Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAM
Uffizi federal d'ambient UFAM

Veröffentlichungen zu angewandt-wissenschaftlichen Studien mit Bezug zum Grundwasser der Schweiz

Literaturzusammenstellung – Jahrgang 2019

Publications d'études en sciences appliquées en relation avec les eaux souterraines en Suisse

Compilation de littérature pour l'année 2019

Inklusive Links zu Artikel-[Abstracts] (Um dem Link zu folgen: **[**klicken**]**)
Liens vers les [Abstracts] inclus (Pour suivre le lien : **[**cliquer**]**)

Fachartikel national / Articles spécialisés nationaux

Kiefer, K., Muller, A., Singer, H., Hollender, J., Reinhardt, M.

Pflanzenschutzmittel-Metaboliten im Grundwasser [1]

Aqua & Gas, 11/19, S.14-23

Hintze, S., Hunkeler, D.

Lanzeitverhalten von PSM-Metaboliten im Grundwasser [2]

Aqua & Gas, 11/19, S.24-29

Moschet, C., Waldvogel, J., Seiler, K., Ramseier, C., Kull, D., Staub Spörri, A., De Rossa, M., Känzig, A., Weber, S., Lacour, W.

Trinkwasserqualität bezüglich Rückständen von PSM [3]

Aqua & Gas, 11/19, S.30-36

Tschumper, R., Bahnmüller, S., Ryser, R., Steiner, O.

Grossflächige Grundwasserverschmutzung im Emmental [4]

Aqua & Gas, 2/19, S. 60-66

Künzli, M., McCall, A., Niederer C.

Grundwasser und Erdwärmenutzung [5]

Aqua & Gas, 3/19, S. 45-50

Reis, V., Olschweski, A.

Umfrage unter SVGW-Wasserversorgern [6]

Aqua & Gas, 6/19, S.44-49

Fachartikel international / Articles spécialisés internationaux

Scheidler, S., Huggenberger, P., Butscher, C., Dresmann, H.

Tools to simulate changes in hydraulic flow systems in complex geologic settings affected by tunnel excavation [7]

Bulletin of Engineering Geology and the Environment, Volume 78, Issue 2, p 969-980

DOI : 10.1007/s10064-017-1113-5

Lapworth, D., Lopez, B., Laabs, V., Kozel, R., Wolter, R., Ward, R., Vargas Amelin, E., Besien, T., Claessens, J., Delloye, F., Ferretti, E., Grath, J.

Developing a groundwater watch list for substances of emerging concern: a European perspective [8]

Environmental Research Letters, Volume 14, Number 3

Weatherl, R., Schirmer, M.

Groundwater recharge and solute transport in the urban environment [9]

Geophysical Research Abstracts, Vol. 21, p 1-1

Sinreich, M.

Fluctuations in regional groundwater volume as an on-line indicator for drought conditions [10]

Geophysical Research Abstracts, Vol. 21, p 1-1

Arnoux, M., Hunkeler, D., Brunner, P., Schaefli, B., Jonas, T.

Hydrogeological controls on dynamic groundwater storage in Alpine catchments [11]

Geophysical Research Abstracts, Vol. 21, p 1-1

Gianni, G., Doherty, J., Brunner, P.

Conceptualization and calibration of anisotropic alluvial systems: Pitfalls and biases [12]

Groundwater, Volume 57, Issue 3, p 409-419

DOI : 10.1111/gwat.12802

Auckenthaler, A.

Grundwasserschutz in urbanen Räumen der Schweiz [13]

Grundwasser, Volume 24, Issue 2, p 99

DOI : 10.1007/s00767-019-00420-3

Scheidler, S., Anders, B., Regli, C., Bolay, S., Huggenberger, P

Geothermal use of an Alpine aquifer-Davos pilot study [14]

Grundwasser, Volume 24, Issue 4, p 277-286

DOI : 10.1007/s00767-019-00433-y

de Palézieux, L., Loew, S.

Long-term transient groundwater pressure and deep infiltration in Alpine mountain slopes (Poschiavo Valley, Switzerland) [15]

Hydrogeology Journal, Volume 27, Issue 8, p 2817-2834

DOI : 10.1007/s10040-019-02025-9

Kiewiet, L., von Freyberg, J., an Meerveld, H.

Spatiotemporal variability in hydrochemistry of shallow groundwater in a small pre-alpine catchment: The importance of landscape elements [16]

Hydrological Processes, Volume 33, Issue 19, p 2502-2522

DOI : 10.1002/hyp.13517

Floriancic, M., Fischer, B., Molnar, P., Kirchner, J., van Meerveld, I.

Spatial variability in specific discharge and streamwater chemistry during low flows: Results from snapshot sampling campaigns in eleven Swiss catchments [17]

Hydrological Processes, Volume 33, Issue 22, p 2847-2866

DOI : 10.1002/hyp.13532

Berg, M., Podgorski, J.

Groundwater assessment platform (GAP): A new GIS tool for risk forecasting and mitigation of geogenic groundwater contamination [18]

Arsenic in the environment - proceedings. Environmental arsenic in a changing world, p 5-6

DOI : 10.1201/9781351046633

Bollhofer, A., Schlosser, C., Schmid, S., Konrad, M., Purtschert, R., Krais, R.

Half a century of Krypton-85 activity concentration measured in air over Central Europe: Trends and relevance for dating young groundwater [19]

Journal of Environmental Radioactivity, Volume 205, p 7-16

DOI : 10.1016/j.jenvrad.2019.04.014

Horgby, A., Canadell, M., Utseth, A., Vennemann, T., Battin, T.

High-resolution spatial sampling identifies groundwater as driver of CO2 dynamics in an alpine stream network [20]

Journal of Geophysical Research-Biogeosciences, Volume 124, Issue 7, p 1961-1976

DOI : 10.1029/2019JG005047

Vivien, R., Lafont, M., Werner, I., Laluc, M., Ferrari, B. **Assessment of the effects of wastewater treatment plant effluents on receiving streams using oligochaete communities of the porous matrix [21]** Knowledge and Management of Aquatic Ecosystems, Issue 420, Article Number 18 DOI : 10.1051/kmae/2019011
Paillex, A., Siebers, A., Ebi, C., Mesman, J., Robinson, C. **High stream intermittency in an alpine fluvial network: Val Roseg, Switzerland [22]** Limnology and Oceanography, Early Access SEP 2019 DOI : 10.1002/lno.11324
Brunner, M., Liechti, K., Zappa, M. **Extremeness of recent drought events in Switzerland: dependence on variable and return period choice [23]** Natural Hazards and Earth System Sciences, Volume 19, Issue 10, p 2311-2323 DOI : 10.5194/nhess-19-2311-2019
Preisig, G. **Long-term effects of deep-seated landslides on transportation infrastructure: a case study from the Swiss Jura Mountains [24]** Quarterly Journal of Engineering Geology and Hydrogeology, Volume 52, Issue 3, p 362-335 DOI : 10.1144/qjegh2017-128
Zuecco, G., Rinderer, M., Penna, D., Borga, M., van Meerveld, H. **Quantification of subsurface hydrologic connectivity in four headwater catchments using graph theory [25]** Science of the Total Environment, Volume 646, p 1265-1280 DOI : 10.1016/j.scitotenv.2018.07.269
Kiefer, K., Muller, A., Singer, H., Hollender, J. **New relevant pesticide transformation products in groundwater detected using target and suspect screening for agricultural and urban micropollutants with LC-HRMS [26]** Water Research, Volume 165, Article Number 114972 DOI : 10.1016/j.watres.2019.114972
Cochand , M., Christe, P., Ornstein, P., Hunkeler, D. **Groundwater storage in high alpine catchments and its contribution to streamflow [27]** Water Resources Research, Volume 55, Issue 5, p 2545-3602 DOI : 10.1029/2018WR022989
Rinderer, M., van Meerveld, H., McGlynn, B. **From points to patterns: Using groundwater time series clustering to investigate subsurface hydrological connectivity and runoff source area dynamics [28]** Water Resources Research, Volume 55, Issue 7, p 5784-5806 DOI : 10.1029/2018WR023886

Kittila, A., Jalali, M., Evans, K., Willmann, M., Saar, M., Kong, X.

Field comparison of DNA-labeled nanoparticle and solute tracer transport in a fractured crystalline rock [29]

Water Resources Research, Volume 55, Issue 8, p 6577-6595

DOI : 10.1029/2019WR025021

17th Swiss Geoscience Meeting

Fribourg, 22nd November – 23rd November 2019

https://geoscience-meeting.ch/sgm2019/

Catrouillet, C., Hirouse, S., Manetti, N., Peña, J.

Arsenic removal from manganese-containing groundwaters using Fe(0) electrocoagulation - modelling [30]

Perrochet, L., Preisig, G., Valley, B.

Assessing fault criticality using seismic monitoring and fluid pressure analysis [31]

Cojean, A., Bartosiewicz, M., Lehmann, M., Kremen, K., Wirth, S.

Different lacustrine pockmark systems in Lake Thun, Switzerland, and their potential influence on the hydrological and biogeochemical budget of the lake [32]

Popp, A., Pardo-Alvarez, A., Schilling, O., 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 [33]

Kiewiet, L., Wicki, A., van Meerveld, I., Seibert, J.

Explaining shallow groundwater concentrations with surface and bedrock topography, and soil and bedrock composition [34]

Kong, X., Kittilä, A., Jalali, M., Somogyvári, M., Evans, K., Saar, M.

Flow path characterization at the Grimsel Underground Rock Laboratory using solute tracer tests [35]

Guglielmetti, L., Eichinger, F., Moscariello, A.

Geochemical Characterization of deep geothermal waters circulation in carbonatic geothermal reservoirs of the Geneva Basin (GB) [36]

Wanner, C., Waber, N., Bucher, K.

Geochemical evidence for large-scale and long-term topography-driven groundwater flow in orogenic crystalline basements [37]

Scheidler, S., Dresmann, H., Huggenberger, P., Epting, J.

