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

Literaturzusammenstellung - Jahrgang 2014

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

Compilation de littérature pour l'année 2014

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Abstracts

Fachartikel Schweiz - articles spécialisés suisses

1. Zellzahlen zum Grundwasser - Bestimmung mittels Durchflusszytometrie

Messungen an Proben der Nationalen Grundwasserbeobachtung NAQUA ermöglichen einen ersten landesweiten Überblick zur Zellzahl im Grundwasser der Schweiz. Damit liegt nun ein zusätzliches Element zur Beschreibung des mikrobiologischen Zustands der Grundwasserressourcen vor. Die Methodik der Durchflusszytometrie konnte im Rahmen dieser Studie nicht nur eine Datenlücke schliessen, sondern auch ihre Anwendbarkeit in einem weiteren Bereich der Wasseranalytik unter Beweis stellen.

2. Entschärfung der Schutz- und Nutzungskonflikte: Trinkwasserversorgung im Aaretal

Der ergiebige Grundwasserstrom im Aaretal zwischen Thun und Bern versorgt etwa 400 000 Menschen mit Trinkwasser. Oft stehen die ufernahen Standorte der bestehenden Grundwasserfassungen in Konflikt mit dem Natur- und Hochwasserschutz. Im Rahmen einer Masterarbeit sind – unter Berücksichtigung der rechtlichen Grundlagen und technischen Gegebenheiten – Lösungen entwickelt worden, um diese Probleme künftig zu entschärfen. Das erarbeitete Wasserbeschaffungskonzept sieht unter einer regionalen Betrachtungsweise vor, leistungsstarke Fassungen durch eine Erhöhung ihrer Fördermenge in Zukunft besser zu nutzen und optimaler zu bewirtschaften.

3. Grundwasserqualität und Bewässerung - Eine Lysimeterstudie zur Schadstoffverfrachtung ins Grundwasser

Zunehmende Sommertrockenheit führt zu vermehrter Bewässerung landwirtschaftlicher Kulturen. In einem Versuch mit zwölf wägbaren Lysimetern wurde über drei Jahre der Einfluss von unterschiedlicher Bewässerung auf die Nitrat- und Pestizid auswaschung ins Grundwasser gemessen. Eine optimale Bewässerung reduzierte die Nitratauswaschung im Vergleich zu übermässiger oder ausbleibender Bewässerung. Pestizide wurden durch die tiefgründigen, lehmigen Böden bei keinem Bewässerungsverfahren ausgewaschen.

4. Hürden auf dem Weg zur Regionalisierung

Fast überall sind die Gemeinden für die öffentliche Wasserversorgung zuständig. Dadurch ist dieser wichtige Service public meist sehr kleinräumig aufgebaut. Aus einer regionalen Perspektive gibt es denn auch häufig zu viele Grundwasserfassungen und Reservoirs. An der Abschlusstagung des inzwischen aufgelösten Vereins Aqua Regio waren sich die Fachleute einig, dass sich mit weniger Primäranlagen eine bessere, robustere und günstigere Versorgung sicherstellen liesse.

5. Webbasierte Erdwärmesondenkarten - Instrumente des Service Public

Seit 2005 hat sich im Kanton Basel-Landschaft (BL) die Zahl der Gesuche für den Anlagenbau zur Nutzung von Geothermie vervielfacht. Ein von der Universität Basel entwickeltes webbasiertes Abfragesystem unterstützt die Behörde beim Baubewilligungsverfahren. Das System zeigt mögliche Nutzen und Grenzen der Erdwärmesonden im Kanton BL auf und berücksichtigt hydrogeologische Aspekte im Besonderen.

6. Energie als Abfall? - Gefragt sind neue thermische Bewirtschaftungskonzepte des oberflächennahen Untergrunds

In urbanen Gebieten nehmen die Grundwassertemperaturen weltweit zu. Untersuchungen im Rahmen eines Projekts der Universität Basel zeigen, dass dafür nicht primär Klimaveränderungen, sondern vielmehr die Abwärme von Gebäuden und die Grundwassernutzung zu Kühlzwecken verantwortlich

sind. Gefordert ist eine gesamtheitliche Betrachtung von zukünftigen Nutzungen im Hinblick auf eine nachhaltige Wärme- und Grundwasserbewirtschaftung. Grundlage hierfür bieten die Resultate des vorgestellten Projekts.

7. Planungsinstrumente für die Geothermie - Zürcher Wärmenutzungsatlas und Grundwassermodell Limmattal

Die nachhaltige und umweltschonende Gewinnung von Wärme und Kälte aus dem Untergrund und dem Grundwasser wird für die künftige Energieversorgung einen wesentlichen Beitrag leisten. Sie ist allerdings auch mit Risiken für unser Grund- und Trinkwasser verbunden. Seit Kurzem wird ein numerisches Grundwassermodell eingesetzt, um die wachsende Anzahl von Konzessionsgesuchen zur Grundwasserwärmenutzung im Limmattal beurteilen zu können und eine möglichst optimale Ausnutzung des Energiepotenzials des Grundwassers zu gewährleisten.

8. Nachhaltige Wassernutzung in der Schweiz - Gesamtsynthese: NFP 61 weist Wege in die Zukunft

Das Nationale Forschungsprogramm «Nachhaltige Wassernutzung» (NFP 61) erarbeitete in 16 Forschungsprojekten wissenschaftliche Grundlagen und Methoden für einen nachhaltigen Umgang mit den Wasserressourcen in der Schweiz. Im Anschluss an eine vierjährige Forschungsphase wurden Anfang November 2014 vier Thematische Synthesen für ein Fachpublikum sowie ein Gesamtsynthesebuch veröffentlicht. Die wichtigsten Ergebnisse und Empfehlungen aus der Gesamtsynthese sind nachfolgend zusammengefasst.

9. Wasserressourcen der Schweiz - Thematische Synthese 1: Dargebot und Nutzung – heute und morgen

Wie viel Wasser haben wir – heute und in Zukunft? Und wie nutzen wir es? Diese grundlegenden Fragen beantwortet die «Thematische Synthese 1» (TS1) anhand der Ergebnisse aus zahlreichen Forschungsprojekten des NFP 61. Sie zeigt auf, dass uns auch in den kommenden Jahrzehnten insgesamt reichlich Wasser zur Verfügung steht, jedoch örtlich und zeitlich der Wasserzugang eingeschränkt ist. Für solche Situationen braucht es eine verantwortungsvolle Vorbereitung.

10. Steigender Nutzungsdruck im Wasserschloss - Thematische Synthese 2: Wasserressourcenbewirtschaftung unter steigendem Nutzungsdruck

In der Schweiz findet ein rascher Wandel von Landschaft und Landschaftsnutzung statt, die Bevölkerung nimmt stark zu und die Wirtschaftsaktivitäten wachsen. Dadurch akzentuieren sich Nutzungskonflikte im Wassersektor: Wo einst verschiedene Nutzergruppen unabhängig voneinander agieren konnten, überlagern sich die verschiedenen Ansprüche immer stärker. Zugleich ändern sich die Rahmenbedingungen der Wasserbewirtschaftung durch den Klimawandel.

11. Nachhaltige Siedlungswasserwirtschaft - Thematische Synthese 3: Ziele und Herausforderungen

Gesellschaftlich und ökonomisch bedingte Veränderungen – wie etwa die Bevölkerungs- und Siedlungsentwicklung oder alternde Infrastrukturen – werden die Wasserversorgung und Abwasserentsorgung in der Schweiz mittelfristig stärker beeinflussen als der Klimawandel. Zu diesem Schluss kommt die im Rahmen des NFP 61 erarbeitete «Thematische Synthese 3» (TS 3). Gestützt auf verschiedene Forschungsprojekte zeigt sie die Ziele und Herausforderungen einer nachhaltigen Siedlungswasserwirtschaft auf, skizziert mögliche Handlungsoptionen und schätzt deren Auswirkungen ab.

12. Wege zur nachhaltigen Wassergouvernanz - Thematische Synthese 4: Notwendige Anpassungsprozesse in der schweizer Wasserwirtschaft

Angesichts der kommenden gesellschaftlichen, wirtschaftlichen und klimatischen Veränderungen ist die Schweizer Wasserwirtschaft nicht optimal gerüstet. Die thematische Synthese 4 «Nachhaltige Wassergouvernanz» fasst die wichtigsten Erkenntnisse aus NFP 61-Projekten zusammen und zeigt mögliche Anpassungsstrategien auf.

13. Klimaeinflüsse auf Grundwassermengen

Welche Wirkung haben Klimawandel und die voraussichtlich wärmeren und trockeneren Sommer auf Menge und Dynamik des Grundwassers? Dieser Frage ging das NFP-61-Projekt GW-TREND nach. Es wurde abgeklärt, wie sich die Grundwasserneubildung verändern könnte, wie sich gespeicherte Wassermengen während Trockenperioden entwickeln und wie rasch sich Grundwasserleiter nach Trockenperioden wieder erholen. Es zeigte sich, dass genutzte Grundwasservorkommen sehr unterschiedlich auf saisonale Trockenperioden reagieren, häufig aber beträchtliche Mengen an Grundwasser verfügbar bleiben.

14. Projet MontanAqua : les principaux résultats - ou comment communiquer avec les acteurs locaux

Le projet MontanAqua a étudié de manière globale la gestion de l'eau dans la région de Crans-Montana-Sierre (Valais). L'objectif était d'obtenir un état des lieux de la gestion à l'heure actuelle, puis de développer des scénarios de gestion pour le futur (vers 2050) en prenant en compte les changements climatiques et socio-économiques. Il s'agissait également d'évaluer la durabilité de la gestion régionale de l'eau. L'article présente les principaux résultats et discute la question du transfert des résultats scientifiques vers les décideurs locaux.

15. Aurèle Parriaux : «Une optimisation de l'utilisation du sous-sol est indispensable.»

Prospecteur et protecteur des eaux souterraines, des missions qu'assume avec succès Aurèle Parriaux. Chacun s'accorde à dire que l'eau potable provenant du sous-sol est vitale. Toutefois, lorsque les intérêts des différents acteurs voulant accéder aux ressources du sous-sol sont en concurrence, notamment dans les régions urbanisées, l'eau est souvent prétéritée. Pour pallier à ces situations et gérer intelligemment ces ressources souterraines, Aurèle Parriaux a conçu une méthodologie connue sous le nom anglais de «Deep City». Dans l'interview ci-après, il nous explique le contexte de l'eau dans le sous-sol et pourquoi la mise en application de «Deep City» est impérative.

16. Spezifische Erkennung von Kontaminationen - Automation für die Beurteilung von Alarmen

Die Online-Überwachung der Trinkwasserqualität stellt hohe Anforderungen an die Messsysteme und den Betreiber. Wann handelt es sich um eine echte Verunreinigung/Kontamination und um welche? Bei der Wasserversorgung Gemeindeverband Blattenheid ist seit 2012 ein System im Einsatz, das auf diese Fragen Antworten liefert.

17. Wie viele Zellen sind im Trinkwasser? - Durchflusszytometrie in der mikrobiologischen Trinkwasseranalyse: wie weiter?

