistry in a small pre-alpine headwater in the Swiss pre-Alps. The catchment is underlain by Flysch bedrock, which is a reworked carbonate rock that is deposited in deep-water.

We sampled groundwater at more than 40 wells during nine baseflow snapshot campaigns. All wells were drilled until the bedrock (determined by manual augering) and screened over the entire length. There was a large spatial variability in shallow groundwater compositions, with concentrations varying over five orders of magnitude for elements such as calcium, manganese and zinc (Kiewiet *et al.*, 2019)(Kiewiet, von Freyberg, & van Meerveld, 2019). The spatial variability in concentrations was larger than the temporal variability in the average concentrations for the different measurement campaigns, indicating that local factors affect shallow groundwater chemistry. There were consistent patterns of high and low concentrations for the nine snapshot campaigns. Random forest and principal component analysis suggested that surface topography does not explain the concentrations of major and trace elements. Clustering of the wells using the mean relative difference (MRD) from the catchment average for each well and element resulted in four groundwater clusters, which had significantly different median values for surface topographic characteristics and water level dynamics, but the differences were not big enough to predict chemistry across the catchment from surface topography alone.

We therefore investigated the depth to bedrock, the distribution of soil moisture, and the bedrock and soil composition to better understand what caused the differences in concentrations. We took electrical resistivity tomography (ERT) measurements at key locations in the catchment using Wenner-Schlumberger arrays at 0.8 m spacing. Inversion results (Figure 1) indicate that the depth of the wells reflected the depth to the bedrock closely at shallower soil sites, but slightly underestimated the depth to bedrock at sites where the soil and regolith layers were thicker. We found that in some locations, the bedrock topography was rugged, and that the surface topography was not always a smoother version of the bedrock topography. Soil moisture at the ERT measurement locations varied, which probably contributed to the spatial variability we observed in the groundwater concentrations.

We performed leaching experiments on three soil samples and two bedrock samples to investigate which elements are released by interaction with water (methods cf. Hissler *et al.*, 2015). We took samples from riparian soil, hillslope soil, and hillslope topsoil as a reference for atmospheric inputs. We furthermore took samples from rather thickly banked sandy carbonate bedrock and thinly banked, silty carbonate bedrock. We found that higher concentrations of transition metals and trace metals were released from the soil samples than the bedrock samples at low acidity (0.05 N HAc). In the second leaching stage (1 N HCl) the release of magnesium, and calcium was particularly high for the silty bedrock, which corresponds to anomalously high concentrations of magnesium in shallow groundwater sampled close to this outcrop.

Our results show that although surface topography affects water movement, it is not sufficient to describe spatial variations in shallow groundwater chemistry. The combined effect of surface and bedrock topography need to be considered together with the chemical composition of soil and bedrock to understand the spatial variability of shallow groundwater composition.

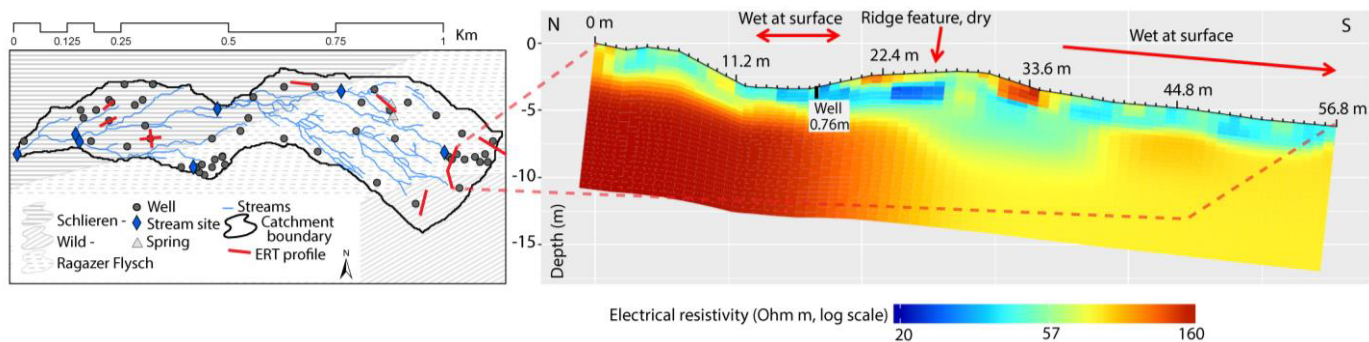


Figure 1: (left) map of the Studibach catchment with locations of the ERT profiles indicated in red and (right) detailed resistivity profile at one location

REFERENCES

- Kiewiet, L., von Freyberg, J., & van Meerveld, H. J. (Ilja). 2019. Spatiotemporal variability in hydrochemistry of shallow groundwater in a small pre-alpine catchment: The importance of landscape elements. *Hydrological Processes*, 1–21.
- Hissler, C., Stille, P., Juilleret, J., François, J., Perrone, T., & Morvan, G. 2015. Elucidating the formation of terra fusca using Sr – Nd – Pb isotopes and rare earth elements. *Applied Geochemistry*, 54, 85–99

12.6

Dissecting the water tower of Europe: a high-resolution ecohydrological modelling of the European Alps

Theodoros Mastrotheodoros¹, Christoforos Pappas², Peter Molnar¹, Paolo Burlando¹, Gabriele Manoli¹, and Simone Fatichi¹

¹*Institute of Environmental Engineering, ETH Zurich, Zürich, Switzerland (simone.fatichi@ifu.baug.ethz.ch)*

²*Département de géographie and Centre d'études nordiques, Université de Montréal, Montréal, QC, Canada*

Mountain ecosystems are intrinsically heterogeneous because the complex terrain creates steep gradients in climate, soil, and vegetation cover. This heterogeneity complicates our understanding and representation of mountain hydrological processes. Here, we used the fully distributed, process-based ecohydrological model Tethys-Chloris (T&C) to perform a high spatiotemporal resolution simulation of the entire European Alps (257,000 km²). By analysing hourly simulation results over three years (2000-2003) with a spatial resolution of 250x250 m² across the study domain, we quantify: (1) the components of the hydrological budget in different seasons and how streamflow may respond to increasing temperature; (2) the role of vegetation water stress or lack of thereof on the Alpine water balance during summer. Uncalibrated ecohydrological simulations were tested in reproducing spatiotemporal patterns of observed snow cover (in more than 550 stations) and discharge (in more than 350 stream gauges). Results are on average unbiased in terms of streamflow magnitude and snow cover duration. Correlations between observed and simulated discharge at the daily scale are typically greater than 0.7. Due to the challenge of projecting climate change forcing in mountainous areas at such a high resolution, we used a space-for-time substitution based on the current climate simulations to infer how an increase in air temperature affects the ecohydrological response. Our results suggest that total annual runoff over the entire Alpine area is strongly controlled by precipitation and therefore it is very resilient to changes in temperature, despite evapotranspiration being energy-limited and temperature-dependent. For instance, a +3°C scenario affects annual runoff similarly to a decrease of only 3% in precipitation. However, patterns of runoff production are spatially complex and several dry areas may become considerably drier in a warmer climate. Results are quite different when the focus is on the growing season only, where evapotranspiration is a significant component of the water budget and an increase in temperature modifies the hydrological response. For instance, evapotranspiration considerably contributed to reduce water yield during the 2003 growing season because vegetation benefited from the unusually warm and sunny conditions in a large part of the Alpine region at higher elevations. In summary, model results with high spatiotemporal resolution are providing novel insights into the underlying ecohydrological processes and help us to better understand the response of Alpine water resources to climatic changes.

12.7

Sediment connectivity in the Rhône Basin: from an isolated thunderstorm at Illgraben to a turbidity current in deep Lake Geneva

François Mettra^{1,2}, Koen Blanckaert³, Ulrich Lemmin⁴ & David Andrew Barry⁴

¹*Institute of Earth Surface Dynamics, University of Lausanne, Géopolis, CH-1015 Lausanne (francois.mettra@unil.ch)*

²*Invited researcher at Institute of Hydraulic Engineering and Water Resources Management, TU Wien, Karlsplatz 13/222, A-1040 Vienna*

³*Institute of Hydraulic Engineering and Water Resources Management, TU Wien, Karlsplatz 13/222, A-1040 Vienna*

⁴*Ecological Engineering Laboratory, Lausanne Federal Institute of Technology, Station 2, CH-1015 Lausanne*

In the Rhône canyon of Lake Geneva (Figure 1), turbidity currents are occasionally present in summer. Based on velocity measurements in the canyon and discharge measurements at Porte du Scex in the Rhône 6 km upstream of Lake Geneva (Figure 1), Lambert and Giovanoli (1988) hypothesized that Rhône River floods and slides of sublacustrine deltaic deposits are the main causes of these turbidity currents. Here, we present another type of initiation: a strong sediment event along the sediment cascade of the Rhône basin, ending in a deep lake turbidity current without a significant increase in water discharge of the Rhône River. Using data available at the Illgraben catchment in Wallis (McArdell, 2016), at Porte du Scex, and our own velocity measurements in the Rhône canyon (Figure 1), we are able to follow the release of a strong sediment pulse from source to sink. At Illgraben, a debris flow, reaching the Rhône River, is triggered by a short and intense convective storm that does not significantly increase the Rhône water discharge (Bennett, 2014). Eleven to thirteen hours later, the fine sediment cloud is observed at Porte du Scex, which is situated 84 km further downstream, and subsequently a turbidity current is measured in the canyon. The observations demonstrate the high and fast sediment connectivity between specific high-alpine areas and the deep part of Lake Geneva.