Geothermal use of an Alpine aquifer – Davos pilot study [38]

Peel, M., Musy, S., Popp, A., Pardo Alvarez, A., Purtschert, R., Hunkeler, D., Brunner, P. **Getting the most out of environmental tracers in complex alluvial systems [39]**
Wirth, S., Bouffard, D., Cojean, A., Zopfi, J. **Giant pockmarks in Lake Neuchatel, Switzerland: new multi-proxy evidence for lacustrine groundwater discharge [40]**
Arnoux, M., Cochand, F., Hunkeler, D., Brunner, P., Schaefli, B., Jonas, T. **Groundwater and discharge regime evolution with climate change in Alpine catchments [41]**
Perego, R., Pera, S., Bulgheroni, M., Boaga, J., Galgaro, A. **Hydro/thermogeological state of the Maggia river delta: potential shallow geothermal energy implications [42]**
Weatherl, R., Henao Salgado, M., Schirmer, M. **Identifying sources and processes impacting groundwater recharge in the human environment [43]**
Beria, H., Larsen, J., Ceperley, N., Michelon, A., Schaefli, B. **Increased snowpack ephemerality augments groundwater recharge in the mid-elevation belt of the Swiss Alps [44]**
Rüegg, A., Preisig, G. **JuraHydroSlide: identifying the principal hydrogeologic ingredients for predicting landslide activity in Jura Mountains [45]**
Jeannin, P.-Y. **KMC: a comparison of various models for assessing karst hydrology [46]**
Cochand F., Hunkeler, D., Sinreich, M., Brunner, P. **Modelling recharge by precipitation at the Swiss scale [47]**
Alt-Epping, P., Diamond, L., Wanner, C. **Regional scale models of fluid flow in the orogenic hydrothermal system at Grimsel Pass, Switzerland [48]**
Wicki, A., Stähli, M., Hauck, C., Lehmann, P. **Soil hydrological monitoring for regional landslide early warning [49]**
Ingold, P., Wanner, C. **Stability and As adsorption of nanocrystalline Al-hydroxysulfates forming during acid rock drainage [50]**
Epting, J., Huggenberger, P. **Thermal potential of urban tunnel infrastructures in unconsolidated rock groundwater resources [51]**

Malard, A., Randles, S., Hausmann, P., Jeannin, P., Vogel, M., Lopez, S., Courrioux, G.

Visual KARSYS, a web-tool for modelling karst aquifers in 3D [52]

Übersichtspublikationen / Publications synoptiques

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Zustand und Entwicklung Grundwasser Schweiz

https://www.bafu.admin.ch/ergebnisse-grundwasserbeobachtung-schweiz-naqua

État et évolution des eaux souterraines en Suisse [53]

https://www.bafu.admin.ch/resultats-observatoire-eaux-souterraines-naqua.html

Umwelt-Zustand - État de l'environnement, UZ-1901-D / UZ-1901-F, 142 p

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Hydrologisches Jahrbuch der Schweiz 2018

https://www.bafu.admin.ch/hydrologisches-jahrbuch-der-schweiz-2018.html

Annuaire hydrologique de la Suisse 2018 [54]

https://www.bafu.admin.ch/annuaire-hydrologique-2018.html

Umwelt-Zustand - État de l'environnement, UZ-1907-D / UZ-1907-F, 40 p

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Hitze und Trockenheit im Sommer 2018

https://www.bafu.admin.ch/hitze-und-trockenheit

La canicule et la sécheresse de l'été 2018 [55]

https://www.bafu.admin.ch/canicule-et-secheresse.html

Umwelt-Zustand - État de l'environnement, UZ-1909-D / UZ-1909-F 91 p

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Flyer-Serie zum Thema Wasser

https://www.bafu.admin.ch/flyer-serie-wasser.html

Série de dépliants sur le thème Eaux [56]

https://www.bafu.admin.ch/depliants-eaux.html

Umwelt-Info - Environnement Info, UI-1923-D / UI-1923-F

Abstracts

Fachartikel national / Articles spécialisés nationaux

1. Pflanzenschutzmittel-Metaboliten im Grundwasser

Mit Screening-Methoden wurden ausgewählte Grundwasser-Proben im Rahmen einer Pilotstudie der Nationalen Grundwasserbeobachtung NAQUA auf mehrere hundert Wirkstoffe und Metaboliten von Pflanzenschutzmitteln (PSM) sowie weitere Mikroverunreinigungen untersucht. Es galt zu prüfen, ob und welche «neuen» PSM-Wirkstoffe oder -Metaboliten die Grundwasserqualität beeinträchtigen und in das NAQUA-Langzeitmonitoring integriert werden sollten. Mehr als 20 PSMMetaboliten wurden erstmals im Grundwasser nachgewiesen. Diejenigen des Fungizids Chlorthalonil waren aufgrund hoher Konzentrationen und weiter Verbreitung besonders auffällig.

2. Lanzeitverhalten von PSM-Metaboliten im Grundwasser

Wie kommen erhöhte PSM-Metaboliten-Konzentrationen in Pumpwerken zustande, und warum zeigen PSM-Verzichtsmassnahmen oft nur mit einer grossen Verzögerung eine Wirkung? Diesen Fragen wurde am Beispiel der Chloridazon-Metaboliten an zwei Pilotstandorten nachgegangen. Die zeitliche Entwicklung der Konzentration hängt dabei nicht nur von der Aufenthaltszeit im genutzten Grundwasservorkommen ab, sondern auch von PSM- und Metaboliten-Reservoiren im Boden sowie von einer Verlagerung von Stoffen aus benachbarten Einzugsgebieten durch Wechselwirkung der Oberflächengewässer.

3. Trinkwasserqualität bezüglich Rückständen von PSM

Das Trinkwasser in der Schweiz wird von den Kantonschemikern regelmässig untersucht. Um einen Überblick über die Rückstände von Pflanzenschutzmitteln und deren Abbauprodukten im Trinkwasser zu gewinnen, wurden im laufenden Jahr die Untersuchungen schweizweit koordiniert. Die Qualität des Trinkwassers in der Schweiz ist gut, regionale Verbesserungen sind jedoch nötig. Dies gilt insbesondere für Trinkwasser, das von Grundwasser aus Ackerbaugebieten stammt.

4. Grossflächige Grundwasserverschmutzung im Emmental

Ende Mai 2017 wurden im Grundwasser des Unteren Emmentals grosse Mengen an Fluorchlorkohlenwasserstoffen (Freone) gefunden. Die Förderung von Trinkwasser aus einer betroffenen Fassung musste umgehend eingestellt werden. Um Ursache und Ausmass des Schadens zu evaluieren, veranlasste ein vom Amt für Wasser und Abfall des Kantons Bern gebildeter Krisenstab ein umfassendes Beprobungs- und Messprogramm. Dieser schwerwiegende Fall zeigt erneut die Vulnerabilität des Grundwassers und belegt die Notwendigkeit konsequenter Vorsorge-, Schutzund Notfallmassnahmen zur Sicherung der Trinkwasserversorgung.

5. Grundwasser und Erdwärmenutzung

Beim Bau und der Nutzung von Erdwärmetechnologien können die dabei eingesetzten Stoffe in das Grundwasser gelangen. Um das Grundwasser nachhaltig zu schützen, wurde im Auftrag des Bundesamts für Umwelt BAFU eine systematische Methodik zur Gefährdungsabschätzung von Stoffen aus der Erdwärmenutzung auf das Grundwasser entwickelt. Mithilfe einer Produktliste können die meisten der Produktbestandteile identifiziert und die jeweiligen Stoffe mithilfe der entsprechenden Stoffliste bewertet werden. Beide Listen sind auf der Website des BAFU verfügbar.

6. Umfrage unter SVGW-Wasserversorgern

Eine Umfrage unter den SVGW-Wasserversorgern zeigt es deutlich: Nutzungskonflikte bei Trinkwasserfassungen stellen in vielen Fällen ein erhebliches Risiko für die Trinkwasserqualität oder eine grosse Belastung für die Wasserversorger dar. Zudem führen sie zu Verlusten bedeutender Wasserfassungen. Im Hinblick auf die zunehmende Häufigkeit von Trockenperioden ist deshalb die flächendeckende Umsetzung des vorsorglichen Schutzes der Trinkwasserressourcen dringender denn je.

Fachartikel international / Articles spécialisés internationaux

7. Tools to simulate changes in hydraulic flow systems in complex geologic settings affected by tunnel excavation

Geotechnical problems during and after tunnel construction are often related to groundwater circulation. In tunnelling projects, however, groundwater flow systems are often only partly known. This uncertainty is manifested by the typically scarce hydraulic data that limits the understanding of subsurface hydrogeological processes. In particular, there is a general lack of data documenting groundwater flow changes caused by tunnelling. The present paper presents a concept involving an iterative understanding of subsurface hydrogeological systems influenced by tunnelling. A major challenge of our approach consists of integrating complex geological geometries from a 3D geological model (GOCAD) into a numerical groundwater flow model (COMSOL Multiphysics). The starting point is a 3D geological model representing a regional tectonic system located in the Jura Mountains in Switzerland. This geological model is transferred into regional and local-scale groundwater flow models. Due to the lack of hydrogeological data, a 3D view of geological-hydrogeological systems is often required to respond to groundwater-induced geotechnical problems in tunnelling. Numerical groundwater flow models make it possible to perform sensitivity analysis and to test how boundary conditions and hydraulic property distributions influence calculated groundwater flow regimes. In addition, our approach enables testing the effects of changes of hydraulic regimes due to tunnel excavation at different scales.

