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

Literaturzusammenstellung - Jahrgang 2015

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

Compilation de littérature pour l'année 2015

Inklusive Links zu Artikel-[Abstracts] (Um dem Link zu folgen: **[klicken]**)
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BAFU – OFEV / 29.01.2016

Abstracts

Fachartikel national - articles spécialisés nationaux

1. Entfernung von Arsen und Uran - FOWA-Projekt: Aufbereitungsverfahren zur Arsen- und Uranentfernung aus Trinkwasser

Die revidierte Fremd- und Inhaltsstoffverordnung (FIV) stellt eine kleinere Anzahl Wasserversorgungen im Alpenraum vor neue Herausforderungen, wurden darin doch der Grenzwert für Arsen im Trinkwasser von 50 µg/l auf 10 µg/l gesenkt sowie ein Grenzwert für Uran (30 µg/l) aufgenommen. Im Rahmen eines FOWA-Projekts wurde in einer Walliser Gemeinde untersucht, welche Aufbereitungsverfahren zur Arsen- und Uranentfernung angewendet werden können. Die demnächst erscheinende SVGW-Empfehlung W1015 bietet Hilfestellung zum Umgang mit geogenen Spurenstoffen (Arsen, Uran).

2. Tiefengrundwasser - Vorkommen, Nutzungspotenzial und Schutzwürdigkeit

Tiefengrundwasser findet sich in allen grosstektonischen Einheiten der Schweiz. Die bekannten, teilweise genutzten Vorkommen von Tiefengrundwasser und insbesondere die chemische Zusammensetzung dieser Wässer werden für die verschiedenen Einheiten aufgezeigt. Im Hinblick auf mögliche Nutzungskonflikte werden die gesetzlichen Grundlagen und Massnahmen zum Schutz dieser Ressource diskutiert.

3. Charakterisierung der Flussinfiltration - Anwendung unterschiedlicher Methoden auf Zeitreihen im Aaretal

Die Analyse von Zeitreihen der elektrischen Leitfähigkeit stellt im Vergleich zur Durchführung eines Markierversuchs eine effiziente und kostengünstige Alternative zur Charakterisierung der Flussinfiltration dar. Die Anwendung unterschiedlicher Methoden auf Zeitreihen im Aaretal zwischen Olten und Aarau hat das Verständnis der Fluss-Grundwasser-Interaktion erhöht. Zudem konnten die Methoden für bislang nicht untersuchte Fliesszeiten und Datencharakteristiken qualifiziert werden.

4. Analyse von Grund-Wasserkörpern mit GIS - GIS-Tool GSIA – Basis für das Prozessverständnis der Interaktion von Grundwassersystemen

Die Kenntnis über Ausdehnung und Mächtigkeit von Grundwasserkörpern im Zusammenhang mit der Lage, Geometrie und Beschaffenheit der Felsoberfläche ist wesentliche Grundlage für das Verständnis regionaler Grundwasserfliessregime. Als Basis für die Analyse von Grundwasserkörpern und das Prozessverständnis der Interaktion von Grundwassersystemen kann das GIS-Tool GSIA (Groundwater System Interaction Assessment) herangezogen werden.

5. Schluckbrunnen im Hardhof - Wasseraufnahmevermögen von Schluckbrunnen zur Grundwasseranreicherung

Schluckbrunnen werden im Grundwasserwerk Hardhof für die Anreicherung des Grundwassers und zur Abwehr von unerwünschten Grundwasserzuflüssen aus den östlich und südlich gelegenen Stadtteilen Zürichs betrieben. Die Brunnen wurden erstmals seit einer längeren Betriebszeit (ca. 15 Jahre) geophysikalisch vermessen, um das Abstromverhalten und die spezifische Leistungsfähigkeit detailliert zu untersuchen. Ziel war u. a. die Bestimmung der vertikalen Abstromzonierung in den vertikalen Filterstrecken der Schluckbrunnen in Relation zu den Entnahmehorizonten der Horizontalfilterbrunnen, die am Standort Hardhof zur Trinkwasserentnahme dienen.

6. Radonbelastung in grossen Wasserwerken - Erfolgreiche Sanierung eines Trinkwasserbrunnens der industriellen Werke Basel

Das Wasserwerk der Stadt Basel (IWB) gewinnt das Trinkwasser teilweise aus Grundwasser aus uranhaltigem Schotter. Dieses Grundwasser ist radonhaltig, da sich das beim radioaktiven Zerfall des

Urans gebildete Radongas darin löst. Zudem stehen die Pumpengebäude und die Gebäude zur Nachbehandlung des Rohwassers im uranhaltigen Schotter. Folglich weisen die Gebäude teilweise Radongaskonzentrationen über dem Grenzwert von 3000 Bq/m3 auf. Dank kurzer Aufenthaltszeiten in den Produktionsgebäuden liegen die akkumulierten Dosen der Mitarbeitenden unter dem Grenzwert von 20 mSv/a.

7. Diffuse Nährstoffeinträge in Gewässer - Schweizweite Modellierung diffuser Stickstoff- und Phosphoreinträge

Die Schweizer Gewässer werden nach wie vor mit Stickstoff- und Phosphoreinträgen belastet. Mit dem statistisch-empirischen Stoffflussmodell MODIFFUS wurden erstmals schweizweit alle diffusen Eintragspfade und -quellen im Hektarraster berechnet. Insgesamt gelangen pro Jahr rund 51 000 t Stickstoff, 3500 t Gesamt-Phosphor bzw. 900 t gelöster Phosphor über diffuse Quellen in die Gewässer der Schweiz.

8. Radioaktivität in Flusswasser unterhalb KKW - das neue Messnetz zur kontinuierlichen Überwachung von Aare und Rhein

Durch den Kernreaktorunfall von Fukushima gelangten 2011 grosse Mengen radioaktiver Stoffe ins Meer. In der Folge wurde die kontinuierliche Überwachung der Radioaktivität in Schweizer Flüssen verstärkt ein Thema. Seit diesem Jahr nun überwachen fünf automatische Sonden fortlaufend die Konzentration von Gammastrahlern in Aare und Rhein flussabwärts der Kernkraftwerke. Dieses Messnetz kann bei erhöhten Werten (z. B. Überschreitung des Toleranzwertes für Cäsium, 137Cs) rasch informieren.

9. Chaos en sous-sol - Ou quand règne la règle du « premier arrivé, premier servi »

Notre société moderne fait un double usage du sous-sol. Elle l'utilise d'une part pour y enfouir des infrastructures pour le transport de personnes, d'eaux et d'énergie ainsi que pour divers stockages, par exemple de déchets. Elle exploite d'autre part ses ressources naturelles, en particulier les nappes phréatiques, la géothermie et les matières premières minérales. En 2009, la Commission fédérale de géologie (CFG) alertait le Conseil fédéral sur l'urgente nécessité de coordonner et planifier l'utilisation du milieu souterrain.

10. Bachoffenlegungen in Schutzzonen - Was tun, wenn's leckt in Grundwasserschutzzonen? – Ein Systemvergleich

Wenn eine Bachleitung in einer Grundwasserschutzzone saniert werden muss, wird anstelle der im Grundsatz geforderten Gewässeroffenlegung meist die Sanierung oder die Erneuerung der Bachleitung angestrebt. Dies in der Annahme, die Fassung damit bestmöglich vor Verunreinigungen durch infiltrierendes Bachwasser zu schützen. Wie die Resultate einer detaillierten Vergleichsanalyse zeigen, bieten Bachoffenlegungen in Kombination mit einer langlebigen Gerinneabdichtung einen mindestens ebenbürtigen Grundwasserschutz. Zudem lassen sich mit der abgedichteten Offenlegung auch wirtschaftliche und ökologische Vorteile realisieren.

11. Permanente Wasserqualitätsanalysen - Mehrwert für Trinkwasserversorgungen durch Datennutzung und Mustererkennung

Natürliche Trinkwasserreserven, z. B. in Lockergesteins- und Karstgrundwasserleitern, weisen bei der Extraktion meist eine komplexe Wasserzusammensetzung auf. Eine rasche Erkennung der qualitätsrelevanten Veränderungen ist Grundlage einer effizienten Überwachung der Trinkwasserqualität und war Ziel eines Projektes der Forschungsgruppe Angewandte und Umweltgeologie der Universität Basel und von Endress+Hauser. Der Lösungsansatz beinhaltet eine multivariate Berechnungsmethode, beruhend auf neuronalen Netzen, hydrogeologischen Prozesskenntnissen sowie Messinstallationen.

12. Die Geothermie-Tiefbohrung St. Gallen GT-1

According to the 2008 energy concept of the city of St. Gallen deep geothermal energy should play a major role. Therefore the city commissioned a feasibility study including a regional 3D-Seismics survey. This study identified potential aquifer-units within the mesozoic sediments and in combination with a regional fault zone. The well GT-1 has been drilled between March and July 2013 and reached a final depth of 4.250 m below ground level or 4.450 m along hole respectively. Below almost 4 km of Tertiary

Molasse sediments the Top Mesozoic was reached, followed by 400 m of Malm and 50 m of Dogger formations. In order to reach the fault zone from the drill site near the Sitter it was necessary to deflect the borehole. In a depth of 950 m the borehole was deflected by about 20° heading NW. The final borehole consists of four sections that have been accomplished mainly with PDC-bits and modern directional drilling equipment. Possible high pressure areas within the triangle zone or gas kicks have been postulated but could not be found. The Malm formations consists of typical swabian facies with spongial limestones, that show partly fractured sections. The fractured sections areinterpreted as part of the St. Gallen Fault Zone. These have been stimulated successfully, causing a sudden gas blowout, accompanied by microseismic activity and a distinct seismic event of magnitude 3.5, urging rigorous well controlll activity. After several weeks of controlling and securing the borehole, aquifer testing was carried out. The extent of the gas reservoir is unkown and the tests could not detect an aquifer zone with sufficient productivity to realize a geothermal power plant.

13. Zweites Messjahr im Bodenmessnetz Nordwestschweiz

Mit momentan 27 Messstandorten betreibt der Aargau zusammen mit den Kantonen Solothurn, Basel-Landschaft und neu Zug das Bodenmessnetz Nordwestschweiz. Die automatischen Messstationen liefern spannende Daten und haben sich in Unterhalt und Betrieb auch im zweiten Messjahr sehr bewährt. Die aktuellen Daten sind stets unter www.bodenmessnetz.ch abrufbar.

14. Chemische Elemente in Aargauer Trinkwasserfassung

Über einen Zeitraum von fünf Jahren wurden neue Erfahrungswerte für chemische Elemente in Trinkwasser aus den Aargauer Grundund Quellwasserfassungen erhoben. Proben mit auffällig erhöhten Elementkonzentrationen können nun besser erkannt und spezifisch abgeklärt werden.

15. Fracking im Aargau?

Mit Blick auf die angestrebte Energiewende muss auch die Nutzung neuer Ressourcen geprüft werden. Dazu gehört ebenfalls das Fracking. Um konventionelle Öl- und Gaslagerstätten zu erschliessen, wird diese Methode seit mehr als 50 Jahren eingesetzt. Neu ist, dass man mit ihrer Hilfe sogenannte unkonventionelle Lagerstätten ausbeuten will – vor allem Schiefergas aus tief liegenden Gesteinsschichten. Der Kanton Aargau hat mit dem «Gesetz über die Nutzung des tiefen Untergrunds und die Gewinnung von Bodenschätzen » Voraussetzungen geschaffen, um beispielsweise die Suche nach Schiefergas umfassend prüfen zu können.

Fachartikel international - articles spécialisés internationaux

16. Flow intermittency, physico-chemistry and function of headwater streams in an Alpine glacial catchment

Relatively little is known regarding the extent of intermittent streams or the general ecology of headwaters in alpine catchments with glacial influence. This study quantified the contribution of intermittent streams to the total length of the stream network along with an ecological assessment during spring-summer of headwater streams (higher than 1,900 m above sea level) in the Val Roseg, a high Alpine glacial catchment. Stream network mapping revealed that ca. 90 % (76.8 km) of the drainage network consisted of intermittent streams. Glacier-fed headwaters experienced diel surface flows in late spring and summer, most going dry during the night due to reduced glacial inputs. In contrast, groundwater-fed streams often went dry in summer with the contraction of groundwater and other subsurface inputs. A principal components analysis of physico-chemical characteristics revealed headwaters to be primarily glacial-fed (kryal), groundwater-fed (krenal), or having a mixed water source. Although quite variable, periphyton biomass reached high levels (ca. 40 mg m−2 chl-a, 10 g m−2 AFDM) by late spring in most headwaters. Organic matter in transport (seston) ranged from 0.03 to 0.09 mg L−1 mostly consisting of fine particulate organic matter (FPOM: 33–76 %). Hyporheic sediment respiration rates varied considerably, ranging from 0.005 to 0.126 mg O2 h−1 kg−1 sediment and primarily related to the amount of loosely attached organic matter. These results indicate that intermittent streams are predominant in alpine landscapes, comprising mostly 1st to 2nd order systems, and that ecosystem properties vary substantially among headwater streams likely in relation to annual/daily changes in flow and water source. Such headwaters may contribute strongly to the production, processing and transport of organic matter to downstream waters, especially in light of the expected increase in intermittent streams in alpine catchments experiencing rapid glacial recession.