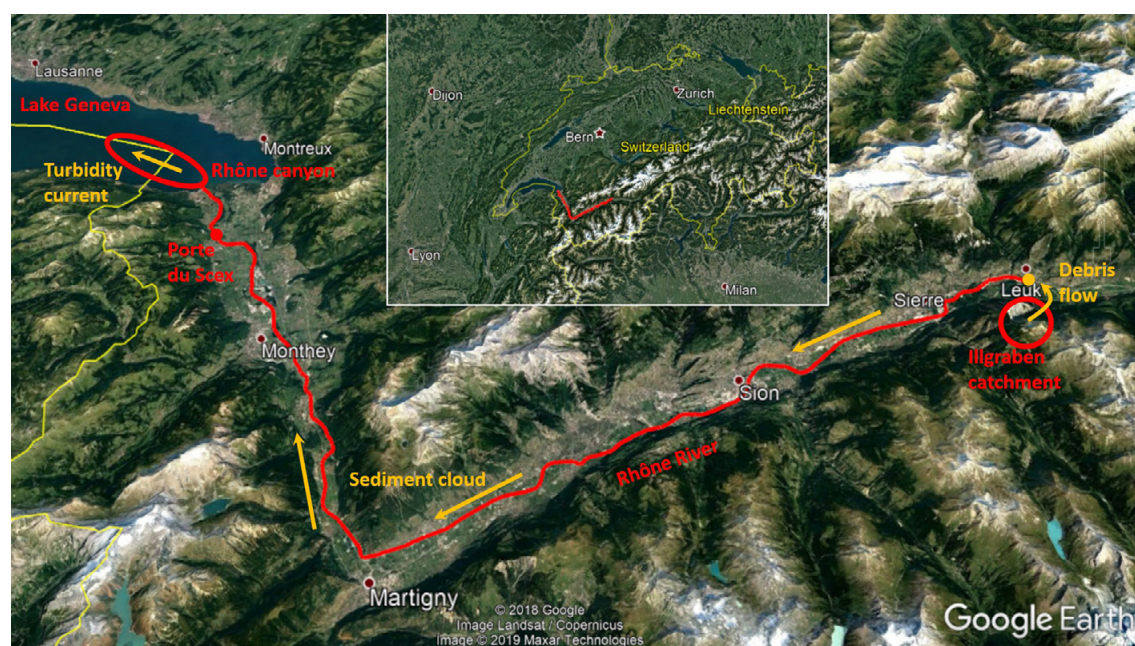


Figure 1. Situation of the observation sites in the upper Rhône catchment and processes involved in the sediment cascade from high alpine slopes to Lake Geneva during a strong sediment event.

REFERENCES

- Bennett, G. L., Molnar, P., McArdell, B. W., & Burlando, P. 2014: A probabilistic sediment cascade model of sediment transfer in the Illgraben. *Water Resources Research*, 50(2), 1225-1244.
- Lambert, A., & Giovanoli, F. 1988: Records of riverborne turbidity currents and indications of slope failures in the Rhone delta of Lake Geneva, *Limnology and Oceanography*, 33(3), 458-468.
- McArdell, B. W. 2016: Field measurements of forces in debris flows at the Illgraben: Implications for channel-bed erosion. *International Journal of Erosion Control Engineering*, 9(4), 194-198.

12.8

Stream Temperature Evolution in Switzerland simulated with downscaled CH2018 Climate Change Scenarios

Adrien Michel^{1,2,3}, Tristan Brauchli^{1,4,5}, Nander Wever⁶, Jannis Epting³ Michael Lehning^{1,2}, & Hendrik Huwald^{1,2}

¹*Ecole Polytechnique Fédérale de Lausanne (EPFL), (adrien.michel@epfl.ch)*

²*WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland*

³*University of Basel (UniBas)*

⁴*University of Lausanne (UNIL)*

⁵*Centre de Recherche sur l'Environnement Alpin (CREALP)*

⁶*University of Colorado, Boulder*

Climate change already has affected many components of our natural environment. Numerous studies have attempted and succeeded in quantifying the observed impact on air temperature, glacier volume, snow cover duration, shifts in vegetation, phenology and many more. While it is very likely that climate change has and will also have an important effect on the temperature of streams with consequences for water quality, the aquatic fauna and fluvial ecosystem services, very little information and quantitative predictions are available on this topic. This study investigates numerically the response of selected streams in Switzerland to the future forcing as provided by the CH2018 climate change scenarios for Switzerland. The approach uses a sequence of physical models composed of Snowpack, Alpine3D and StreamFlow. The simulations are forced by using CH2018 scenarios which have been down-scaled to an hourly time step using a novel approach based on a delta method which preserves the seasonal aspect of the climate change scenario. Preliminary results suggest that the observed warming of water temperature will continue with any of the scenarios used (RCP2.6, RCP 4.5, RCP8.5) due to the rise of air temperature and the decrease in discharge in summer. As a consequence, river ecosystems will be impacted and current legal limits for the usage of water for cooling in the energy production sector and in the industry will be reached more often in the future. These results are analysed and interpreted by comparing to a present-day reference situation and in view of a recent, comprehensive analysis of historical stream temperature data in Switzerland (Michel et al., 2019).

REFERENCES

Michel, A., Brauchli, T., Lehning, M., Schaeffli, B., & Huwald, H.: Stream temperature evolution in Switzerland over the last 50 years, *Hydrol. Earth Syst. Sci. Discuss.*, <https://doi.org/10.5194/hess-2019-366>, in review, 2019.

12.9

Hydro/thermogeological state of the Maggia river delta: potential shallow geothermal energy implications

Rodolfo Perego¹, Sebastian Pera¹, Monica Bulgheroni¹, Jacopo Boaga² & Antonio Galgaro²

¹*Institute of Earth Science, SUPSI, Campus Trevano, CH-6952 Canobbio, Switzerland (rodolfo.perego@supsi.ch)*

²*Department of Geosciences, Università degli Studi di Padova, Italy*

In Cantone Ticino, located in southern Switzerland, there is a constant growth of subsurface heat exploitation through the use of shallow geothermal systems (SGS) both closed and open-loop. Such a density (10 probes/km² if we consider only major valleys, where population density is greater) will raise issues regarding short probe distances and adjoining probe fields that will influence ground temperatures and system performances in the long term.

The scope of the present work is to study the processes governing interferences between closed and open loop systems to obtain results that in turn would be used to efficiently allocate ground heat, in a long-term sustainable manner.

We identified an interesting case study where mutual interactions between closed and open systems could be analyzed: the delta of Maggia river, a torrential regime stream that flows into Lake Maggiore and hosts the cities of Locarno and Ascona. In this area there is a large presence of both closed and open SGS at relatively small distances. In particular, an area in the north-western part of the Maggia delta (which already hosts many SGS) within the city of Locarno will be interested by the installation of large closed-loop systems. To properly study the local interactions between SGS, firstly the regional actual conditions from both groundwater level and temperature had to be assessed.

The workplan therefore started with the hydrogeological and thermal characterization of the case study subsurface in order to acquire information aimed at the creation of a regional scale numerical model. The steady-state simulation of initial piezometric level and groundwater temperature will be subsequently implemented in the local scale numerical model which will be used to assess the mutual interferences between closed-loop and open-loop SGS.

To build the physical model of the Maggia delta available literature was initially analyzed [1] and field work was performed. Different campaigns of passive microseismic measurements were planned and executed, in order to detect the shape of the lithological discontinuity between thick Quaternary alluvial sediments and the underlying bedrock formation [2]. The collected signals and spectral ratio, along with literature data, were investigated and used to produce a 3D continuous reconstruction of the bedrock top throughout the study area. Moreover, a groundwater monitoring network was conceived and applied from scratch. Piezometric level and groundwater temperature measurements [3] were performed in order to hydrogeologically and thermally characterize the subsurface. A regional numerical model was consequently developed with the commercial software FEFLOW [4] to represent average hydrogeological conditions (both for hydraulic head and temperature), considering the period between 2015 and 2018. The regional flow and heat transport model [Figure 1] is currently under calibration against both hydraulic head and temperature observations. It will provide insights on the regional behavior of the groundwater. Moreover the regional model will describe the initial conditions for the local scale assessment, where the mutual impact of closed and open geothermal systems will be investigated in detail.