8. Developing a groundwater watch list for substances of emerging concern: a European perspective

There is growing concern globally about the occurrence of anthropogenic organic contaminants in the environment, including pharmaceuticals and personal care products. This concern extends to groundwater, which is a critical water resource in Europe, and its protection is a priority to the European Commission, the European Union (EU) Member States and national agencies across Europe. Maintaining good groundwater status supports improved public health, economic growth and sustains groundwater dependant ecosystems. A range of measures have been introduced for regulating several substances that have impacted groundwater (e.g. nitrate and pesticides). However, these measures only cover a small fraction of anthropogenic substances that could pollute groundwater. Monitoring for these unregulated substances is currently very limited or not carried out at all. Therefore, a coordinated European-wide approach is needed to identify, monitor and characterise priority substances or groups of substances that have the potential to pollute groundwater. This evidence base is critical for policy development and controls on these currently unregulated substances. The European Commission highlighted this as a need during the review of the EU Groundwater Directive Annexes in 2014, when the requirement to develop a Groundwater Watch List (GWWL) was established. This paper describes the approach that has been developed through a voluntary initiative as part of the EU CIS Working Group Groundwater to establish the voluntary EU GWWL. The process for developing the GWWL is one that has brought together researchers, regulators and industry, and is described here for the first time. A summary of the key principles behind the methodology is presented as well as results from pilot studies using per- and polyfluoroalkyl substances and pharmaceuticals. These explore and support the viability of the GWWL process, an important step towards its adoption and its future use for groundwater protection across Europe.

9. Groundwater recharge and solute transport in the urban environment

Understanding groundwater dynamics around cities and other areas of major human influence is of crucial importance for water resource management and protection in the 21st century, a time of active environmental and societal change. The human environment presents a unique challenge in terms of hydrological characterization due to the alteration of natural conditions. In these areas, the water cycle is partially artificial, and emissions of synthetic organic compounds from accidental leakages, spills, or deliberate release of wastewater into the aquatic environment tend to disrupt the quality and quantity of water in nature. We present here results of a site investigation carried out on a small aquifer (15 km2) in the Swiss municipality of Fehraltorf, in the canton of Zürich. The purpose is to use novel site investigation and monitoring techniques to best characterize recharge in the anthropogenic environment, as well as the presence of emerging contaminants (pharmaceuticals, pesticides and biocides) from the city. Fehraltorf sources a large percentage of its water supply from the local glacio-fluvial aquifer, which signifies that any vulnerability of the local aquifer has major implications for human health. We give detail on the wireless sensor network being utilized as part of the groundwater monitoring network in Fehraltorf. Analysis from sampling campaigns of this network attempts to delineate sources and pathways of micropollutants into groundwater. Our approach puts emphasis on the relationship between land use and the hydrologic cycle on the sub-catchment scale. Significant uncertainties still exist in the understanding of land development and how it affects groundwater recharge, and our research attempts to make a contribution to better understand these dynamics

10. Fluctuations in regional groundwater volume as an on-line indicator for drought conditions

Groundwater shortage during drought periods will become more important in future and of relevance even in water-rich regions. Switzerland as considered Europe's water tower disposes of large groundwater resources in the range of 150 km3, but some problems may arise under extreme conditions, such as in 2018 with dramatic precipitation deficit over more than 6 months. Therefore, additional tools going beyond classical monitoring are needed to better characterize such situations and to improve the knowledge on the state and evolution of groundwater quantity on regional and national scales. An approach was developed accordingly for assessing dynamic groundwater volumes for Swiss unconsolidated porous aquifers, corresponding to areas of high water demand. Fluctuations in the regional groundwater volume are deduced from water level records in the framework of the national groundwater monitoring. Those are representative for typical groundwater settings and were linked to static groundwater estimates. Upscaling of normalized level amplitudes with respect to long-term mean values thereby allowed for the regionalization of the measurements. This provides complementary on-line information on the groundwater filling level, i.e. the ratio of volume variation and total volume, which in turn indicates sensitivity to drought. The spatial pattern of the filling level is of particular interest in low-level situations, and identifies actual and potential areas at risk. The example of 2018 illustrates the decrease and recovery of groundwater volumes in the different regions of the country, many of which are provided with sufficient reserves despite very low groundwater levels reached. The groundwater volume indicator in this context gives useful advice for characterizing the impact of drought conditions for the different groundwater regimes. It represents a tool for administrations and water managers to define critical low-level values and to adapt regional groundwater planning. This also implies infrastructural measures, such as the interconnection of differing water resources, in order to ensure water supply today and related to expected climate change scenarios.

11. Hydrogeological controls on dynamic groundwater storage in Alpine catchments

Recent studies suggest a shift of snow-influenced discharges towards earlier periods of the year and a concentration in time of the snow melt discharge. For water resources management, this seasonal pattern is particularly relevant, as shifts to lower flows in summer combined with increased water needs could lead to water shortage. The magnitude of change in discharge dynamics will most probably be influenced by the dynamic groundwater storage (DGS; part of groundwater contributing to streamflow) dynamics in alpine areas and buffer capacity of groundwater. However, the groundwater storage of these areas remains poorly understood.The main objective of this study is therefore to investigate groundwater storage dynamics in alpine catchments. DGS is firstly quantified for a selection of 14 small alpine catchments across the Swiss Alps using conceptual hydrological modelling and water balances. Results allow an evaluation on how groundwater storage influences the discharge regime under different hydrogeological conditions. Parameters controlling DGS are then identified and the dominant role of geology is highlighted. Finally, we discuss the hypothesis that catchments with higher DGS will show smaller changes in their discharge regime under future conditions due to the buffering effect of groundwater.

12. Conceptualization and calibration of anisotropic alluvial systems: Pitfalls and biases

Physical properties of alluvial environments typically feature a high degree of anisotropy and are characterized by dynamic interactions between the surface and the subsurface. Hydrogeological models are often calibrated under the assumptions of isotropic hydraulic conductivity fields and steady-state conditions. We aim at understanding how these simplifications affect predictions of the water table using physically based models and advanced calibration and uncertainty analysis approaches based on singular value decomposition and Bayesian analysis. Specifically, we present an analysis of the information content provided by steady-state hydraulic data compared to transient data with respect to the estimation of aquifer and riverbed hydraulic properties. We show that assuming isotropy or fixed anisotropy may generate biases both in the estimation of aquifer and riverbed parameters as well as in the predictive uncertainty of the water table. We further demonstrate that the information content provided by steady-state hydraulic heads is insufficient to jointly estimate the aquifer anisotropy together with the aquifer and riverbed hydraulic conductivities and that transient data can help to reduce the predictive uncertainty to a greater extent. The outcomes of the synthetic analysis are applied to the calibration of a dynamic and anisotropic alluvial aquifer in Switzerland (The Rhone River). The results of the synthetic and real world modeling and calibration exercises documented herein provide insight on future data acquisition as well as modeling and calibration strategies for these environments. They also provide an incentive for evaluation and estimation of commonly made simplifying assumptions in order to prevent underestimation of the predictive uncertainty.

13. Grundwasserschutz in urbanen Räumen der Schweiz

Viele von uns leben in dicht besiedelten urbanen Gebieten. Für die Schweiz betrachtet, liegen die Siedlungs- und Gewerbegebiete meist in den größeren Tälern und dem Mittelland, wo auch die bedeutenden Lockergesteinsgrundwasservorkommen sind. Dieses Grundwasser versorgt rund 80 % der Bevölkerung mit Trinkwasser. Für die Fassungen wurden in den 1970er und 1980er Jahren Schutzzonen (S1, S2 und S3) ausgeschieden. Die S2 soll möglichst frei von Nutzungen sein und dient dem Schutz vor mikrobiellen Verunreinigungen. Von deren Grenze soll das Grundwasser mindestens 10 Tage im Untergrund fließen, bis es zur Fassung gelangt.

Leider wurden die Fließzeiten des Grundwassers, die man für die Dimensionierung der Schutzzonen herangezogen hatte, in etlichen Fällen deutlich unterschätzt. Dies führt dazu, dass die überarbeiteten, nun hydrogeologisch korrekten Schutzzonen deutlich größer werden. In der Zwischenzeit sind jedoch auch die Siedlungsgebiete gewachsen, sodass Nutzungskonflikte vorprogrammiert sind.

Das schweizerische Bundesamt für Umwelt (BAFU) hat bei einer Umfrage in den Kantonen festgestellt, dass rund 1 Mio. Menschen in der Schweiz Trinkwasser von ungenügend geschützten Fassungen trinken. Alternative Standorte für diese Fassungen sind kaum zu finden, da ein Großteil der Flächen über den Grundwasserleitern bereits besiedelt ist. Wegen der Versorgungssicherheit müssen die Fassungen meist trotzdem weiter betrieben werden. Es gilt also, die noch zu schützenden Flächen für den Grundwasserschutz möglichst freizuhalten.

Was sind nun aber die Auswirkungen des mangelhaften Grundwasserschutzes auf die Grundwasserqualität? Ist es für die Trinkwasserkonsumenten wirklich ein Problem, wenn die Schutzzonen zu klein dimensioniert sind? Und was ist die richtige Bemessung für eine Schutzzone? Im Vergleich zu Deutschland und Österreich sind die Schutzzonen S2 in der Schweiz sehr klein bemessen.

In seltenen Fällen führen die zu kleinen Schutzzonen direkt zu fäkalen Verunreinigungen des Trinkwassers. Pumpwerke mit zeitweise größeren Verunreinigungen liegen praktisch ausschließlich flussnah mit einem bedeutenden Anteil an jungem Flusswasserinfiltrat. Jedoch findet man fast in jedem für Trinkwasser genutztem Grundwasser Mikroverunreinigungen. Gerade Haushaltchemikalien stammen hingegen nicht nur aus via Flüssen infiltriertem gereinigten Abwasser. Neuere Untersuchungen in der Nordwestschweiz zeigen, dass Medikamente, Lebensmittelzusatzstoffe und weitere Chemikalien auch über lecke Kanalisationen ins Grundwasser eingetragen werden und wesentlich zur allgemeinen Belastung beitragen können.

Die zu kleinen Schutzzonen bewirken also nicht per se eine Belastung des Grundwassers. Sie bilden aber einen kleineren natürlichen Filter und führen dadurch zu einer höheren Gefährdung. Diese manifestiert sich bis heute jedoch kaum. Bei Nutzungskonflikten durch die Erweiterung von Schutzzonen in urbanen Räumen sollen die Fassungen deshalb, sofern die Wasserqualität nicht negativ beeinflusst ist, nicht aufgegeben werden. Es sollen jedoch griffige technische Maßnahmen getroffen werden, um das Versickern von verschmutztem Abwasser sicher zu verhindern. Diese Aufgabe müssen die

Wasserversorgungen veranlassen und falls die Nutzungseinschränkungen für die Betreiber einer Anlage zu groß sind, auch finanzieren.