17. Assessing the contribution of karst to flood peaks of the Suze river, potentially affecting the city of Bienne (Switzerland)

The city of Bienne (BE, Switzerland) located downstream of the Suze River is exposed to flooding caused by the River overflows. Although the infrastructures were designed for a maximal discharge rate of 100 m3/s (return period of 100 years), it appears that the River threatened to flood the city more than 6 times during the past century. The frequency analysis of the River discharge rates shows an abrupt increase for discharge rates >75 m3/s and a plateau at 95 m3/s; in other words discharge rates for return period events between 30 years and 150 years appear to be almost the same… Such a plateau could be produced by a significant storage upstream of the city, which smooth extreme discharge peaks. This storage was assessed to about 17 millions of cubic meters for a T100 flood. However, the storage is not visible along the river and it was suggested that karst aquifers may be responsible for it. The questions are (1) “Does such a storage exist in the karst aquifer?”, (2) “What is its capacity and how does it work?”, (3) “What could happen if this capacity is suddenly exceeded?”, (4) “What is the real contribution of karst water to the flows peak in Bienne?” In this view, a pragmatic approach is proposed to assess the contribution of the karst systems in the River flood generation. As the work is ongoing only the conceptual approach is here presented.

18. Assessing Karst Aquifers in Switzerland: The 2010/2013 Swisskarst Project

As karst groundwater represents a significant part of the Swiss water reserve (120 km3) and resource (6.6 to 9.1 km3), the Swisskarst project (01/2010–12/2013) was included as a component of the National Research Program 61 dedicated to the sustainable management of water. Karst aquifers are sensitive to contamination and they may be disturbed by land management or civil construction. Furthermore their evolution according to climate changes strongly depends on contexts (low-land or alpine karts). In order to improve the management of karst aquifers, the project focused on two aspects: (i) the documentation of karst aquifers through a dedicated and systematic approach, maps and 3D models and (ii), the comparison and selection of applicable hydrological simulation tools, including karst recharge and karst hydraulics, which can adequately address pragmatic topics in karst such as flood hazards, low-flow recessions, etc., as well as mid-term behavior (climate changes, glaciers melting,…). Between 2010 and 2013 it was possible to document about one third of karst areas in Switzerland, including nearly one hundred karst systems. Water authorities at federal, cantonal and community levels were directly involved. This documentation clearly improved the understanding of karst aquifers and the way to manage them. Results of the project are available on www.swisskarst.ch. The work will continue along

the coming years. Only results concerning the characterization of karst aquifers and systems, as well as some mapping procedures are discussed here.

19. Global warming in the Alps: vulnerability and climatic dependency of Alpine springs in Italy, regione Valle d'Aosta and Switzerland, canton Valais

Mountain springs at mid to high altitudes are particularly sensitive to climatic variations, as documented by spatio-temporal discharge measurements. Recent models predict significant modifications of the hydrological system in the Alps within the next 100 years. In order to better understanding short- and long-term mountain spring behavior related to hydrogeological settings, and to anticipate global warming effects an Operational Program was set up: Project STRADA's Action 3—"Strategies for adaptation to climate change for the management of natural hazards in the border region—Italy/Switzerland 2007/2013" (http://www.progettostrada.net). Based on the interaction mechanisms between surface and groundwater, the physico-chemical parameters of springs are correlated with climatic events and used to determine general aquifer behavior. Particular attention is given to the role of snow melting in discharge basins. The resulting characterization of monitored springs provides an objective solution to adequately survey alpine hydrogeological systems. Furthermore, the approach supports the efforts of authorities in developing efficient strategies for sustainable groundwater resources management.

20. Hydrogeological controls on the swelling of clay-sulfate rocks in tunneling

The swelling of clay-sulfate rocks often poses a severe threat to tunnels. It causes serious damage and produces high additional costs during construction and operation. The swelling of clay-sulfate rocks is triggered by water access to anhydrite-bearing layers. Therefore, we propose that groundwater flow is a key factor controlling the swelling process. A case study from the Jura Mountains in Switzerland is presented that uses numerical groundwater models to calculate flow rates at the anhydrite level in different tunnel sections. The approach assumes that an increase of groundwater flow rates into anhydrite-bearing layers after tunnel excavation corresponds to an increase in swelling. A sensitivity study analyzes the impact of hydraulic parameters on calculated flow rates. Analyzed parameters include the hydraulic conductivity of geological units, properties of the excavation-damaged zone and the hydraulic potential in aquifers near the tunnel. Implications for site investigation and potential measures to counteract the swelling problem are suggested.

21. Darcy flux as hydrological indicator for the swelling potential of clay-sulfate rocks in tunneling

Swelling of clay-sulfate rocks often poses a severe threat in tunneling. It causes serious damage and produces high additional costs during tunnel construction and operation. The swelling of clay-sulfate rocks requires groundwater inflow into anhydrite-bearing layers. Therefore, the Darcy flux into anhydrite-bearing layers surrounding the tunnel is suggested as a hydrological indicator for the swelling potential. A case study from Switzerland is presented that uses numerical groundwater models to calculate the Darcy flux at the anhydrite level in different tunnel sections after tunnel excavation. The approach, which assumes that a high Darcy flux at the anhydrite level after excavation indicates a high swelling potential, is tested at the study site. The results suggest that the Darcy flux can serve as a hydrological indicator for the swelling potential in tunneling. Equally important, however, is the fact that the Darcy flux depends on many parameters, all of which are uncertain. Hence, a sensitivity study is conducted to analyze the influence of these parameters. The sensitivity study shows that the significant parameters in the case study are the hydraulic conductivity of the aquifer above the tunnel, the groundwater level in this aquifer, as well as the hydraulic properties of the excavation damaged zone, of the tunnel lining and of faults. Based on the results of the sensitivity study, implications for site investigation and measures to counteract the swelling problem are discussed. The major contributions of this paper are therefore the development of an approach to estimate the swelling potential of clay-sulfate rocks based on a hydrological indicator, and the derivation of the parameters that have the strongest impact on the swelling potential of such rock.

22. Evaluation of the risk to groundwater after treating logs with cypermethrin

In order to protect conifer logs against attacks from the striped ambrosia beetle (Trypodendron lineatum) during spring in Swiss forests, logs are treated with the insecticide cypermethrin. Rainfall can cause the insecticide to leach into the ground, potentially threatening the groundwater quality. Forest groundwater is widely used for drinking water, which means that any contaminants within it should be avoided. This study assesses the risk of groundwater contamination in field conditions. The two study areas are located on unconsolidated sediments (Censières, or CS) and on karstic rocks (Grand Bochat, or GB).

An analytical method was developed to determine the concentration of cypermethrin and its degradation products 3-PBA and DCVA in water samples. Intensive rainfall was simulated in order to mimic a situation that threatens groundwater. The study's results show that, when treated according to the manufacturer's instructions, a certain amount of insecticide was leached during the first rainfall event (2.2 g or 4.4 % of the applied cypermethrin). This leaching threatens groundwater quality, but can be avoided by decreasing the pesticide amount applied while maintaining a satisfactory protection. The insecticide amount that reached the groundwater was very low and was related to simulated rainfall, not natural rainfall. In Censières, only one groundwater sample presented a cypermethrin concentration (4 µg/l). In Grand Bochat, after a simulated rainfall of 36 mm, 3.3 % of the insecticide (5 g) was leached and 0.05 % of the total applied insecticide amount (corresponding to 1.5 % of the leached insecticide) reached the groundwater under the epikarst layer.

23. A historical overview of Geneva's artificial recharge system and its crisis management plans for future usage

The artificial recharge of transboundary Genevese groundwater uses treated water from the Arve River to recharge the aquifer. This system has been in place since 1980. Although the system has demonstrated its worth and has helped to offset the excessive use of the 1960s and 1970s by raising the average water levels in the aquifer by more than 6 m, the region is still subject to water supply problems. In 2011, several events took place at the local, regional and even international levels which prompted the committee responsible for the use of the transboundary aquifer to tackle the water problem as a result of two events: the Fukushima accident of March 2011 with its radioactive cloud travelling across the globe and passing over Switzerland, and the drought of 2010–2011 which ravaged a large part of Western Europe. The present article examines the effects of these potential problems and raises the issue of the role of the Genevese aquifer in the provision of drinking water and its artificial recharge as the subjects of a strategic study on water distribution in crisis situations.

24. Assessing karst-hydraulic hazards in tunneling - the Brunnmühle spring system - Bernese Jura, Switzerland

Drilling a tunnel in a karst region requires the assessment of disturbances in the hydrogeological functioning of aquifers and flow-systems as well as disturbances for the tunnel itself. A complete characterization of the karst hydrogeological functioning and the establishment of prevention measures are essential in order to insure a suitable construction. The paper relates investigations which were conducted in the frame of the construction of a safety gallery (Sisto) in the bernese Jura (Switzerland). This gallery is located close to the outlet of a regional karst system and parallel to an existing highway tunnel, which met numerous disorders in the past due to the intersection of active karst conduits with a discharge reate exceeding 1 m3/s. The KarstALEA method was applied along the Sisto trace in order to identify sections with a high probability of karst occurrences and to characterize the type of karst related problems. The main issue turned out to be related to water head and discharge, which could potentially be cut by the tunnel construction. The system discharge rate may frequently exceed 10 m3/s, and most of this water could potentially flow into the tunnel. Therefore, a hydraulic model was set up in order to assess expected flow rates and heads if conduits are intersected during the construction. Based on this model and on meteorological and hydrological real-time measurements, a predictive model was established in order to anticipate high-flows events.

25. Evaluation of molecular- and culture-dependent MST markers to detect fecal contamination and indicate viral presence in good quality groundwater

Microbial contamination of groundwater represents a significant health risk to resource users. Culture-dependent Bacteroides phage and molecular-dependent Bacteroidales 16S rRNA assays are employed in microbial source tracking (MST) studies globally, however little is known regarding how these important groups relate to each other in the environment and which is more suitable to indicate the presence of waterborne fecal pollution and human enteric viruses. This study addresses this knowledge gap by examining 64 groundwater samples from sites with varying hydrogeological properties using a MST toolbox containing two bacteriophage groups (phage infecting GB-124 and ARABA-84), and two Bacteroidales 16S rRNA markers (Hf183 and BacR); those were compared to fecal indicator bacteria, somatic coliphage, Bacteroidales 16S rRNA marker AllBac, four human enteric viruses (norovirus GI and II, enterovirus and group A rotavirus) and supplementary hydrogeological/chemical data. Bacteroidales 16S rRNA indicators offered a more sensitive assessment of both human-specific and general fecal contamination than phage indicators, but may overestimate the risk from enteric viral pathogens. Comparison with hydrogeological and land use site characteristics as well as auxiliary

microbiological and chemical data proved the plausibility of the MST findings. Sites representing karst aquifers were of significantly worse microbial quality than those with unconsolidated or fissured aquifers, highlighting the vulnerability of these hydrogeological settings.

26. Estrogenic activity in drainage water: a field study on a Swiss cattle pasture

Background: Dairy cow manure applied to pastures is a significant potential source of estrogenic contamination in nearby streams. One possible pathway is through infiltration via preferential flow to drainage pipes, particularly after heavy rainfall events. In a period of 73 days in the spring of 2010, a drainage catchment in a cattle pasture in the Swiss lowlands was closely monitored. Manure was applied three times during the study, and part of the catchment was also subjected to grazing. During five field campaigns, water samples from two sampling locations were taken for 4–24 h in consecutive sampling intervals. 17β-estradiol equivalents (EEQ) were determined with the yeast estrogen screen (YES) and the ER-CALUX assay. Some water chemistry parameters, pH, conductivity, oxygen content and soil moisture tension were also monitored. Results: Washout of estrogenic activity was highest during or right after heavy rainfall events, shortly after manure spreading, when peak values of >10 ng/l EEQ were found in several samples. However, in two field campaigns, high EEQ values were also found 14 and 28 days, after the last manure application, in one case during a dry weather period. This indicates that estrogenic compounds are more stable in natural soils than what is expected from data gathered in lab studies. Conclusions: Streams in agricultural areas with a high proportion of drained land may be subject to numerous peaks of EEQ during the course of the year. This may have a negative effect on aquatic organisms, namely fish embryos, living in these streams.