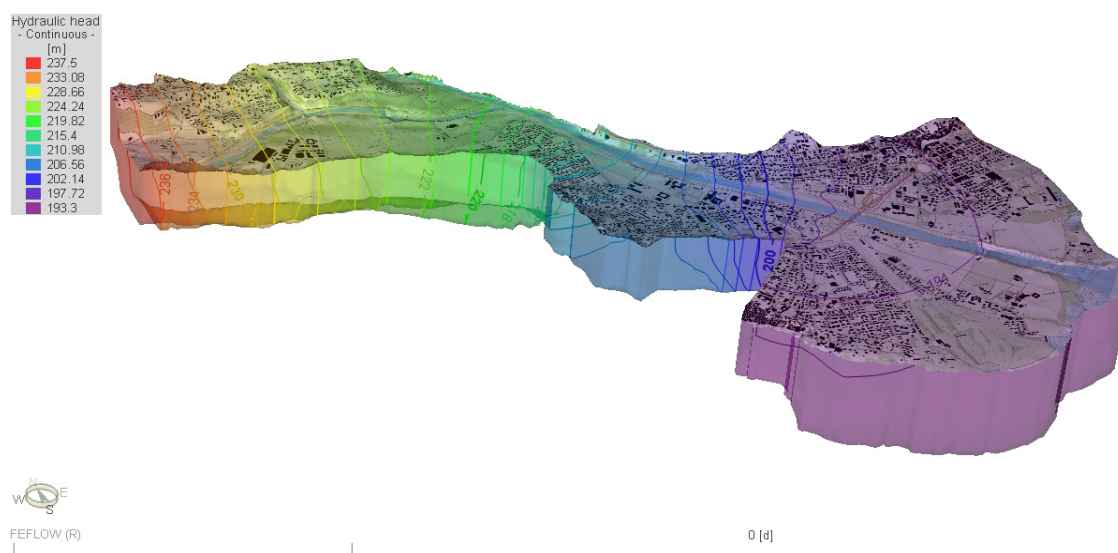


Figure 1 - Hydrogeological model of the Maggia river delta with preliminary results of the calculated hydraulic head

REFERENCES

- Fondazione Lerici 1970: Studio geofisico dei fondovalle del Canton Ticino, eseguito per conto della Sezione Cantonale delle Bonifiche e del Catasto, Bellinzona. Milano, Fondazione Ing. C.M. Lerici, Ricerca No. 535
- Trevisani, S., Boaga, J., Agostini, L., & Galgaro, A. 2017: Insights into bedrock surface morphology using low-cost passive seismic surveys and integrated geostatistical analysis. *Science of The Total Environment*, 578, 186-202.
- Farr, G. J., Patton, A. M., Boon, D. P., James, D. R., Williams, B., & Schofield, D. I. 2017: Mapping shallow urban groundwater temperatures, a case study from Cardiff, UK. *Quarterly Journal of Engineering Geology and Hydrogeology*, 50(2), 187-198.
- Diersch, H. J. G. 2005: FEFLOW finite element subsurface flow and transport simulation system. Inst. for Water Resources Planning and System Res., Berlin

12.10

Identifying sources and processes impacting groundwater recharge in the human environment

Robin Weatherl^{1,2}, Maria Henao Salgado^{3,1}, Mario Schirmer^{1,2}

¹Swiss Federal Institute of Aquatic Science and Technology (Eawag)

²University of Neuchâtel Center for Hydrogeology and Geothermie (CHYN)

³ETH Zürich Institute of Environmental Engineering (IfU)

Understanding groundwater dynamics around areas of human influence is of critical importance for ensuring sustainable resource management in the 21st century and beyond. Groundwater supplies in agricultural or urban areas are at a particular risk of quality degradation due to their proximity to human activity. These supplies are also at risk of depletion due to heightened consumption in such areas. These risks and the dynamics that feed into them can no longer be determined considering natural controls only. Exploitation of the land can have significant impacts on a local water cycle, by changing the magnitude of existing parameters, changing the nature of surface water-groundwater interactions, changing infiltration pathways, or creating new, artificial sources and sinks of groundwater. All of these changes are consequential for the resulting quality of a groundwater body.

We intend to present here the results of a site investigation being carried out in a small catchment aquifer located in the Canton of Zürich, Switzerland. We have tested a number of methods in an attempt to characterize the above-mentioned anthropogenic groundwater dynamics. A first approach involves the estimation of groundwater recharge via water balance. Our water balance has attempted to account for changes in runoff and evapotranspiration terms due to changes in land cover, and has considered the impact of artificial source and sink terms from infrastructure and from practices such as groundwater pumping and irrigation. We have then made use of synthetic organic compounds (here referred to as *micropollutants*) as indicators of specific recharge sources and potential pathways from the surface into the water. Micropollutants are fully absent in the natural environment and thus offer unequivocal evidence of input from the human environment when measured in groundwater. They may be used to trace input from treated or untreated wastewater, irrigation runoff, and surface waters. Micropollutant datasets at our site have proven to be highly censored, requiring appropriate statistical methods (including a robust regression on order statistics) for proper interpretation that avoids bias. Emphasis is given to these statistical methods as they are fundamental to the analysis of micropollutant datasets, yet are often ignored in the environmental sciences. Finally, stable water isotopes and inorganic chemistry are used as independent validation (or dissent) of the conclusions drawn from micropollutant data. From these analyses, a conceptual model of the modified water cycle in this catchment is offered.

Contact Information: Robin Weatherl, Department of Water Resources and Drinking Water, Eawag, Email: robin.weatherl@eawag.ch

12.11

Giant pockmarks in Lake Neuchatel, Switzerland: new multi-proxy evidence for lacustrine groundwater discharge

Stefanie B. Wirth¹, Damien Bouffard², Adeline Cojean¹ & Jakob Zopfi³

¹Centre for Hydrogeology and Geothermics, University of Neuchatel, Rue Emile-Argand 11, CH-2000 Neuchâtel (stefanie.wirth@unine.ch)

²Eawag, Seestrasse 79, CH-6047 Kastanienbaum

³Department of Environmental Sciences, University of Basel, Bernoullistrasse 30, CH-4056 Basel

Four giant pockmarks (80 to 150 m in diameter) are located in Lake Neuchatel, Switzerland, along its northern shore and adjacent to the karst system of the Jura Mountains (Reusch et al. 2015, 2016). Two pockmarks have a ~60 m-deep chimney filled with mud; two are funnel-shaped 12 m and 29 m deep holes. We present evidence for the presence of groundwater in the chimneys and active lacustrine groundwater discharge (LGD) at both pockmark types. Temperature, electrical conductivity and Ca²⁺ concentrations of the pore water in the chimneys show values typical for karst water. TOC and TIC indicate that the chimney mud consists of liquefied sediments from the entire deglacial to Holocene lacustrine sediment succession. Mini mud volcanoes apparent on the suspension surface imaged with a remotely operated vehicle (ROV) localize the groundwater exit points and confirm LGD. LGD is further corroborated by electrical conductivity anomalies detected above the lutoclines and within a funnel-shaped pockmark during the ROV survey. We conclude that the giant pockmarks in Lake Neuchatel represent a type of subaquatic spring that connects the water body of the lake with the karst system. Quantifying LGD via the pockmarks will be an essential next research step in order to assess their lake-wide relevance. Overall, this study underlines the existing need for research on the connectivity of lakes and oceans with groundwater systems for completing our understanding of the hydrological cycle.

REFERENCES

- Reusch, A., Loher, M., Bouffard, D., Moernaut, J., Hellmich, F., Anselmetti, F.S., Bernasconi, S.M., Hilbe, M., Kopf, A., Lilley, M.D., Meinecke, G. & Strasser, M. 2015: Giant lacustrine pockmarks with subaqueous groundwater discharge and subsurface sediment mobilization, *Geophysical Research Letters*, 42, 3465-3473.
- Reusch, A., Moernaut, J., Anselmetti, F.S. and Strasser, M. 2016: Sediment mobilization deposits from episodic subsurface fluid flow—A new tool to reveal long-term earthquake records? *Geology*, 44, 243-246.

P 12.1

Solute generation and C-Q relations: is solute input frequency or depth of solute generation the key-player?

Martina Botter¹, Paolo Burlando¹, Simone Fatichi¹

¹*Institute of Environmental Engineering, ETH Zurich, Zurich, Switzerland (botter@ifu.baug.ethz.ch)*

Understanding how different solutes are exported and how their concentrations change in rivers is an open question for catchment hydrology, which is particularly challenging due to the general lack of solutes input data.

In order to gain information on the role of the solute generation in the export dynamics, this study collects and compares publicly available or published solutes concentrations data at the outlet of 585 catchments across 9 countries around the world. The magnitude of the concentrations of different solutes (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Cl^- , NO_3^- , DOC and DRP) is compared and its spatial variability across catchment and temporal variability within catchments is quantified by means of the metrics CV-time and CV-space. The solute behavior, defined by the b-exponent of the C-Q relation $C = aQ^b$, which can determine chemostatic ($b \approx 0$), diluting ($b < 0$) or enriching ($b > 0$) dynamics, is also investigated. Evidence in the data analysis suggests that both the timing and the vertical distribution of the solute supply play a role in determining the dynamics of the solute concentrations at the catchment outlet.

The concentrations of exogenous solutes (i.e. solutes often linked to anthropogenic sources such as Na^+ , Cl^- , NO_3^- and DRP) exhibit not only higher variability in time than concentrations of geogenic solutes (i.e., Ca^{2+} , Mg^{2+} , K^+) and DOC, but also more variable behavior ranging between highly diluting to enriching for NO_3^- and DRP and severely diluting for Na^+ , Cl^- . When combining the CV-time with the b-exponent, two clear clusters emerge. One group of solutes with low temporal variability and pronounced dilution behavior, including the geogenic solutes (Ca^{2+} , Mg^{2+} , K^+) and the salt species (Na^+ , Cl^-), and another group including nutrients (NO_3^- , DRP and DOC) with larger and highly variable CV-time and nearly zero or slightly positive b-exponent. We associate the higher variability in time to a more sporadic rather than continuous input typical of the exogenous solute applications and ascribe the different b-exponent behaviors mainly to the vertical distribution of the solute supply. Based on this evidence, we design numerical experiments and run simulations with a tracer-aided distributed hydrological model to test the relative contribution of these two factors as determinants of the solute behavior.

The results of the numerical simulations represent well the various CV-time/b-exponent relations observed in nature and therefore allow to corroborate our hypotheses. Numerical experiments prove that decreasing the depth of solute generation reduces the values of b, from chemostatic to strongly diluting. Instead, enriching behavior is obtained either assigning a threshold on soil moisture above which the solute export is activated or introducing residence-time dependant solute degradation in the groundwater when the solute enters the catchment through deposition. These results support the hypothesis that the vertical distribution of the solute supply drives the C-Q relations.

