

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

Literaturzusammenstellung Jahrgang 2010

Inklusive Links zu Artikel-[Abstracts]

Fachartikel Schweiz

Valsangiacomo C, Brändle A., Pedrazzi L.

Radon in Tessiner Wasserwerken – Messkampagne der SUVA [1]

Gas Wasser Abwasser, gwa 6/2010, S. 489-495

Schürch M., Kozel R., Biaggi D., Weingartner R.

Typisierung von Grundwasserregimen in der Schweiz – Konzept und Fallbeispiele [2]

Gas Wasser Abwasser, gwa 11/2010, S. 955-965

Reinhardt M., Tresp J., Zoller O., Rupp H., Hoehn E.

Perfluorierte Chemikalien im Grundwasser – Grundlagen und Pilotstudie Schweiz [3]

Gas Wasser Abwasser, gwa 11/2010, S. 967-978

Parriaux A., Tacher L., Turberg P., Kozel R., Loup B.

Hydrogéologie et glissement de terrain – Concept et assainissement [4]

Gas Wasser Abwasser, gwa 11/2010, S. 979-985

Pronk M., Sinreich M., Guhl F., Egli T., Kötzsch S., Felleisen R., Koch M., Köster O., Raetz E., Ramseier C., Rossi P., Schürch N.

Mikroorganismen im Grundwasser – Ein erster landesweiter Überblick [5]

Gas Wasser Abwasser, gwa 12/2010, S. 1059-1071

Schotterer U., Schürch M., Rickli R., Stichler W.

Wasserisotope in der Schweiz – Neue Ergebnisse und Erfahrungen aus dem nationalen Messnetz ISOT [6]

Gas Wasser Abwasser, gwa 12/2010, S. 1073-1081

Baillieux A., Hunkeler D., Perrochet P., Zimmermann S.

Evolution de la qualité des eaux souterraines captées – Outils pour la prévision [7]

Gas Wasser Abwasser, gwa 12/2010, S. 1083-1094

Hessenauer M., Flury F.

Prospection d'eau souterraine par forage profond incliné à Miécourt (Canton du Jura, Suisse) [8]

Swiss Bulletin für angewandte Geologie, Vol. 15/1, 2010, S. 23-42

Siddiqi G., Minder R.

The Swiss federal office of energy's path on the road to utilizing Switzerland's geothermal resources – From research & development to pilot- and demonstration projects

Swiss Bulletin für angewandte Geologie, Vol. 15/1, 2010, S. 79-93

Fachartikel international

Affolter A., Huggenberger P., Scheidler S., Epting J.

Adaptive groundwater management in urban areas: effect of surface water – groundwater interaction using the example of artificial groundwater recharge and in- and exfiltration of the river Birs (Switzerland) [9]

Grundwasser, 15/3, 2010, p. 147-161

Masset O., Loew S.

Hydraulic conductivity distribution in crystalline rocks, derived from inflows to tunnels and galleries in the Central Alps, Switzerland [10]

Hydrogeology Journal, 18/4, 2010, p. 863-891

Rieckermann J., Borsuk M. E., Sydler D., Gujer W., Reichert P.

Bayesian experimental design of tracer studies to monitor wastewater leakage from sewer networks [11]

Water Resources Research, 46, Art. Nr. W08513, 2010

Flynn R. M., Sinreich M.

Characterisation of virus transport and attenuation in epikarst using short pulse and prolonged injection multi-tracer testing [12]

Water Research, 44/4, 2010, p. 1138-1149

Bauser G., Franssen H.-J. H., Kaiser H.-P., Kuhlmann U., Stauffer F., Kinzelbach W.

Real-time management of an urban groundwater well field threatened by pollution [13]

Environmental Science and Technology, 44/17, 2010, p. 6802-6807

Froidevaux P., Steinmann P., Pourcelot L.

Long-Term and Long-Range migration of radioactive fallout in a Karst system [14]

Environmental Science and Technology, 44/22, 2010, p. 8479-8484

de Moel M., Bach P. M., Bouazza A., Singh R. M., Sun J.L. O.

Technological advances and applications of geothermal energy pile foundations and their feasibility in Australia [15]

Renewable & Sustainable Energy Reviews, 14/9, 2010, p. 2683-2696

Shabarova T., Pernthaler J.

Karst pools in subsurface environments: collectors of microbial diversity or temporary residence between habitat types [16]

Environmental Microbiology, 12/4, 2010, p. 1061-1074

Pesendorfer M., Loew S.