Die neuen, im Schweizerischen Lebensmittelbuch SLMB festgehaltenen Durchflusszytometrie-(DFZ)-Methoden lassen uns die wichtige Funktion der natürlichen mikrobiellen Trinkwasserflora besser verstehen. DFZ-Messungen zeigen, dass es normal ist, dass im Trinkwasser um die 100 000 Zellen/ml vorliegen. Als Platzhalter besetzen diese Mikroorganismen die Nische Trinkwasser und können so das Aufwachsen unerwünschter mikrobieller Eindringlinge be- oder sogar verhindern. DFZ-Geräte für die Online-Messung der Totalzellzahl werden in Kürze kommerziell verfügbar sein. Sie können in der Routineüberwachung und als biologische Frühwarnsysteme eingesetzt werden.

18. Volkswirtschaftliche Kosten des Pestizideinsatzes in der Schweiz - Pilotberechnung

Pestizide sind ein verbreitet eingesetztes Hilfsmittel der modernen landwirtschaftlichen Produktionsweise, die auf (kurzfristige) Effizienz und Leistungsfähigkeit getrimmt ist. Der Einsatz von Pestiziden ist mit vielfältigen, in der Regel unerwünschten Nebenwirkungen auf Mensch und Umwelt verbunden. Diese Wirkungen des Pestizideinsatzes auf die menschliche Gesundheit und Ökosysteme sind komplex und zum Teil unvollständig erforscht. Die mit diesen Wirkungen zusammenhängenden Schäden können zu volkswirtschaftlichen Kosten führen, die durch die Allgemeinheit getragen werden. Das Hauptziel der vorliegenden Studie besteht darin, die volkswirtschaftlichen Kosten des Pestizideinsatzes in der Schweiz im Rahmen einer Pilotberechnung erstmals abzuschätzen.

19. Ausserordentlicher Wasseranfall im Teilabschnitt Erstfeld des Gotthard-Basistunnel

The most northern section of the Gotthard Base Tunnel was cut through the Erstfelder Gneis which is part of the variscan crystallin basement. Surprisingly, the tunnel inflow rate of water exceeded the anticipated value a number of times. In the second half of May, the inflow rate increases from

prevailing values of 150-250 l/s to a peak value of 465 l/s. The inflows to the tunnel are since following a pronounced yearly hydrograph. The peak values correlate in time with the snowmelt and depend on the thickness of the snow layer. Around 2,000 small springs were documented during tunnel mining. The most intense water-bearing section with length of 1.65 km is situated at a distance of about 4 km from the start of the underground mining. Within this section, both water and rock temperatures decreased in parts by 8 °C below the anticipated value. The described phenomena is caused by a mass movement in the catchment area above this section. This leads to a high permeability and therefore a high infiltration rate as well as to a large storage capacity in the loosened bedrock. The drainage caused by the tunnel affected surface springs used to capture drinking water. The main drainage pipe is dimensioned for a water amount of 555 l/s which is adequate due to a small inflow rate in the southern sections of the tunnel.

20. Eine CKW-Grundwassersanierung - ein Fallbericht

Most of the groundwater remediation projects in Switzerland concern pollutions with chlorinated hydrocarbons. Experiences from the last 30 years have shown the many difficulties for a successful remediation and failures are numerous. With an successful example from Switzerland important findings of the detailed investigations are reported and the remediation measures are described. The pollution concerns an important groundwater occurrence within periglacial gravels of moderate thickness. Large quantities of organic solvents (mainly tetrachloroethene = PCE) have penetrated the underground during less than 20 years. The PCE did percolate as non-aqueous dense liquid (DNAPL) across the saturated gravel and accumulated on top of the underlying tertiary sandstone serving as aquiclude. During the first remediation phase an area with high PCE concentrations was completely cleaned up by excavation of the contaminated gravel and pumping out the water/PCE mixture from the rock surface. The excavation was carried out within a dig completely closed by sheet piling. This required an extensive lowering of the groundwater table and the cleanup of large quantities of contaminated groundwater. Removing the PCE from the groundwater was performed by activated carbon filters and air stripping. During the first remediation works a second pollution source was detected. As an excavation could not be used here for the cleanup the in-situ chemical oxidation (ISCO) was applied to destroy the solvents in the underground. For this purpose existing monitoring wells were complemented by some additional wells and used for the remediation. The wells are used alternately for injection of sodium permanganate and extraction of groundwater. A circulation system was thereby installed. The remediation measures since beginning in 2007 have strongly reduced the PCE source. Approximately 2.5 tons of PCE have so far been destructed. The reduction of the pollution downstream of the site amounts to about 50%.

21. Neues Musterreglement für Grundwasserschutzzonen

Grundwasserschutzzonen sichern unser wichtigstes Lebensmittel – das Trinkwasser. Die dafür notwendigen planerischen Instrumente sind das Schutzzonenreglement mit Schutzzonenplan und der Gefahrenkataster. Die Abteilung für Umwelt hat die Mustervorlagen dieser Dokumente in enger Zusammenarbeit mit Ingenieuren und Geologen überarbeitet.

22. An absorption method for extraction and characterization of porewater from low-permeability rocks using cellulosic sheets

Characterization of porewater chemistry in low-permeability rocks can provide insight into the origin and residence time of porewater, the history of fluid movement and the nature of transport and reaction processes. However, the measurement of porewater chemistry in low-permeability rocks is challenging because of the small fluid volume and the difficulty of extracting representative samples. Several techniques are available, but the results they provide can be affected by ion exchange and mineral dissolution, and they may require independent porosity measurements. The objective of this work is to develop a method of extracting representative samples of in situ porewater from low-permeability rocks and accurately quantify solute concentrations in the extracted porewater. A preliminary trial demonstrated the feasibility of extracting porewater by absorption into hydrophilic cellulosic membranes from low-permeability shale (Georgian Bay Formation, Michigan Basin, southwest Ontario, Canada). Solute concentrations are calculated from independent measurements of solute mass quantified by Inductively-Coupled-Plasma Mass Spectrometry (ICP-MS) and water-content quantified by Near Infrared (NIR) spectrometry. Sorption experiments indicate that there is no preferential sorption of solutes (Na, Cl, Mg, Ca, K, Sr, and Br) to the cellulosic membrane. The results indicate that the method is capable of determining solute concentrations on absorbed porewater with analytical precision that is within the margins of error recommended by EPA Method 6020a for analysis of saline water samples.

23. Determination of spatiotemporal variability of tree water uptake using stable isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) in an alluvial system supplied by a high- altitude watershed, Pfyn forest, Switzerland

Sources of water use by 10 alluvial trees in various hydrogeological and ecological situations at the Pfyn forest (Wallis canton, Switzerland) were assessed by analysing O-18 and H-2 isotopes of precipitation, soil water at different depths, surface water, groundwater and xylem sap. The soil water line in a O-18 versus H-2 diagram shows evidence of kinetic fractionation related to evaporation. The tree water line is close to the soil trend; however, an additional enrichment may occur and could be related to xylem-phloem communication under water stress. At sites where the water table was at least 2m below the ground surface, isotopic temporal variability of soils and trees was strongly linked with seasonal variation of soil water content. When soil water content was low and water table shallow, trees used both soil water and groundwater. When soil water content was high, this source was usually the dominant source for transpiration. In addition, some ecological strategies, reproduction or growth competition, could explain shifts in the utilization of different water sources, for example, from soil water to a mix of soil water and groundwater. At one site where soil water and groundwater were abundant throughout the year (next to the river course), neighbouring trees permanently used distinct water sources. This is consistent with a strategy of competition limitation, which would favour bank colonization. These results provide insight into the ecohydrological functioning of this system and will aid future management responses to both local and climate changes.

24. Assessing the contribution of karst to flood 35 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 "Does such a storage exist in the karst aquifer?", "What is its capacity and how does it work?", "What could happen if this capacity is suddenly exceeded?", "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.

25. Microbiological monitoring and classification of karst springs

The use of groundwater as a drinking water resource requires knowledge of its microbiological status and quality. In contrast to conventional microbiological monitoring of groundwater, the present study not only considers faecal indicator bacteria, but also covers a wide spectrum of microorganisms, including bacterial pathogens (verotoxin-producing *E. coli*, *Campylobacter* spp. and *Salmonella* spp., as well as *Pseudomonas aeruginosa*), human enteric viruses (norovirus, enterovirus, rotavirus and adenovirus) and parasitic protozoa (*Cryptosporidium* oocysts and *Giardia* cysts). Samples collected at karst sites of the Swiss National Groundwater Monitoring network revealed the presence of a large diversity of microorganisms of faecal origin, the occurrence of which could be linked to specific hydrogeological settings and situations. The findings represent a 'snapshot' of the microbiological status at the monitoring sites and provide a national overview of the types and presence of microorganisms in Swiss karst groundwater. In addition to microbiological parameters related to faecal contamination, the overall bacterial load in groundwater was assessed using cell density measurements (i.e. total cell count), which yielded typical ranges for this ecological parameter. The study highlights differential vulnerability of karst groundwater to microbiological contamination, as well as its relationship with the microbial biocenoses, i.e. the interplay of allochthonous and autochthonous microbial components. On the basis of this data set, a microbiological classification of karst aquifers is proposed and discussed with respect to spring dynamics and vulnerability.

26. In-situ sonication for enhanced recovery of aquifer microbial communities

Sampling methods for characterization of microbial communities in aquifers should target both suspended and attached microorganisms (biofilms). We investigated the effectiveness and reproducibility of low-frequency (200 Hz) sonication pulses on improving extraction efficiency and quality of microorganisms from a petroleum-contaminated aquifer in Studen (Switzerland). Sonication pulses at different power levels (0.65, 0.9, and 1.1 kW) were applied to three different groundwater monitoring wells. Groundwater samples extracted after each pulse were compared with background groundwater samples for cell and adenosine tri-phosphate concentration. Turbidity values were obtained to assess the release of sediment fines and associated microorganisms. The bacterial community in extracted groundwater samples was analyzed by terminal-restriction-fragment-length polymorphism and compared with communities obtained from background groundwater samples and from sediment cores. Sonication enhanced the extraction efficiency up to 13-fold, with most of the biomass being associated with the sediment fines extracted with groundwater. Consecutive pulses at constant power were decreasingly effective, while pulses with higher power yielded the best results both in terms of extraction efficiency and quality. Our results indicate that low-frequency sonication may be a viable and cost-effective tool to improve the extraction of microorganisms from aquifers, taking advantage of existing groundwater monitoring wells.

27. First insights in the prospection and characterisation of the aquifer of the Arosa Dolomites, Switzerland

In urban areas of the Swiss Alps the use of geothermal energy from several hundred meters depth becomes increasingly important. For this mainly open systems have priority. This work presents the first insights in the prospection and characterisation of the so far unexplored, utilizable, and abundant Aquifer of the Arosa Dolomites. Besides the use of established methods and techniques, such as seismic measurements, an exploration drilling, borehole geophysical measurements, and pumping tests, the application of the KARSYS-approach for geological and conceptual hydrogeological 3D-modelling of the aquifer is illustrated. In addition, the development of a viewer for 3D-visualization of drillings is documented. The hydrogeological and metrological approaches allow a lithological facies differentiation of the Arosa Dolomites, and a differentiation of the fractured and karstified areas within the aquifer. The results represent the basis for advanced findings optimizing and risks minimising exploration and drilling planning, and for sustainable utilization planning.