In summary, while the input frequency has an impact on CV-time and adds some uncertainty to C-Q relations, the vertical distribution of solute generation plays the key-role in the determination of the solute behavior for highly diluting (Na^+ , Cl^-), weakly diluting (Ca^{2+} , Mg^{2+} , K^+) and enriching solutes (e.g., DOC).

P 12.2

Stream temperature and discharge evolution over the last 50 years in Switzerland

Tristan Brauchli^{1,2,4}, Adrien Michel^{1,3}, Michael Lehning^{1,3}, Bettina Schaepli^{4,5} & Hendrik Huwald^{1,3}

¹*Ecole Polytechnique Fédérale de Lausanne (EPFL), tristan.brauchli@crealp.vs.ch*

²*Centre de Recherche sur l'Environnement Alpin (CREALP), Sion*

³*WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland*

⁴*University of Lausanne (UNIL)*

⁵*Institute of Geography, University of Bern, Bern*

Stream temperature and discharge are key variables for water resources management but also for ecosystems: they strongly influence the fauna and flora along with biogeochemical cycles. In a changing climate, river water temperature is generally assumed to increase (due to a change of the energy budget) while streamflow should decrease during summer months (low base flow, droughts). The amplitudes of these changes are however hard to quantify given the complexity of the system and the natural climate variability. In addition, many anthropogenic activities (hydropower plants, river correction and lake regulation) significantly impact river systems and associated water temperatures.

In Switzerland, hydrological observations are available since the beginning of the 20th century. However, few studies have quantified stream discharge and temperature trends. In the present study (Michel et al., 2019), we propose a robust countrywide historical analysis: the data set is composed of 52 gauging stations measuring water temperature and discharge back to 1960. The stations are clustered into coherent entities based on their hydrological regime (snow or ice vs rain-dominated, natural vs disturbed discharge). Thanks to a seasonal-trend decomposition (STL), we show how climate change differently impacts the various types of rivers. Stream temperature has significantly increased over the past 5 decades, with positive trends for all four seasons. The mean trends for the last 20 years are +0.37 °C per decade for water temperature, resulting from joint effects of trends in air temperature (+0.39 °C per decade) in discharge (−10.1 % per decade) and in precipitation (−9.3 % per decade). For a longer time period (1979–2018), the trends are +0.33 °C per decade for water temperature, +0.46 °C per decade for air temperature, −3.0 % per decade for discharge and −1.3 % per decade for precipitation. We furthermore show that in alpine streams, snow and glacier melt compensates air temperature warming trends in a transient way. Lakes, on the contrary have a strengthening effect on downstream water temperature trends at all elevations. The identified stream temperature trends are furthermore shown to have critical impacts on ecological temperature thresholds, especially in lowland rivers, suggesting that these are becoming more vulnerable to the increasing air temperature forcing. Resilient alpine rivers are expected to become more vulnerable to warming in the near future due to the expected reductions in snow- and glacier melt inputs.

REFERENCES

Michel, A., Brauchli, T., Lehning, M., Schaepli, B., & Huwald, H.: Stream temperature evolution in Switzerland over the last 50 years, *Hydrol. Earth Syst. Sci. Discuss.*, <https://doi.org/10.5194/hess-2019-366>, in review, 2019.

P 12.3

Does the Rhône River fertilise Lake Geneva ? (in the context of its re-oligotrophisation)

Cotte Gabriel¹, Vennemann Torsten¹

¹IDYST, University of Lausanne, Géopolis 1015 Lausanne (Gabriel.Cotte@unil.ch)

After a period of eutrophication during the 60's and 70's with annual average of total phosphorus reaching 90 µgP/L, Lake Geneva has been on the way of re-oligotrophisation. Since the 80's, after Swiss and French measures were taken to limit the phosphorus input into the lake, the concentration decreased to 10 µgP/L (CIPEL, 2018). Despite this important reduction, the amount of biomass measured every years does not decline. Nowadays, because the phosphorus becomes a limiting factor earlier and earlier during the season, it is important to evaluate (i) which nutrients are coming from the river inputs, (ii) where it is transported and (iii) how it is metabolized.

The Rhône River is the principal tributary to Lake Geneva, both in terms of discharge of water and sediment load (CIPEL, 2018). Therefore, it influences the physical and chemical properties of the lake and so the lake ecological functioning as primary production (Bouffard and Perga, 2016).

The objective of this study is to determine the potential chemical gradient related to the Rhône water intrusion in the river-lake transition zone and how it can influence locally the phytoplankton growth.

During 2019, a consortium of researchers from the ISE (UNIGE), the ECOL (EPFL) and the IDYST (UNIL) organised field campaigns at different seasons in order to establish the link between hydrodynamics, chemistry and biology in the Rhône rivermouth area. Three transects were defined by ADCP profiling: one longitudinal and two transversals, in and out of the near field, defined as the area where the Rhône is still visible in terms of current velocities (Fig.1). Systematic depth sampling (2.5, 5, 7.5, 10, 15, 20, 30, 100 m, bottom) and CTD profiles were done using a Rosette autosampler at the different sampling locations. As it been shown that the stable H- and O-isotope composition of water for this Alpine lake is a powerful tool to trace the Rhône River intrusion (Halder et al., 2013), this method was used to determine the river mixing rates. Major ions and cations as well as the phytoplankton communities and concentrations have been analysed. In this contribution, we'll focus on the nutrient dispersion linked to the Rhône intrusion and show how it can change depending on the Rhône discharge, the lake stratification and the wind conditions.

REFERENCES

- Bouffard, D. and Perga, M.-E., 2016 Are flood-driven turbidity currents hot spots for priming effect in lakes?, *Biogeosciences*, 13, 3573-3584.
- Conseil scientifique de la commission internationale pour la protection des eaux du Léman contre la pollution. 2018. Rapports sur les études et recherches entreprises dans le bassin lémanique. Campagne 2017. CIPEL.
- Halder, J., L. Decrouy, and T. W. Vennemann, 2013. Mixing of Rhône River water in Lake Geneva (Switzerland- France) inferred from stable hydrogen and oxygen isotope profiles. *J. Hydrol.* 477: 152–164.

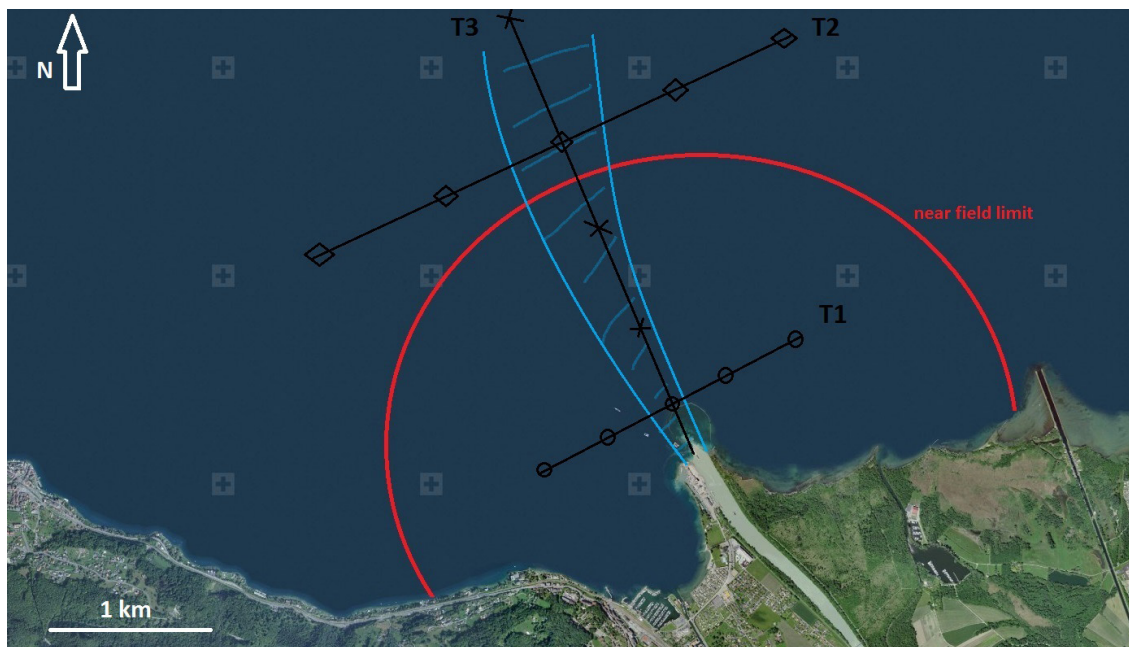


Figure 1. Sampling locations in the Rhône rivermouth area in Lake Geneva.

P 12.4

Thermal potential of urban tunnel infrastructures in unconsolidated rock groundwater resources

Jannis Epting¹, Peter Huggenberger¹

¹*Applied and Environmental Geology, Department of Environmental Sciences, University of Basel, Bernoullistrasse 32, CH-4056 Basel (jannis.epting@unibas.ch)*

The current development of energy geostructures often lacks the scientific foundations and knowledge of how the various systems interact in the shallow subsurface and influence the hydraulic and thermal regimes in the subsurface. This contribution in collaboration with the SFOE (SI/501646-01) presents preliminary evaluation elements for geothermal potential assessment and thermal influences of planned tunnel infrastructures for the urban agglomeration of Basel (Switzerland).

In dependence of the tunnel type (motorway or railway) as well as its location related to the geological and hydrogeological settings different solutions for shallow geothermal energy systems (SGE) are investigated. 'Passive' and 'active' SGE have been evaluated, including heat-exchanging segments installed in tunnel lining structures and thermal exploitation of water circulating in culvert systems.