Die lokal begrenzen Maßnahmen in den Grundwasserschutzzonen reichen jedoch nicht aus. Für die Reduktion von Mikroverunreinigungen im Grundwasser braucht es einen wirkungsvollen Gewässerschutz. Dabei spielt die Zusammenarbeit der Akteure in verschiedenen Sektoren wie der Wasserwirtschaft, der Raumplanung und der Politik und von uns allen als Trinkwasserkonsumenten eine entscheidende Rolle.

14. Geothermal use of an Alpine aquifer-Davos pilot study

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. Based on data from a large pumping test, we were able to calibrate the hydraulic model and to calculate basics for various usage scenarios of energetic exploitation for the Arosa Dolomite aquifer. 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 manifold similar geological and hydrogeological settings of the Alpine belt.

15. Long-term transient groundwater pressure and deep infiltration in Alpine mountain slopes (Poschiavo Valley, Switzerland)

Bedrock aquifers in alpine catchments are important regional sources of freshwater. Data regarding bedrock groundwater-recharge processes are scarce and governing dynamics are poorly understood. The main datasets used to constrain regional groundwater recharge and flow, so far, have been based on indirect methods (environmental isotopes, river discharge rates, tunnel inflows). Here, a unique dataset is presented of long-term pore-water-pressure measurements from five deep boreholes situated in the upper reaches of a mountain slope at 1,500–2,300 m above sea level. In addition to multilevel pore pressure records, a detailed analysis of the hydrogeological conditions in the Alpine catchment is provided, along with the results from investigations of groundwater recharge mechanisms in response to variations in climatic conditions and hydraulic rock-mass properties. The recorded pressure data show annual pressure variations with amplitudes of 5–45 m and responses within a few days to summer rainstorms in the available depth range of 45–277 m below ground surface. One-dimensional analytical pore-pressure diffusion models and numerical infiltration models were applied to investigate pore-pressure dynamics and water-table variations. The model results reproduced the following parameters for the uppermost 100-m-thick layer: the observed amplitudes, rates and delays of pressure increase with porosities of 0.05–0.1%, specific storage of 5E-5 to 5E-7 m-1, and hydraulic diffusivities of 1E-1 to 1E-3 m2/s. Boreholes located in high-diffusivity areas (strongly fractured bedrock below coarse slope debris) had the strongest pressure variations and were most sensitive to weather conditions.

16. Spatiotemporal variability in hydrochemistry of shallow groundwater in a small pre-alpine catchment: The importance of landscape elements

Topography and landscape characteristics affect the storage and release of water and, thus, groundwater dynamics and chemistry. Quantification of catchment scale variability in groundwater chemistry and groundwater dynamics may therefore help to delineate different groundwater types and improve our understanding of which parts of the catchment contribute to streamflow. We sampled shallow groundwater from 34 to 47 wells and streamflow at seven locations in a 20-ha steep mountainous catchment in the Swiss pre-Alps, during nine baseflow snapshot campaigns. The spatial variability in electrical conductivity, stable water isotopic composition, and major and trace ion concentrations was large and for almost all parameters larger than the temporal variability. Concentrations of copper, zinc, and lead were highest at sites that were relatively dry, whereas concentrations of manganese and iron were highest at sites that had persistent shallow groundwater levels. The major cation and anion concentrations were only weakly correlated to individual topographic or hydrodynamic characteristics. However, we could distinguish four shallow groundwater types based on differences from the catchment average concentrations: riparian zone-like groundwater, hillslopes and areas with small upslope contributing areas, deeper groundwater, and sites characterized by high magnesium and sulfate concentrations that likely reflect different bedrock material. Baseflow was not an equal mixture of the different groundwater types. For the majority of the campaigns, baseflow chemistry most strongly resembled riparian-like groundwater for all but one subcatchment. However, the similarity to the hillslope-type groundwater was larger shortly after snowmelt, reflecting differences in hydrologic connectivity. We expect that similar groundwater types can be found in other catchments with steep hillslopes and wet areas with shallow groundwater levels and recommend sampling of groundwater from all landscape elements to understand groundwater chemistry and groundwater contributions to streamflow.

17. **Spatial variability in specific discharge and streamwater chemistry during low flows: Results from snapshot sampling campaigns in eleven Swiss catchments**

Catchments consist of distinct landforms that affect the storage and release of subsurface water. Certain landforms may be the main contributors to streamflow during extended dry periods, and these may vary for different catchments in a given region. We present a unique dataset from snapshot field campaigns during low-flow conditions in 11 catchments across Switzerland to illustrate this. The catchments differed in size (10 to 110 km(2)), varied from predominantly agricultural lowlands to Alpine areas, and covered a range of physical characteristics. During each snapshot campaign, we jointly measured streamflow and collected water samples for the analysis of major ions and stable water isotopes. For every sampling location (basin), we determined several landscape characteristics from national geo-datasets, including drainage area, elevation, slope, flowpath length, dominant land use, and geological and geomorphological characteristics, such as the lithology and fraction of quaternary deposits. The results demonstrate very large spatial variability in specific low-flow discharge and water chemistry: Neighboring sampling locations could differ significantly in their specific discharge, isotopic composition, and ion concentrations, indicating that different sources contribute to streamflow during extended dry periods. However, none of the landscape characteristics that we analysed could explain the spatial variability in specific discharge or streamwater chemistry in multiple catchments. This suggests that local features determine the spatial differences in discharge and water chemistry during low-flow conditions and that this variability cannot be assessed a priori from available geodata and statistical relations to landscape characteristics. The results furthermore suggest that measurements at the catchment outlet during low-flow conditions do not reflect the heterogeneity of the different source areas in the catchment that contribute to streamflow.

18. **Groundwater assessment platform (GAP): A new GIS tool for risk forecasting and mitigation of geogenic groundwater contamination**

Over 400 million people worldwide use groundwater contaminated with arsenic and/or fluoride as a source of drinking water. The Swiss Federal Institute of Aquatic Science and Technology (Eawag) has developed a method to estimate the risk of contamination in a given area using geological, topographical and other environmental data without having to test samples from every single well. The research group's knowledge is now being made available free of charge on the interactive Groundwater Assessment Platform (GAP, www.gapmaps.org). GAP is an online GIS platform for risk forecasting and mitigation of geogenic groundwater contamination. GAP enables researchers, authorities, NGOs and other professionals to visualize their own data and generate hazard risk maps for their areas of interest.

19. **Half a century of Krypton-85 activity concentration measured in air over Central Europe: Trends and relevance for dating young groundwater**

For almost half a century weekly samples for the measurement of krypton-85 (Kr-85) activity concentrations in surface air have been collected by the Bundesamt fur Strahlenschutz (BfS), Germany. Sampling started at Freiburg (230m asl) in 1973, Mt Schauinsland (1205m asl) in 1976 and Mt Jungfraujoch in Switzerland (3454 asl) in 1990. Distinct maxima in the time series of atmospheric Kr-85 activity concentration are caused by emissions from nuclear reprocessing plants in Europe, mainly the La Hague, France, and Sellafield, UK, reprocessing plants. Between 1970 and 1990 peak activity concentrations measured in winter along the Rhine Rift in Freiburg are often higher than at Mt Schauinsland, due to emissions from the operating pilot reprocessing plant in Karlsruhe - approximately 130 km to the north - and large-scale inversions that inhibit exchange of air masses within the Rhine Rift with those at higher altitudes. From the early 1990s onwards, after the shut-down of the pilot plant, differences between Freiburg and Schauinsland are much smaller. Activity concentrations measured at Jungfraujoch are generally lower and close to baseline levels, due to its location in the free troposphere. Weekly baseline and average Kr-85 activity concentration in the atmosphere in Central Europe were modelled from almost 12,000 individual measurements at 11 stations. The baseline and average have continuously increased, interrupted by a relatively stable period between 2009 and the end of 2014 with a baseline activity concentration of about 1.39 Bq/m(3). Depending on the geographical location and hydrological conditions, the modelled baseline or average Kr-85 activity concentration time series can be used as input functions for the dating of young groundwater.

20. High-resolution spatial sampling identifies groundwater as driver of CO2 dynamics in an alpine stream network

Inland waters are major sources of CO2 to the atmosphere. The origin of this CO2 is often elusive, especially in high-altitude streams that remain poorly studied at present. Here we study the spatial and seasonal variations in streamwater CO2, its potential sources and drivers in an Alpine stream network (Switzerland). High-resolution sampling combined with stable isotope analysis and mixing models enabled us to capture the fine-scale spatial heterogeneity in streamwater pCO(2) as the stream network expanded and contracted during seasons. We identified soil respiration as a major source of CO2 to the stream. We also identified a major groundwater upwelling zone as an ecosystem control point that disproportionately influenced stream biogeochemistry. This was particularly pronounced when the stream network expanded during snowmelt, when it covered a five times larger area compared to winter (35,300 m(2) compared to 7,100 m(2)). Downstream from this control point, CO2 evaded rapidly owing to high gas transfer velocity. The stream network was a net source of CO2 to the atmosphere with an average areal evasion flux of 30.1 (18.0-43.1) mu mol.m(-2).s(-1) and a total flux at network scale ranging from 237 (141-339) kg C/day in winter to 1793 (1069-2565) kg C/day during spring snowmelt. Our study highlights the role of stream network dynamics and control points for the CO2 dynamics in high-altitude streams.

21. Assessment of the effects of wastewater treatment plant effluents on receiving streams using oligochaete communities of the porous matrix

Human activities can disturb the natural dynamics of exchanges between surface water and groundwater in rivers. Such exchanges contribute to the self-purification of the environment and an excess of infiltration can lead to contamination of groundwater. In addition, the porous matrix (coarse surface sediments and hyporheic zone), through which water exchanges occur, is a sink for pollutants. For environmental monitoring programs, it is therefore essential to take into account both the dynamics of vertical hydrological exchanges and the biological quality of this matrix. The functional trait (FTR) method, which is based on the study of oligochaete communities in coarse surface sediments and the hyporheic zone, was proposed as a tool to simultaneously assess the dynamics of vertical hydrological exchanges and the effects of pollutants present in the porous matrix. Here, we applied this method during two different periods (in March and September 2016), upstream and downstream of locations affected by discharges from wastewater treatment plants (WWTP) located in Switzerland. The biological quality of surface sediments and the hyporheic zone was shown to be better upstream of the WWTP in both campaigns. In addition, results suggested that the capacity for self-purification was lower downstream of the WWTP, and that groundwater at these locations was vulnerable to pollution by surface water. The FTR method proved valuable as a field method for detecting the effects of point source contamination on receiving streams. In the near future, this community-based approach will benefit from advances in the use of DNA barcodes for oligochaete species identification.