27. Giant lacustrine pockmarks with subaqueous groundwater discharge and subsurface sediment mobilization

Subsurface fluid flow in oceans and lakes affects bathymetric morphology, sediment distribution, and water composition. We present newly discovered giant lacustrine pockmarks in Lake Neuchâtel (up to 160m diameter and 30m deep) that rank among the largest known pockmarks in lakes. Our multidisciplinary study reveals ~60m of suspended sediment inside a pockmark. The sediment suspension is 2.6° warmer and isotopically lighter in δ18OH2O by 1.5‰than the ambient lake water, documenting currently active fluid flow by karstic groundwater discharge from the Jura Mountain front into the Swiss Plateau hydrological system. Strikingly, the levees of the pockmarks comprise subsurface sediment mobilization deposits representing episodic phases of sediment expulsion during the past. They strongly resemble subsurface fluid flow features in the marine realm. Comparable processes are expected to also be relevant for other carbonate-dominated mountain front ranges, where karstic groundwater discharges into lacustrine or marine settings.

28. Forecasting groundwater temperature with linear regression models using historical data

Although temperature is an important determinant of many biogeochemical processes in groundwater, very few studies have attempted to forecast the response of groundwater temperature to future climate warming. Using a composite linear regression model based on the lagged relationship between historical groundwater and regional air temperature data, empirical forecasts were made of groundwater temperature in several aquifers in Switzerland up to the end of the current century. The model was fed with regional air temperature projections calculated for greenhouse-gas emissions scenarios A2, A1B, and RCP3PD. Model evaluation revealed that the approach taken is adequate only when the data used to calibrate the models are sufficiently long and contain sufficient variability. These conditions were satisfied for three aquifers, all fed by riverbank infiltration. The forecasts suggest that with respect to the reference period 1980 to 2009, groundwater temperature in these aquifers will most likely increase by 1.1 to 3.8 K by the end of the current century, depending on the greenhouse-gas emissions scenario employed.

29. Generation of 3D spatially variable anisotropy for groundwater flow simulations

Sedimentary units generally present anisotropy in their hydraulic properties, with higher hydraulic conductivity along bedding planes, rather than perpendicular to them. This common property leads to a modeling challenge if the sedimentary structure is folded. In this paper, we show that the gradient of the geological potential used by implicit geological modeling techniques can be used to compute full hydraulic conductivity tensors varying in space according to the geological orientation. For that purpose, the gradient of the potential, a vector normal to the bedding, is used to construct a rotation matrix that

allows the estimation of the 3D hydraulic conductivity tensor in a single matrix operation. A synthetic 2D cross section example is used to illustrate the method and show that flow simulations performed in such a folded environment are highly influenced by this rotating anisotropy. When using the proposed method, the streamlines follow very closely the folded formation. This is not the case with an isotropic model.

30. Perchlorethen-Quellendifferenzierung mittels Kohlenstoff-Chlor-Isotopenanalyse: Felduntersuchungen zur Beurteilung der Variabilität der Isotopensignatur

Bei der Untersuchung von belasteten Standorten stellt sich häufig die Frage, ob unterschiedliche Schadstoffquellen zu einer Grundwasserbelastung beitragen. Chlorierte Kohlenwasserstoffe (CKWs) von verschiedenen Produzenten können unterschiedliche Kohlenstoffund Chlor-Isotopensignaturen (C-Cl-Isotopensignaturen) aufweisen, was eine Differenzierung von CKW-Quellen ermöglicht. Dazu muss aber die Variabilität der Isotopensignatur bekannt sein. Da die ursprünglich verwendeten Lösungsmittel meist nicht mehr zugänglich sind, werden in dieser Studie die Perchlorethen (PCE) C-Cl-Isotopensignaturen an belasteten Standorten in der Schweiz untersucht. Zehn Standorte wurden ausgewählt, die verschiedene Branchen und Landesregionen abdecken. Eine Variabilität der C-Cl-Isotopensignaturen zwischen einigen Standorten bestätigt die Anwendbarkeit dieser Methode zur Quellendifferenzierung. Gewisse Standorte zeigen jedoch ähnliche Isotopensignaturen. Deswegen ist der Erfolg dieser Identifikationsmethode standortspezifisch. Außerdem ist die Variabilität geringer als publizierte Isotopensignaturen von nordamerikanischen Herstellern. Es hat sich außerdem bestätigt, dass der biologische Abbau von PCE durch reduktive Dechlorierung bei der Identifikation der Kontaminationsquellen berücksichtigt werden muss.

31. Standardized approach for conducting tracing tests in order to validate and refine vulnerability mapping criteria

An approach for conducting tracer tests in karst systems is proposed in order to assess differing degrees of groundwater vulnerability. It consists of (i) a standardized artificial recharge scenario, (ii) the selection of conservative tracers, and (iii) application to contrasting vulnerability situations within a catchment. Results from multi-tracer testing at a karst site in Switzerland provided breakthrough curves that were significantly different in terms of mass recovery, which is considered the key parameter for defining a quantitative protection effect. The presented approach may provide a better basis for both punctual validation of vulnerability maps and refinement of associated assessment methods.

32. Impact of a tunnel on a karst aquifer: application on the Brunnmühle springs (Bernese Jura, Switzerland)

Tunnel drilling in karst regions often leads to major disturbances in the hydrogeological functioning of aquifers and flow-systems. Numerous examples are documented in Switzerland and induced significant costs, which were not or rarely anticipated (e.g.: Flims, Jeannin et al. 2009). The Ligerztunnel is one of these example. The tunnel was built a few hundreds of meters upstream from the Brunnmühle spring, which contributes to the drinking water supply of communities of Twann and Ligerz. During the construction, a major karst conduit with a huge discharge rate was intersected in a side exploration tunnel. Overflowing water was diverted into the Twannbach canyon. In the main section, smaller conduits were found and drained outside by pipe leading water close to the Brunnmühle spring. Actually, authorities want to add a safety tunnel parallel to the main tunnel. In this view, SISKA is in charge of evaluating the hydrological disturbances on the spring regime. The paper presents the approach applied to assess the potential effect of the drilling of a new tunnel near to a group of karst springs and pumping wells. The approach combines available spatial information and a hydraulic model. The KARSYS approach is first applied on this system in order to set up a 3D geological and hydrogeological model of the karst aquifer and the related systems. The spatial distribution of karst conduits within the massif is assessed based on a speleogenetical and inception horizons model (KarstALEA method). Inferring from these models, a karst conduits network is generated. The hydraulic model of the downstream part of the conduits network, which concerns the close vicinity of the safety tunnel project, is precisely calibrated using head and discharge data. Flow in this conduits network is then simulated using SWMM 5.0 in order to reproduce the hydrological responses of the different outlets (permanent springs, drainage devices, overflow springs, etc.).

33. The impact of hillslope groundwater dynamics and landscape functioning in event-flow generation: a field study in the Rietholzbach catchment, Switzerland

A reliable prediction of hydrograph responses in mountainous headwater catchments requires a mechanistic understanding of the coupled hydro-climatic processes in these regions. This study shows

that only a small fraction of the total area in a pre-Alpine headwater catchment actively regulates streamflow responses to hydro-climatic forcing, which facilitates the application of a parsimonious framework for hydrograph time-series prediction. Based on landscape analysis and hydrometric data from the Upper Rietholzbach catchment (URHB, 0.94 km2, northeast Switzerland), a conceptual model was established. Here, the rainfall-event-driven contribution of surface runoff and subsurface flow (event flow) accounts for around 50 % of total river discharge. The event-flow hydrograph is generated from approximately 25 % of the entire area consisting of riparian zones (8 %) and adjacent hillslopes (17 %), each with characteristic streamflowgenerating mechanisms. Baseflow generation is attributed to deep groundwater discharge from a fractured-rock aquifer covering ~75 % of the catchment area. A minimalistic model, that represents event flow as depletion of two parallel linear reservoirs, verified the conceptual model of the URHB with adequate hydrograph simulations (R2=0.67, Nash-Sutcliffe efficiency (NSE)=0.64). Hereby, the expansion of the event-flow contributing areas was found to be particularly significant during long and high-intensity rainfall events. These findings provide a generalized approach for the large-scale characterization of groundwater recharge and hydrological behavior of mountainous catchments with similar landscape properties.

34. An integrated approach for catchment delineation and conduit-network modeling in karst aquifers: application to a site in the Swiss tabular Jura

An essential issue in karst hydrology is the characterization of the hydrogeological flow systems, i.e., the delineation of catchment areas and the organization of the main flow paths (conduit network) feeding one or several outlets. The proposed approach provides an explicit way to sketch catchment areas, and to generate karst conduits on the basis of a three-dimensional (3D) conceptual model of the aquifer (KARSYS approach). The approach follows three main principles: (1) conduits develop according to the hydraulic gradient, which depends on the aquifer zonation, (2) conduits are guided by preferential guidance features (or inception horizons) prevailing in the unsaturated and saturated zones of the aquifer, and (3) conduits initiate on a regular basis below the autogenic zone of the catchment area. This approach was applied to a site in the Swiss Jura as a base for the assessment of flood-hazard risks. The resulting model proposes a new delineation of the system catchment area and appears fairer regarding hydrological measurements than previous interpretations, which under-estimated the catchment area by about 20 %. Furthermore, the proposed conduit network for the whole aquifer is also consistent with local cave surveys and dye-tracing observations. These interesting results demonstrate that the combination of this approach with the KARSYS 3D model provides an integrated and effective way for the characterization of karst-flow systems.

35. Assessing groundwater quality trends in pumping wells using spatially varying transfer functions

When implementing remediation programs to mitigate diffuse-source contamination of aquifers, tools are required to anticipate if the measures are sufficient to meet groundwater quality objectives and, if so, in what time frame. Transfer function methods are an attractive approach, as they are easier to implement than numerical groundwater models. However, transfer function approaches as commonly applied in environmental tracer studies are limited to a homogenous input of solute across the catchment area and a unique transfer compartment. The objective of this study was to develop and test an original approach suitable for the transfer of spatially varying inputs across multiple compartments (e.g. unsaturated and saturated zone). The method makes use of a double convolution equation accounting for transfer across two compartments separately. The modified transfer function approach was applied to the Wohlenschwil aquifer (Switzerland), using a formulation of the exponential model of solute transfer for application to subareas of aquifer catchments. A minimum of information was required: (1) delimitation of the capture zone of the outlet of interest; (2) spatial distribution of historical and future pollution input within the capture zone; (3) contribution of each subarea of the recharge zone to the flow at the outlet; (4) transfer functions of the pollutant in the aquifer. A good fit to historical nitrate concentrations at the pumping well was obtained. This suggests that the modified transfer function approach is suitable to explore the effect of environmental projects on groundwater concentration trends, especially at an early screening stage.

36. A multi-method field experiment to determine local groundwater flow in a glacier forefield

We implemented multiple independent field techniques to determine the direction and velocity of groundwater flow at a specific stream reach in a glacier forefield. Time-lapse experiments were conducted using two electrical resistivity tomography (ERT) lines installed in a cross pattern. A circular

array of groundwater tubes was also installed to monitor groundwater flow via discrete salt injections. Both inter-borehole and ERT results confirmed this stream section as a losing reach and enabled quantification of the flow direction. Both techniques yielded advection velocities varying between 5.7 and 21.8m/day. Estimates of groundwater flow direction and velocity indicated that groundwater infiltrates from the stream nearby and not from the adjacent lateral moraine. Groundwater age estimated from radon concentration measurements supported this hypothesis. Despite uncertainties inherent to each of the methods deployed, the combination of multiple field techniques allowed drawing consistent conclusions about local groundwater flow. We thus regard our multi-method approach as a reliable way to characterize the two-dimensional groundwater flow at sites where more invasive groundwater investigation techniques are difficult to carry out and local heterogeneities can make single measurements unreliable.

37. Quantifying sensitivity to droughts - an experimental modeling approach

Meteorological droughts like those in summer 2003 or spring 2011 in Europe are expected to become more frequent in the future. Although the spatial extent of these drought events was large, not all regions were affected in the same way. Many catchments reacted strongly to the meteorological droughts showing low levels of streamflow and groundwater, while others hardly reacted. Also, the extent of the hydrological drought for specific catchments was different between these two historical events due to different initial conditions and drought propagation processes. This leads to the important question of how to detect and quantify the sensitivity of a catchment to meteorological droughts. To assess this question we designed hydrological model experiments using a conceptual rainfall-runoff model. Two drought scenarios were constructed by selecting precipitation and temperature observations based on certain criteria: one scenario was a modest but constant progression of drying based on sorting the years of observations according to annual precipitation amounts. The other scenario was a more extreme progression of drying based on selecting months from different years, forming a year with the wettest months through to a year with the driest months. Both scenarios retained the observed intra-annual seasonality for the region. We evaluated the sensitivity of 24 Swiss catchments to these scenarios by analyzing the simulated discharge time series and modeled storage. Mean catchment elevation, slope and area were the main controls on the sensitivity of catchment discharge to precipitation. Generally, catchments at higher elevation and with steeper slopes appeared less sensitive to meteorological droughts than catchments at lower elevations with less steep slopes.