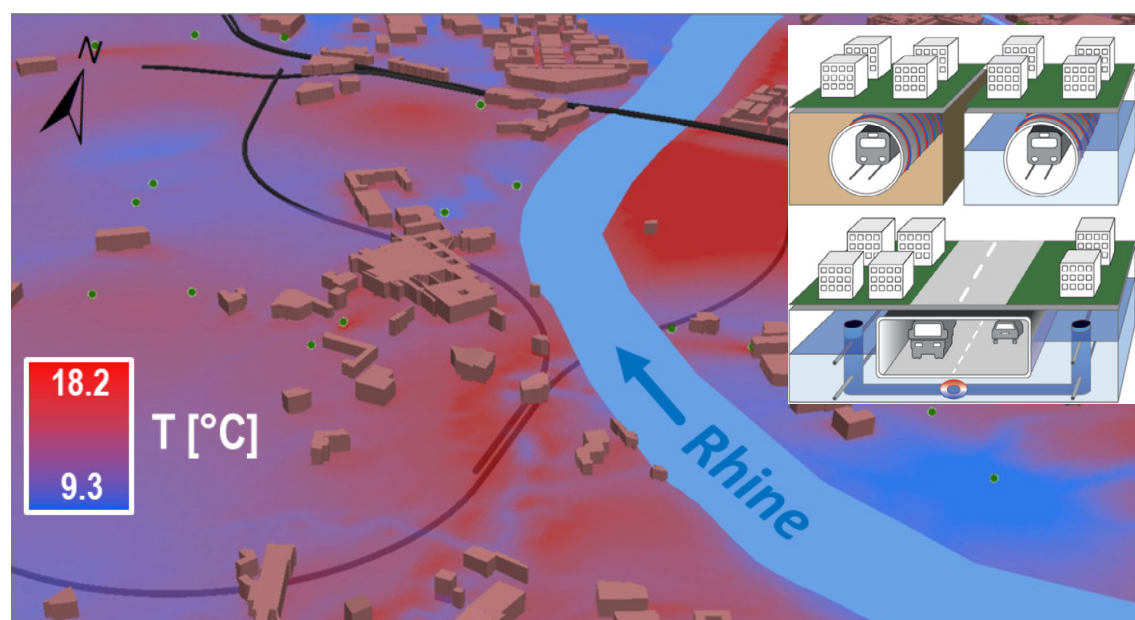


Figure 1. Groundwater temperatures and urban subsurface constructions, including progression of planned and existent tunnels, at the bend of the river Rhine in the city of Basel, Switzerland.

REFERENCES

Epting J., Baralis M., Künze R., Mueller M.H., Insana A., Barla M. & Hug-genberger P. 2019: Geothermal Potential of Tunnel Infrastructures – Development of Tools at the City-Scale of Basel, Switzerland. *Geothermics*

P 12.5

Geothermal use of an Alpine aquifer – Davos pilot study

Stefan Scheidler¹, Horst Dresmann¹, Peter Huggenberger¹, Jannis Epting¹

¹*Applied and Environmental Geology, Department of Environmental Sciences, University of Basel, Bernoullistrasse 32, CH-4056 Basel (jannis.epting@unibas.ch)*

Topographically induced Alpine regional groundwater flow systems below the unconsolidated valley fillings constitute a substantial unused geothermal resource.

Within the framework of the INTERREG VB project GRETA (shallow geothermal energy in the Alpine region), we developed a method to quantify the groundwater flux of complex alpine aquifers. The basis of the study is a regional-scale hydraulic groundwater model, which is based on a 3D tectonic model of the Davos region in Switzerland.

Favourable conditions for an energetic exploitation are related to large-scale topography differences between groundwater recharge and potential exfiltration areas in the valleys, thanks to the 3D geometry of the large-area tectonic nappe units with their root zone located within river valleys.

In general, the proposed concept could be applied to a variety of similar geological and hydrogeological conditions in the tourist regions of the Alpine belt.

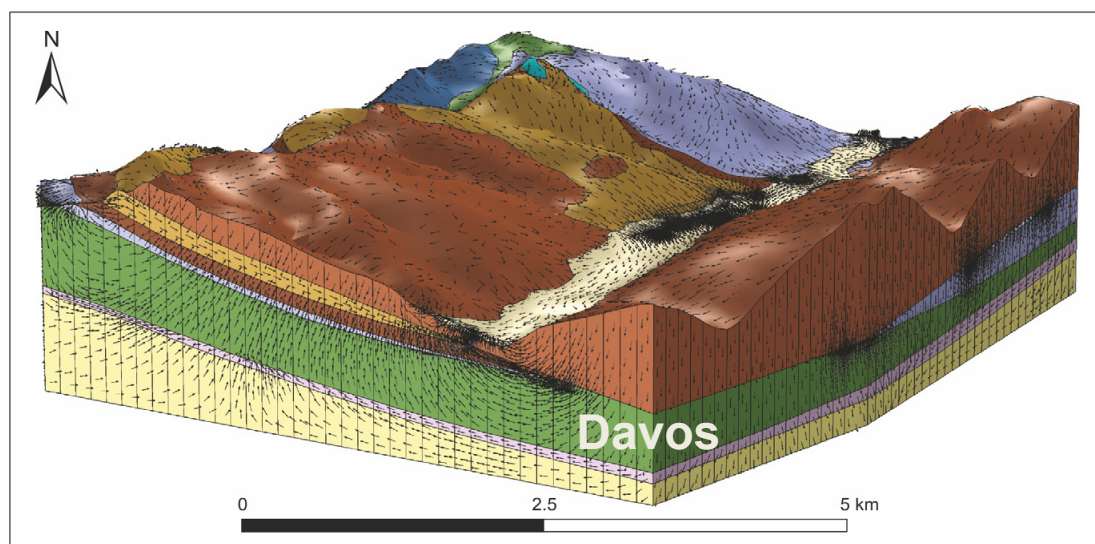


Figure 1. Result of regional scale groundwater modelling: the arrows represent the flow direction.

REFERENCES

- Scheidler S., Anders B., Regli C., Bolay S., Huggenberger P. 2019: Geothermal use of an Alpine aquifer – Davos pilot study. *Grundwasser*
- Scheidler, S., Huggenberger, P., Butscher, C. and Dresmann, H. 2019: Tools to simulate changes in hydraulic flow systems in complex geologic settings affected by tunnel excavation. *Bulletin of Engineering Geology and the Environment* 78(2), 969-980

P 12.6

Accuracy of citizen science water level class observations

Simon Etter¹, Barbara Strobl¹, Jan Seibert^{1,2} & H.J. (Ilja) van Meerveld¹

¹Department of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland
(simon.etter@geo.uzh.ch)

²Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, P.O. Box 7050, 75007 Uppsala, Sweden.

We will present the first results of real citizen generated WL-class time series from the CrowdWater project. The CrowdWater citizen science project (www.crowdwater.ch, Seibert et al., 2019) aims to collect hydrological data in remote regions where hydrological data are scarce. Previously, we assessed the accuracy of streamflow and water level class (WL-class) estimates from passers-by in street surveys (Strobl et al., 2019). For the WL-class estimates, citizens compared the actual water level in a stream with a picture of the stream taken at a different time in which a sticker of a staff gauge was placed as a reference. To assess the potential value of crowd-sourced water level class and streamflow data for hydrological model calibration we used these errors to create synthetic datasets that represented the characteristics of citizen generated time series of streamflow or water level class data. These data were then used to calibrate a hydrological model which we evaluated by comparing the simulations to the measured streamflow (Etter et al. (2018), Etter et al. (submitted)).

Because the surveys with the passers-by may be influenced by the presence of experts at the site, in this study we evaluated the accuracy of citizen science based stream level class observations using data collected with the CrowdWater app and survey sheets. Since the launch of the “CrowdWater | SPOTTERON” smartphone application in spring 2017 (Seibert et al. (2019) and Figure 1 - left), citizen scientists can start their own timeseries at any stream. For this study we selected eight such locations across Switzerland and Austria where measured water level data was available by national or local authorities. Furthermore, we collected WL-class data with survey sheets where passers-by estimated WL-classes independently (Figure 1 - right) at 13 locations across Switzerland where streamlevel data were available from the Federal Office of the Environment, the École Polytechnique Fédérale de Lausanne or measured by ourselves. We compared the crowdsourced and measured timeseries to assess the accuracy of the crowdsourced data and their ability to represent the streamflow dynamics over time. We show that the accuracy of the crowd-sourced water level class data varied for the different streams and the quality of the reference image.