22. High stream intermittency in an alpine fluvial network: Val Roseg, Switzerland

More than one-third of the world's rivers cease to flow and go dry on a periodic basis-so-called intermittent rivers. The frequency and duration of flow intermittency in running waters are increasing due to climate change and water demands for human use. Intermittency effects on stream biodiversity and ecosystem functioning are dramatic and are expected to become increasingly prevalent in alpine landscapes in the near future. This project used modified field sensors to measure flow intermittency, temperature, and water origin (groundwater, precipitation, glacier) at high spatio-temporal resolution throughout an alpine fluvial network (Val Roseg, Switzerland). We continuously recorded water presence in 30 tributary streams and validated sensor performance with field-collected measures. Three different flow regimes were observed in the network, including periodically intermittent, seasonally intermittent, and permanently flowing streams. Twenty-four streams (80% of recorded streams) dried at least once during the sampling period. Principal components analysis along with generalized additive models showed alpine streams with low average temperature and high conductivity (groundwater-fed) were prone to permanent flow, whereas streams with higher average temperature and low conductivity (glacier-fed) typically had intermittent flow. The field sensors proved precise for simultaneously measuring flow intermittency, temperature, and water origin at high resolution throughout the river network. Overall, this approach provides an effective way to develop eco-hydrological models that examine the effects of flow intermittency on biodiversity and ecosystem functioning in riverine networks.

23. Extremeness of recent drought events in Switzerland: dependence on variable and return period choice

The 2018 drought event had severe ecological, economic, and social impacts. How extreme was it in Switzerland? We addressed this question by looking at different types of drought, including meteorological, hydrological, agricultural, and groundwater drought, and at the two characteristics deficit and deficit duration. The analysis consisted of three main steps: (1) event identification using a threshold-level approach, (2) drought frequency analysis, and (3) comparison of the 2018 event to the severe 2003 and 2015 events. In Step 2 the variables precipitation, discharge, soil moisture, and low-flow storage were first considered separately in a univariate frequency analysis; pairs of variables were then investigated jointly in a bivariate frequency analysis using a copula model for expressing the dependence between the two variables under consideration. Our results show that the 2018 event was especially severe in north-eastern Switzerland in terms of soil moisture, with return periods locally exceeding 100 years. Slightly longer return periods were estimated when discharge and soil moisture deficits were considered together. The return period estimates depended on the region, variable, and return period considered. A single answer to the question of how extreme the 2018 drought event was in Switzerland is therefore not possible - rather, it depends on the processes one is interested in.

24. Long-term effects of deep-seated landslides on transportation infrastructure: a case study from the Swiss Jura Mountains

Deep-seated landslides (DSLs) involve large-scale deformation and likely affect transportation infrastructure. Movement rates are in general very slow (less than a metre per year) with acceleration periods controlled by external factors such as the seasonal fluctuation of groundwater pressure. Acceleration response may change from season to season depending on hydrogeological conditions, changes in slope geometry and degradation of geological materials. More localized landslide types are associated with and develop within DSLs, such as rock falls, topples and debris slides. Management of hazards related to DSLs requires first the assessment of geological, hydrogeological and geomechanical processes. This is the starting point for developing a management strategy. This paper presents the characterization of a deep-seated landslide located in the Swiss Jura Mountains, Les Buges landslide, where a railway line, a power line and an aqueduct of regional importance cross the slide, as well as a highly frequented hiking trail beneath the landslide toe. Slide kinematics is governed by the geology and hydrogeology of the slope, which can be subdivided into two dominant bodies. A management strategy is subsequently discussed for this DSL. Les Buges is a good example illustrating that hazards related to deep-seated landslides must be tackled first of all by means of the observational method.

25. Quantification of subsurface hydrologic connectivity in four headwater catchments using graph theory

Hillslope-stream connectivity significantly affects streamflow and water quality responses during rainfall and snowmelt events, but is difficult to quantify. One approach to quantify subsurface hillslope-stream connectivity is graph theory, which considers linear connections between groundwater measurement sites. We quantified subsurface connectivity based on surface topography and shallow groundwater data from four small (<14 ha) headwater catchments in the Italian Dolomites and the Swiss pre-Alps, determined the relation between rainfall, antecedent wetness conditions and subsurface connectivity and assessed the sensitivity of the results to changes in the measurement network. Event total stormflow was correlated to maximum subsurface connectivity. Subsurface connectivity increased during rainfall events but maximum connectivity occurred later than peak streamflow, resulting in anti-clockwise hysteretic relations between the two. Subsurface connectivity was positively correlated to rainfall amount. Maximum subsurface connectivity was related to the sum of total rainfall plus antecedent rainfall for the Dolomitic catchments, but these relations were less clear for the pre-alpine catchments. For the pre-alpine catchments, the fractions of time that the groundwater monitoring sites were connected to the stream were significantly correlated to the upslope site characteristics, such as the Topographic Wetness Index. For the Dolomitic catchments, the fractions of time that the monitoring sites were connected to the stream were correlated to the topographic characteristics of the upslope contributing area for the catchment with the small riparian zone, and with the distance to the nearest stream for the catchment with the large riparian zone. The leave-one-out sensitivity analysis showed that small changes in the structure of the groundwater monitoring networks had a limited influence on the results, suggesting that graph-theory approaches can be used to describe subsurface hydrologic connectivity. However, the proposed graph-theory approach should be verified in other catchments with different groundwater monitoring networks

26. New relevant pesticide transformation products in groundwater detected using target and suspect screening for agricultural and urban micropollutants with LC-HRMS

Groundwater is a major drinking water resource, but its quality is threatened by a broad variety of anthropogenic micropollutants (MPs), originating from agriculture, industry, or households, and undergoing various transformation processes during subsurface passage. To determine a worst case impact of pesticide application in agriculture on groundwater quality, a target and suspect screening for more than 300 pesticides and more than 1100 pesticide transformation products (TPs) was performed in 31 Swiss groundwater samples which predominantly originated from areas with intensive agriculture. To assess additional urban contamination sources, more than 250 common urban MPs were quantified. Most of the screened pesticide TPs were experimentally observed by the pesticide producers within the European pesticide registration. To cover very polar pesticide TPs, vacuum-assisted evaporative concentration was used for enrichment, followed by liquid chromatography high-resolution tandem mass spectrometry (LC-HRMS/MS). Based on intensity, isotope pattern, retention time, and in silico fragmentation, the suspect hits were prioritised and verified. We identified 22 suspects unequivocally and five tentatively; 13 TPs are reported here for the first time to be detected in groundwater. In 13 out of 31 groundwater samples, the total concentration of the 20 identified and quantified suspects (1 pesticide and 19 pesticide TPs) exceeded the total concentration of the 519 targets (236 pesticides and TPs; 283 urban MPs) for which we screened. Pesticide TPs had higher concentrations than the parent pesticides, illustrating their importance for groundwater quality. The newly identified very polar chlorothalonil TP R471811 was the only compound detected in all samples with concentrations ranging from 3 to 2700 ng/L Agricultural MP concentration and detection frequency correlated with agricultural land use in the catchment, except for aquifers, where protective top layers reduced MP transport from the surface. In contrast to agricultural MPs, urban MPs displayed almost no correlation with land use. The dominating entry pathway of urban MPs was river bank filtration.

27. Groundwater storage in high alpine catchments and its contribution to streamflow

There is limited knowledge about groundwater storage in alpine catchments, although it might strongly influence how these catchments react to earlier snowmelt due to climate change. The objective of the study was to develop and test a method to quantify seasonal groundwater storage in alpine catchments and evaluate how groundwater storage is related to hydrogeological properties. As representative water table observations are challenging to acquire in such environments, we used a water balance approach targeting the main snowmelt period when most groundwater recharge is expected to occur. Based on a detailed quantification of the snow water equivalent at the onset of snowmelt combined with discharge measurements, it is possible to quantify groundwater storage with a low uncertainty even if other terms of the water balance are less well constrained. The application of the method to an 11-km2 research catchment revealed a large seasonal increase of groundwater storage by 300 mm or 45% of the premelt snow water equivalent. An independent quantification of groundwater storage depletion during the 7-month-long recession period provided a similar value of 330 mm, demonstrating that the stored groundwater is available to sustain streamflow. At the end of the recession, catchment outflow still amounted to 0.9 mm/day with a composite bedrock aquifer providing a disproportionally high share as demonstrated by hydrochemical data. The study demonstrates that high alpine aquifers can seasonally redistribute water and stabilize catchment outflow in an otherwise very dynamic environment and thus might strongly influence the response of such catchments to climate change.

28. From points to patterns: Using groundwater time series clustering to investigate subsurface hydrological connectivity and runoff source area dynamics

Groundwater levels are typically measured at only a limited number of points in a catchment. Thus, upscaling these point measurements to the catchment scale is necessary to determine subsurface flow paths and runoff source areas. Here we present a data-driven approach composed of time series clustering and topography-based upscaling of shallow, perched groundwater dynamics using groundwater data from 51 monitoring sites in a 20-ha prealpine headwater catchment in Switzerland. The agreement between the upscaled (modeled) and measured groundwater dynamics was strong for most of the 19-month study period for the upslope and footslope locations but weaker at the beginning of events and for the midslope locations. However, these differences between measured and modeled groundwater levels did not significantly affect modeled groundwater activation, that is, the time when groundwater levels were within the more transmissive soil layers near the soil surface. The resulting groundwater activation maps represent the groundwater response across the catchment and highlight the dynamic expansion and contraction of the subsurface runoff source areas, particularly along the channel network. This is in agreement with the variable source area concept. However, there were also isolated active zones that did not get connected to the stream during rainfall events, highlighting the need to distinguish between variable active and variable stream-connected runoff source areas. Our data-driven approach to upscale point measurements of shallow groundwater levels appears useful for studying catchment-scale variations in groundwater storage and connectivity and thus may help to better understand runoff generation in mountain catchments.