38. Linking baseflow separation and groundwater storage dynamics in an alpine basin (Dammagletscher, Switzerland)

This study aims at understanding interactions between stream and aquifer in a glacierized alpine catchment. We specifically focused on a glacier forefield, for which continuous measurements of stream water electrical conductivity, discharge and depth to the water table were available over 4 consecutive years. Based on this data set, we developed a two-component mixing model in which the groundwater component was modelled using measured groundwater levels. The aquifer actively contributing to streamflow was assumed to be constituted of two linear storage units. Calibrating the model against measured total discharge yielded reliable sub-hourly estimates of discharge and insights into groundwater storage properties. Our conceptual model suggests that a near-surface aquifer with high hydraulic conductivity overlies a larger reservoir with longer response time.

39. Transient surface deformations caused by the Gotthard Base Tunnel

The Gotthard Base Tunnel (GBT) is a 57 km long and up to 2500 m deep railway tunnel constructed between 2000 and 2011 in the Central Alps of Switzerland. As drainage of fractured rocks by deep tunnels accompanied by significant decrease in groundwater pressure causes large-scale deformations even in hard crystalline rocks, a comprehensive surface deformation and tunnel inflow monitoring system has been established and operated for more than ten years. This paper presents the results from this monitoring system and explains the observed hydro-mechanically coupled and transient rock mass behavior based on detailed assessments of geological, geomechanical and hydrogeological conditions and conceptual continuum models. The collected data show that significant tunnel-drainage induced surface deformations also develop in rock masses with moderate hydraulic conductivity (2E - 9 m/s) and small cumulative tunnel inflows (a few liters per second per kilometer). In this case deformations are caused by pore pressure reductions and rock mass deformations around the draining tunnel at depth, and not by groundwater table elevation changes. The pattern of surface settlements observed along the tunnel axis is very irregular (up to 11 cm in 2013) and strongly influenced by hectometer scale hydro mechanical heterogeneities of steeply dipping geological units striking at large

angle to the tunnel axes. At the depth of the studied tunnel section (1500-2500 m) about 50% of the surface settlements can be recorded. The surface settlements are connected to horizontal displacements and strains directed towards the tunnel axes or advancing tunnel face. The resulting horizontal displacement at the Nalps dam has reached about 65 mm in 2013. Compressive strains in the order of 20-50 microstrain are typically observed within a corridor of about 1 to 1.5 km width. Outside the reversal point of the settlement trough, extensile strains of similar magnitude develop.

40. Uranium transport in a crushed granodiorite: Experiments and reactive transport modeling

The primary objective of this study was to develop and demonstrate an experimental method to refine and better parameterize process models for reactive contaminant transport in aqueous subsurface environments and to reduce conservatism in such models without attempting to fully describe the geochemical system. Uranium was used as an example of a moderately adsorbing contaminant because of its relevance in geologic disposal of spent nuclear fuel. A fractured granodiorite from the Grimsel Test Site (GTS) in Switzerland was selected because this system has been studied extensively and field experiments have been conducted with radionuclides including uranium. We evaluated the role of pH, porous media size fraction, and flow interruptions on uranium transport. Rock cores drilled from the GTS were shipped to Los Alamos National Laboratory, characterized by x-ray diffraction and optical microscopy, and used in uranium batch sorption and column breakthrough experiments. A synthetic water was prepared that represented the porewater that would be present after groundwater interacts with bentonite backfill material near a nuclear waste package. Uranium was conservatively transported at pH 8.8. Significant adsorption and subsequent desorption was observed at pH similar to 7, with long desorption tails resulting after switching the column injection solution to uranium-free groundwater. Our experiments were designed to better interrogate this slow desorption behavior. A three-site model predicted sorption rate constants for a pH 72 solution with a 75-150 pm granodiorite fraction to be 3.5, 0.012, and 0.012 mL/g-h for the forward reactions and 0.49, 0.0025, and 0.001 h(-1) for the reverse reactions. Surface site densities were 13, 0.042, and 0.042 mu mol/g for the first, second, and third sites, respectively. 10-year simulations show that including a slow binding site increases the arrival time of a uranium pulse by similar to 70%.

41. Comparative modeling of an in situ diffusion experiment in granite at the Grimsel Test Site

An in situ diffusion experiment was performed at the Grimsel Test Site (Switzerland). Several tracers (H-3 as HTO, Na-22(+), Cs-134(+), I-131(-) with stable I- as carrier) were continuously circulated through a packed-off borehole and the decrease in tracer concentrations in the liquid phase was monitored for a period of about 2 years. Subsequently, the borehole section was overcored and the tracer profiles in the rock analyzed (H-3, Na-22(+), Cs-134(+)) H-3 and Na-22(+) showed a similar decrease in activity in the circulation system (slightly larger drop for H-3). The drop in activity for Cs-134(+) was much more pronounced. Transport distances in the rock were about 20 cm for H-3, 10 cm for Na-22(+), and 1 cm for Cs-134(+). The dataset (except for I-131(-) because of complete decay at the end of the experiment) was analyzed with different diffusion-sorption models by different teams (IDAEA-CSIC, UJV-Rez, JAEA) using different codes, with the goal of obtaining effective diffusion coefficients (D-e) and porosity (phi) or rock capacity (alpha) values. From the activity measurements in the rock, it was observed that it was not possible to recover the full tracer activity in the rock (no activity balance when adding the activities in the rock and in the fluid circulation system). A Borehole Disturbed Zone (BDZ) had to be taken into account to fit the experimental observations. The extension of the BDZ (1-2 mm) is about the same magnitude than the mean grain size of the quartz and feldspar grains. IDAEA-CSIC and UJV-Rez tried directly to match the results of the in situ experiment, without forcing any laboratory-based parameter values into the models. JAEA conducted a predictive modeling based on laboratory diffusion data and their scaling to in situ conditions. The results from the different codes have been compared, also with results from small-scale laboratory experiments. Outstanding issues to be resolved are the need for a very large capacity factor in the BDZ for H-3 and the difference between apparent diffusion coefficients (D-a) from the in situ experiment and out-leaching laboratory tests.

42. Laboratory investigation of the role of desorption kinetics on americium transport associated with bentonite colloids

Understanding the parameters that control colloid-mediated transport of radionuclides is important for the safe disposal of used nuclear fuel. We report an experimental and reactive transport modeling examination of americium transport in a groundwater-bentonite-fracture fill material system. A series of

batch sorption and column transport experiments were conducted to determine the role of desorption kinetics from bentonite colloids in the transport of americium through fracture materials. We used fracture fill material from a shear zone in altered granodiorite collected from the Grimsel Test Site (GTS) in Switzerland and colloidal suspensions generated from FEBEX bentonite, a potential repository backfill material. The colloidal suspension (100 mg L-1) was prepared in synthetic groundwater that matched the natural water chemistry at GTS and was spiked with 5.5 x 10(-10) M Am-241. Batch characterizations indicated that 97% of the americium in the stock suspension was adsorbed to the colloids. Breakthrough experiments conducted by injecting the americium colloidal suspension through three identical columns in series, each with mean residence times of 6 h, show that more than 95% of the bentonite colloids were transported through each of the columns, with modeled colloid filtration rates (k(f)) of 0.01-0.02 h(-1). Am recoveries in each column were 55-60%, and Am desorption rate constants from the colloids, determined from 1-D transport modeling, were 0.96, 0.98, and 0.91 h(-1) in the three columns, respectively. The consistency in Am recoveries and desorption rate constants in each column indicates that the Am was not associated with binding sites of widely-varying strengths on the colloids, as one binding site with fast kinetics represented the system accurately for all three sequential columns. Our data suggest that colloid-mediated transport of Am in a bentonite-fracture fill material system is unlikely to result in transport over long distance scales because of the ability of the fracture materials to rapidly strip Am from the bentonite colloids and the apparent lack of a strong binding site that would keep a fraction of the Am strongly-associated with the colloids.

43. Modelling susceptibility of grassland soil to macropore flow

Investigating preferential flow, including macropore flow, is crucial to predicting and preventing point sources of contamination in soil, for example in the vicinity of pumping wells. With a view to advancing groundwater protection, this study aimed (i) to quantify the strength of macropore flow in four representative natural grassland soils on the Swiss plateau, and (ii) to define the parameters that significantly control macropore flow in grassland soil. For each soil type we selected three measurement points on which three successive irrigation experiments were carried out, resulting in a total of 36 irrigations. The strength of macropore flow, parameterized as the cumulated water volume flowing from macropores at a depth of 1 m in response to an irrigation of 60 mm h(-1) intensity and 1 h duration, was simulated using the dual-permeability MACRO model. The model calibration was based on the key soil parameters and fine measurements of water content at different depths. Modelling results indicate high performance of macropore flow in all investigated soil types except in gleysols. The volume of water that flowed from macropores and was hence expected to reach groundwater varied between 81% and 94% in brown soils, 59% and 67% in para-brown soils, 43% and 56% in acid brown soils, and 22% and 35% in gleysols. These results show that spreading pesticides and herbicides in pumping well protection zones poses a high risk of contamination and must be strictly prohibited. We also found that organic carbon content was not correlated with the strength of macropore flow, probably due to its very weak variation in our study, while saturated water content showed a negative correlation with macropore flow. The correlation between saturated hydraulic conductivity (KO and macropore flow was negative as well, but weak. Macropore flow appears to be controlled by the interaction between the bulk density of the uppermost topsoil layer (0-0.10 m) and the macroporosity of the soil below. This interaction also affects the variations in K-s and saturated water content. Further investigations are needed to better understand the combined effect of all these processes including the exchange between micropore and macropore domains.

44. Estimation of groundwater recharge and drought severity with varying model complexity

A reliable quantification of groundwater recharge (GR) is essential for sustainable water resources management. This can be particularly relevant in regions where an increase in the duration and frequency of drought events is predicted due to future climate change. Although there exists a large variety of GR estimation methods, their results can differ considerably for an individual site due to the spatio-temporal scales and complexities they represent. Therefore, it is crucial to evaluate the potential range of GR estimates to allow for consistency and objective inter-comparison of modeling results among different sites. The current study systematically assesses the performance of six frequently used GR estimation methods, which differ in terms of their underlying conceptual framework and complexity. These methods utilize experimental data (lysimeter, river streamflow, groundwater-table variations) as well as soil-water-balance and physically-based modeling concepts. 13 years of hydro-climatic data were analyzed from the Swiss Rietholzbach research catchment for different temporal resolutions and extreme climatic conditions (i.e., dry periods). The major limitations and strengths of the six GR

estimation methods were identified and summarized in a comprehensive overview, which will facilitate the selection of an adequate technique for the estimation of GR in future studies.

45. Snowmelt infiltration and storage within a karstic environment, Vers Chez le Brandt, Switzerland

Even though karstic aquifers are important freshwater resources and frequently occur in mountainous areas, recharge processes related to snowmelt have received little attention thus far. Given the context of climate change, where alterations to seasonal snow patterns are anticipated, and the often-strong coupling between recharge and discharge in karst aquifers, this research area is of great importance. Therefore, we investigated how snowmelt water transits through the vadose and phreatic zone of a karst aquifer. This was accomplished by evaluating the relationships between meteorological data, soil–water content, vadose zone flow in a cave 53 m below ground and aquifer discharge. Time series data indicate that the quantity and duration of meltwater input at the soil surface influences flow and storage within the soil and epikarst. Prolonged periods of snowmelt promote perched storage in surficial soils and encourage surficial, lateral flow to preferential flow paths. Thus, in karstic watersheds overlain by crystalline loess, a typical pedologic and lithologic pairing in central Europe and parts of North America, soils can serve as the dominant mechanism impeding infiltration and promoting shallow lateral flow. Further, hydrograph analysis of vadose zone flow and aquifer discharge, suggests that storage associated with shallow soils is the dominant source of discharge at time scales of up to several weeks after melt events, while phreatic storage becomes import during prolonged periods without input. Soils can moderate karst aquifer dynamics and play a more governing role on karst aquifer storage and discharge than previously credited. Overall, this signifies that a fundamental understanding of soil structure and distribution is critical when assessing recharge to karstic aquifers, particularly in cold regions.

46. Assessment of source tracking methods for application in spring water

For discriminating between human and animal faecal contamination in water, microbial source tracking (MST) approaches using different indicators have been employed. In the current study, a range of 10 such MST indicators described in the scientific literature were comparatively assessed. Bacteriophages infecting host strains of Bacteroides (GA-17, GB-124 and ARABA 84) as well as sorbitol-fermenting bifidobacteria proved useful for indicating human faecal contamination while Rhodococcus coprophilus was associated with animal-derived faecal contamination. These potential source indicators were present in samples of faecal origin, i.e. either in human wastewater or animal waste, from many different regions in Switzerland and therefore showed a geographic stability. In addition, the MST indicators were abundant in surface water and were even sensitive enough to detect faecal contamination in spring water from two study areas in Switzerland. This is the first study that has compared and successfully applied MST methods in spring water.