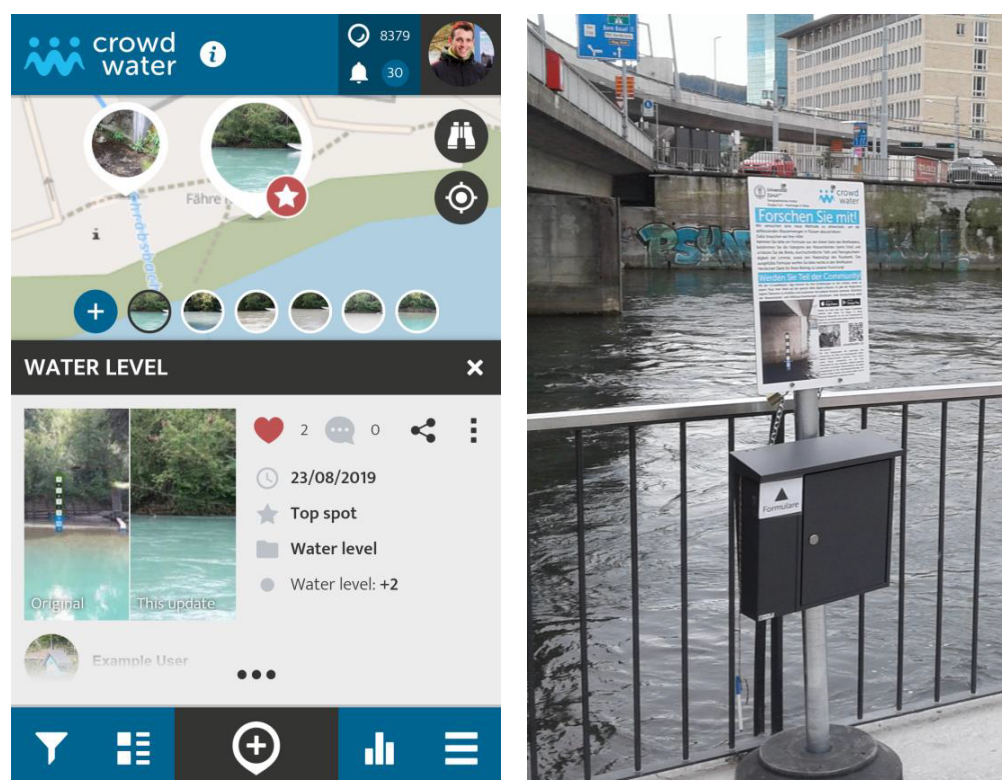


Figure 1. Left: Screenshot of the CrowdWater | SPOTTERON smartphone application. On the lower left, the reference picture with a virtual staff gauge and a picture of the stream at a the time of the contribution. The citizen scientist chose the level +2 for the new observation based on the comparison with the reference image. Right: CrowdWater station at the Limmat in Zurich, Switzerland. Passers-by could independently submit their observations using forms and the letterbox. The reference picture was provided on a sign board with information about CrowdWater and the explanation of how to contribute.

REFERENCES

- Etter, S., Strobl, B., Seibert, J. and van Meerveld, I.: Value of uncertain streamflow observations for hydrological modelling, *Hydrol. Earth Syst. Sci.*, 22, 5243–5257, doi:<https://doi.org/10.5194/hess-22-5243-2018>, 2018.
- Etter, S., Strobl, B., van Meerveld, H. J. (Ilja) and Seibert, J.: Value of crowd-based water level class observations for hydrological model calibration, submitted to *Water Resources Research* (Aug 2019).
- van Meerveld, H. J., Vis, M. J. P. and Seibert, J.: Information content of stream level class data for hydrological model calibration, *Hydrol. Earth Syst. Sci.*, 21(9), 4895–4905, doi:[10.5194/hess-21-4895-2017](https://doi.org/10.5194/hess-21-4895-2017), 2017.
- Seibert, J., Strobl, B., Etter, S., Hummer, P. and van Meerveld, H. J.: Virtual Staff Gauges for Crowd-Based Stream Level Observations, *Front. Earth Sci.*, 7, doi:[10.3389/feart.2019.00070](https://doi.org/10.3389/feart.2019.00070), 2019.
- Strobl, B., Etter, S., van Meerveld, I. and Seibert, J.: Accuracy of crowdsourced streamflow and stream level class estimates, *Hydrol. Sci. J.*, (Special issue on hydrological data: opportunities and barriers), 1–19, doi:[10.1080/02626667.2019.1578966](https://doi.org/10.1080/02626667.2019.1578966), 2019.

P 12.7

KMC : a comparison of various models for assessing karst hydrology

Pierre-Yves Jeannin¹

¹*Swiss Institute for Speleology and Karst-Studies, SISKa (pierre-yves.jeannin@isska.ch)*

The idea of the Karst Modelling Challenge (KMC) was to invite various research groups to apply their models to the same data set in order to compare approaches and results, and finally to discuss advantages and disadvantages of the respective approaches.

Data from the Milandre underground laboratory (Switzerland) are used for the comparison. The first step in the challenge is to simulate spring hydrograph from measured meteorological data. Ten research groups are participating.

The definition of common evaluation criteria, as well as of time steps for the simulations lead to some interesting discussions. The Kling-Gupta Evaluation criteria (KGE) was considered as the best criteria, and an hourly time-step was chosen for the given catchment area. Volume conservation as well as Nash-Sutcliffe criteria are being considered in the evaluation too.

Most models provided reasonable results, some of them being very close to measured discharge rates. The required effort for conducting the simulation exercise ranged between a few hours to several weeks depending on the models. The best results were mainly obtained by the simplest models (least number of parameters, i.e. black-box type of models), which appear to be the most efficient for the given exercise. However, the next (future) step of the challenge will be to simulate the spatial distribution of heads and flow-rates within the karst massif, which will be difficult with the simplest models...

P 12.8

Continuous time random walk model for non-uniform bed-load transportZhiPeng Li¹, HongGuang Sun¹, Yong Zhang², Renat T. Sibatov³¹*College of Mechanics and Materials, Hohai University, Nanjing, Jiangsu 210098, China (zhipenghhu@gmail.com)*²*Department of Geological Sciences, University of Alabama, Tuscaloosa, AL 35487, United States*³*Ulyanovsk State University, 42 Leo Tolstoy str., Ulyanovsk 432017, Russia*

Bed-load transport along widely graded river-beds typically exhibits anomalous dynamics, whose efficient characterization may require parsimonious stochastic models with pre-defined statistics involving the waiting time and hop distance distributions for sediment particles. This study employs a continuous time random walk (CTRW) model to characterize bed-load particle motions on a widely graded gravel-bed with cluster microforms built in our lab. Flume experiments guide the selection of the Mittag-Leffler (M-L) function as the waiting time distribution function, and the Lévy α -stable density for the hop distance distribution function in the CTRW model. Monte Carlo simulations show that the resulting CTRW model can well capture the observed flume experimental data (with either a continuous or an instantaneous source) with coexisting super- and sub-dispersion behaviors in the bed-load transport process. Analyses further discover the dual impact of clusters on the dynamics of fine sediment particles, namely, some particles are more likely to be blocked or trapped by clusters, while others have a high probability to be accelerated by the "flow accelerating belts" between the clusters. Therefore, with proper statistical distributions and relevant parameters for sediment waiting times and hop distances, the CTRW model may efficiently capture the complex dynamics in sediment transport.

P 12.9

Getting the most out of environmental tracers in complex alluvial systems

Morgan Peel¹, Stéphanie Musy², Andrea Popp³, Alvaro Pardo Alvarez¹, Roland Purtschert², Daniel Hunkeler¹, Philip Brunner¹

¹*Centre d'hydrogéologie et de géothermie, Université de Neuchâtel, Emile Argand 11, CH-2000 Neuchâtel (morgan.peel@unine.ch)*

²*Climate and Environmental Physics, University of Bern, Silderstrasse 5, CH-3012 Bern*

³*Department Water Resources & Drinking Water, Eawag, Überlandstrasse 133, CH-8600 Dübendorf*

Alluvial aquifers and adjacent streams play a critical role for drinking water supply and irrigation. However, a sound characterization of the spatial and temporal dynamics of water in alluvial systems remains elusive, due to highly anisotropic subsurface properties as well as complex interactions between surface water (SW) and groundwater (GW).

The combination of multiple environmental tracers with different chemical properties and measurement time-scales can provide valuable information on GW/SW mixing ratios and exchange dynamics. However, the interpretation of tracer concentrations in terms of GW residence time often relies on simplified approaches (e.g. assuming homogenous aquifer properties, simplified geometries, uniform tracer inputs, ...), which are unable to capture the complexity of dynamic natural systems. One promising yet seldom-used method is the explicit simulation of environmental tracers in physically-based numerical models of alluvial aquifer systems, which can realistically account for most processes affecting measured tracer concentrations.

This study aims to explore in which circumstances and to what extent the explicit simulation of tracers can improve the reliability of numerical models, and better help constrain the properties of alluvial aquifers.

As a first step in this endeavour, a comprehensive dataset was collected during a unique 6-week transient pumping test at an important alluvial aquifer in Switzerland (Emme site). Over this period, the GW abstraction rate was gradually increased from zero to 35'000 l/min, providing the optimal conditions for analysing how tracer measurements reflect system transience. Multiple environmental tracers (²²²Rn, ³⁷Ar, stable noble gases) were acquired at high spatial and temporal resolutions before, during, and after the experiment. Moreover, core samples recovered from the test site were used to quantify the variability of subsurface ²²²Rn production rates in the study area.

The acquired dataset forms the basis of a future numerical model, in which measured tracer concentrations and spatially variable ²²²Rn production rates will be explicitly simulated and integrated into the calibration process. This will allow systematic exploration of the data worth of tracers in terms of informing model parameters and reducing predictive uncertainties of model outputs.

P 12.10**Temperature effects on extreme rainfall modify catchment response**Nadav Peleg¹ & Peter Molnar¹¹*Institute of Environmental Engineering, ETH Zurich, Zurich, Switzerland (nadav.peleg@sccer-soe.ethz.ch)*

Heavy rainfall is expected to intensify with increasing temperatures. The rainfall spatial characteristics also change with increasing temperature, but the type of change (e.g. increase or decrease in the area of the storm) depends on many factors, such as the local vertical uplift conditions (convection) and available humidity. These changes can affect streamflow and sediment transport volumes and peaks. Using a combination of a numerical rainfall generator model and a landscape evolution model, we explored the sensitivity of the hydro-morphological response to heavy rainfall at the small-scale of minutes and hundreds of meters. We examined two types of rainfall, stratiform and convective, using a design storm that represents a typical extreme rainfall event in Alpine region. The design storm was modified to follow different spatial rainfall scenarios, associated with increasing temperatures. We found that the response of the stream discharge and sediment yields are sensitive to changes in the rainfall structure at the small-scale, in particular to changes in the areal rainfall intensity and in the area of heavy rainfall, which controls the total rainfall volume. Surprisingly, the hydro-morphologic response was less sensitive to changes in the peak rainfall intensity. The response was also found to be more sensitive to convective rainfall than stratiform rainfall because of localized runoff and erosion production.