28. Praxisorientierter Ansatz zur kartographischen Darstellung von Karst-Grundwasserressourcen

Trotz ihrer großen Bedeutung als Wasserressource steht für Karst-Grundwasserleiter auch in der Schweiz eine systematische Abgrenzung und quantitative Beschreibung noch aus. Das Fehlen eines integralen Ansatzes zur Charakterisierung von Karstsystemen mag dazu beigetragen haben. Im

Rahmen eines Projektes zur Dokumentation der Karst-Grundwasserleiter in der Schweiz (SWISSKARST) war mit der KARSYS-Methode ein pragmatischer Ansatz zur hydraulischen Charakterisierung einzelner Grundwasserleiter und Karstsysteme entwickelt worden. Eine Weiterentwicklung dieses Ansatzes beinhaltet ein Verfahren zur kartographischen 2D-Darstellung des erstellten 3D-Modellkonzepts, welche sowohl auf wissenschaftliche als auch auf Fragestellungen der Praxis ausgerichtet ist. Dazu werden zunächst mehrere thematische Karten mit den wichtigsten Eigenschaften der Karst-Grundwassersysteme erstellt, welche dann zu einer synthetisierten Karte zusammengefasst werden.

29. Contaminant attenuation in karst aquifers: A paradigm shift

Significant advances have been made in the characterization of transport and storage in karst aquifers over recent decades. This improved understanding permits further integration of the behaviour of individual contaminants and their specific transport, enabling comparisons to be made. This has been particularly challenging as it is necessary to consider different flow components encountered in karst aquifers, including fast conduit flow and storage in less permeable rock volumes. Comparative tracing experiments using contaminant surrogates have proved to be an appropriate method for estimating the specific attenuation of selected substances at the field scale. Several attenuation processes may be involved and could be identified. Examples from Swiss karst aquifers highlight the in situ effectiveness of such attenuation processes, some of which can be described using first-order kinetics. It could be shown that solute and colloid tracers are able to interact with aquifer material despite the dominance of preferential and conduit flow components. Consequently, if reactive and/or non-persistent contaminants are involved, the arrival at karst springs is determined by contaminant-specific properties and hydrochemical characteristics rather than by the intrinsic vulnerability of the aquifer. This demands more refined conceptual transport models and also represents a paradigm shift in the assessment of karst groundwater vulnerability and contaminant attenuation.

30. Hydraulic subsurface measurements and hydrodynamic modelling as indicators for groundwater flow systems in the Rotondo granite, Central Alps (Switzerland)

Regional groundwater flow in high mountainous terrain is governed by a multitude of factors such as geology, topography, recharge conditions, structural elements such as fracturation and regional fault zones as well as man-made underground structures. By means of a numerical groundwater flow model, we consider the impact of deep underground tunnels and of an idealized major fault zone on the groundwater flow systems within the fractured Rotondo granite. The position of the free groundwater table as response to the above subsurface structures and, in particular, with regard to the influence of spatial distributed groundwater recharge rates is addressed. The model results show significant unsaturated zones below the mountain ridges in the study area with a thickness of up to several hundred metres. The subsurface galleries are shown to have a strong effect on the head distribution in the model domain, causing locally a reversal of natural head gradients. With respect to the position of the catchment areas to the tunnel and the corresponding type of recharge source for the tunnel inflows (i.e. glaciers or recent precipitation), as well as water table elevation, the influence of spatial distributed recharge rates is compared to uniform recharge rates. Water table elevations below the well exposed high-relief mountain ridges are observed to be more sensitive to changes in groundwater recharge rates and permeability than below ridges with less topographic relief. In the conceptual framework of the numerical simulations, the model fault zone has less influence on the groundwater table position, but more importantly acts as fast flow path for recharge from glaciated areas towards the subsurface galleries. This is in agreement with a previous study, where the imprint of glacial recharge was observed in the environmental isotope composition of groundwater sampled in the subsurface galleries.

31. Melt water driven stream and groundwater stage fluctuations on a glacier forefield (Dammagletscher, Switzerland)

In many mountain regions, large land areas with heterogeneous soils have become ice-free with the ongoing glacier retreat. On these recently formed proglacial fields, the melt of the remaining glaciers typically drives pronounced diurnal stream level fluctuations that propagate into the riparian zone. This behaviour was measured on the Damma glacier forefield in central Switzerland with stage recorders in the stream and groundwater monitoring wells along four transects. In spite of the large groundwater stage variations, radon measurements in the near-stream riparian zone indicate that there is little mixing between stream water and groundwater on daily time scales. At all four transects, including both losing and gaining reaches, the groundwater level fluctuations lagged the stream stage variations

and were often damped with distance from the stream. Similar behaviours have been modelled using the diffusion equation in coastal regions influenced by tidal sea level variations. We thus tested the ability of such a model to predict groundwater level fluctuations in proglacial fields. The model reproduced several key features of the observed fluctuations at three of four locations, although discrepancies also arise due to non representative input data and model simplifications. Nevertheless, calibration of the model for the individual transects yielded realistic estimates of hydraulic diffusivities between the stream and groundwater monitoring wells. We conclude that studying diurnal groundwater fluctuations can provide important information about the subsurface hydrology of alpine watersheds dominated by glacier melt.

32. 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 four consecutive years. Based on this dataset, we developed a two-component mixing model in which the groundwater component was modelled using measured groundwater levels. The aquifer actively contributing to stream flow was assumed to be a superposition 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. We found that a near-surface aquifer with high hydraulic conductivity overlies a larger reservoir with longer response time. Analyzing the mass balance of infiltration into the groundwater reservoir against exfiltration into the stream provided results that were in line with previous findings at this catchment.

33. True colors - experimental identification of hydrological processes at a hillslope prone to slide

This study investigated runoff formation processes of a pre-alpine hillslope prone to slide. The experimental pasture plot (40mx60 m) is located in the northern front range of the Swiss Alps on a 30 degrees steep hillslope (1180m a.s.l., 1500+ mm annual precipitation). A gleysol (H-Go-Gr) overlies weathered marlstone and conglomerate of subalpine molasse. We conducted sprinkling experiments on a subplot (10 mx10 m) with variable rainfall intensities. During both experiments fluorescein line-tracer injections into the topsoil, and sodium chloride (NaCl) injections into the sprinkling water were used to monitor flow velocities in the soil. The observed flow velocities for fluorescein in the soil were 1.2 and 1.4×10^{-3} ms⁻¹. The NaCl breakthrough occurred almost simultaneously in all monitored discharge levels (0.05, 0.25 and 1.0m depth), indicating a high-infiltration capacity and efficient drainage of the soil. These initial observations suggested "transmissivity feedback", a form of subsurface stormflow, as the dominant runoff process. However, the results of a brilliant blue dye tracer experiment completely changed our perceptions of the hillslope's hydrological processes. Excavation of the dye-stained soils highlighted the dominance of "organic layer interflow", a form of shallow subsurface stormflow. The dye stained the entire H horizon, vertical soil fractures, and macropores (mostly worm burrows) up to 0.5m depth. Lateral drainage in the subsoil or at the soil-bedrock interface was not observed, and thus was limited to the organic topsoil. In the context of shallow landslides, the subsoil (Go/Gr) acted as an infiltration and exfiltration barrier, which produced significant lateral saturated drainage in the topsoil (H) and possibly a confined aquifer in the bedrock.

34. Morphological, hydrological, biogeochemical and ecological changes and challenges in river restoration - the Thur River case study

River restoration can enhance river dynamics, environmental heterogeneity and biodiversity, but the underlying processes governing the dynamic changes need to be understood to ensure that restoration projects meet their goals, and adverse effects are prevented. In particular, we need to comprehend how hydromorphological variability quantitatively relates to ecosystem functioning and services, biodiversity as well as ground-and surface water quality in restored river corridors. This involves physical processes and structural properties, determining erosion and sedimentation, as well as solute and heat transport behavior in surface water and within the subsurface; biogeochemical processes and characteristics, including the turnover of nutrients and natural water constituents; and ecological processes and indicators related to biodiversity and ecological functioning. All these aspects are interlinked, requiring an interdisciplinary investigation approach. Here, we present an overview of the recently completed RECORD (REstored CORridor Dynamics) project in which we combined physical, chemical, and biological observations with modeling at a restored river corridor of

the perialpine Thur River in Switzerland. Our results show that river restoration, beyond inducing morphologic changes that reshape the river bed and banks, triggered complex spatial patterns of bank infiltration, and affected habitat type, biotic communities and biogeochemical processes. We adopted an interdisciplinary approach of monitoring the continuing changes due to restoration measures to address the following questions: How stable is the morphological variability established by restoration? Does morphological variability guarantee an improvement in biodiversity? How does morphological variability affect biogeochemical transformations in the river corridor? What are some potential adverse effects of river restoration? How is river restoration influenced by catchment-scale hydraulics and which feedbacks exist on the large scale? Beyond summarizing the major results of individual studies within the project, we show that these overarching questions could only be addressed in an interdisciplinary framework.

35. Validating a spatially distributed hydrological model with soil morphology data

Spatially distributed models are popular tools in hydrology claimed to be useful to support management decisions. Despite the high spatial resolution of the computed variables, calibration and validation is often carried out only on discharge time series at specific locations due to the lack of spatially distributed reference data. Because of this restriction, the predictive power of these models, with regard to predicted spatial patterns, can usually not be judged. An example of spatial predictions in hydrology is the prediction of saturated areas in agricultural catchments. These areas can be important source areas for inputs of agrochemicals to the stream. We set up a spatially distributed model to predict saturated areas in a 1.2 km catchment in Switzerland with moderate topography and artificial drainage. We translated soil morphological data available from soil maps into an estimate of the duration of soil saturation in the soil horizons. This resulted in a data set with high spatial coverage on which the model predictions were validated. In general, these saturation estimates corresponded well to the measured groundwater levels.

36. On the effects of subsurface parameters on evaporite dissolution (Switzerland)

Uncontrolled subsurface evaporite dissolution could lead to hazards such as land subsidence. Observed subsidences in a study area of Northwestern Switzerland were mainly due to subsurface dissolution (subrosion) of evaporites such as halite and gypsum. A set of 2D density driven flow simulations were evaluated along 1000 m long and 150 m deep 2D cross sections within the study area that is characterized by tectonic horst and graben structures. The simulations were conducted to study the effect of the different subsurface parameters that could affect the dissolution process. The heterogeneity of normal faults and its impact on the dissolution of evaporites is studied by considering several permeable faults that include non-permeable areas. The mixed finite element method (MFE) is used to solve the flow equation, coupled with the multipoint flux approximation (MPFA) and the discontinuous Galerkin method (DG) to solve the diffusion and the advection parts of the transport equation. Results show that the number of faults above the lower aquifer that contains the salt layer is considered as the most important factor that affects the dissolution compared to the other investigated parameters of thickness of the zone above the halite formation, a dynamic conductivity of the lower aquifer, and varying boundary conditions in the upper aquifer.