47. Triple isotope (delta D, delta O-17, delta O-18) study on precipitation, drip water and speleothem fluid inclusions for a Western Central European cave (NW Switzerland)

Deuterium (SD) and oxygen (delta O-18) isotopes are powerful tracers of the hydrological cycle and have been extensively used for paleoclimate reconstructions as they can provide information on past precipitation, temperature and atmospheric circulation. More recently, the use of O-17(excess) derived from precise measurement of delta O-17 and delta O-18 gives new and additional insights in tracing the hydrological cycle whereas uncertainties surround this proxy. However, O-17(excess) could provide additional information on the atmospheric conditions at the moisture source as well as about fractionations associated with transport and site processes. In this paper we trace water stable isotopes (delta D, delta O-17 and delta O-18) along their path from precipitation to cave drip water and finally to speleothem fluid inclusions for Milandre cave in northwestern Switzerland. A two year-long daily resolved precipitation isotope record close to the cave site is compared to collected cave drip water (3 months average resolution) and fluid inclusions of modern and Holocene stalagmites. Amount weighted mean SD, delta O-18 and delta O-17 are -71.0 parts per thousand, -9.9 parts per thousand, -5.2 parts per thousand for precipitation, -60.3 parts per thousand, -8.7 parts per thousand, -4.6 parts per thousand for cave drip water and -61.3 parts per thousand, -8.3 parts per thousand, -4.7 parts per thousand for recent fluid inclusions respectively. Second order parameters have also been derived in precipitation and drip water and present similar values with 18 per meg for O-17(excess) whereas d-excess is 1.5 parts per thousand more negative in drip water. Furthermore, the atmospheric signal is shifted towards enriched values in the drip water and fluid inclusions (Delta of - 10 parts per thousand for delta D). The isotopic composition of cave drip water exhibits a weak seasonal signal which is shifted by around 8-10

months (groundwater residence time) when compared to the precipitation. Moreover, we carried out the first delta O-17 measurement in speleothem fluid inclusions, as well as the first comparison of the delta O-17 behaviour from the meteoric water to the fluid inclusions entrapment in speleothems. This study on precipitation, drip water and fluid inclusions will be used as a speleothem proxy calibration for Milandre cave in order to reconstruct paleotemperatures and moisture source variations for Western Central Europe.

48. Impact of global change on karst groundwater mineralization in the Jura Mountains

Chemistry of karst groundwater is related to conditions prevailing within the karst underground as well as at the land-surface within the recharge area. It is dominated by the dissolution of calcite and/or dolomite, which is strongly triggered by the presence of high pCO2 in soils at the top of the bedrock. Dissolution (water mineralization) is clearly influenced by soil pCO2, i.e. by global changes such as land-use, agriculture practices and climate change. However, the dissolution of carbonates is considered as a quite significant carbon sink for the Earth Atmosphere. Assessing the evolution of carbonate water mineralization can thus help characterizing the evolution of the carbon sink related to carbonate dissolution. The main goal of the study is to check the presence of trends with a high statistical relevance in groundwater quality data along the past 20years. Causes potentially explaining the observed trends, such as land-use, agriculture practices and global warming are analyzed and discussed. The long term evolution of parameters related to carbonate dissolution are discussed and extrapolated as they may have consequences for the Global Carbon Cycle. The analysis is based on three independent data-sets stretching over more than 20years each, coming from more than 40 sources. Statistical tests (Mann-Kendall trend test) indicate clear trends for compounds related to groundwater mineralization: increase in temperature (by about 0.5°C/25years), decrease in pH, increase in bicarbonate (by about 5%), and positive or negative trends for major ions directly related to human practices. Data and analysis suggest that carbonate dissolution is quickly increasing as a consequence of climate warming. Considering the largely accepted fact that carbonate dissolution acts as carbon sink for the atmosphere, it can be postulated that the observed increase could act as a negative feedback mechanism, tending to slow down the atmospheric increase in CO2.

49. Deciphering neotectonics from river profile analysis in the karst Jura Mountains (northern Alpine foreland)

The study of the neotectonic activity in the Jura Mountains (northwestern most belt of the European Alps) represents a challenge in the application of quantitative geomorphology to extract landscape metrics and discuss potential coupling between tectonic, climatic and lithospheric mechanisms during the evolution of this mountain belt. The Jura Mountains are characterized by a karst calcareous bedrock, slightly affected by Quaternary glaciations, and by moderated uplift rates (<1 mm/year). In this study, we performed river profile analyses to decipher comparable geomorphological signals along tectonic structures within the entire Jura arc. Our results suggest higher tectonic activity in the High Range of the belt (internal part) than in the External Range, which is discussed in terms of deformation mechanisms. Integration of our results with previous geomorphological, neotectonic and geodetic studies from the literature leads us to propose new potential lithospheric and tectonic mechanism(s) driving the Plio-Quaternary deformation of the Jura Mountains. Our study finally reveals a regional-scale correlation between neotectonic deformations recorded by the Jura drainage network and the predicted isostatic rebound in response to Alpine Quaternary erosion. However, the correlation between our geomorphic signals and compressive structures suggests that the Jura Mountains could be still in horizontal shortening in both the High Range and the External Range.

50. Controls on the diurnal streamflow cycles in two subbasins of an alpine headwater catchment

In high-altitude alpine catchments, diurnal streamflow cycles are typically dominated by snowmelt or ice melt. Evapotranspiration-induced diurnal streamflow cycles are less observed in these catchments but might happen simultaneously. During a field campaign in the summer 2012 in an alpine catchment in the Swiss Alps (Val Ferret catchment, 20.4 km(2), glaciarized area: 2%), we observed a transition in the early season from a snowmelt to an evapotranspiration-induced diurnal streamflow cycle in one of two monitored subbasins. The two different cycles were of comparable amplitudes and the transition happened within a time span of several days. In the second monitored subbasin, we observed an ice melt-dominated diurnal cycle during the entire season due to the presence of a small glacier. Comparisons between ice melt and evapotranspiration cycles showed that the two processes were happening at the same times of day but with a different sign and a different shape. The amplitude of the

ice melt cycle decreased exponentially during the season and was larger than the amplitude of the evapotranspiration cycle which was relatively constant during the season. Our study suggests that an evapotranspiration-dominated diurnal streamflow cycle could damp the ice melt-dominated diurnal streamflow cycle. The two types of diurnal streamflow cycles were separated using a method based on the identification of the active riparian area and measurement of evapotranspiration.

Übersichtspublikationen – publications synoptiques

51. Hydrologisches Jahrbuch der Schweiz 2014 - Abfluss, Wasserstand und Wasserqualität der Schweizer Gewässer
Annuaire hydrologique de la Suisse 2014 - Débit, niveau et qualité des eaux suisses
Annuario idrologico della Svizzera 2014 - Deflussi, livelli idrometrici e qualità delle acque in Svizzera
Hydrological Yearbook of Switzerland 2014 - Discharge, water level and water quality of the Swiss water bodies

Das «Hydrologische Jahrbuch der Schweiz» wird vom 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.

Publié par l'OFEV, l'Annuaire hydrologique donne une vue d'ensemble des événements hydrologiques de l'année en Suisse. 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 suisses y figurent également. La plupart des données proviennent des relevés de l'OFEV.

L'«Annuario idrologico», edito dall'UFAM, fornisce una visione d'insieme degli eventi idrologici in Svizzera. Illustra l'andamento dei livelli idrometrici e delle portate dei laghi, dei corsi d'acqua e delle acque sotterranee e contiene informazioni sulle temperature e sulle proprietà fisiche e chimiche dei principali corsi d'acqua in Svizzera. I dati in esso pubblicati provengono in gran parte da rilevazioni effettuate dall'UFAM.

The "Hydrological Yearbook" is published by the Federal FOEN and gives an overview of the hydrological situation in Switzerland. It shows the changes in water levels and discharge rates from lakes, rivers and groundwater and provides information on water temperatures and the physical and chemical properties of the principal rivers in Switzerland. Most of the data is derived from FOEN surveys.

52. Airborne exploration of anomalous high uranium contents in water and soil in the region of the "Lyssbach" – Canton of Bern

The water and soil protection laboratory of the Canton of Bern detected anomalous high uranium concentrations in the creek "Lyssbach" at the locality of Lätti between between Lyss and Schönbühl (canton of Bern) as part of the standard water monitoring programm. Values up to 45 mg/l of dissolved uranium in creekwater and at up to 400 mg/l in groundwater samples have been measured. The average concentration of dissolved uranium in Swiss creeks is in the range of a few mg/l (Baertschi & Keil 1992).

Water samples were collected from the "Lyssbach" and from groundwater inflows in the creek to explore the possible uranium source. Two suspicious contaminated sites were evaluated using a radiation detector as a payload of a octocopter (Figure 1). Airborne radiation mapping turned out to be a very effectiv and low budget instrument to detect anomalous radiation aereas within short time.

It was possible to scan several 100'000 m2 within a day with a resolution of approximately 10 m2 and a detection limit of the flying Na(Ti) detector ~ 50 cps. In order to increase the resolution to 2 m2 within the resulting anomalous radiation, the area was mesured with the same detector by foot. Soil samples, taken from core drillings, were analysed by gammaspectrometry and X-ray fluorescence spectroscopy, watersamples by alphaspectrometry. In addition, piezometer measurements were made. The resulting radiation map is shown in Figure 2. The obtained uranium concentrations of the soil samples showed a max. value of 220 ppm U at a depth from 0.60 m. The uranium content of the watersample from the piezometer (420 mg U/l) showed the same value as earlier (Schmidt 2013) measurements from the drainagewater.

Several possible uranium sources could been evaluated, based on a historical investigation: disposal sites, fertilisers /waste of fertiliser production or geogene origin. The deposition age of tht solid uranium compounds in the soil could be estimated to 10'000 years b.p., based on the ratio of Ra-226 and Th-234. Therefore any present-day anthropogene origin of the uranium compounds can be excluded. However, during in the past 150 years the redox conditions may have changed by draining the swampy fields to gain agricultural land. This could have caused the input of oxygene into the soil to remobilze the uranium.

53. Applying Compound-Specific Isotope Analysis (CSIA) to identify biodegradation of chlorinated hydrocarbons in low permeability sediments

As a result of improper use and disposal, chlorinated solvents are major subsurface contaminants. Due to the high density and low viscosity, chlorinated solvents migrate through the unsaturated zone into aquifer systems and often accumulate on top of low permeability sediments. With time chlorinated solvents diffuse into these low permeable units, which then potentially serve as a long-term contaminant source to the adjacent aquifer. However, due to the presence of more reducing conditions in these units, (bio)degradation might occur, which reduces the risk of long-term groundwater contamination. Compound-specific stable isotope analysis (CSIA) is increasingly used to quantify (bio)degradation processes in aquifer systems affecting organic contaminants. This method makes use of isotope effects associated with (bio)degradation. In contrast to aquifers, it is not yet clear to what extent CSIA can also be used for tracking (bio)degradation in saturated low permeability sediments, where transport is likely diffusion dominated.

To address this gap of knowledge, several detailed C and Cl isotope ratio profiles of chlorinated solvents were determined for a contaminated clayey aquitard underlying a sandy aquifer. The contaminant source originated from a controlled-solvent release on top of the aquitard 14.5 years ago. Large shifts towards lighter isotope signature (e.g. 23‰ for C isotopes in TCE) of compound-specific isotope ratios were observed in the isotope ratio profiles, suggesting that (bio)degradation of chlorinated solvents is also occurring in saturated low permeability sediments. Furthermore, the results of numerical modeling gained more insight into the governing processes and allowed us to determine (bio)degradation rates affecting chlorinated solvents in the clayey aquitard.

Our findings demonstrate that CSIA is also applicable in saturated low permeability sediments for the identification of reactive processes. Moreover, our results revealed that (bio)degradation is potentially superimposed on diffusion and thus, it is difficult to identify based on concentration profiles only.

Therefore, isotope information is an important complement additionally to concentration data to identify (bio)degradation in low permeability sediments.