Subsurface exploration and transient pressure testing from a deep tunnel in fractured and karstified limestones (Lotschberg Base Tunnel, Switzerland) [17]

International Journal of Rock Mechanics and Mining Sciences, 47/1, 2010, p. 121-137

Goldscheider N., Pronk M., Zopfi J.

New insights into the transport of sediments and microorganisms in karst groundwater by continuous monitoring of particle-size distribution [18]

Geologia Croatia, 63/2, 2010, p. 137-142

Gremaud V., Goldscheider N.

Geometry and drainage of a retreating glacier overlying and recharging a karst aquifer, Tsanfleuron-Sanetsch, Swiss Alps [19]

Acta Carsologica, 39/2, 2010, p. 289-300

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Baumann M., Jordan P., Hoehn E., Geisser H. (Hrsg.)

Ein neues Grundwassermodell für das Thurtal

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Symposium 17 "Groundwater and climate change"

Alt-Epping P., Diamond Larry W.

Reactive-transport modeling applied to geological sequestration of CO₂ in Switzerland

Diem S., Schirmer M.

RIBACLIM – Riverbank filtration under climate change scenarios

Figura S., Livingstone D., Hoehn E., Kipfer R.

Climate change and groundwater quality: analysis of historical records

Hessenauer M., Flury F.

Evolution, sur plus de 20 ans, de quelques paramètres hydrochimiques des eaux souterraines suivies dans le cadre de l'étude d'impact de l'autoroute la Transjurane (A16, Canton du Jura)

Käser D., Perrochet P., Renard P., Schirmer M., Zwahlen F., Hunkeler D.

Influence of groundwater/stream water interactions in sustaining environmental flow and water supply in a changing climate: the case of an Alpine alluvial aquifer, the Upper Emme

Möck C., Baillieux A., Schirmer M., Hunkeler D.

Groundwater shortage due to climate change

Stoll S., Hendricks Franssen H.-J., Butts M., Kinzelbach W.

Analysis of the impact of climate change on groundwater related hydrological fluxes

Tacher L., Turberg P., Breguet A., Parriaux A.

Modelling the sensibility of the alpine and perialpine hydrogeological systems in climate change

Vögeli Albisser C., Prasuhn V.

Irrigation and groundwater quality in times of climate change

Symposium 14 "Geoscience and Geoinformation - From data acquisition to modelling and visualization"

Burri T., Kündig R., Sinreich M.

The Hydrogeological Map of Switzerland 1:100'000: From a pure print product of the 1970's to an interactive GIS-tool

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Herfort M.

Geologische Tiefenlagerung radioaktiver Abfälle in der Schweiz – Hydrogeologische Aspekte

Goldscheider N., Gremaud V.

Hydrogeologie des Gletscher-Karst-Systems „Tsanfleuron-Sanetsch“ (Schweizer Alpen) und mögliche Auswirkungen des Klimawandels

Kozel R., Schürch M.

Erwartete Auswirkungen der Klimaänderung auf das Grundwasser in der Schweiz

Diem S., Vogt T., Hoehn E.

Räumliche Verteilung der hydraulischen Leitfähigkeit in voralpinen und alpinen alluvialen Schotter-Grundwasserleitern

Hendricks Franssen H.-J., Kuhlman U., Kaiser H.P., Bauser G., Müller R., Stauffer F., Kinzelbach W.

Echtzeitmodellierung des oberen Limmattalaquifers mit Aktualisierung räumlich verteilter Parameterfelder

Morasch B., Kohn T.

Auftreten von Micropollutants in einem Karstgrundwasserleiter (Yverdon-les-Bains, Schweiz)

Schirmer M., Cirpla O. A., Vogt T., Schneider P., Huntscha S.

Flussrevitalisierung - Auswirkungen auf Grundwasser- / Oberflächenwasserinteraktionen: Das RECORD-Projekt

Engeler I., Hendricks Franssen H.-J., Müller R., Stauffer F.

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Butscher C., Huggenberger P., Auckenthaler A., Bänninger D., Epting J., Kirchhofer R.

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Zopfi J., Pronk M., Peyret P., Goldscheider N.

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Vogt T., Schneider P., Freund A., Schirmer M., Cirpka O. A.

Zeitreihenanalyse natürlicher Tracer bei der Flusswasserinfiltration – Anwendung und Vergleich an kanalisiertem und revitalisiertem Flussabschnitt eines voralpinen Flusses in der Schweiz

Altdorff D., Huber E., Schindler Y., Epting J., Dietrich P., Huggenberger P.

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Assessing Groundwater Travel Times and Biogeochemical Processes during Riverbank Filtration under the Aspect of River Restoration

Peter S., Rechsteiner R., Lehmann M. F., Tockner K., Vogt T., Wehrli B., Durisch-Kaiser E.