37. Regional water quality patterns in an alluvial aquifer: Direct and indirect influences of rivers

The influence of rivers on the groundwater quality in alluvial aquifers can be twofold; direct and indirect. Rivers can have a direct influence via recharge and an indirect one by controlling the distribution of fine-grained, organic-carbon rich flood deposits that induce reducing conditions. These direct and indirect influences were quantified for a large alluvial aquifer on the Swiss Plateau (50 km) in interaction with an Alpine river using nitrate as an example. The hydrochemistry and stable isotope composition of water were characterized using a network of 115 piezometers and pumping stations covering the entire aquifer. Aquifer properties, land use and recharge zones were evaluated as well. This information provided detailed insight into the factors that control the spatial variability of groundwater quality. Three main factors were identified; diffuse agricultural pollution sources; dilution processes resulting from river water infiltrations, revealed by the delta O-18(H₂O) and delta H-2(H₂O) contents of groundwater; and denitrification processes, controlled by the spatial variability of flood deposits governed by fluvial depositional processes. It was possible to quantify the dependence of the nitrate concentration on these three factors at any sampling point of the aquifer using an end-member mixing model, where the average nitrate concentration in recharge from the agricultural area was evaluated at 52 mg/L, and the nitrate concentration of infiltrating river at approximately 6 mg/L. The

study shows the importance of considering the indirect and direct impacts of rivers on alluvial aquifers and provides a methodological framework to evaluate aquifer scale water quality patterns.

38. Vertical displacement rates in the Upper Rhine Graben area derived from precise leveling

The recent vertical displacement field of the Upper Rhine Graben (URG) located in the tri-national region between Germany, France and Switzerland is investigated using repeatedly measured leveling data. We estimate vertical displacement rates at leveling benchmarks by applying a kinematic network adjustment on more than 40,000 height differences measured by German, French and Swiss surveying agencies. Focusing on an optimal solution for the adjusted rates in the URG area also historical data (measured before 1900) are used, significantly increasing the time span of available measurements and the number of transnational connections between the three countries. To account for inhomogeneities apparent in the database, we apply an iterative variance component estimation within the adjustment procedure, particularly revealing more realistic information on the accuracy of the estimated rates. A special focus within our analysis is put on the statistical testing of gross errors in the observations and model-related errors at benchmarks with non-linear movement. As some of the estimated vertical rates behave significantly different compared to the vertical rates of adjacent benchmarks, a filtering of outliers is applied after the adjustment procedure. The resulting map of linear height changes in an area of 280 km in N-S and 230 km in E-W direction provides detailed insight into the recent vertical displacements of the URG and neighboring regions. In the German part of the study area, it was possible for the first time to consistently constrain an average subsidence rate of 0.5 mm/a (0.2 mm/a) of the Graben interior w.r.t. the Black Forest. In addition to the tectonic displacements, some man-induced surface movements, e.g., caused by oil and groundwater extraction, are observed and discussed.

39. Assessing the effect of different river water level interpolation schemes on modeled groundwater residence times

Obtaining a quantitative understanding of river-groundwater interactions is of high practical relevance, for instance within the context of riverbank filtration and river restoration. Modeling interactions between river and groundwater requires knowledge of the river's spatiotemporal water level distribution. The dynamic nature of riverbed morphology in restored river reaches might result in complex river water level distributions, including disconnected river branches, nonlinear longitudinal water level profiles and morphologically induced lateral water level gradients. Recently, two new methods were proposed to accurately and efficiently capture 2D water level distributions of dynamic rivers. In this study, we assessed the predictive capability of these methods with respect to simulated groundwater residence times. Both methods were used to generate surface water level distributions of a 1.2 km long partly restored river reach of the Thur River in northeastern Switzerland. We then assigned these water level distributions as boundary conditions to a 3D steady-state groundwater flow and transport model. When applying either of the new methods, the calibration-constrained groundwater flow field accurately predicted the spatial distribution of groundwater residence times; deviations were within a range of 30% when compared to residence times obtained using a reference method. We further tested the sensitivity of the simulated groundwater residence times to a simplified river water level distribution. The negligence of lateral river water level gradients of 20-30 cm on a length of 200 m caused errors of 40-80% in the calibration-constrained groundwater residence time distribution compared to results that included lateral water level gradients. The additional assumption of a linear water level distribution in longitudinal river direction led to deviations from the complete river water level distribution of up to 50 cm, which caused wide-spread errors in simulated groundwater residence times of 200-500%. For an accurate simulation of groundwater residence times, it is therefore imperative that the longitudinal water level distribution is correctly captured and described. Based on the confirmed predictive capability of the new methods to estimate 2D river water level distributions, we can recommend their application to future studies that model dynamic river-groundwater systems.

40. Geogenic arsenic in groundwaters in the western Alps

Groundwater arsenic (As) of geogenic origin in the western Alps is generally associated with aquifers in crystalline rock. The External Crystalline Massifs (ECM) are in particular noted for occurrences of elevated concentrations of As in groundwaters. The present study is based on As in groundwaters that have been measured in the ECM in both France and Switzerland. Arsenic-bearing sulfide minerals, such as pyrite, arsenian pyrite, and arsenopyrite, are the most likely sources of As leached within the

crystalline ECM rocks. While it is not known how As concentrations vary with time at all of the reported water sources, we measured on a weekly basis the concentration of As at one thermal source over a period of one year and found the As concentrations to be variable; however, the cause of the variability is at present not understood. Even though many studies have applied delta S-34(So4) as a tool for understanding As mobilization in the ECM, there is no consensus at present. Finally, we present some perspectives on the possible effects of climate change and anthropogenic activities on As mobility in the ECM. In particular, droughts have the potential to increase As concentrations in groundwaters.

41. Predictability of low flow - An assessment with simulation experiments

Since the extreme summer of 2003 the importance of early drought warning has become increasingly recognized even in water-rich countries such as Switzerland. Spring 2011 illustrated drought conditions in Switzerland again, which are expected to become more frequent in the future. Two fundamental questions related to drought early warning are: (1) How long before a hydrological drought occurs can it be predicted? (2) How long are initial conditions important for streamflow simulations? To address these questions, we assessed the relative importance of the current hydrological state and weather during the prediction period. Ensemble streamflow prediction (ESP) and reverse ESP (ESP_{rev}) experiments were performed with the conceptual catchment model, HBV, for 21 Swiss catchments. The relative importance of the initial hydrological state and weather during the prediction period was evaluated by comparing the simulations of both experiments to a common reference simulation. To further distinguish between effects of weather and catchment properties, a catchment relaxation time was calculated using temporally constant average meteorological input. The relative importance of the initial conditions varied with the start of the simulation. The maximum detectable influences of initial conditions ranged from 50 days to at least a year. Drier initial conditions of soil moisture and groundwater as well as more initial snow resulted in longer influences of initial conditions. The catchment relaxation varied seasonally for higher elevation catchments, but remained constant for lower catchments, which indicates the importance of snow for streamflow predictability. Longer persistence seemed to also stem from larger groundwater storages in mountainous catchments, which may motivate a reconsideration of the sensitivity of these catchments to low flows in a changing climate.

42. Non-stationary nonparametric inference of river-to-groundwater travel-time distributions

The travel-time distribution between rivers and groundwater observation points and the mixing of freshly infiltrated river water with groundwater of other origin is of high relevance in riverbank filtration. These characteristics usually are inferred from the analysis of natural-tracer time series, typically relying on a stationary input-output relationship. However, non-stationarity is a significant feature of the riparian zone causing time-varying river-to-groundwater transfer functions. We present a non-stationary extension of nonparametric deconvolution by performing stationary deconvolution with windowed time series, enforcing smoothness of the determined transfer function in time and travel time. The nonparametric approach facilitates the identification of unconventional features in travel-time distributions, such as broad peaks, and the sliding-window approach is an easy way to accommodate the method to dynamic changes of the system under consideration. By this, we obtain time-varying signal-recovery rates and travel-time distributions, from which we derive the mean travel time and the spread of the distribution as function of time. We apply our method to electric-conductivity data collected at River Thur, Switzerland, and adjacent piezometers. The non-stationary approach reproduces the groundwater observations significantly better than the stationary one, both in terms of overall metrics and in matching individual peaks. We compare characteristics of the transient transfer function to base flow which indicates shorter travel times at higher river stages.

43. Two-phase flow modeling with tough2-mp of a deep geological repository within the first benchmark of the forge project

FORGE (Fate of Repository Gases) is an international research project supported by funding under the European Commission FP7 Euratom program and lasting four years from 2009 to 2013. The project is dedicated to understanding gas generation and migration as part of the quantitative assessment of a geological repository for radioactive waste. Within the FORGE project, Work Package 1 is dedicated to numerical modeling of a two-phase flow system (hydrogen gas due to corrosion and groundwater) in a geological repository for radioactive waste. Several benchmark exercises were proposed that cover the modeling of a deep geological repository from the disposal cell scale to the

repository scale with different codes. During the definition of the exercises, special emphasis was given to the roles of the excavation-disturbed zone and of the interfaces between materials, which could act as a conduit for preferential flow. Some changes were made in the TOUGH2 code to enable the implementation of the prescribed conditions, models, and parameters of the benchmark. The results of the calculations performed with different codes show that TOUGH2 gives comparable results under the numerically challenging conditions defined in the exercise. Some differences were observed resulting from the use of different codes and also from some simplifications in the parameters and models adopted by the participating teams. In this paper, the cell-scale benchmark exercise and the results obtained by the Swiss Federal Nuclear Safety Inspectorate (EN SI) with TOUGH2 will be described, together with some difficulties encountered during the simulation, e.g., convergence problems. The results of other teams participating in the benchmark are in good agreement with the ENSI results.

44. Diversity and distribution of freshwater amphipod species in Switzerland (Crustacea: Amphipoda)

Amphipods are key organisms in many freshwater systems and contribute substantially to the diversity and functioning of macroinvertebrate communities. Furthermore, they are commonly used as bioindicators and for ecotoxicological tests. For many areas, however, diversity and distribution of amphipods is inadequately known, which limits their use in ecological and ecotoxicological studies and handicaps conservation initiatives. We studied the diversity and distribution of amphipods in Switzerland (Central Europe), covering four major drainage basins, an altitudinal gradient of >2,500 m, and various habitats (rivers, streams, lakes and groundwater). We provide the first provisional checklist and detailed information on the distribution and diversity of all amphipod species from Switzerland. In total, we found 29 amphipod species. This includes 16 native and 13 non-native species, one of the latter (*Orchestia cavimana*) reported here for the first time for Switzerland. The diversity is compared to neighboring countries. We specifically discuss species of the genus *Niphargus*, which are often receiving less attention. We also found evidence of an even higher level of hidden diversity, and the potential occurrence of further cryptic species. This diversity reflects the biogeographic past of Switzerland, and suggests that amphipods are ideally suited to address questions on endemism and adaptive radiations, post-glaciation re-colonization and invasion dynamics as well as biodiversity-ecosystem functioning relationships in aquatic systems.