54. Assessing surface water contribution to groundwater recharge: An example from Traversagna Valley, Ticino.

Tracer tests are widely used to evaluate a variety of hydrogeological issues. By using them is possible to know groundwater flow velocity, study transport of dissolved solids, evaluate porosity of aquifers, etc. while discharge measurements allow tracer recovery calculations and are also routinely used to study hydrology of watersheds. Arbedo Castione water distribution system relies entirely on groundwater from a small aquifer located in the Traversagna Valley, before its confluence with the Ticino River. The aquifer was formed after the sediments carried by the Traversagna river (mostly gravel, sand and blocks) arriving to a srcreen dam, completely filled it. 5 drains were therefore drilled within the aquifer starting from the screen dam to exploit it. Those drains used for drinking water provide a continuous discharge of roughly 0.03 m3/s (Pedrozzi, 1990). Given the small surface/volume of the aquifer of about 0.012 Km2 / 3*105 m3, and considering the fact that it is limited by gneiss which could be considered as impervious, the Traversagna River should play a role in recharge of the acquifer besides meteoric events, to maintain piezometric levels and therefore the observed discharge from drains.

In order to study the contribution of the Traversagna River to recharge, discharge measurements by using an electronic gauge were performed in date 5.3.2015, in 3 points see figure 1: Upstream (Q1) where the river leaves the gneiss and start to flow through the alluvial sediments, at the spillway (Q2) of the screen dam and downstream after the drains (Q3). A tracer test was also performed in April 2015 with continuous injection of a solution containing 200 g/l of Uranine in the river at point U1. River discharge was measured and tracer injection rate was determined in order to reach a constant concentration in the river of 500 ppb. That concentration was maintained for approximately 30 min. 3 fluorimeters Ggun from Neuchâtel University for continuous tracer monitoring were placed. One in top of the screen dam at the spillway (F1) to analyse the tracer leaving the area through the Traversagna river, the second (F2) in the basin collecting water from the drains, and the third (F3) between the overflow pipe of the drains and the screen dam to get the tracer leaving the aquifer through holes in the dam placed at lower level respect to the spillway. Water conductivity and pH were also measured in the river and in the drains.

According with the results, water conductivity in the river and form the drains present almost no difference with 266 mS/cm and 245 mS/cm respectively, pH values are also similar with 8.28 and 8.20 units indicating that is almost the same water. The contribution of river to recharge is confirmed by discharge measurements. In Q1 discharge was 0.255 m3/s in Q2 180 m3/s and in Q3 0.270 m3/s. Indicating that the river contributed with 0.075 m3/s to the recharge at the time of the measure. Concerning the tracer test, river discharge at the moment of injection was in Q1 of 0.45 m3/s, a concentration of 450 ppb was reached and maintained approximately constant during 25 minutes. Uranine started to arrive to the drains 3.5 hours after tracer injection, reaching a peak of 3.3 ppb 48 hours after injection with a tail reaching values of 0.12 ppb 10 days after injection.

The study shows that the Traversagna river plays a decisive role in recharging the aquifer, with both significant volumes and quick links with the drains providing drinking water to Arbedo - Castione. In terms of management and protection special attention should be paid to the Traversagna River since it is the main source of recharge and any pollution will quickly reach the drains.

55. Bridging the conceptual gaps between hydrology and hydrogeology

Hydrology and hydrogeology have to a certain extent developed as independent scientific disciplines. This separate development is reflected in the conceptual models of the two communities: Hydrological models typically simulate surface processes in a detailed way, but simplify groundwater flow processes. Hydrogeologists, on the other hand, often reduce the complexity and dynamics of the surface to a simple boundary condition. As surface water and groundwater form a natural continuum, this separation has been an impediment for a holistic understanding of the water cycle. However, recent developments in fully-coupled, physically based models allow for a better integration of the two domains. In this presentation two examples to illustrate this point are shown. In the first example a model simulating surface watergroundwater interactions as well as the feedback mechanisms with riparian vegetation is presented. The model was calibrated using tree ring data. In the second example a new approach for the full spatial and temporal deconvolution of a hydrograph is presented. Both examples illustrate the importance to integrate surface and subsurface flow processes in a holistic way.

56. Combining approaches of monitoring and modelling groundwater temperatures to investigate the subsurface urban heat island of Basel, Switzerland

The temperatures of the shallow subsurface in urban areas are affected by numerous natural factors and anthropogenic influences. The latter comprise the thermal influence of tunnels, buildings in the subsurface, open and closed-loop geothermal systems, sealed surfaces, and infrastructure installations (e.g. district heating networks) (e.g. Epting et al. 2013, Benz et al. 2015). Groundwater in unconsolidated, highly permeable sediments plays an important role for advective heat transport, and therefore for the spatial (re)distribution of energy in the subsurface (e.g. Lo Russo & Taddia 2010). The effect of the current increase of groundwater temperatures, which can be observed in many urban areas (e.g. Zhu et al. 2010), on future thermal management of groundwater is not known yet. Therefore, adequate management strategies, which are based on monitoring and modelling tools, are required for urban groundwater bodies.

The groundwater and shallow subsurface temperatures in the urban area of Basel City are currently investigated. The use of conventional groundwater observation wells to investigate the influence of thermal groundwater use as well as deep and shallow building structures on groundwater temperatures is restricted since these wells rarely are located appropriately downstream of the thermal impact. Furthermore, conductive heat transport within conventional wells might bias the monitored temperature data. Therefore, besides conventional groundwater observation wells a series of multilevel temperature wells at specific locations and 3D numerical groundwater flow and heat transport models are used to assess thermal groundwater regimes in urban areas.

First results reveal that mean annual groundwater temperatures in urban areas range from about 11 to 17 °C (Figure 1). On average, they are 3.0 K higher compared to the mean annual air temperature, and 1.4 K higher compared to the mean annual groundwater temperatures in non-urban areas (open space, non-sealed areas), which range from 10 to 14 °C (Figure 1). The temperatures measured with the multilevel wells, which also measure temperatures in the unsaturated zone, range from 2 to 30 °C in 0.5 m depth below the asphalt. The soil temperatures measured at a meteorological station (MeteoSwiss 2015) in a non-urban area outside the city range from 2 to 23 °C in 0.5 m depth below the surface. This corroborates the importance of the influence of sealed surfaces for the elevated groundwater temperatures in urban areas. The subsurface temperature of a multilevel temperature well in 19.5 m below ground near a building (reaching the groundwater level) was seasonally varying around 15 ± 0.5 °C (mean ± standard deviation). This suggests that heating periods in deep building structures can affect subsurface temperatures in urban areas. The temporal temperature variations of some conventional observation wells could be simulated adequately within a subarea of Basel, whereas at other locations no good match between observed and simulated temperatures could be acquired. These results indicate that the complex flow and thermal boundary conditions in some areas of the modelled sub-area are not yet entirely understood. However, the mean simulated annual groundwater temperatures in the observation wells, ranging from about 12.5 to 18.5 °C, correspond to the measured range of annual mean groundwater temperatures. This allows time integrated calculation of heat balances across model boundaries and defined cross-sections. The model is further used to conduct simulation tests, using different boundary conditions for the heat input on the top boundary and additional subsurface structures (e.g. sewage system networks) reaching the groundwater level. Further work will include the evaluation of the level of detail which is needed for the implementation of sealed or open surfaces and subsurface structures reaching the groundwater levels in the model.

57. Der digitale Hydrogeologische Datensatz 1:100000 als Teil einer massstabsübergreifenden Raumdatenhaltung: Anforderungen und Potential

Im Herbst 2015 wird vom Bundesamt für Umwelt BAFU die digitale Hydrogeologische Karte 1:100000 Nordwest-Schweiz veröffentlicht. Dieser vektorielle Datensatz stellt einen weiteren wichtigen Teil einer massstabs-übergreifenden thematischen Raumdatenhaltung dar, mit der die Themen Hydrologie, Grundwasser und Geologie verknüpft werden. Er veranschaulicht die speziellen Anforderungen an Datenrückerfassung und Digitalisierung, Generalisierung, blattschnittfreie Darstellung und insbesondere an die Massstabsfrage bei der Zurverfügungstellung von digitalen Geodaten. In der Schweiz existieren auf Bundesebene sechs, auf kantonaler Ebene zwei offizielle Massstabsabstufungen. Diese wurden im vordigitalen Zeitalter als grundlegendes Instrument zur Erstellung und Nutzung geobasierter Daten eingeführt. Die bewusste Wahl eines Massstabs wurde damit zur ersten Frage jeder Datenerstellung. Die Festlegung auf einen Zielmassstab hat u.a. folgende wichtigen Funktionen:

– Erstellung von Atlaswerken

– Darstellung von Themen auf nationaler, regionaler und lokaler Ebene

– Benutzergerechte Publikation von Geodaten

– Verknüpfung von Themen

– Flächendeckende Darstellung von Themen mit geringem oder lückenhaftem Wissensstand (abgeleitete oder interpretierte Geodaten).

Bei gedruckten Karten wird die Aussagekraft der Daten von den meisten Nutzern intuitiv richtig eingeschätzt. Im Zuge der Digitalisierung und Nutzung der Daten am Bildschirm wird jedoch der Massstabsfrage deutlich weniger Gewicht geschenkt, wobei durch die Vergrösserungsfunktion der Detaillierungsgrad der Daten oft überschätzt wird. Prinzipiell hat aber jeder Datensatz – ob analog gedruckt oder digital in GIS-Systemen gehalten – bei der Erstellung und Aktualisierung einen Zielmassstab sowie einen Massstabsbereich, innerhalb dessen eine Nutzung der Informationen sinnvoll und zulässig ist. Zur intuitiven Erfassung des Zielmassstabs erscheint es daher notwendig, neue grafische Werkzeuge zu entwickeln. Zudem gibt es konzeptionellen Bedarf sowie hinsichtlich der technischen Möglichkeiten, eine generalisierte Karte automatisch aus grossmassstäblichen Datensätzen abzuleiten. Im Sinne einer umfassenden digitalen Raumdatenhaltung wird dies im Zusammenhang mit den Hydrogeologischen Karten derzeit geprüft, da noch grosses Potential zur Inwertsetzung bereits vorhandener Daten im Bereich Grundwasser besteht.

58. Enhancement of permeability in geothermal reservoirs: the example of the Salanfe lake – Val d'Illiez geothermal area

Extraction of deep groundwater for accessing geothermal heat is an innovative method in the field of renewable energies. In engineered geothermal systems (EGS), targeting depths >3 km, the circulation and extraction of water is promoted by means of a doublets of wells and a stimulated reservoir. In geothermal projects of medium temperature, natural groundwater is extracted from deep aquifer systems located at depths from 1 to 3 km. Both cases are often characterized by a very low permeability of the reservoir, which limits the capacity to produce cost-efficient flow rates. This is principally because of mechanical, i.e. increasing stress with depth, and chemical, i.e. clogging of fractures by mineral filling, processes. Thus, reservoir stimulation by means of hydraulic shearing events is a critical method for the geothermics industry. To ensure permanent fracture permeability, hydraulic shearing aims to activate in shear natural pre-existing fractures favorably oriented, i.e. having an angle ranging between 15-45° with the maximum principal stress σ1, by means of injecting a fluid pressure lower than the minimum principal stress σ3. However, it is still unclear (i) how much the reservoir permeability is enhanced during hydroshear slip events and (ii) what is the resulting reservoir geometry.

The Salanfe lake – Val d'Illiez geothermal area (Valais, Switzerland) is an interesting field case for addressing these questions. In this work, we have analyzed the seismic events in the Salanfe lake – Val d'Illiez area between 1953 – 2000 (data from the Earthquake catalog, Fäh et al. 2011). First, all the recorded seismic events with moment magnitudes having an impact on shear dilation and fracture permeability, i.e. Mw >0, have been plotted as a function of time and superimposed on the seasonal fluctuation of water levels in the Salanfe dam lake. At least 8 clouds of seismic events can be linked to the seasonal fluctuation of water levels in the lake. For these clouds, the time lag between maximum water level and the occurrence of the seismic event with higher moment magnitude, has increased over the years, suggesting a gain in reservoir volume and permeability. Second, shallow events (depth <5 km) for the period 1980-2000, have been superimposed on the fracturation map of Pantet (2004). Although the position of seismic events may imply important errors, two major deep flow paths can be interpreted. These have an orientation which is in agreement with the strike of the major fractured zones (N300°) highlighted in Pantet (2004), which are furthermore favourably oriented for hydroshear reactivation (Figure 1). One of the two major flow paths has been accidentally created in 1953 via the reactivation of a pre-existing shear zone. This zone has subsequently been stimulated several times with the fluctuation of water levels in the Salanfe lake, especially in 1996. In this year, the second major flow path has been created through the reactivation of another preexisting shear zone. These observations are promising within the framework of efficient stimulation of geothermal reservoirs by means of multi-stage hydro-shearing injections.

59. Hydrodynamic model of deep flow systems in Northern Switzerland

In Northern Switzerland, thermal springs indicate the existence of deep reaching groundwater flow systems, as for example the Baden springs. In the last years, the deep aquifers were of increasing

interest for the sequestration of CO2 or for geothermal energy production. The presented model was elaborated in the framework of the Swiss Sectoral Plan to establish deep geological repositories for radioactive waste (Gmünder et al. 2014).