P 12.11**Modelling the effect of irrigation modernization on groundwater recharge**

Sandra Pool^{1,2}, Felix Frances³, Alberto Garcia-Prats³, Cristina Puertes³, Manuel Pulido-Velazquez³, Carles Sanchis-Ibor⁴, Mario Schirmer^{1,5}, Hong Yang^{2,6} & Joaquin Jimenez-Martinez^{1,7}

¹*Department of Water Resources and Drinking Water, Eawag, Überlandstrasse 133, CH-8600 Dübendorf (sandra.pool@eawag.ch)*

²*Department Systems Analysis, Integrated Assessment and Modelling, Eawag, Überlandstrasse 133, CH-8600 Dübendorf*

³*Research Institute of Water and Environmental Engineering (IIAMA), Polytechnic University of Valencia, Camino de Vera s/n, E-46022 Valencia*

⁴*Valencian Center for Irrigation Studies, Polytechnic University of Valencia, Camino de Vera s/n, E-46022 Valencia*

⁵*Centre of Hydrogeology and Geothermics (CHYN), University of Neuchâtel, Rue Emile-Argand 11, CH-2000 Neuchâtel*

⁶*Department of Environmental Science, University of Basel, Bernoullistrasse 32, CH- 4056 Basel*

⁷*Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Stefano-Franscini-Platz 5, CH-8093 Zürich*

The region of Valencia (Spain) is one of the major citrus producers in Europe. The high citrus productivity in the prevailing semi-arid conditions can only be sustained by irrigation with a considerable volume of freshwater. With the aim of moving towards a more sustainable use of freshwater resources, during the last decades national and regional governments have promoted the installation of pressurized drip irrigation systems to replace traditional flood irrigation schemes. However, the (positive) effect of such a modernization on the regional water balance is highly debated. The aim of this study is therefore to improve the understanding of the hydrological functioning of a landscape under irrigation modernization. The core of this study is a distributed hydrological model that was specifically adapted to model the difference in evapotranspiration as a function of irrigation method and crop type. Information about irrigation transition and irrigation volumes at farm level was used to run the model at the aquifer scale of about 500 km². Model simulations were checked for plausibility at different spatiotemporal scales for three variables. First, the annual water balance was evaluated with respect to the evaporative index of flood- and drip-irrigated fields. Second, seasonal dynamics of groundwater fluctuations were evaluated at 22 observation wells. And third, daily dynamics of soil moisture in drip-irrigated fields were assessed for their reliability based on process understanding gained at an experimental plot. We found that a spatially distributed multi-variable evaluation was an essential step in evaluating the success of the implementation of drip and flood irrigation into the hydrological model. The results will ultimately help to improve the prediction of groundwater recharge under changing conditions, such as irrigation modernization or climate change.

P 12.12

Elucidating stream-groundwater interactions using real-time, in situ noble gas analysis and numerical modeling

Andrea L. Popp¹, Alvaro Pardo-Alvarez², Oliver S. Schilling³, Stephanie Musy⁴, Andreas Scheidegger¹, Morgan Peel², Roland Purtschert⁴, Daniel Hunkeler², Philip Brunner², Rolf Kipfer¹

¹*Department of Water Resources and Drinking Water, Eawag, Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, CH-8600 Dübendorf (andrea.popp@eawag.ch)*

²*Centre d'Hydrogéologie et de Géothermie, University of Neuchâtel, CH-2000 Neuchâtel*

³*National Centre for Groundwater Research and Training, Flinders University, AUS-5042 Adelaide*

⁴*Climate and Environmental Physics, University of Bern, CH-3012 Bern*

The quality and quantity of shallow, alluvial groundwater in mountainous areas are particularly vulnerable to the effects of climate change as well as increasing pollution from agriculture and urbanization. Understanding groundwater mixing and travel times in such systems is thus crucial to sustain a safe and sufficient water supply. We used a novel combination of real-time, in situ noble gas analysis to quantify groundwater mixing ratios and travel times during a two-month groundwater pumping test carried out at a drinking water wellfield in the Emmental. Transient groundwater mixing ratios were calculated using He/Ar time series combined with a Bayesian end-member mixing model. Having identified the fraction of recently infiltrated river water allowed us to estimate the mean groundwater travel times using Radon-222. Additionally, we calculated groundwater mixing ratios using a previously calibrated groundwater model built with the physically-based flow simulator *HydroGeoSphere*. The two independently obtained groundwater mixing ratios (i.e., tracer-based and model-based) are in excellent agreement for the majority of our observation time. Our findings show that (i) mean travel times of recently infiltrated river water are in the order of two weeks, (ii) for the majority of the experiment, the fraction of recently infiltrated river water in the sampled groundwater pumping well is high (~70%), and (iii) increased groundwater pumping only has a marginal effect on groundwater mixing ratios and travel times. These insights emphasize that groundwater in pre-alpine alluvial valleys is highly vulnerable to potential pollution originating from surface water due to the high fraction of recently infiltrated river water and short groundwater travel times.

P 12.13

Towards decadal hydro-glaciological forecasts for the hydropower sector

Davide Saurwein¹

¹*Institute of Earth Sciences, University of Applied Sciences and Arts of Southern Switzerland, Campus Trevano, Via Trevano, CH-6952 Canobbio (davide.saurwein@supsi.ch)*

Hydropower and water resources management are an important issue in most countries of the world, included Switzerland. The scientific community is currently engaged to produce numerical models and simulations which aim at understanding the most important concurring factors of climate with the support of different tools and methods, at both regional and global scales. In this case, the purpose is to simplify reality while reducing errors and uncertainties related to streamflow prediction. The latter uncertainties can be due to different sources, such as the initial hydrologic conditions of a catchment, the hydrological model's input data and structure, or a too high amount of subjectivity which is applied while implementing such modelling procedures (Beven, 2012).

The aim of this work is to investigate the propagation of uncertainties from the input meteorological forecasts to the resulting streamflow predictions. A weather generator has been used to create synthetic weather decadal forecasts (Ailliot *et al.*, 2015). These forecasts have then been fed into the hydrological model *Hydrologiska Byråns Vattenbalansavdelning* (HBV), and simulations have been run in order to obtain corresponding runoff forecasts. The accuracy of the meteorological and runoff forecasts has been calculated with similar statistical metrics with the aim to assess uncertainty propagation. Three statistical metrics, defined as “skill scores”, have been applied for this purpose (Hamill and Juras, 2006). The experiment was performed for two glacierized catchments located in the Swiss Alps, Findelen and Gries. The simulations were performed by assuming different scenarios of glacier extent in order to observe the influence of the amount of ice present in the catchment on the results. The effect of a varying input glacier extent on simulated runoff has then been studied, together with an assessment of the modifications on the hydrological regime. Simulations have been run by applying the recently-implemented glacier routine in the hydrological model with different settings in order to analyze how skill transfer can be affected. In addition, a sensitivity analysis has been performed on parameters and routines of the hydrological model in order to study their contribution to model efficiency.

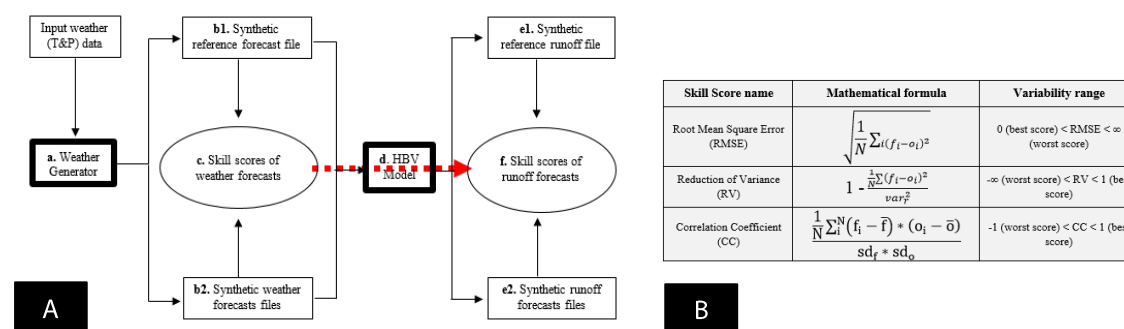


Figure 1. Methodology of the project. (A) General description of the methodology; (B) Skill scores used for the quantification of decadal forecasts.