45. Effects of river morphology, hydraulic gradients, and sediment deposition on water exchange and oxygen dynamics in salmonid redds

Fine sediment decreasing gravel permeability and oxygen supply to incubating salmonid embryos, is often considered the main contributing factor for the observed decline of salmonid populations. However, oxygen supply to salmonid embryos also depends on hydraulic conditions driving water flow through the redd. A more generalized perspective is needed to better understand the constraints on successful salmonid incubation in the many heavily modified fluvial ecosystems of the Northern Hemisphere. The effects of hydraulic gradients, riverbed and redd morphology as well as fine sediment deposition on dissolved oxygen (DO) and water exchange was studied in 18 artificial redds at three sites along a modified river. Fifty percent of the redds in the two downstream sites were lost during high flow events, while redd loss at the upstream site was substantially lower (8%). This pattern was likely related to increasing flood heights from up- to downstream. Specific water infiltration rates (q) and DO were highly dynamic and driven on multiple temporal and spatial scales. Temporally, the high permeability of the redd gravel and the typical pit-tail structure of the new built redds, leading to high DO, disappeared within a month, when fine sediment had infiltrated and the redd structure was leveled. On the scale of hours to days, DO concentrations and q increased during high flows, but decreased during the falling limb of the water level, most likely related to exfiltration of oxygen depleted groundwater or hyporheic water. DO concentrations also decreased under prolonged base flow conditions, when increased infiltration of silt and clay particles clogged the riverbed and reduced q . Spatially, artificial log steps affected fine sediment infiltration, q and interstitial DO in the redds. The results demonstrate that multiple factors have to be considered for successful river management in salmonid streams, including riverbed structure and local and regional hydrogeological conditions.

46. Joint assimilation of piezometric heads and groundwater temperatures for improved modeling of river-aquifer interactions

The ensemble Kalman filter (EnKF) is increasingly used to improve the real-time prediction of groundwater states and the estimation of uncertain hydraulic subsurface parameters through

assimilation of measurement data like groundwater levels and concentration data. At the interface between surface water and groundwater, measured groundwater temperature data can provide an additional source of information for subsurface characterizations with EnKF. Additionally, an improved prediction of the temperature field itself is often desirable for groundwater management. In this work, we investigate the worth of a joint assimilation of hydraulic and thermal observation data on the state and parameter estimation with EnKF for two different model setups: a simple synthetic model of a river-aquifer system where the parameters and simulation conditions were perfectly known and a model of the Limmat aquifer in Zurich (Switzerland) where an exhaustive set of real-world observations of groundwater levels (87) and temperatures (22) was available for assimilation (year 2007) and verification (year 2011). Results for the synthetic case suggest that a joint assimilation of piezometric heads and groundwater temperatures together with updating of uncertain hydraulic parameters gives the best estimation of states and hydraulic properties of the model. For the real-world case, the prediction of groundwater temperatures could also be improved through data assimilation with EnKF. For the validation period, it was found that parameter fields updated with piezometric heads reduced RMSE's of states significantly (heads -49%, temperature -15%), but an additional conditioning of parameters on groundwater temperatures only influenced the characterization of the temperature field.

47. Topographic controls on shallow groundwater levels in a steep, prealpine catchment: When are the TWI assumptions valid?

Topographic indices like the Topographic Wetness Index (TWI) have been used to predict spatial patterns of average groundwater levels and to model the dynamics of the saturated zone during events (e. g., TOPMODEL). However, the assumptions underlying the use of the TWI in hydrological models, of which the most important is that groundwater level variation can be approximated by a series of steady state situations, are rarely tested. It is also not clear how well findings from existing hillslope studies on sites with transmissive soil can be transferred to entire catchments with less permeable soils. This study, therefore, evaluated the suitability of selected topographic indices to describe spatial groundwater level variations based on time series from 51 groundwater wells in a 20 ha catchment with low-permeability soils in Switzerland. Results showed that median groundwater levels were correlated to slope, curvature, and TWI, but the strength of correlation depended on whether the indices characterized the local topography or the topography of the upslope contributing area. The correlation between TWI and groundwater levels was not constant over time but decreased at the beginning of rainfall events, indicating large spatial differences in groundwater responses, and increased after peak flow, when groundwater levels could be considered to be spatially in a steady state. Our findings indicate that topographic indices are useful to predict median groundwater levels in catchments with low-permeability soils and that the TWI assumptions are best met when groundwater levels change slowly.

Übersichtspublikationen – publications synoptiques

48. Hydrologisches Jahrbuch der Schweiz 2013 - Abfluss, Wasserstand und Wasserqualität der Schweizer Gewässer

Annuaire hydrologique de la Suisse 2013 - Débit, niveau et qualité des eaux suisses

Annuario idrologico della Svizzera 2013 - Deflussi, livelli idrometrici e qualità delle acque in Svizzera

Hydrological Yearbook of Switzerland 2013 - Discharge, water level and water quality of the Swiss water bodies

Das «Hydrologische Jahrbuch der Schweiz» 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.

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» 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" 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.

49. Nachhaltige Wassernutzung in der Schweiz - NFP 61 weist Wege in die Zukunft

Gestion durable de l'eau en Suisse - Le PNR 61 montre les voies à suivre pour l'avenir

Im Nationalen Forschungsprogramm NFP 61 "Nachhaltige Wassernutzung" wagten 16 inter- und transdisziplinär zusammengesetzte Projektteams einen ganzheitlichen Blick in die Wasserkunft der Schweiz im 21. Jahrhundert. Gemeinsam mit der Praxis haben Forschende aus verschiedenen Disziplinen wissenschaftliche Grundlagen und Methoden für einen nachhaltigen Umgang mit den Wasserressourcen erarbeitet und erste Umsetzungsprozesse eingeleitet. Die Rahmenbedingungen für die Wasserwirtschaft werden sich mit der sozioökonomischen Entwicklung und dem Klimawandel ändern. Im Jahr 2050 werden viele Gletscher geschmolzen sein, mit mannigfachen Auswirkungen. Die Ressource Wasser wird vermehrt unter Druck stehen und Nutzungskonflikte werden zunehmen.

Le Programme national de recherche "Gestion durable de l'eau" (PNR 61) a réuni 16 équipes de projet, qui, adoptant une approche interdisciplinaire et transdisciplinaire, ont tenté de donner une vision globale de l'avenir de l'eau en Suisse au XXI^e siècle. En collaboration avec les acteurs de terrain, des chercheurs issus de différentes disciplines scientifiques ont élaboré des bases et méthodes favorisant une gestion durable des ressources en eau et introduit des premiers processus de mise en œuvre. Les conditions générales de l'économie des eaux se modifieront du fait du développement socio-économique et du changement climatique. En 2050, la fonte de nombreux glaciers aura eu d'innombrables répercussions. La pression sur les ressources en eau et les conflits d'utilisation augmenteront.

50. Wasserressourcen der Schweiz - Dargebot und Nutzung – heute und morgen

Ressources en eau de la Suisse - Ressources disponibles et utilisation – aujourd'hui et demain

Die Alpen stellen sich quer. Mit Berggipfeln bis zu 4810 m Höhe wirkt das Alpenmassiv als Wetterbarriere, welche feuchte Luftmassen in kühlere Höhen leitet und überdurchschnittliche Mengen über der Schweiz zum Ausregnen oder Ausschneien bringt. Als Ursprungsland wichtiger Ströme gilt die Schweiz als Wasserschloss Europas. Dieses wird bereits heute durch den Klimawandel merklich beeinflusst. Gleichfalls wirken demografische, wirtschaftliche und politische Kräfte auf die Wasserverfügbarkeit sowie auf die Nutzungsansprüche in der Schweiz. Die vorliegende Thematische Synthese präsentiert Grundlagen zum heutigen Wasserdargebot und dessen Nutzung in der Schweiz und skizziert die zukünftigen Rahmenbedingungen aus klimatischer und gesellschaftlicher Sicht. Sie macht deutlich, dass selbst in der Schweiz Wasser keine unendliche Ressource darstellt und Anpassungen notwendig werden. Dies betrifft v.a. die Wasser- und Elektrizitätswirtschaft, die Industrie und das Gewerbe, die Landwirtschaft, die Schifffahrt und den Tourismus. Um auch zukünftig genügend Wasser in ausreichender Qualität zur Verfügung zu haben, ist die Wasserforschung der Schweiz aufgefordert, neben fundiertem Systemwissen auch Grundlagen für die Formulierung von gesellschaftlichen Zielen und die dazu notwendigen Weichenstellungen bereitzustellen.

En Suisse, le massif des Alpes et ses sommets culminant jusqu'à 4810 m d'altitude forment une barrière climatique qui entraîne les masses d'air humide en altitude. La Suisse bénéficie dès lors de précipitations pluvieuses et neigeuses supérieures à la moyenne. Le pays est considéré comme le château d'eau de l'Europe, car d'importants fleuves y prennent leur source. Les effets déjà tangibles du changement climatique, conjugués aux évolutions démographiques, économiques et politiques, pèsent considérablement sur les ressources en eau et leur utilisation en Suisse. La présente synthèse thématique décrit les principes régissant les ressources en eau actuelles et leur utilisation en Suisse et esquisse les futures conditions cadres climatiques et sociales. Elle montre clairement que les ressources en eau sont limitées et que des ajustements s'imposent dans de nombreux secteurs, principalement la gestion de l'eau et de l'électricité, l'industrie et le commerce, l'agriculture, la navigation et le tourisme. Afin de disposer, à l'avenir également, de ressources en qualité et en quantité suffisantes, la recherche sur l'eau en Suisse se doit de proposer, en plus de connaissances systémiques fiables, des grands principes pour définir des objectifs sociaux et poser les bons jalons.

51. Bewirtschaftung der Wasserressourcen unter steigendem Nutzungsdruck

La gestion des ressources en eau face à la pression accrue de leur utilisation

Dieser im Rahmen des NFP 61 entstandene Bericht beschreibt die Bewirtschaftung der Wasserressourcen in der Schweiz und die daraus resultierenden Nutzungskonflikte und Synergiepotenziale heute und – so weit absehbar – in der Zukunft. Wo immer möglich, stützt er sich auf Erkenntnisse aus den NFP 61-Forschungsprojekten, bezieht darüber hinaus aber auch Ergebnisse anderer Forschungsprojekte, behördliche Fachberichte und sonstige Publikationen ein. Der Bericht fasst damit den Stand des Wissens zum Thema Wasserbewirtschaftung in der Schweiz zusammen. Um die wesentlichen Synergien und Konflikte identifizieren zu können, wurden sämtliche relevanten Ansprüche an Wasser und Gewässer zusammengestellt. Dabei wurden auch Aktivitäten einbezogen, die nicht primär auf eine Nutzung von Gewässern abzielen, aber dennoch Einfluss auf deren Zustand oder auf andere Nutzungen haben.