Occurrence of biogeochemical hot spots and hot moments in a restored riparian groundwater system

Wanner C., Eggenberger U., Kurz D., Zink S.

Natural attenuation of a chromate contamination by Fe²⁺ bearing minerals and organic rich sediments in Rivera (Switzerland)

Buerge I. J., Buser H.-R., Kahle M., Müller M. D., Poiger T.

The artificial sweetener acesulfame as marker of domestic wastewater in groundwater

Auckenthaler A., Baenninger D., Affolter A., Zechner E., Huggenberger P.

Drinking water production close to contaminant sites

Stauffer F., Stoll S.

Modelling nitrate dynamics in the well catchment Baltenswil (Zurich, Switzerland)

Sinreich M.

Towards developing conceptual models for reactive contaminant transport in karst

**Ohne Gewähr / Ohne Anspruch auf Vollständigkeit
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Abstracts

Fachartikel Schweiz

1. Radon in Tessiner Wasserwerken – Messkampagne der SUVA

Der Kanton Tessin ist ein Gebiet mit hohem Radonpotenzial. Die Suva1 hat mit der SUPSI2 flächendeckende Radonmessungen in Tessiner Wasserwerken durchgeführt um zu überprüfen, ob der Grenzwert an den Arbeitsplätzen eingehalten wird. Zuerst wurden Radondosimeter an die Betreiber der Wasserwerke verteilt. Bei einer Konzentration höher als 3000 Bq/m³ wurde mit einem aktiven Messgerät vor Ort weiteruntersucht. Zudem wurde die Aufenthaltszeit des Personals in den betroffenen Räumen ermittelt. Die Untersuchungen ergaben Radonkonzentrationen in der Luft bis zu über 100 000 Bq/m³. Dank der kurzen Aufenthaltszeiten resultierte aber aus der Exposition keine Grenzwertüberschreitung für die Arbeitnehmenden. Gleichzeitige Wasseranalysen haben gezeigt, dass es keine klare Korrelation der Radonkonzentrationen im Wasser und in der Luft gab.

2. Typisierung von Grundwasserregimen in der Schweiz – Konzept und Fallbeispiele

Zeigen Grundwasserstände einen charakteristischen langjährigen mittleren Jahresgang, so lässt sich dieser durch ein Grundwasserregime beschreiben. In Anlehnung an die Regimedefinition des Abflusses von Fliessgewässern wird ein Konzept vorgestellt, anhand dessen sich das Schwankungsverhalten insbesondere von Grundwasserständen in Lockergesteins-Grundwasserleitern der Schweiz beschreiben und typisieren lässt. Drei Grundwasserregime – pluvial, pluvio-nival und nivo-glazial – können identifiziert werden. Des Weiteren wird zwischen einem standorttypischen und einem importierten Grundwasserregime unterschieden. Das Konzept wird anhand von Fallbeispielen erläutert.

3. Perfluorierte Chemikalien im Grundwasser – Grundlagen und Pilotstudie Schweiz

Perfluorierte Chemikalien (PFC) werden aufgrund ihrer chemischen Stabilität und ihrer wasser- und fettabweisenden Eigenschaften in verschiedenen industriellen Prozessen verwendet und sind Bestandteil zahlreicher Gebrauchsgegenstände. Persistenz und Mobilität mehrerer PFC haben zur weltweiten Verbreitung dieser Substanzen in der Umwelt geführt.

Das Auftreten von PFC im Grundwasser der Schweiz wurde im Rahmen einer Pilotstudie der Nationalen Grundwasserbeobachtung NAQUA analysiert. An 21 der 49 beprobten NAQUA-Messstellen wurden PFC im Grundwasser nachgewiesen. Die betroffenen Messstellen liegen in der Regel in der Nähe von Flüssen und werden zu einem beträchtlichen Anteil durch die Infiltration von Flusswasser gespiesen. Mit Ausnahme einer Messstelle lagen die PFC-Konzentrationen unter 100 ng/l, Konzentrationen, die nach gegenwärtigem Kenntnisstand die Nutzung des Grundwassers als Trinkwasserressource nicht in Frage stellen.

4. Hydrogéologie et glissement de terrain – Concept et assainissement

Le rôle important de l'eau dans les glissements de terrain est connu de longue date. Souvent, l'analyse se borne à lier mouvements et précipitations. Or, les glissements dépendent plutôt du comportement des eaux souterraines dans le versant et des interactions de celles-ci avec le sous-sol. Le présent article synthétise les moyens d'appréhender ces mécanismes, d'instrumenter le terrain et de modéliser les écoulements, afin de poser un pronostic d'évolution et de concevoir des actions de stabilisation. La compréhension du comportement hydrogéologique est une des clés de la prévention des dangers liés aux glissements de terrain.