Plain Language Summary For a better understanding of how runoff in streams is generated, we need to know how groundwater levels respond across a catchment. However, groundwater can usually only be measured at a few selected points, and interpolation between these points does often not result in realistic groundwater response patterns. Here we present a data-driven approach based on groundwater level data from 51 sites in a catchment in Switzerland for a 19-month study period. We grouped the monitoring sites into six clusters with similar groundwater level dynamics. We then determined the topographic characteristics of the sites in each cluster and assigned the average relative groundwater level for the monitoring sites in a cluster to all other sites in the catchment with similar topographic characteristics. By doing so, we created sequences of maps of groundwater levels across the entire study catchments. These maps show an expansion and contraction of the areas where the groundwater level is close to the surface and which of these areas are connected to the stream channels. These maps are useful to identify from which parts of the catchment streamwater may come during a rain event, which helps to improve our understanding of runoff generation processes.

29. Field comparison of DNA-labeled nanoparticle and solute tracer transport in a fractured crystalline rock

Field tracer experiments were conducted to examine tracer transport properties in a fracture-dominated crystalline rock mass at the Grimsel Test Site, Switzerland. In the experiments reported here, both the DNA nanotracers and solute dye tracers were simultaneously injected. We compare the transport of DNA nanotracers to solute dye tracers by performing temporal moment analysis on the recorded tracer breakthrough curves and estimate the swept volumes and flow geometries. The DNA nanotracers, approximately 166 nm in diameter, are observed to travel at a higher average velocity than the solutes but with lower mass recoveries, lower swept volumes, and less dispersion. Moreover, size exclusion and potentially, particle density effects are observed during the transport of the DNA nanotracers. Compared to solute tracers, the greatest strength of DNA nanotracers is the demonstrated zero signal interference of background noise during repeat or multitracer tests. This work provides encouraging results in advancing the use of DNA nanotracers in hydrogeological applications, for example, during contaminant transport investigations or geothermal reservoir characterization.

17th Swiss Geoscience Meeting

30. Arsenic removal from manganese-containing groundwaters using Fe(0) electrocoagulation - modelling

Arsenic (As) occurs naturally in some groundwaters that serve as the main source of drinking water for people worldwide, especially in South-East of Asia (Bengladesh, India, etc.). This large-scale contamination of groundwater and the high toxicity and carconegicity of As is responsible for millions of deaths around the world. Therefore, strategies to remove As from water using efficient and low-cost treatement systems are critically needed. Iron(0) electrocoagulation (EC) has gained attention as a low-cost method for As removal from groundwater because it has short supply chain and low energy requirements (small solar panels or car battery provide sufficient power) and, is easy to operate. In EC, a current is passed through an Fe(0) electrode, such that Fe(0) is oxidized to Fe(II). The production of Fe(II) generates reactive oxidants that readily oxidize As(III) to As(V) – a less toxic form of As, and Fe(II) to Fe(III), which forms nanoscale iron precipitates that remove As from solution (Li et al., 2012 ; Nidheesh and Singh, 2017). However, the mechanism and efficiency of As removal depend strongly on the chemical composition of the groundwater.

The co-occurrence of high concentrations of As and Mn has been documented in several places, including the Peruvian Amazon (de Meyer et al., 2017). Recent work shows that like As,3 Mn(II) can be removed from water using an EC system through the oxidation of Mn(II) to Mn(III) by reactive oxidants (i.e., OH● or Fe(IV)) and its incorporation into Fe oxides (Hug and Leupin, 2003). These studies suggest that As and Mn compete for the same pool of oxidants in an EC system and, therefore that the efficiency of As removal may be lowered by the presence of Mn. The main goal of this work is thus to understand the extent to which As and Mn are removed during EC when aqueous As(III) and Mn(II) are initially present in the groundwater. In addition, knowledge of the speciation of As and Mn in the solid phase is needed in order to understand the mechanism of contaminant removal (oxidation and sorption) at the different conditions (concentrations of Mn, pH, oxidants). Finally, based on our results, the mechanisms of oxidation of As, Fe and Mn by Fe(IV) and OH● will be modeled in order to simulate diverse Mn- and As-containing waters.

In this study, experiments were conducted using a simple NaCl/HCO3- electrolyte with either 10 and 100 µM As(III) and 0 and 100 Mn(II) at pH values 4.5, 6.5 and 8.5. In addition, 250 µM H2O2 was added to the experiments to favor the production of OH● and Fe(IV) oxidants instead of O2●-, which does not oxidize As(III) at appreciable rates relative to OH● and Fe(IV). All the experiments were conducted in triplicate and speciation of the aqueous and solid phase (as determined by X-ray absorption spectroscopy, Stanford Synchrotron Radiation Lightsource, BL 4-1) followed over time for 32 minutes.

Results showed that in the absence of Mn, the 10 µg L-1 (WHO recommendation) is achieved at pH 4.5 and 6.5 but would require longer time of EC at pH 8.5. Arsenic oxidation was quasi complete after 32 min of EC for all pH. In the presence of Mn, the kinetics and mechanism of As removal varied but still reached As levels below the WHO limit for pH 4.5.Specifically, As in the aqueous and solid phase showed greater As oxidation at pH 4.5 (by OH●) than at pH 8.5 (by Fe(IV)), whereas, greater Mn oxidation was observed at pH 8.5 than at pH 4.5. While Mn(II) oxidation to Mn(III,IV) by Fe(IV) competes with As(III) oxidation to As(V), favorable As(III) sorption allowed for As removal from solution. This work shows that the kinetics of As and Mn oxidation and mechanisms of removal from the aqueous phase to the solid phase vary strongly according to the type of oxidant present in the system (e.g., OH● and Fe(IV), respectively). Furthermore, these data can be used to constrain the constants of oxidation of Mn by OH● and Fe(IV), which are needed before a kinetic model to predict As removal.

31. Assessing fault criticality using seismic monitoring and fluid pressure analysis

Better understanding fault criticality, the proximity of a fault to shear failure, is of primary interest when planning underground projects. Stress perturbations in the surroundings of a critically stressed fault, resulting from human activities, can affect the fault's stability – and eventually lead to a forced interruption of projects due to seismic risk. Changes in the stress state also occur naturally. It has been observed (Miller 2008) that in karstic regions, an increase in groundwater pressure following significant recharge (precipitations and/or seasonal snowmelt) can result in a fault reactivation, inducing microseismicity.

The aim of this study is to combine the natural microseismicity and groundwater level fluctuations observations to estimate the fault criticality. The research is carried out on two major strike-slip faults on the northern shore of Lake Neuchâtel (Fig.1) – La Lance Fault and La Ferrière Fault – most likely critically stressed according to their position in the global stressregime. Data acquisition mainly consists in hydrogeologic and seismic monitoring. The objectives are to have continuous discharge rates of the major karstic springs and to produce a seismic catalog for the area of interest. Combining both data sets will allow to determine relations between increasing spring discharge rates and low magnitude earthquakes and eventually to acquire a quantitative knowledge on what pressure change is affecting the fault's stability. This knowledge will be used to develop a straighforward methodology to assess fault criticality. In addition, the study of a possible time lag between aquifer response and fault activation, as well as back-analysis of seismic events can provide, respectively, important information about the deep-seated fluid circulation and the local stress-regime.

32. Different lacustrine pockmark systems in Lake Thun, Switzerland, and their potential influence on the hydrological and biogeochemical budget of the lake

Pockmarks are crater-like depressions formed by upward transport of fluid and gas through the unconsolidated sediment column. The fluid flow through marine pockmarks is considered to enhance hydrological and biogeochemical exchanges between the water column and the seafloor. While a similar relevance can be expected in lakes, the importance of lacustrine pockmarks in this regard is virtually unexplored.

Lake Thun is an excellent system to study lacustrine pockmarks as it exhibits several sites with different sedimentological and biogeochemical regimes. The Daerligen pockmark site, which is located close to the mouth of the Aar river, is characterized by evident signs of methane (CH_4) ebullition, and high CH_4 concentration from ~2.4 to 8.9 mM within the sediments. At Tannmoos, spikes in electrical conductivity detected during a survey with a remotely operated vehicle (ROV) indicate a hydrological connection with the groundwater system in the Triassic bedrock. The third pockmark site is located adjacent to the rock wall of the Beatenberg karst system and might thus be associated with large groundwater discharge into the lake.

Further biogeochemical and molecular analyses (e.g. 16S rRNA sequencing) of the sediments and the water column will help to better assess the influence of methane emission and groundwater discharge via these pockmarks on the biogeochemistry and microbial community of the lake, as well as to expand our limited knowledge on the mechanism of lacustrine pockmarks in general.

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

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 modelbased) 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.

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

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 understimated 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.

35. Flow path characterization at the Grimsel Underground Rock Laboratory using solute tracer tests

The sustainable development and utilization of geothermal energy is one of the recommended approaches to meet the increasing demand for global renewable energy. In particular, Switzerland has set an ambitious goal of increasing the supply of electricity from deep geothermal energy from 0 to 4.4 TWh by 2050. It is known that the productivity of a geothermal reservoir is strongly influenced by the characteristics of flow paths between the injection and the production wells. In this study, we report solute tracer tests that were conducted as part of a pre- and post-stimulation hydraulic characterization of the In-Situ Stimulation and Circulation (ISC) experiment at the Grimsel Underground Rock Laboratory in Switzerland. Our tracer tests aim at understanding and characterizing the changes in the hydraulic properties controlling fluid flow in the fractured crystalline rock mass induced by hydraulic stimulation.