Elaboré dans le cadre du PNR 61, le présent rapport décrit la gestion des ressources en eau en Suisse ainsi que les conflits d'utilisation et les potentiels de synergie qui en résultent, aujourd'hui et demain – pour autant que l'on puisse le prévoir. Il s'appuie autant que faire se peut sur les enseignements tirés des projets de recherche du PNR 61, tout en se référant également aux résultats d'autres projets de recherche, à des rapports techniques rédigés par l'administration ainsi qu'à d'autres publications. Le rapport entend ainsi faire un résumé de l'état actuel des connaissances sur le thème de la gestion de l'eau en Suisse. L'ensemble des exigences pertinentes relatives à l'eau et aux cours d'eau ont été compilées afin d'identifier les synergies et les conflits fondamentaux. Les activités qui n'impliquent pas une utilisation directe de l'eau, mais influent néanmoins sur son état ou sur d'autres utilisations, ont également été intégrées à ce processus.

52. Nachhaltige Wasserversorgung und Abwasserentsorgung in der Schweiz - Herausforderungen und Handlungsoptionen

Approvisionnement en eau et assainissement des eaux usées durables en Suisse - Défis et mesures possibles

Zielsetzung und Abgrenzung Diese Thematische Synthese 3 ist Teil des Nationalen Forschungsprogramms (NFP 61) «Nachhaltige Wassernutzung» des Schweizerischen Nationalfonds. Sie untersucht die aktuellen und künftigen Herausforderungen einer nachhaltigen

Siedlungswasserwirtschaft (SWW) in der Schweiz. Dabei fokussiert sie auf die Analyse der kausalen Zusammenhänge (DPSIR-Ansatz), die Formulierung von Nachhaltigkeitszielen, die Erarbeitung von Handlungsoptionen sowie die Abschätzung von

deren Auswirkungen. Die Siedlungswasserwirtschaft wird dabei als System betrachtet und im Kontext von Grund- und Oberflächenwasserressourcen analysiert. Erstere dienen als Quellen für Trinkwasser, letztere als Senken für Abwasser. Eine quantitative Übersicht über die Wasserressourcen der Schweiz ist in der Thematischen Synthese 1 zusammengestellt, Nutzungskonflikte werden in der Thematischen Synthese 2 diskutiert und Gouvernanzfragen in der Thematischen Synthese 4 behandelt.

Objectifs et limites La synthèse thématique 3 fait partie du Programme national de recherche «Gestion durable de l'eau» (PNR 61) du Fonds national suisse. Elle étudie les défis actuels et futurs à relever pour garantir une gestion durable des eaux urbaines en Suisse, en analysant les liens de causalité (approche DPSIR), formulant des objectifs de développement durable, élaborant des mesures et en évaluant les répercussions. La gestion des eaux urbaines est considérée comme système global et analysé en tenant compte des ressources en eaux souterraines et en eaux de surface. Les eaux souterraines sont utilisées comme sources d'eau potable et les eaux de surface comme récepteur pour les eaux usées. La synthèse thématique 1 fournit une vue d'ensemble de la quantité des ressources en eau de Suisse. La synthèse thématique 2 analyse les conflits d'utilisation, et la synthèse thématique 4 (ST 4) examine les questions de gouvernance de l'eau.

53. Nachhaltige Wassergouvernanz - Herausforderungen und Wege in die Zukunft

Gouvernance durable de l'eau - Enjeux et voies pour l'avenir

Ein nachhaltiger Umgang mit der Ressource Wasser ist eine Frage von naturwissenschaftlichen und technischen Zusammenhängen, aber auch – und immer mehr – eine Frage der Wassergouvernanz. Damit sind folgende Fragen gemeint: Wie soll der Umgang mit Wasser und mit den Nutzungs- und Interessenkonflikten rund um Wasser am besten organisiert werden? Welche Regeln und Steuerungsinstrumente sind nötig, welche institutionellen Strukturen braucht es? Wie ist die Zusammenarbeit über räumliche und sektorale Grenzen sowie über die Staatsebenen hinweg am wirksamsten zu bewerkstelligen?

La gestion durable des ressources en eau est une question de rapports biologiques et techniques, mais aussi – et toujours plus – une question de gouvernance de l'eau. Ces constatations soulèvent les questions suivantes : Comment organiser au mieux la gestion de l'eau et des conflits d'utilisation et d'intérêts relatifs à l'eau ? Quels sont les instruments de gestion et les règles nécessaires, de quelles structures institutionnelles avons-nous besoin ? Comment réaliser un travail de coopération des plus efficaces au-delà des frontières spatiales et sectorielles ainsi que des niveaux institutionnels ?

12th Swiss Geoscience Meeting

54. 3D visualization of the structures at Grimsel Test Site GTS and their link with sampled groundwaters

We present preliminary results from a research project aiming at the development of structural and hydrochemical models in the Grimsel region. For the last 30 years, numerous experiments and research investigations in the Grimsel Test Site (GTS) delivered a vast number of structural, physical and geochemical data (e.g. Keusen et al. 1989). In the context of the present study, the natural fluid flow paths are investigated in 3D space by a combination of 3D structural modelling and geochemical approaches incorporating groundwater inflow rates and geochemistry. For this purpose, a 3D structural model will be developed in a first step, which links structures at the level of the GTS tunnels with the topographic surface. Information compiled from previous studies are combined with newly acquired tunnel and surface mappings. The subsequent structural 3D visualization of the geometry is performed with the MoveTM software (from Midland Valley Exploration Ltd).

55. Groundwater vulnerability mapping in forested catchments

Groundwater vulnerability mapping provides the basis for the delimitation of groundwater protection zones. In Switzerland, three methods have been defined to establish groundwater protection zones. These methods depend of the type of aquifer: karstic (EPIK: (Doerfliger and Zwahlen 1998)), fractured (DISCO: (Pochon and Zwahlen 2003)) and unconsolidated aquifers (Biaggi, Schwienbacher et al. 2012). These methods, in particular EPIK, tend to overestimate the vulnerability of groundwater originated from forested catchment and therefore overestimate the protection zones in such kind of ecosystems. This effect is particularly important in Switzerland, where 42% of groundwater protection zones are located in forests (Meylan 2003). Until now, none of the existing methods has taken into account the specific characteristics of forest hydrology.

56. Improving the understanding of river-groundwater interactions by analyzing time series of electrical conductivity

The residence time and the fraction of infiltrated river water are important parameters that determine the quality of drinking water derived by riverbank filtration. Hence, estimating these parameters is of high practical relevance and of particular interest within the context of river restoration projects, which might affect the residence time in the aquifer and thus the quality of the produced drinking water.

57. KARSYS: a GIS- and 3D-based approach for the characterization of karst aquifers

Only few methods do exist for the characterization of karst aquifers and rare are those which explicitly integrate 3D geological / hydrological data and hydraulic principles in a systematic way. The KARSYS approach (Jeannin et al. 2013) – already presented during the previous SGM's meetings – has been applied over a large part of the Swiss karst territory and abroad (Swisskarst project, Malard 2013) and it now entails a concrete and continuous workflow which basically combines: Database, GIS procedures and 3D Geological and hydrological modeling in order to address a large spectrum of pragmatic karst-related questions (mostly spatial issues as resources mapping, hazards in construction, geothermal probes regulations, etc.). Recent improvements and extensions have been implemented to the basic approach with the aim to address questions related to hydrological simulations (temporal issues: resources assessment, flood hazards, hazards in construction, etc.) whose results could be coupled with the physical karst model to provide a concrete image of the aquifer / system's functioning. The approach requires the use of common GIS, 3D modelling and hydrologic software programs as well as various dedicated home-made scripts and plugins to ensure the programs interoperability and the data integrity all along the workflow. The approach also includes a GIS dedicated data model which has been developed for applying KARSYS and documenting karst aquifers properties.

58. Regional hydrogeological modelling of the central Jura in the area of Neuchâtel. Part 1 : 3D geological modelling

The canton of Neuchâtel is located in the central part of the Jura fold and thrust belt at the northwestern limit of the Molasse basin. The structure of this part of the Jura is a succession of thrust-

related folds, composed of Mesozoic to Cenozoic cover rocks detached from their pre-Triassic basement, and limited by several major tear faults. Three main aquifers are recognised within the cover series in this area. These are from top to bottom: the upper Malm, the Dogger and the upper Muschelkalk. The main goal of this study is to understand the behaviour of groundwater flow in this multi-layered aquifer system and especially in the two main regional reservoirs, namely the upper Malm and the Dogger. This study is divided in two parts: part 1 presents the construction of the 3D geological model (this abstract) and part 2 (see companion abstract) the results of 3D groundwater flow and mass transport modelling.

59. Regional hydrogeological modelling of the central Jura in the area of Neuchâtel. Part 2 : 3D groundwater flow and mass transport modelling

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). This study aims to synthesize the available data in order to setup a regional hydrogeological numerical model that can be used : to understand the behaviour of groundwater flow and mass transfer in the multilayered aquifer system and especially in the two main regional reservoirs, namely the upper Malm and the Dogger; to evaluate groundwater resources and their vulnerability; and further to evaluate the regional geothermal potential. This study is presented in two parts: part 1 presents the building of the 3D geological model (see companion abstract) and part 2 (this abstract) the results of 3D groundwater flow and mass transport modelling.

60. Supersaturation, a phenomenon ignored by most hydrogeologists

Dissolved gases in groundwater are only rarely in equilibrium with the atmosphere. Hydrostatic pressure on soil gas bubbles dissolving in percolating water, compression of air pockets in karst systems, air leaks in pumps or pipes, releases of water from dams or drilling with compressed air all lead to supersaturation. Supersaturation means that the Total Dissolved Gas Pressure (TDGP), the sum of the partial pressures of the dissolved gases is higher than the atmospheric pressure. In the field of rare gas or isotope age determination this is frequently called "excess air".

61. The water circulation In the fractured rock: The role of stylolites in the development of karst

Karst development is strongly influenced by the tectonic deformation of the area where they occur. This is because, the structure of the rock mass in which it occurs (eg. lithology, primary porosity, environmental conditions, etc.) affects the water circulation, thereby affecting permeability and porosity. Traditionally, in the field of karstology, it is maintained that water circulation is essentially related to extensional structures which, it is assumed, are more favorable to water circulation. In fact, the permeability of the fault zone is sufficiently high only in the early stages of the movement , because after a short period the deposition of minerals (e.g., calcite) coming from these same fluids reduces its porosity/permeability. Fault zones and fractures play an important role in fluid circulation, acting as permeability barriers or conductors, depending on the specific conditions (lithological and structural in particular), and on the distribution of other structures associated with them. Therefore, structural analysis can provide both qualitative and quantitative assessments of the relationship between structure and fluid circulation and allow us to determine whether a fault zone acts as a barrier or as a hydraulic conductor (Caine 1996).The stylolites (Rawling 2001), structure associated with the faults play an important role in the fluid circulation and in particular in the development of the karst. In this study, conducted in the karst area of Fasano it was verified that the karst tends to develop along tectonic stylolites formed by compression.