A 3D geological model based on seismic profiles, borehole data and isopach maps is a basis of the work. The model extends from the Bodensee area in the East to the area of Olten in the West. In the North, it includes the outcrops of the Muschelkalk in the Wutach area. The southern margin is striking parallel to the Alpine deformation front and was chosen based on preliminary 2D models. This geometry was implemented in the numerical code FEFLOW in order to perform stationary hydrodynamic modelling. The model includes 15 hydrogeological layers of regional importance from Mittlerer Muschelkalk up to the Quaternary. The regional fault structures are represented by 20 discrete faults. They are implemented as 3 parallel rows of elements; this allows to test different scenarios of their hydraulic properties. In order to minimize the number of elements, the faults were distorted into the vertical maintaining the outcrop positions and the elevations of hydrogeologic units. Once the geometry of the hydrogeological 3D model had been implemented, it was a versatile tool to model the flow systems and to test scenarios. Hydraulic conductivities have been assigned to the hydrogeological units based on measured values taking into account the tectonic regime, major facies changes and depth. The inspection of the available data showed that the Muschelkalk aquifer (middle triassic carbonates) is typically characterized by elevated conductivities down to c. 400 m below sea level (c. 800 m below ground). In contrast, the zone of elevated conductivities of the Malm aquifer appears to be restricted to a comparably shallow zone (c. 200 m below ground). The potential hydraulic impact of the regional fault zones was studied in scenarios: C1 considers the displacement at the faults only. Additional scenarios simulate sealing respectively transmissive faults.

In C1, the general flow direction in Malm and Muschelkalk aquifer is from the southern margin and from the elevated outcrops in Folded and Tabular Jura towards the large river valleys where the units crop out typically below Quaternary gravel aquifers (Figs. 1 & 2). For the Malm aquifer, the particle tracking highlights the exchange with the Molasse: In the south western model aerea recharge occurs from the Molasse, in the north east, Malm groundwater exfiltrates via Molasse into Untersee. In the case of the Muschelkalk aquifer south of the Jura Main Thrust, the model shows converging flow lines towards the outcrops in the Aare-, Reuss- and Limmat-valley. This explains at least partly the occurrence of thermal springs in this area.

60. Hydrogeological and topographic controls on watershed vulnerability to droughts

The frequency and intensity of periods with scarce water availability are likely to increase under changing climatic conditions. Even temperate and relatively humid regions like Switzerland are subject to seasonal and regional effects of such low-flow events. In order to manage water supply in the future, regions vulnerable to droughts therefore need to be identified. Groundwater, as one of the main fresh water reservoirs, greatly impacts hydrological catchment dynamics, especially during droughts. Numerous studies have analysed watershed processes, however, they have mainly concentrated on surface flows and streamflow statistics. In fact, classical hydrological models oversimplify groundwater flow processes, leading to poor reproduction of low flows. Our approach is thus to improve the understanding of low-flow watershed dynamics by considering all relevant physical processes: surface runoff, saturated and unsaturated subsurface flow, the interaction between surface water and groundwater, snowmelt and evapotranspiration. With the physically based numerical model HydroGeoSphere, synthetic models are developed to quantify how basin properties control low-flow dynamics independently from each other and frommeteorological conditions. Geological, hydrogeological, topographic and geomorphological characteristics as well as soil properties are tested. 59 Swiss gauged watersheds are then used in order to validate the identified interdependency between basin features and low-flow dynamics. Once the control of watershed characteristics on low flow generating mechanisms is identified, drought sensitivity indicators can be developed, an essential tool for water resources management of ungauged basins under dry conditions.

61. Hydrogeology at Grimsel Test Site: hydrochemistry and flow paths

Knowledge about fluid percolation through crystalline rocks is of importance within the framework of radioactive waste disposal, geothermal energy and groundwater supply projects. The underground laboratory at the Grimsel Test Site (GTS, www.grimsel.com), operated by Nagra, offers a unique possibility to investigate fluid flow in crystalline rocks based on structural data combined with long-term hydrochemical and hydrological monitoring. The area is composed of the Central Aar Granite (CAGr) and the Grimsel Granodiorite (GRGr), which are both cut by metabasic dykes. During the Alpine orogeny these rocks underwent greenschist metamorphic and tectonic overprint (Steck, 1968). This resulted in

the formation of two steeply dipping shear zone networks, one dipping towards SE and the other towards SSW (Wehrens, 2015). The last, cataclastic stage of the Alpine deformation produced discrete zones of increased permeability and thus led to a channelling of the fluid flow through the crystalline rocks. The present study focuses on a systematic hydrochemical monitoring of the groundwater collected from packed-off borehole sections in order to relate hydrochemical differences to the different structural features in the CAGr and GRGr. Over a one year period of sampling no statistically relevant seasonal trends were observed in the chemical and isotopic composition of the various groundwaters. This suggests homogenisation and attenuation of such variable infiltration signals along flow paths (up to 520 m rock overburden). Such homogenisation is in agreement with low tritium activities (0.6-4.8 TU) obtained earlier for few localities, which indicate average subsurface residence times in the order a few decades (Keppler, 1996). Groundwater at all localities at the GTS is alkaline, of a similar Na-Ca-CO3-F-(SO4) chemical type, has low total mineralisation (TDS = 57 ± 7 mg/L), partial pressures of CO2 below that of the atmosphere and is of meteoric origin. Over the entire monitoring period, groundwater collected in the southern, GRGr-dominated part has higher pH-values and higher concentrations in Na, K, Li, and Cl, but lower concentrations in Ca, SO4 and NO3 compared to groundwater collected in the northern, CAGr-dominated part of the GTS. Similarly, the ratios of Na/Cl, Na/K, Li/Cl, SO4/Cl, Sr/Ca, and Ca/Mg differ markedly between the two hydrogeological systems. In contrast, concentrations of Al, Si and F are remarkably similar between the two groups suggesting a similar solubility control in both systems. In combination with the lower d18O and d2H values of the southern, GRGr-dominated groundwater, which indicate a higher infiltration area, differences in the chemical composition can be related to longer flow paths and residence time and consequently intensified water-rock interaction. The results indicate that despite small differences in groundwater composition, the systematic long-term hydrochemical survey in combination with structural data allows deciphering different hydrogeological systems in crystalline rock environments.

62. Identification of transience in streambed hydraulic conductivity

Streambed hydraulic conductivity controls the interactions between surface and groundwater. Streambed properties are often subjected to transience due to deposition and erosion processes. However, monitoring this transience using current field methods remains challenging. Here we present a straightforward method to detect transience in streambed hydraulic conductivity. Input data are time series of stream stage and near stream groundwater head. The method is based on the inversion of a floodwave response. This method is applied on dataset from the Rhône River and its alluvial aquifer (Valais, Switzerland). The results show causality between climatic events driven fluvial dynamics, such as flood (100-year flood event of October 2000) or heatwave (2003), and variations in the streambed hydrogeological properties.

63. Monitoring riparian vegetation water stress in the Maggia river, Switzerland

Riparian vegetation on gravel bars and banks in braided Alpine rivers plays an important ecological role in riverine habitat creation. Riparian vegetation patches vary along rivers according to channel morphology, sediment supply, and hydrological dynamics. Furthermore, vegetation plays an active role in shaping channels by protecting banks, generating deposition areas, and influencing surface-groundwater exchanges (e.g. Gurnell et al., 2012). Water stress and flood disturbance are the major hydrological factors impacting riparian vegetation distribution. Low groundwater levels and soil moisture, as well as frequent and erosive flooding, are potentially detrimental to riparian vegetation establishment and growth. In this study, we investigate the feedback between hydrology and vegetation erosion/growth in the Maggia River in Switzerland on the basis of a new terrestrial camera monitoring system with near-infrared sensitivity, 2d hydrodynamic river/aquifer modelling, and plant scale measurement of growth rates by dendrometers and tree ring dating.

At the reach scale we demonstrate the sensitivity of a customer-grade digital camera system to objectively separate different surfaces (gravel, water, vegetation) and to quantify vegetation activity by means of the normalized difference vegetation index (NDVI). We monitor the progression of vegetation activity estimated by NDVI through four years, water stress is evident in periods with low precipitation and streamflow, e.g. spring and early summer in 2011 (Figure 1). We also quantify the immediate response of riparian vegetation to the five largest floods in our monitoring period on three distinct floodplain units. We find both a negative (damage) and positive (enhancement) response of vegetation within 1 week following the floods, with a selective impact determined by pre-flood vegetation vigour, geomorphological setting, and intensity of the flood forcing (Dzubakova et al., 2014). Most affected are saplings and young plants within the inundation zone with high flow velocity.

At the plant scale we observe the effects of water stress using dendrometers installed on four Populus nigra and Salix eleagnos species on a gravel bar in spring 2015. First data are indicating that growth rates are reacting rapidly to climatic conditions given by solar radiation, precipitation, air temperature and vapour pressure defict. A longer-term perspective on water stress is provided by tree ring growth increments which were sampled on several trees in the study area in 2014 and which indicate a weak correlation between tree ring increments and early season precipitation.

We conclude that vegetation response to flood disturbance may be effectively monitored by terrestrial photography with near-infrared sensitivity and by plant scale growth measurement. This type of monitoring can be useful for calibrating-validating stochastic riparian zone disturbance models (e.g., Perona et al., 2009) as well as for long-term assessments in river management and restoration projects in Alpine rivers affected by hydropower regulation (e.g. Molnar et al., 2008).

64. Numerical upscaling of seismic characteristics of fractured media

The seismic and hydraulic characterization of fractured rocks is still challenging, yet it has a number of important applications, such as, the sustainable use of groundwater, the optimized production of hydrocarbons and geothermal energy, and the safe storage of nuclear waste. While fractures and cracks tend to control the mechanical and hydraulic properties they can in general not be resolved directly, which makes it difficult to relate measured seismic attributes to the characteristics of the probed medium. In view of this, it is essential to understand how the effective properties of fracture rocks affect seismic observations.

Numerous effective medium theories were proposed to relate the effects of fractures to the overall elastic and hydraulicproperties of the medium. Recent studies have shown that the attenuation and the velocity dispersion of seismic waves are sensitive to the elastic as well as the hydraulic properties of the probed medium and thus might provide critical insights into fracture characteristics. However, effective medium models tend to be based on analytical approaches and hence are inherently limited to simple geometries, low fracture densities, and/ or non-interacting fractures.These rather restrictive criteria are generally not fulfilled by actual fracture networks.

One way to overcome the inherent limitations of analytical models is through numerical upscaling procedures. In this study, we utilise a numerical approach based on the theory of quasi-static poroelasticity (Rubino et al. 2009, Quintal et al. 2011). A homogeneous oscillating displacement field is applied to a subvolume of a fractured porous medium. By spatial averaging of the resulting complex-valued stress and strain fields, the phase velocities and the attenuation as functions of frequency can be inferred. Since this approach is limited to a finite size of the investigated medium, the considered subvolume has to be at least the size of a representative elementary volume (REV) for the upscaled medium properties to be representative of the effective behaviour of the underlying heterogeneous medium.The adequate definition of an REV for a given upscaling problem is therefore of critical importance.

Hill's (1963) classical approach for elastic composites defines an REV as a sub volume which is (i) independent of the applied boundary conditions and (ii) structurally representative of the entire medium. The first aspect was studied in detail by Milani et al. (2014) for peridically fractured porous media. In this work, we extend this analysis to media containing randomly distributed horizontal and vertical fractures. The question then arises if the considered subvolumes represent the overall statistical properties of the underlying heterogeneous fractured media. To adress the problem, we adapt a combiened statistical and numerical approach proposed for elastic composite media (Kanit et al. 2003). Our results indicate that the overall statistical properties of the considered fracture distributions can be described with reasonable accuracy for computationally feasible REV sizes.

65. Rethinking the role of alluvial groundwater in sustaining mountain baseflow: a mesoscale study based on continuous measurements of fluxes and storage

The present research challenges this conception and investigates whether alluvial aquifers may provide sufficient storage to sustain extended baseflow. This study focuses on a 6 km2 alluvial plain located in the peri-alpine region of Emmental (Switzerland). The plain covers only 3% of catchment area. However, the underlying material is highly permeable and exhibits relatively high storativity values.

The methodological setup relies on surface and subsurface water-level measurements conducted during one year. Twentysix observation wells were equipped with pressure loggers and three coupled gauging stations were installed to monitor simultaneously river and alluvial groundwater discharge at key locations. This approach provided continuous estimations of both total catchment outflow and

groundwater storage variations for the main catchment (196 km2) and for a sub-catchment (52 km2). The key results pertain to the study's driest month and may be summarized as follow:

• At the end of the dry spell, alluvial groundwater storage sustained a considerable fraction of catchment outflow.