During the ISC experiments, a total of nine solute tracer tests were conducted in the manner of the cross-well short-pulse test framework. These nine experiments yielded 5 and 18 tracer breakthrough curves (BTCs) before and after the hydraulic stimulations, respectively. Analysing the tracer BTCs and their intrinsic temporal moments, we delineate hydraulic properties of the connected flow paths in the fractured crystalline rock mass before and after the hydraulic stimulation. Our analyses focus on the tracer residence time distribution curves and the spatial distribution of hydraulic conductivities evaluated by tomographic inversion. The calculated tracer swept volumes increased considerably at all three monitoring locations, suggesting that new and/or additional flow paths were accessed by the tracers after the hydraulic stimulations. Moreover, the tomographic inversion of the hydraulic conductivity distribution indicated an increase in the geometric mean of hydraulic conductivity and a decrease in the heterogeneity of hydraulic conductivity distribution. These observations suggest that the stimulated rock volume became hydraulically more conductive, where the injected fluid travelled through fractures with higher hydraulic conductivities than before hydraulic stimulations. Our study provides a valuable framework for field-scale geothermal reservoir characterizations.

36. Geochemical characterization of deep geothermal waters circulation in carbonatic geothermal reservoirs of the Geneva Basin (GB)

This study focuses on the interpretation of geochemical data collected at springs and at two deep geothermal exploration wells located on the edges and within the Geneva Basin (GB Canton of Geneva, Switzerland). The sampling sites have been selected across one North-South trending sections following the main groundwater flow from the recharge zone to the deep geothermal reservoirs in the Mesozoic carbonatic units. These formations have been drilled by two geothermal exploration wells; the 745 m deep GEO-01 well, where water with a temperature of 34°C and an artesian flow rate of 50l/s is encountered, and at the 2530 m deep Thonex-01 well, which produces app. 0.1 l/s by artesian flow at reservoir temperature of 80°C. Major ions, trace elements, stable isotopes of Oxygen and Hydrogen, Tritium, Sulphur and Carbon isotopes as well as noble gas samples have been collected and analysed. The analyses aim at characterizing the fluid circulation in terms of recharge zone, origin of the water, mean residence times, reservoir temperature, and water-rock interactions. The interpretations show that the geothermal waters have a meteoric origin with the main recharge zone being located in the Jura Mountains towards the North. The infiltration is dominated by secondary porosity controlled by intense fracture conditions. Infiltrating water circulates in the Mesozoic Units and the groundwater flow direction is controlled by the geometry of these formations, which gently dip towards south with a 3° average dip. Fracture zones associated to subvertical strike- slip faults represent the main corridors where waters as well as hydrocarbons and dissolved gas rise towards the surface. Moreover, the highly porous and permeable karstified horizons at the Lower Cretaceous level and the reef complex in the Upper Jurassic represent very promising potential geothermal reservoirs across the whole Geneva Canton for heat production with temperatures ranging from about 30°C to more than 110°C.

37. Geochemical evidence for large-scale and long-term topography-driven groundwater flow in orogenic crystalline basements

Detailed knowledge about the circulation of meteoric water in amagmatic, orogenic belts is fundamental for assessing the potential of such settings for geothermal power production. To get more general insight into these large-scale hydrological processes, we have conducted large-scale (20 x 10 x 9 km) thermal-hydraulic-chemical (THC) simulations of meteoric water circulation in the orogenic, crystalline basement of the Aar Massif in the Central Alps, Switzerland. Model results were compared to numerous geochemical and isotopic analyses of groundwater discharging into the longest and deepest tunnel of the world, the Gotthard railbase tunnel located within the model domain. Explicitly considering the surface topography and stable water isotopologues in our model was sufficient to reproduce all key characteristics of the tunnel inflows (e.g. salinity and temperature distribution, tunnel discharge rates, $\delta^{18}O$ values, up- and downward directed flow zones inferred from geochemical constraints). This quantitatively confirms that surface topography operates as the governing control on fluid flow in orogenic crystalline basements with meteoric water infiltration occurring at high altitude and resulting upward directed flow zones (i.e. exfiltration) along major valleys. Owing to the low flow rates (<2 m/year), computed residence times of the longest flow paths were above 100 k years, confirming that groundwater and/or porewater in orogenic crystalline basements may act as an archive for palaeohydrologic variations. Moreover, simulation results show that down to the lower model boundary at 9 km depth, penetration of meteoric water is not limited by the decrease in permeability with depth that is typically observed in granitic rocks. This suggests that advective fluid transport in orogenic crystalline basement likely reaches the brittle-ductile transition zone. Without the occurrence of major fault zones, however, the permeability and hence the flow rates are too low for the formation of major thermal anomalies despite that meteoric water attains temperature well above 150 °C during such deep circulation. Nevertheless, based on the upward directed flow zones identified along major valleys our simulations suggest that positive temperature anomalies preferentially form when steeply-dipping, major faults zones with elevated permeability intersect with valley floors. Since such conditions are frequently found in the Alps as manifested by the occurrence of thermal springs, we conclude that orogenic geothermal systems are promising plays for geothermal power production.

38. Geothermal use of an Alpine aquifer – Davos pilot study

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.

39. Getting the most out of environmental tracers in complex alluvial systems

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.

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

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 lakewide 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

41. Groundwater and discharge regime evolution with climate change in Alpine catchments

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.

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

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.

43. Identifying sources and processes impacting groundwater recharge in the human environment

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 dissention) of the conclusions drawn from micropollutant data. From these analyses, a conceptual model of the modified water cycle in this catchment is offered.

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

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.

45. JuraHydroSlide: identifying the principal hydrogeologic ingredients for predicting landslide activity in Jura Mountains

Landslides phenomena are a type of natural hazard that can compromise people’s safety and infrastructures, especially in mountainous areas. Each year in Switzerland, several accidents and damage to infrastructure are recorded in the Alps, on the Plateau or in the Jura massif due to landslide activities. Thus, in 2018, landslides have been introduced in the governmental program for protecting and alerting the Swiss population against natural hazards. However, large-scale predictions of landslide activity can be tedious and complex due to their high dependence on local rock and soil properties, as well as environmental conditions. In addition, monitoring systems of slope deformation for anticipating incipient failure or enhanced slope activity are simply too expensive for covering large spatial and temporal scales. Thus, the objective of the JuraHydroslide project is to find alternative hydrogeologic indicators and develop innovative tools for making short- and long-term predictions of landslide activity in the Jura Mountains, as well as assess the interaction between karst systems and slope stability. The study sites are distributed along the Jura massif to cover several types of landslides, such as permanent deep-seated landslides, superficial spontaneous landslides, peat landslides or rock avalanches. Particular attention will be paid to the role of groundwater in these different landslide phenomena, especially in the triggering and propagation aspects of these natural processes. The pre-historic Chasseral landslide (Nods, BE), described as a rock avalanche, takes part in the first development step of the JuraHydroslide project, by exploring its geometrical properties, via the acquisition and processing of Electrical Resistivity Tomographies (ERT).This permits the assessment of pre-failure and post-failure geologic and hydrogeologic conditions. Hence, this landslide was studied in order to precisely assess the thickness of the deposit area along multiple ERT cross sections, the source and deposit volumes, the travel angle, the travel distance and the mean flow velocity (Fig. 1). These field data will be used to constrain numerical models of slope stability and landslide propagation for evaluating and better understanding the triggering and propagation mechanisms.

46. KMC: a comparison of various models for assessing karst hydrology

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.

47. Modelling recharge by precipitation at the Swiss scale

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 collum 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 collum, 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. Subsequnetly, 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.

48. Regional scale models of fluid flow in the orogenic hydrothermal system at Grimsel Pass, Switzerland

Thermal waters at temperatures ranging between 17 - 28 °C discharge at a rate of ≤ 10 L/min into a tunnel underneath Grimsel Pass (2164 m) in the Central Alps. Fluid discharge occurs at the intersection with a brecciated fault zone (Grimsel Breccia Fault (GBF)), a late Neogene exhumed strike-slip fault (Belgrano et al, 2016). The chemical composition of the water sampled in the tunnel shows that the water is a mixture of old geothermal water and younger cold water. Both components have meteoric isotope signatures, but the thermal water is derived from a higher altitude. Residence times of the old and young waters are ≤30 ky and ~7 years, respectively (Waber et al., 2017).

The breccia in the GBF formed about 3 Ma years ago. It shows hydrothermal alteration by heated meteoric water at about 165 °C (Hofmann et al., 2004). However, results from Na-K geothermometry on present-day fluid samples indicate the maximum temperature at depth could be as high as 250 °C. Given the local geothermal gradient this corresponds to a circulation depth of meteoric water to at least 9 km (Diamond et al., 2018).

The breccia in the GBF has a sub-vertical, pipe-like structure in 3D, and it constitutes a permeable linkage zone between parallel segments of the main shear-zone. Another such linkage zone exists in the Sidelhorn area to the west (Belgrano et al., 2016). Thus, it can be expected that these permeable linkage zones are common structural features along the fault. In this study we use numerical modelling to better understand the regional flow system leading to discharge of thermal water at Grimsel Pass. Questions we aim to answer include the following:

1) What is the role of the GBF in generating upflow under Grimsel Pass? 2) What causes infiltration of meteoric water to a depth of at least 9 km? 3) What is the permeability (k) of the fault and its permeability distribution that reproduces flow rates and temperatures observed at the thermal springs? 4) What conditions induce mixing of the ascending hydrothermal fluid with shallow groundwater at mixing ratios observed at the springs?

To answer these questions a thermal-hydraulic model was constructed, using the high performance reactive transport code PFLOTRAN (www.pflotran.org). The model incorporates the topography of the region as the top boundary and extends to a depth of 12.5 km. The upflow zone at Grimsel Pass is incorporated as a vertical permeable conduit (k = 1e-13 m2) within a low permeability granitic rock (k = 3e-20 m2).