62. Trenderhebung, Früherkennung und Erfolgskontrolle im Grundwassermonitoring - Konzepte der Nationalen Grundwasserbeobachtung NAQUA

Grundwasser ist in allen Ländern Europas ein wichtiger einheimischer Rohstoff. So werden über 80% des Trinkwassers in der Schweiz aus Grundwasser gewonnen. Neben einer zunehmenden Versiegelung des Bodens durch das Siedlungswachstum wird das Grundwasser insbesondere durch Schadstoffe aus Landwirtschaft, Industrie, Gewerbe, Haushalten und Verkehr aber auch durch klimatische Veränderungen beeinflusst. Einmal ins Grundwasser gelangt, werden Schadstoffe dort kaum mehr abgebaut. Da sich Grundwasser zudem nur langsam erneuert, kommt vorausschauenden, präventiven Massnahmen zum Schutz des Grundwassers besondere Bedeutung zu. Um die Grundwasserressourcen zu erhalten und bestehende Beeinträchtigungen zu beheben, ist eine

nachhaltige Bewirtschaftung und ein integraler Schutz der Ressource Grundwasser unerlässlich. Um hierfür zielgerichtete Massnahmen entwickeln zu können, müssen die entscheidenden Zusammenhänge und Einflussgrössen verstanden und Defizite bzw. Handlungsfelder identifiziert werden. Diese Grundlagen kann ein landesweites Monitoring wie die Nationale Grundwasserbeobachtung NAQUA zur Verfügung stellen.

Swiss Society for Microbiology

63. Assessment of bioremediation potential and monitoring of biological reductive dechlorination in sites contaminated with chlorinated ethenes

Chlorinated ethenes (CEs), such as perchloroethene (PCE) and trichloroethene, are one of the most common classes of groundwater contaminants. In this project, the contaminant biodegradation capacities of two aquifers, presenting both dichloroethene (DCE) and vinyl chloride (VC) accumulation, was carried out. Aquifers are considered nowadays as dynamic ecosystems, showing multiple interactions between the physical, chemical and biotic components. In this sense, an integrative methodology using multivariate statistics and combining together bacterial community structures, detection of dechlorinating bacteria and genes, and water geochemical data were used to investigate these aquifers. Results from multifactorial analysis of data collected from a PCE-contaminated site in Switzerland (25 groundwater samples) showed that manganese reduction (MR) was a key terminal electron accepting process, suggesting a potential competition between MR and DCE degradation to VC and ethene. Dehalococcoides sp. and VC reductive dehalogenase genes were detected but ethene concentration was below 0.007mg/L. Potential for a complete natural biodegradation of PCE was present in this aquifer. However, DCE reduction is strongly inhibited under local conditions as long as oxidized manganese resources are present. The second site located in Czech Republic (Velamos) and sampled at 7 different dates (35 groundwater samples) was under an active biostimulation process. Multifactorial analysis showed that successive cheese whey injections modified the aquifer habitat that became favourable not only for a complete dechlorination, but also for sulfate reduction (SR) and methanogenesis. DCE and VC accumulated along with the production of ethene, methane and hydrogen sulphide, indicating a competition between CEs dechlorination and SR and methanogenesis. This possibly explained the transitional slower reaction of CEs dechlorination observed during the remediation process. In conclusion, the used methodology allowed evaluation of the bioremediation potential present in contaminated aquifers and monitoring biostimulation processes.

European Geoscience Union EGU

64. Characterization of CO₂ reservoir rock in Switzerland

Anthropogenic emissions of Carbon Dioxide (CO₂) are one of the key drivers regarding global climate change (IPCC, 2007). Carbon Dioxide Capture and Storage (CCS) is one valuable technology to mitigate current climate change with an immediate impact. The IPCC special report on CCS predicted a potential capture range of 4.7 to 37.5 Gt of CO₂ by 2050. Among several countries, Switzerland has started to investigate its potential for CO₂ storage (Chevalier et al., 2010) and is currently performing research on the characterization of the most promising reservoir/seal rocks for CO₂ sequestration. For Switzerland, the most feasible option is to store CO₂ in saline aquifers, sealed by impermeable formations. One aquifer of regional scale in the Swiss Molasse Basin is a carbonate sequence consisting of reworked shallow marine limestones and accumulations of shell fragments. The upper part of the formation presents the most promising permeability values and storage properties. The storage potential has been estimated of 706 Mt of CO₂, based on the specific ranking scheme proposed by Chevalier et al. 2010. In this study, key parameters such as porosity, permeability and acoustic velocities in compressional and shear mode have been measured in laboratory at pressures and temperatures simulating in situ conditions. Reservoir rock samples have been investigated. Permeability has been estimated before and after CO₂ injection in supercritical state. The simulation of typical reservoir

conditions allows us to go one step further towards a significant evaluation of the reservoir's true capacities for CO₂ sequestration. It seems of major importance to notice that the permeability crucially depends on confining pressure, temperature and pore pressure conditions of the sample. Especially at in situ conditions with CO₂ being at supercritical state, a substantial loss in permeability have to be taken into consideration when it comes to the calculation of potential injection rates. The correlation between the permeability and confining pressure, temperature and pore pressure conditions of the sample is a first important result of the study.

65. Comparison of different investigation methods to characterise alluvial gravel aquifers

For reliable groundwater transport modelling of unconsolidated porous aquifers, high resolution characterisation of spatially heterogeneous hydraulic and transport properties is of great importance. Predictions of first-arrival times and long term behaviour depend strongly on the quality of estimated hydraulic and transport parameters. By neglecting small-scale structures such as sand lenses and sediment intra-channel deposits, predictions are hardly accurate. This paper deals with the comparison of methods to characterize hydraulic parameters governing solute transport in unconsolidated porous aquifer materials. A large number of single-well slug tests, cross-well slug tests, a pumping test and a multi-level tracer test were conducted in a shallow alluvial gravel aquifer. This facilitated describing the spatial variation of hydraulic and transport parameters with high resolution. Multi-level slug tests results show distinct positive correlation with porosity-logs and drill cores and are thus an effective means to identify and characterize subsurface structures at high resolution. Values for hydraulic conductivity gained from pumping tests and cross-well slug tests revealed good accordance but were around one order of magnitude higher than the values derived from multi-level slug tests. This might be due to the fact that the three methods are involving different test-volumes. Hence, the determination of hydraulic conductivity underlies a scale dependency: larger test volumes tend to be characterized by larger K-values. Furthermore, our pumping test results show the importance of a high sampling rate, in our case 50 Hz, in order to determine reliably the hydraulic properties storage and anisotropy of hydraulic conductivity. Although pumping tests typically estimate hydraulic parameters on large-scale, small-scale heterogeneity could also be identified and characterized. This was again possible through the high resolution records of the early time drawdown. Finally, results of multi-level tracer testing supported observations from slug tests and porosity logs.

66. Groundwater flow systems in the great Aletsch glacier region (Valais, Switzerland)

Groundwater flow systems in Alpine areas are often complex and challenging to investigate due to special topographic and climatic conditions governing groundwater recharge and bedrock flow. Studies seeking to characterize high-alpine groundwater systems remain rare, but are of high interest, e.g. for water supply, hydropower systems, traffic tunnels or rock slope deformation and landslide hazards. The goal of this study is to better understand the current and past groundwater flow systems of the UNESCO World Heritage mountain ridge separating the great Aletsch glacier and the Rhone valley, considering climatic and glacier fluctuations during the Lateglacial and Holocene periods. This ridge is crossed by a hydropower bypass drift (Riederhornstollen) and is composed of fractured crystalline rocks overlain by various types of landslides and glacial deposits. Surface hydrology observations (fracture properties, groundwater seepage, spring lines and physico-chemical parameters) and hydropower drift inflow measurements contributed to the characterization of bedrock hydraulic conductivities and preferential groundwater pathways. Basic conceptual hydrogeological models were tested with observed drift inflows and the occurrence of springs using free-surface, variably saturated, vertical 2D groundwater flow models (using the code SEEP/W from GeoStudio 2007). Already simple two-layer models, representing profile sections orthogonal to the mountain ridge, provided useful results. Simulations show that differences in the occurrence of springs on each side of the mountain ridge are likely caused by the occurrence of glacial till (generating perched groundwater), the deep-seated sagging landslide mass, faults and asymmetric ridge topography, which together force the main groundwater flow direction to be oriented towards the Rhone valley, even from beyond the mountain ridge. Surprisingly, the most important springs (those with high discharge rates) are located at high elevations above the terraces of Riederalp and Bettmeralp in or near steeply dipping fault zones striking parallel to the ridge, suggesting locally a near-surface groundwater table. Drying up of several of these springs (at lateral distances up to 4 km) after construction of the Riederhornstollen, as well as associated large tunnel water inflows, demonstrates large scale hydraulic connections along strike of these fault zones. The catchment areas of these springs have to be located close to the ridge crest, above the terraces of Riederalp and Bettmeralp, and extend over many kilometers. This fault system thus drains significant portions of the high-altitude

recharge and induces a complex 3D groundwater flow field of the Aletsch area. Variations in glacial ice extent due to different climatic conditions during the Lateglacial and Holocene periods were studied by varying the boundary condition of the great Aletsch glacier. Results have to be interpreted with care, as the glacier pressure boundary conditions were modelled like a lake. Detailed investigations of these boundary conditions have been initialized by glacier drillings equipped with melt water pressure sensors. With the simplified boundary conditions applied to the glacier bed, elevated ice surfaces during the Little Ice Age stage only slightly influence the flow field and total hydraulic head conditions on the NW side of the ridge. On the other hand, the Egesen stadial causes a fundamental change of the groundwater divide with all flow lines, even from below the Aletsch glacier, oriented towards the Rhone valley.

67. Groundwater temperature in the Limmat Valley aquifer, Zurich

In metropolitan areas, the thermal environment is strongly influenced by the effects of urbanization. Urban climate is often described by Urban Heat Islands (UHIs), which are also observed in the shallow subsurface. On the one hand, these temperature anomalies may put sustainable development of urban ground at a risk, but on the other hand, enhanced ground temperatures represent potential energy reservoirs. In this contribution, we focus on the role of hydrogeological conditions for the development subsurface UHIs. As a study case, the Limmat valley forming the city center of Zurich is chosen. The Limmat valley is filled with widely heterogeneous, high-conductive moraine deposits, which host groundwater reaching close to the urban surface. By rigorous temperature-depth metering of the Limmat valley aquifer since the summer of 2013, and by compiling previously measured data, the intensity of Zurich's subsurface UHI is examined. This is done with respect to its special hydrogeology, which is dominated by large-scale infiltrations from the rivers Limmat and Sihl. These generate seasonal temperature variations in the groundwater, with increasing amplitudes in the vicinity of the rivers. The seasonal groundwater temperature changes in the Limmat valley are assessed by complementing measurements from summer and winter. The measurements reveal that groundwater temperatures in Zurich are generally high. Across the Limmat valley, values of beyond 13°C are regionally observed, which is around 4 K higher than annual surface air temperature and around 3 K higher than groundwater temperature in the rural surrounding. Though, urbanization is interpreted as a secondary factor (1-1.5K), as the river infiltration naturally causes high groundwater temperatures in the Limmat valley. In the permeable gravel, the temperature-depth-profiles measured in city wells often show little fluctuation. This may be due to horizontal and vertical mixing of the groundwater, and reflects the dominant role of advective heat transport. However, this is different at locations where hydraulic conductivity is small, and accordingly groundwater flow velocity is only minor. We find increasing temperatures towards the ground surface, showing that here heat is accumulated. This leads to maximum groundwater temperatures of 27°C at certain wells. These observations point out that there is a strong coherence between hydrogeological parameters and subsurface temperature in Zurich.