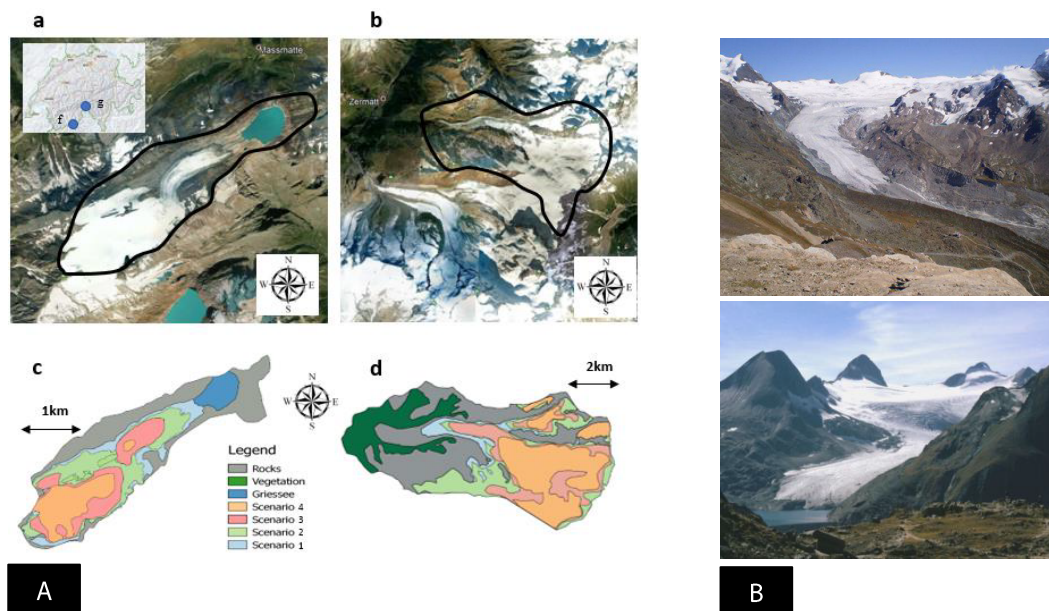


Figure 2. (A) Geographic situation of Gries and Findelen glacierized catchments. In the localization map of the two catchments, “f” indicates the Findelen catchment, while “g” represents the Gries catchment. (B) Visual representations of Findelen glacier (upper picture) and Gries glacier (lower picture).

It has been observed that the influence of precipitation on runoff forecasts is lower than the one of temperature for highly-glacierized catchments. This influence increases with diminishing glacierization. In a hypothetical ice-free catchment, the effect of precipitation on skill transfer tends to become more relevant, for both Findelen and Gries catchments. Other important factors of skill transfer are the lead time from which a forecast is produced and the application of different settings of the glacier routine of the hydrological model.

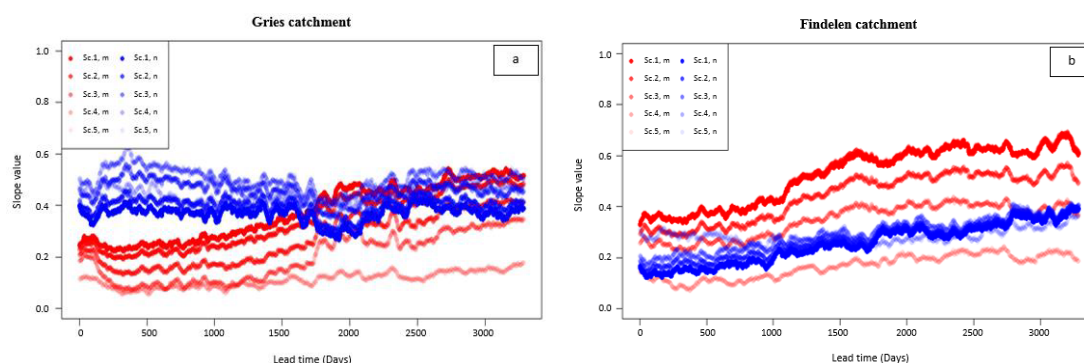


Figure 3. Evolution of slope parameters ‘m’ and ‘n’, the colour saturation is related to the degree of glacierization related to each Scenario (“Sc.” in the figure).

REFERENCES

- Ailliot, P., Allard, D., Monbet, V. & Naveau P. 2015: Stochastic weather generators: an overview of weather type models, *Journal de la Société Française de Statistique* 156, 101-113.
- Beven, K. 2012: *Rainfall-Runoff Modelling* (2nd Edition), Wiley-Blackwell Editors, Lancaster University, UK.
- Hamill, T.M. & Juras J. 2006: Measuring forecast skill: is it real skill or is it the varying climatology? *Quarterly Journal of the Royal Meteorological Society* 132, 2905-2923.

P 12.14

The influence of trophic history and lake mixing regime on long-term phosphorus fractions retention in sediments of deep, eutrophic lakes: a case study from Lake Burgäschi, Switzerland

Luyao Tu¹, Sönke Szidat², Hendrik Vogel², Paul Zander¹, Martin Grosjean¹

¹Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Switzerland

²Oeschger Centre for Climate Change Research and Institute of Chemistry and Biochemistry, University of Bern, Switzerland

Lake eutrophication and anoxic conditions in the hypolimnion can influence the sediment phosphorus (P) release on short time scales, which is the main cause of the delay of lake recovery in many freshwater deep lakes (Burley et al., 2001). It is yet not clear how long-term sediment P-fraction retention responded to hypolimnion-water redox conditions and eutrophication history in the further past. In this study, we investigated the P species and changes of P-fraction retention in sediment profiles since the early 1900s in Lake Burgäschi, a deep eutrophic lake in Swiss Plateau. The changes of sediment P-fraction retention were assessed with respect to lake trophic evolution (sedimentary green-pigments proxy; Schneider et al., 2018), hypolimnion oxygenation regime (Fe/Mn ratio proxy; Zarczynski et al., 2019) and sediment geochemical characteristics. The results show that dominant factors controlling the long-term retention of labile P-fractions (NaCl-TP, NaBD-TP, and NaOH-TP) were autochthonous Fe- and Mn preserved in anoxic sediments, which were determined by past redox conditions in hypolimnion water. The considerable declines in total P and these labile P fractions retention during 1977 to 2017 CE were suggested to be related to eutrophication-incurred anoxic conditions and hypolimnetic withdrawal restoration in the lake during the period. By comparison, refractory HCl-P (Ca-P) fraction retention, to a large extent, resulted from authigenic CaCO₃-P precipitation and increased with higher eutrophic levels. Large amounts of Ca-P fraction predominated in the surface sediments after 1977 CE, indicating a potential negative feedback to eutrophication. The study implies that in seasonally-stratified deep lakes like Lake Burgäschi, hypolimnetic withdrawal might be an effective restoration method to reduce the retention and availability of sediment P.

REFERENCES

- Burley, K. L., E. E. Prepas, and P. A. Chambers, 2001, Phosphorus release from sediments in hardwater eutrophic lakes: the effects of redox-sensitive and -insensitive chemical treatments: *Freshwater Biology*, v. 46, p. 1061-1074.
- Schneider, T., D. Rimer, C. Butz, and M. Grosjean, 2018, A high-resolution pigment and productivity record from the varved Ponte Tresa basin (Lake Lugano, Switzerland) since 1919: insight from an approach that combines hyperspectral imaging and high-performance liquid chromatography: *Journal of Paleolimnology*, p. 1-18
- Zarczynski, M., A. Wacnik, and W. Tylmann, 2019, Tracing lake mixing and oxygenation regime using the Fe/Mn ratio in varved sediments: 2000-year-long record of human-induced changes from Lake Zabinskie (NE Poland): *Sci Total Environ*, v. 657, p. 585-596.

P 12.15

Soil hydrological monitoring for regional landslide early warning

Adrian Wicki¹, Manfred Stähli¹, Christian Hauck², Peter Lehmann³

¹Swiss Federal Research Institute WSL, Mountain Hydrology and Mass Movements, Zürcherstrasse 111, CH-8903 Birmensdorf (adrian.wicki@wsl.ch)

²University of Fribourg, Departement of Geosciences, Chemin du Musée 4, CH-1700 Fribourg

³Eidgenössische Technische Hochschule Zürich, Institute of Biogeochemistry and Pollutant Dynamics, Universitätstrasse 16, CH-8092 Zürich

In mountainous terrain, rainfall-induced shallow landslides pose a serious risk to people and infrastructure due to a widespread occurrence and the short time interval between activation and failure. Regional landslide early warning systems (LEWS), which are mostly based on empirically derived rainfall exceedance thresholds, have demonstrated to be a valuable tool to inform decision makers about the imminent landslide danger or to issue warnings to the public.

Recent studies have shown that the forecast quality of LEWS can be improved significantly after the inclusion of soil hydrological measurements. In Switzerland, it could be demonstrated that soil moisture data alone from existing monitoring networks inhibits specific information about the regional landslide activity, particularly the antecedent wetness state and the increase of soil moisture during an infiltration event (Wicki et al., in preparation). Questions remain whether the predominantly flat measurement sites are representative for critical saturated conditions at landslide prone hillslopes and which instrumentation is most suitable to monitor these conditions.

To answer this, a hillslope and a flat location in a landslide prone area in the Napf region (Swiss Prealps) were equipped with soil moisture probes, tensiometers, electrical resistivity tomography (ERT) profile lines and shallow groundwater wells. Differences in the hydrological dynamics between the two sites are analysed to assess the representativeness of flat sites for critical hydrological conditions at hillslope locations. Further, different sensor types are compared with regards to their ability to detect such conditions and their suitability for the use in a real-time monitoring system.

First results from summer 2019 indicate that the local topography imposes distinct differences on the soil moisture dynamics. Near the surface, soil moisture variability is larger at the flat site which can be attributed to higher evaporation rates (aspect, shading), less surface runoff and different soil properties. At the hillslope site, soil wetness variability is higher at depth due to subsurface flow near the shallow bedrock interface. Further, it could be shown that soil moisture probe readings can be affected considerably by the installation surroundings, and near-surface tensiometers can be rapidly out of measurements range during very dry conditions. While both effects are problematic with respect to the use in a monitoring system, the combination of the two sensor types can help to partially cope with these problems.