Depletion, which occurred mostly in the highest part of the aquifer, supported:

− 35% of the total catchment outflow

− 75% of the sub-catchment outflow

• During this same period, the river gauging stations missed a substantial part of outflow (the subsurface component).

This represented :

− 15% of the total catchment outflow

− 85% of the sub-catchment outflow

• During this same period, the discharge ratio 'groundwater:river' varied spatially along the valley: the aquifer conveyed 15% of total outflow at the outlet (196 km2) and 100% (0.45 m3/s) only 4 km upstream (186 km2) The role of mountainous alluvial aquifers in seasonal water storage appears indeed to be overlooked. Characterization of the aquifer-catchment linkage may be challenging. Yet, as this study shows, continuous monitoring solutions in appropriate locations might help constrain flux estimations and provide significant insight into the system's functioning. In particular, coupled river/groundwater gauging stations could prove useful for monitoring total catchment outflow and thus improve the reliability of rainfall-runoff models, especially for drought predictions.

66. Seismic energy dissipation due to wave-induced fluid flow in fractured network: comparison of laboratory data from creep tests with numerical simulations

The geophysical and hydraulic characterization of fractured rocks is widely regarded as something like an ultimate objective. Yet it has a lot of applications, such as, the sustainable use of groundwater, the production of hydrocarbons and geothermal energy, the storage of nuclear waste... Recent evidences indicate that the attenuation of seismic waves, in such environments, is not only sensitive to the presence of fractures per se, but also to the parameters defining the corresponding fracture networks, (like the fracture interconnectivity). This in turn may offer the perspective of linking seismic observations to the hydraulic properties of fractured rocks. To further explore this and to test and complement the few existing numerical studies, we confront them to laboratory data from creep tests performed on thermally cracked watersaturated glass samples. We consider glass because this material con provide an useful reference when compared to more complex material such as rocks. Especially, studies on cracked glass samples play a key role in understanding the fundamentals of fracture effects.

The 2D geometry of the crack network is digitized based on corresponding SEM pictures from vertical cuts through the cylindrical samples. Together with the well-known physical properties of the non-fractured glass matrix, this forms the basis for our corresponding numerical simulations. The comparison of the observed and simulated seismic attenuation indicates that our 2D model is able to represent the basic characteristics of the laboratory observations, notably, the overall shape and frequency dependence of the attenuation curves. However, the predicted attenuation amplitudes are, overall, ~75% higher than the observed ones. Some of this discrepancy might be attributed to poorly constrained rock physical properties, such as the compressibility of the cracks. Moreover, the comparison of the attenuation behavior of a simpler 3D model to that of a corresponding 2D model indicates that this difference might be also due to the 2D simplification of the real 3D structure.

67. Temporal and spatial analysis of the redox plume in the groundwater at Aarberg, Switzerland

The Seeland aquifer is a very important source of water for drinking as well as for industrial and agricultural purposes. It mainly consists of gravels and sands with only small amounts of fine-grained material. This study concentrates on the eastern central part of the aquifer between Aarberg and Lyss. The hydrology in this area is strongly influenced by bank filtration that occurs in the Hagneck-Kanal to the southwest and the Alte Aare River, which runs through the study area.

The sugar factory at Aarberg has been producing sugar for more than 100 years. Open ponds along the Alte Aare River were used to dispose wastewater and sludge from the sugar beet processing until the

1980ies. These wastes released large amounts of organic carbon, which was oxidized in the subsurface by different microbially-mediated redox processes.

The main electron acceptors are dissolved oxygen, nitrate, iron and manganese. Due to leaking ponds a substantial part of the aquifer is characterized by manganese and iron reducing conditions as well as by elevated ammonium concentrations and increased alkalinity. All these processes deteriorate the water quality in the aquifer.

The aim of this study is to unravel the temporal evolution of the redox-plume in the study area. To do so, water analyses from a long-term monitoring of up to 60 years were analyzed in detail. Time series from different observation boreholes all show maximum concentration of reduced species in the 1950ies and 1960ies, with a later trend towards more oxidizing conditions. In addition to the analyses of historical data, we also performed two sampling campaigns to assess the current state of the redox plume in detail. Results from both campaigns show areas with different attenuation progress of the redox plume. Areas close to the deposits have generally higher concentrations of reducing species. However, the local concentrations are strongly variable. For instance, the area to the west of the Alte Aare generally features low concentrations of reduced species, while the area to the east of the Alte Aare (i.e., north-west of Lyss) shows higher iron, manganese and ammonium concentrations. We suspect that this variability is caused by heterogeneous river infiltration along the Alte Aare River. Accordingly, the influx of oxygen-rich river water is likely higher in the western area, which results in an increased attenuation of the reducing conditions when compared to the area east of the Alte Aare. Whether the wastes of the sugar factory are responsible for the large-scale reducing conditions north of Lyss is not completely resolved. Forests and swampy areas along the Alte Aare River as well as organic rich sediments could be another source of organic matter.

68. The influence of faults on groundwater flow and mass transport dynamics in the area of Neuchâtel

The knowledge of the role of faults on a regional scale on groundwater flow and mass transport dynamics is very important to better evaluate the groundwater resources and their vulnerability; and also to evaluate the role of such structures on regional geothermal potential. The main objectives of this study are (i) to evaluate the ability of an equivalent porous media model to simulate regional groundwater flow in highly karstified and faulted aquifer system; and (ii) to point out the effects of major faults (e.g. St-Blaise, la Ferrière and Yverdon faults) on the groundwater flow in the multi-layered aquifer of the central Jura in the area of Neuchâtel.

In this study, a 3D hydrogeological numerical model was used (Kerrou and Negro, 2014). It was elaborated based on a large number of studies have been conducted on the geology and the groundwater resources in the region of Neuchâtel (e.g. Kiraly, 1973; Pasquier et al., 1999, 2006; Negro and Kerrou 2014). The model of 2200 Km2 area extends from the Pontarlier fault to the city of Biel and from the Doubs river to the Lake of Neuchâtel. It represents a multi-layered system of 10 hydrogeological units from Trias to Tertiary age including the two main regional aquifers, namely the upper Malm and the Dogger. Only major faults relevant for groundwater flow have been included. The 3D Finite element steady state flow model was calibrated by adjusting the inflow fluxes and the hydraulic conductivities of the outcropping formations against hundreds of hydraulic heads and springs flow rates measurements. The depth-dependent hydraulic parameters of the main aquifers were calibrated by inverse modelling using PEST algorithm. Once the model was calibrated without active faults, it was used to evaluate the effects of faults on groundwater flow dynamics.

From a conceptual point of view, the role of the faults on groundwater flow, i.e. transmissive or barrier was defined based on their orientation relative to principal stress. The NW directed thrusts were considered to be impervious, whereas the NNE-SSW strike slip faults were considered to be transmissive. Afterward, the estimation of the hydraulic conductivity of transmissive faults was realised by sensitivity analysis using a combination of trial and error and automated inverse methods. Vertically, the hydraulic parameters of the faults depend on the affected lithology. For different distributed faults parameters the reproduced potentiometric surface by the model was compared to measured hydraulic heads. The comparison was also evaluated in term of groundwater fluxes in some springs. The impact of permeable faults on the interaction between multi-layered aquifers with different water qualities was evaluated.

The results showed that the numerical model reproduced well the main flow directions (Fig. 1) and that the equivalent medium approach can be used to simulate groundwater flow at the scale of Neuchâtel

Canton. With regards to faults, first results showed that these tectonic structures have a local effect on hydraulic head distributions, however, they represent a preferential flow path for mass transport.

69. The thermal structure of high-enthalpy geothermal systems

Most of the electricity harnessed from geothermal heat is generated from high-enthalpy geothermal systems associated with subsurface magmatic intrusions driving active groundwater convection (White, 1961). Geologic conditions such as rock permeability and intrusion emplacement depth influence the thermal structure and the ability of the system to advect heat (Hayba and Ingebritsen, 1997). Major characteristics such as the subsurface temperature distribution, the depth of boiling zones, and the location of surface expressions change over time as the upper crust is heated and the intrusive heat source is cooled.

In this study, we use the Complex Systems Modeling Platform (CSMP++) to model porous media fluid flow around cooling magmatic intrusions (Weis et al., 2014). The key geologic factors investigated in our simulations include the host rock permeability, the initial geometry and depth of the intrusion, and the rock brittle-ductile transition temperature (Scott et al., 2015).

Host rock permeability strongly influences the deep thermal structure of geothermal systems. Systems with a permeability of 10-14 m2 (‘high’ permeability) generally consist of dominantly liquid at depths >1 km, whereas systems with a permeability of 10-15 m2 (‘intermediate’) may develop extensive deep vapor-rich boiling or supercritical zones. Greater intrusion depth reduces the tendency to form deep boiling zones, as intermediate permeability systems driven by an intrusion emplaced at 2 km feature boiling from the intrusion to the surface while a equivalent system driven by an intrusion at do not develop boiling zones below ~1.5 km depth.

While a brittle-ductile transition temperature >450 °C allows the advection of supercritical water near the intrusion, the extent and temperature of supercritical water reservoirs depends greatly on host rock permeability. In high permeability host rocks (Fig. 1a), efficient recharge of relatively cool (~200 °C) liquid to the sides and top of the intrusion limits the development of supercritical conditions to a thin permeable zone around the intrusion at temperatures near >375 °C. Liquid saturation in such systems generally exceeds 0.7, but can be much lower within the upper 500 m of the surface. In intermediate permeability systems (Fig. 1b), recharge is more stagnant and extensive supercritical zones at temperatures >400 °C develop. Liquid saturation in the core of the upflow is near 0.3-0.5, implying that the liquid phase is nearly immobile in such systems and mass and heat transport is dominantly controlled by vapor fluxes.

70. Using multiple isotopic tracers to measure the influence of groundwater abstraction on groundwater-surface water interactions in the Emmental

Around 45% of drinking water for the Swiss capital Bern and its surroundigs is extracted groundwater of the alluvial aquifer in the immediate vicinity of the highly dynamic, pre-alpine Emme River. The Emme is the main source of recharge to this alluvial aquifer. The high transience of the Emme, coupled with frequent extreme events, particularily droughts, requires a solid understanding of the local surface water-groundwater (SW-GW) interactions. In a collaborative effort between UniNE, UniBE, EAWAG, and the water works of the Canton of Bern (WVRB), groundwater abstraction was reduced during one week to the smallest technically possible rate (approx. 200 l/s) after a long period of high groundwater abstraction (approx. 350 l/s). This controlled transient forcing of the river-aquifer system provided an ideal framework to study SW-GW interactions, and to compare a wide range of methods and approaches to monitor and quantify the exchanges between the river and the aquifer. Besides standard chemical and physical measurements (e.g. of pressure, temperature, electrical conductivity, ions, pH and stable H2O isotopes), a number of innovative approaches were employed during the experiment: Distributed Temperature Sensing (DTS) on the riverbed to detect locations of GW exfiltration, a combination of widely used unstable isotopic tracers (222Rn (T1/2=3.8d), 3H/3He (T1/2=12.4y) and a never before employed natural tracer for SW-GW interactions (37Ar (T1/2=35d)). Moreover, stream water gauging to measure exfiltration using a fluorescent tracer, freezecoresampling of the riverbed, as well as geophysical measurements on the geological structure of the streambed were employed. The applied methods, with a focus on the unstable isotopic tracers, are presented. In particular, we show how 37Ar can provide an ideal complement to the standard unstable isotopic tracers in order to ensure measuring of the right temporal and spatial scale.

71. Using natural tracers for transport model calibration

Riverbank filtration provides an important drinking water resouce in several European countries. Within this context, groundwater flow and transport modeling is a valuable tool for the risk assessment of existing and planned drinking water wells close to rivers, as it quantitatively links flow paths, travel times and the fraction of infiltrated river water. However, the calibration of flow and transport models requires both head and concentration observations in order to reduce the predictive uncertainty of transport simulations.

The conventional approach to obtain concentration observations for river – groundwater systems is to inject a pulse of artificial tracer into the river and observe its breakthrough at selected observation wells after infiltration and transport through groundwater. These breakthrough curves contain information on the travel times and the fraction of freshly infiltrated river water. As an efficient and cost-effective alternative, one may take advantage of existing natural tracers in the river, such as fluctuations of electrical conductivity (EC): Analyzing measured EC time series in the river and in observation wells by deconvolution allows the reconstruction of breakthrough curves from a tracer test without the need of injecting any artificial tracer mass into the river.

In our presentation, we introduce the deconvolution method and demonstrate its application to measured EC time series in a river – groundwater system in the Aare Valley between the cities of Olten and Aarau in northern Switzerland. Furthermore, we compare the resulting travel time distributions (breakthrough curves) with those obtained in a former conventional tracer test. Finally, we show how we use the results from both the tracer test and the EC time series analysis to calibrate a 3D groundwater flow and transport model.