68. Hydrological responses in a pre-alpine head watershed: the role of hillslopes and riparian zones

Mountainous watersheds are characterized by generally high precipitation inputs and very heterogeneous landscape properties, which make them very dynamic hydrologic systems that play an important role in the water cycle. Their groundwater systems sustain downstream baseflow in larger catchments in many parts of the world, particularly in the densely populated lowlands of Switzerland. Hillslope aquifers are often categorized as one of the dominant groundwater resources in mountainous watersheds. These aquifers may also act as source areas for pollutants in rivers due to intensive agricultural land use. In our study we seek to improve the understanding of the groundwater flow processes and runoff generation mechanisms in high altitude watersheds, under explicit consideration of the joint behaviors of climate and groundwater. The role of the hillslope groundwater contribution to catchment outflow and streamflow composition was investigated in the pre-alpine Rietholzbach catchment (~1 sq km) in northeast Switzerland. The field site, equipped with an extensive hydrometric setup, facilitates the monitoring of annual, inter-seasonal and short-term dynamics of water flow and composition, as well as its links to associated parameters describing atmospheric, surface and subsurface properties. In this study, we focused on the effects of antecedent moisture, rainfall characteristics and landscape properties on groundwater and river responses in order to develop a conceptual model of runoff generation. Our observations indicate generally low hydraulic conductivities and average groundwater travel times of several months in the hillslope aquifers resulting from high clay-contents of the unconsolidated glacial Moraine deposits. Event analysis revealed that only a small portion of the total watershed area generates event discharge and we have identified the saturated

valley bottom (riparian zones) and lower hillslopes as the two dominant hydrological landscape units. Runoff generation from the riparian zones is mainly driven by rainfall characteristics, whereas antecedent moisture conditions regulate groundwater discharge from the hillslopes. For the late summer season 2012, we could correlate an accumulation of nutrients in the riparian zones with agricultural land use on the hillslopes and downhill groundwater flux. From this, we expect an increased flushing-out of nutrients from the near-stream areas into the river during rainfall events. In order to incorporate solute transport into our conceptual model, the ongoing research focuses on the role of rainfall characteristics and antecedent moisture conditions on the buffer-capacity of the riparian zones to filter the nutrient input from the hillslopes.

69. Impact of river restoration on groundwater - surface water - interactions

Since the end of the 19th century, flood protection was increasingly based on the construction of impermeable dams and side walls (BWG, 2003). In spite of providing flood protection, these measures also limited the connectivity between the river and the land, restricted the area available for flooding, and hampered the natural flow dynamics of the river. Apart from the debilitating effect on riverine ecosystems due to loss of habitats, these measures also limited bank filtration, inhibited the infiltration of storm water, and affected groundwater-surface water-interactions. This in turn had a profound effect on ecosystem health, as a lack of groundwater-surface water interactions led to decreased cycling of pollutants and nutrients in the hyporheic zone and limited the moderation of the water temperature (EA, 2009). In recent decades, it has become apparent that further damages to riverine ecosystems must be prohibited, as the damages to ecology, economy and society surmount any benefits gained from exploiting them. Nowadays, the restoration of rivers is a globally accepted means to restore ecosystem functioning, protect water resources and amend flood protection (Andrea et al., 2012; Palmer et al., 2005; Wortley et al., 2013). In spite of huge efforts regarding the restoration of rivers over the last 30 years, the question of its effectiveness remains, as river restorations often reconstruct a naturally looking rather than a naturally functioning stream (EA, 2009). We therefore focussed our research on the effectiveness of river restorations, represented by the groundwater-surface water-interactions. Given a sufficiently high groundwater level, a lack of groundwater-surface water-interactions after restoration may indicate that the vertical connectivity in the stream was not fully restored. In order to investigate groundwater-surface water-interactions we determined the thermal signature on the stream bed and in +/- 40 cm depth by using Distributed Temperature Sensing (DTS), a fibre optical method for temperature determination over long distances (Selker et al., 2006). Thermal signatures were determined in a small urban stream before and after restoration and compared to streams in natural and near-natural settings.

70. Stochastic collocation and lagrangian sampling for passive tracer transport in an aquifer with random permeability

To a large extent, the flow and transport behavior within an aquifer is governed by its permeability. Typically, permeability measurements of an aquifer are affordable at few spatial locations only. Due to this lack of information, permeability fields are preferably described by stochastic models rather than deterministically. A stochastic method is needed to assess the transition of the input uncertainty in permeability through the system of partial differential equations describing flow and transport to the output quantity of interest. The stochastic collocation method is an elegant and efficient tool for uncertainty quantification in subsurface problems. Several contributions (e.g., Li and Zhang, WRR, 2007) have successfully applied stochastic collocation-based frameworks for the flow problem. For the transport problem, however, Lin and Tartakovsky (AWR, 2009) have shown that an accurate solution via stochastic collocation is more challenging. We propose a hybrid approach that utilizes stochastic collocation to solve the flow problem only and Monte Carlo-type sampling for transport: By means of stochastic collocation, we approximate the random flow field with a polynomial chaos expansion. Subsequently, a conventional Monte Carlo sampling technique is used for passive tracer transport. Here, the computational costs per flow field sample are very low thanks to the polynomial chaos expansion. In case of negligible pore-scale dispersion, the same holds true for a passive tracer transport sample, since a Lagrangian transport formulation can be employed. Our approach avoids problems related to the accurate collocation-based solution of the transport problem, while being significantly faster than full Monte Carlo. (Full Monte Carlo does not rely on a polynomial chaos expansion of the random flow field). The proposed method is applied for passive tracer transport within a two-dimensional aquifer. A multi-point Gaussian logarithmic permeability field is assumed.

71. When is the steady state assumption valid? - Topographic controls on shallow groundwater levels in a steep, pre-alpine catchment

Spatial and temporal variation in groundwater levels govern the spatio-temporal distribution of runoff source areas, catchment-wide hydrological connectivity and thus streamflow responses in headwater catchments. Topography is an important control on the spatial variability of groundwater levels. In this study we monitored groundwater levels at 51 sites in a 20 ha pre-alpine catchment in Switzerland for 27 months to evaluate the role of topography on median groundwater levels, the importance of local versus upslope topographic characteristics on median groundwater levels and the temporal variation in the correlation between the Topographic Wetness Index (TWI) and groundwater levels. Median groundwater levels were correlated to local and upslope topographic indices, namely the mean curvature of the upslope contributing area, TWI, the upslope contributing area, the local slope gradient and the mean TWI of the upslope contributing area. The correlation between TWI and groundwater levels decreased at the beginning of rainfall events, reflecting spatially variable groundwater responses, and increased after peak flow, indicating a state of hydrological connection closer to steady state. TWI and groundwater levels were most strongly correlated during the late snowmelt period, when groundwater levels were high and the catchment was closest to steady state and lowest during long dry periods, when large parts of the catchment were hydrologically disconnected.

American Geophysical Union AGU

72. Controls on groundwater response timing of a subalpine catchment

Lateral subsurface storm flow within the soil profile is one of the main processes that efficiently transfers soil water between runoff source areas in a catchment and the channel network (Weiler et al. 2005). Groundwater dynamics are therefore important in understanding states of hydrologic connectivity and runoff response during rainfall events. In order to better understand how catchments are organized we need to study spatial patterns of rainfall-runoff processes and the governing mechanisms and controls that determine them. (McDonnell et al. 2007). In mountain headwater catchments topography, soil and vegetation properties are expected to play an important role in groundwater response dynamics but only a few studies have tried to identify the dominant catchment characteristics that allow prediction of spatial groundwater dynamics. Groundwater responses were shown to be related to topography on steep slopes and under wet environmental conditions, where groundwater levels are predominantly shallow (Anderson & Burt 1978; Burt & Butcher 1985; Lana-Renault et al. 2013). In flatter and drier conditions (Detty & McGuire 2010), and especially in permeable soils (Seibert et al. 1997; Dhakal & Sullivan 2014; Anderson et al. 2010), it has been difficult to demonstrate the impact of the topography of groundwater levels and dynamics. Some topographically based conceptual models (like TOPMODEL) assume groundwater levels to respond in unison across a catchment and approximate groundwater variations by a succession of steady-state situations. This implies a spatially persistent pattern of groundwater levels in a catchment, which can be modeled by the Topographic Wetness Index (TWI) (Beven & Kirkby 1979). However from existing studies we know that groundwater levels do not always respond in unison across a hillslope or an entire catchment (Penna et al. 2014; Bachmair & Weiler 2012; Fannin et al. 2000) but differ between landforms (Detty & McGuire 2010), shallow and deep soils (Tromp-van Meerveld & McDonnell 2006) and the upper or lower part of hillslopes (Haught & van Meerveld 2011). Locations in the riparian zone and in subsurface depressions react earlier to rainfall events than upslope locations (Detty & McGuire 2010). Haught & van Meerveld (2011) found that groundwater lagtimes got shorter with increasing antecedent moisture content.

73. Parsimonious modeling of mountainous catchment hydrology at various spatial scales – initial results and evaluation

Mountainous catchments serve as important freshwater resources that sustain surface water bodies and groundwater aquifers in the lowlands. However, the understanding and description of the hydrologic behavior of mountainous catchments remains a challenging task due to complex landscape properties and flashy rainfall-runoff responses. Further, these regions are often used intensively as agricultural landscapes, which poses a potential risk of pollution of the local aquatic systems.

Therefore, the identification of hydrologically active landscape units and the improvement of the existing understanding about dominant physical processes controlling streamflow generation and solute export is required in order to preserve the vitality of mountainous catchments. By analyzing rainfall-response dynamics of shallow groundwater and river discharge, as well as identifying the relevant geomorphological properties in an extensively equipped pre-Alpine catchment in north-east Switzerland (Rietholzbach, ~1km²), a conceptual model could be developed, which reflects the spatial organization and hydrological functioning of the landscape. It was found that only a small fraction of the entire catchment area (~25%) generates event flow, from which approximately 30% and 70% were riparian zones and hillslopes, respectively. Both landscape units differ in terms of their major hydrological and hydrogeological processes. The conceptualization was verified by a parsimonious modeling approach that accounts for spatial variability and represents catchment outflow as linear depletion of several linear storage reservoirs. The simulation results successfully reflected the hydrological behavior of the chosen case-study site.