Simulations confirm that the GBF, if represented as an unconfined permeable vertical plane extending into the high mountains towards the west and to depths of 12.5 km, can sustain hydrothermal upflow at Grimsel Pass. The driving force of flow is the increase in recharge elevation towards the west. The infiltration of meteoric recharge becomes progressively deeper towards the west and can easily exceed the 9 km circulation depth consistent with geochemical evidence (Fig. 1A). The region around Lake Oberaar constitues a broad discharge zone of groundwater from shallower depths (Fig. 1) which indicates a (relatively minor) contribution of groundwater to the source of the river Aare. Local hill-and-valley topography induces shallow groundwater flow which at Grimsel Pass leads to mixing of the ascending thermal water with cold meteoric water recharging in the Sidelhorn area. This type of mixing is consistent with geochemical evidence from the thermal springs.

Models calibrated to match discharge rates and temperatures at the thermal springs suggest permeabilities of the GBF between 1e-15 m2 and 1e-14 m2. At permeabilities exceeding 5e-15 m2 (fault-zone width of 100 m), the flow system in the fault becomes unstable and convection cells begin to form which induce transient flow and transient temperature conditions at the discharge site.

Although meteoric water can infiltrate the fault to depths > 9 km without permeability forcing (e.g. a homogeneous permeability distribution), results indicate that significant mixing of fluids from different circulation depths occurs in the upflow zone (Fig. 1A). This is inconsistent with obervations which suggest a distinct geochemical signature of the spring water acquired at a depth > 9 km. To preserve this signature, mixing during upflow has to be minimal. We propose a permeable pipe-like breccia zone, analogous the upflow conduit at Grimsel Pass, situated at higher elevation in the west and acting as the preferential path of meteoric recharge into the deep fault zone (Fig. 1B). Such focussed recharge would lead to focussed inflow into the deep section (> 9 km) of the upflow zone.

49. Soil hydrological monitoring for regional landslide early warning

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.

50. Stability and As adsorption of nanocrystalline Al-hydroxysulfates forming during acid rock drainage

In the streambed of a small acidic (pH ~ 4.0) mountainous stream located in the Engadin area, Switzerland, white precipitates can be observed, which have formed on boulders (Fig. 1). These precipitates form due to the neutralization of the stream by mixing with several circumneutral tributaries. A Precent study identified basaluminite, a nanocrystalline hydroxysulfate with an idealized stochiometry of Al4OH10(SO4)•3-5H2O, as the dominating phase of the white streambed coating (Wanner et al., 2018). Chemical analyses revealed an elevated As concentration of up to 600 µg/g, which is inherited from adsorption of As on basaluminite as well as an anion exchange reaction where SO42- in the basaluminite structure is replaced by arsenate anions (H2AsO4-). Similar Al-hydroxysulfates are observed downstream of the Fe-Cu mine Servette-Chuc, located in the Aosta Valley in Northern Italy (Tumiati et al., 2008). Their rather low SO4 content, however, does not seem plausible with the precipitation of pure basaluminite. A potential explanation for the low sulfate content is the transformation of previously formed basaluminite to Al-hydroxides (e.g. Al(OH)3) due to the alkaline pH of ca. 8.0 to which the Aosta Valley precipitates are exposed to during most of the year.

To study the potential transformation of basaluminite and to assess the fate of As during such reactions, we have experimentally investigated (i) the initial formation of Al-hydroxysulfates by titrating the acid mine drainage solution collected at the Servette-Chuc mine in the Aosta Valley (pH ~ 3.0) and (ii) the fate of basaluminite sampled in the Engadin area when exposed to a solution with a pH of 8.0 (i.e. stability experiments). Infrared spectroscopy and acid digestion followed by ICPOES analyses of the precipitates obtained from the titration experiment demonstrate that the precipitates found downstream of the Servette-Chuc mine initially refer to basaluminite.Applying the same analytical techniques to the precipitates used in the stability experiments suggests that the transformation of basaluminite to Al(OH)3 is indeed occuring at pH 8.0 within a few weeks. Chemical analyses of the corresponding solutions, however, showed that such transformation is only associated with a minor mobilization of previously sorbed As. This confirms that basaluminite of similar Al-hydroxysulfates may serve as powerful filter material for the treatment of As contaminated groundwater (Mertens et al., 2012).

51. Thermal potential of urban tunnel infrastructures in unconsolidated rock groundwater resources

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.

52. Visual KARSYS, a web-tool for modelling karst aquifers in 3D

Visual KARSYS is a web-tool available at www.visualkarsys.com. It has been developed to address modelers and endusers working for the documentation and/or the management of geology and groundwater resources in karst areas. It makes possible for modelers to setup projects, to entry geol. and hydrogeol. data and to design geological 3D model in order to subsequently apply the KARSYS approach On one side, Visual KARSYS offers an intuitive interface in which modelers are guided through the steps of the approach. On the other side, Visual KARSYS offers a dedicated output page for end-users which displays formatted data and resulting models built by modelers. Editing and reading permissions can be allotted by the project administrator to different users (both modelers and end-users). End users can arrange data and results as they want (form, layout, views, etc.) and different analysis tools are at their disposal (slicer, drawing tool, etc.). They can export different data or print maps.

Visual KARSYS is actually free-of-use and we encourage users to use it.

Übersichtspublikationen / Publications synoptiques

53. Zustand und Entwicklung Grundwasser Schweiz / État et évolution des eaux souterraines en Suisse

Die Nationale Grundwasserbeobachtung NAQUA ist das gemeinsame Monitoringprogramm von Bund und Kantonen, das die Grundwasser-Quantität und -Qualität landesweit an rund 600 Messstellen erfasst. Der vorliegende NAQUA-Bericht zeigt, dass vor allem Nitrat und Rückstände von Pflanzenschutzmitteln die Grundwa sser-Qualität nachhaltig beeinträchtigen. Auch künstliche, langlebige Substanzen aus Industrie,

Gewerbe und Haushalten sind im Grundwasser, der wichtigsten Trinkwasserressource der Schweiz, nachweisbar. Betroffen sind vor allem die Grundwasservorkommen im intensiv landwirtschaftlich genutzten und dicht besiedelten Mittelland. Da sich Grundwasser nur langsam erneuert, kommt vorausschauenden Massnahmen zu Schutz und Erhalt der Grundwasserressourcen besondere Bedeutung zu.

Gerée conjointement par la Confédération et les cantons, l'Observation nationale des eaux souterraines NAQUA suit, auprès de quelque 600 stations de mesure, l'évolution de la quantité et de la qualité des eaux souterraines en Suisse. Le présent rapport NAQUA montre que les nitrates et les résidus de produits phytosanitaires, en particulier, compromettent durablement leur qualité. Les relevés attestent cependant aussi de la présence dans les eaux souterraines – la principale ressource d'eau potable du pays – de substances artificielles persistantes provenant de l'industrie, de l'artisanat et des ménages. Cette atteinte est observée avant tout sur le Plateau, région densément peuplée et vouée à une exploitation agricole intensive. Étant donné que les eaux souterraines ne se renouvellent que lentement, les mesures préventives revêtent une importance toute particulière afin de protéger cette ressource à long terme.

54. Hydrologisches Jahrbuch der Schweiz 2018 / Annuaire hydrologique de la Suisse 2018

Abfluss, Wasserstand und Wasserqualität der Schweizer Gewässer

Das Hydrologische Jahrbuch der Schweiz wird vom Bundesamt für Umwelt (BAFU) herausgegeben und liefert einen Überblick über das hydrologische Geschehen auf nationaler Ebene. Es zeigt die Entwicklung der Wasserstände und Abflussmengen von Seen, Fliessgewässern und Grundwasser auf und enthält Angaben zu Wassertemperaturen sowie zu physikalischen und chemischen Eigenschaften der wichtigsten Fliessgewässer der Schweiz. Die meisten Daten stammen aus Erhebungen des BAFU.

Débit, niveau et qualité des eaux suisses

Publié par l'Office fédéral de l'environnement (OFEV), l'Annuaire hydrologique de la Suisse donne une vue d'ensemble des événements hydrologiques de l'année au niveau national. Il présente l'évolution des niveaux et des débits des lacs, des cours d'eau et des eaux souterraines. Des informations sur les températures de l'eau ainsi que sur les propriétés physiques et chimiques des principaux cours d'eau du pays y figurent également. La plupart des données proviennent des relevés de l'OFEV.

55. Hitze und Trockenheit im Sommer 2018 / La canicule et la sécheresse de l'été 2018

Auswirkungen auf Mensch und Umwelt

Die Schweiz erlebte 2018 erneut einen aussergewöhnlich heissen Sommer. Mit einer durchschnittlichen Temperatur von 15,3 Grad in den Monaten Juni, Juli und August war er nach 2003 und 2015 der drittwärmste Sommer seit Messbeginn 1864. Auch die Niederschlagsmengen waren sehr gering. Im landesweiten Mittel fielen im Sommerhalbjahr von April bis September nur 69 Prozent der Normperiode 1981 bis 2010. Hitze und Trockenheit hatten gravierende Auswirkungen. Wegen der hohen Temperaturen waren ungefähr 200 Todesfälle mehr zu beklagen als in einem normalen Jahr. Im Wald hinterliess die Trockenheit deutliche Spuren. Vielerorts verfärbten sich die Laubbäume bereits im Juli. Mit dem Klimawandel dürften Verhältnisse wie in den Sommern 2003, 2015 und 2018 zum Normalfall werden.

Impacts sur l'homme et l'environnement

En 2018, la Suisse a essuyé une nouvelle fois un été exceptionnellement chaud. Avec une température moyenne de 15,3 °C pour les mois de juin, de juillet et d'août, ce fut le troisième été le plus chaud depuis le début des mesures en 1864, après ceux de 2003 et de 2015. De plus, les cumuls des précipitations ont été très faibles. En comparaison avec la période de référence (1981-2010), les précipitations du semestre d'été 2018, soit d'avril à septembre, n'ont en moyenne atteint que 69 % des cumuls usuels. La canicule et la sécheresse ont eu des répercussions graves. Si les températures élevées ont provoqué environ 200 décès de plus par rapport à une année normale, la sécheresse a laissé, elle, des traces visibles en forêt. En de nombreux endroits, les feuillus ont commencé à changer de couleur dès le mois de juillet. Si les changements climatiques se poursuivent ainsi, les étés 2003, 2015 et 2018 deviendront la norme.

56. Flyer-Serie zum Thema Wasser
Série de dépliants sur le thème Eaux