5. Mikroorganismen im Grundwasser – Ein erster landesweiter Überblick

Die Nutzung der Ressource Grundwasser für die Trinkwasserversorgung erfordert Kenntnisse über deren mikrobiologischen Zustand. Untersuchungen an 50 Messstellen der Nationalen Grundwasser-beobachtung NAQUA erlauben einen ersten landesweiten Überblick zu Art und Auftreten von Mikro-organismen im Grundwasser der Schweiz. An einzelnen Messstellen wurden Bakterien, Viren und Protozoen festgestellt, allerdings ohne den Nachweis von Organismen mit infektiöser Wirkung. Art und Häufigkeit des Auftretens lassen sich mit dem Grundwasserleitertyp in Beziehung setzen, wobei Grundwasservorkommen in Lockergesteinen am wenigsten und Karst-Grundwasserleiter am meisten betroffen sind. Die Ergebnisse stellen eine Momentaufnahme des mikrobiologischen Zustands des Grundwassers an den beprobten Messstellen dar und erfassen dabei typische Situationen hinsichtlich Hydrogeologie und Bodennutzung sowie die wichtigsten Grundwasservorkommen des Landes.

6. Wasserisotope in der Schweiz – Neue Ergebnisse und Erfahrungen aus dem nationalen Messnetz ISOT

Wasserisotope übertragen Signale von klimatischen Veränderungen im Niederschlag flächendeckend auf Oberflächen- und Grundwasser. Das Isotopenmessnetz in der Schweiz (ISOT) sammelt diese Informationen für Praxis und Wissenschaft an repräsentativen Messstellen. Die stabilen Isotope dokumentieren vor allem die Herkunft der Niederschläge und die Änderung an ihren Quellen, den Temperaturanstieg, Verdunstungsprozesse und die verzögerte Abflussbildung durch Schneeschmelze. Als Referenzdatenset sind sie geeignet, die hydro-klimatischen Verhältnisse in den Einzugsgebieten der grossen Flüsse und deren Auswirkung auf Grundwassersysteme abzubilden.

7. Evolution de la qualité des eaux souterraines captées – Outils pour la prévision

L'évolution de la concentration en contaminant d'une eau souterraine dans un puits peut être déterminée par l'équation de la convolution intégrale. Cette équation se base sur deux paramètres: l'historique et la distribution spatiale des flux d'un contaminant entrant dans le bassin d'alimentation du captage et les temps de transit d'un contaminant dissout à travers la zone non saturée et saturée de l'aquifère. Dans le cadre d'un « projet Nitrates », l'évolution de la concentration en nitrates a été déterminée de cette manière au captage de l'aquifère de Wohlenschwil (AG). La distribution des temps de transit des contaminants est calculée en couplant les approches bilans hydrologiques, traçages artificiels et modèles analytiques.

8. Prospection d'eau souterraine par forage profond incliné à Miécourt (Canton du Jura, Suisse)

Une exploration des eaux souterraines profondes de la plaine au Sud-Est de l'Ajoie a été réalisée entre 2002 et 2009 dans la région de Miécourt (Canton du Jura). Après une première étape de prospection géophysique par sismique hybride, le projet s'est concrétisé par l'exécution, en 2008, d'un forage profond. Cet ouvrage, incliné de 35° par rapport à la verticale, a atteint une longueur forée de 565 m (450 m de profondeur verticale). Il a apporté de nouvelles connaissances sur le modèle hydrogéologique du secteur étudié et a mis en valeur le réservoir karstique contenu dans l'aquifère des calcaires du Malm. Le débit critique a atteint 300 l/min, alors que le débit artésien de l'ouvrage, de l'ordre de 100 l/min, a pu être suivi plusieurs mois après le chantier. Les analyses chimiques ont clairement démontré une signature chimique particulière des eaux pompées et leur qualité pour l'alimentation en eau potable, conséquence d'une excellente protection contre les influences anthropiques.

Fachartikel international

9. Adaptive groundwater management in urban areas: effect of surface water – groundwater interaction using the example of artificial groundwater recharge and in- and exfiltration of the river Birs (Switzerland)

Groundwater resources in urban areas are under increasing pressure. The purpose of this manuscript is to demonstrate how adaptive groundwater management techniques can establish conditions for sustainable use of groundwater resources. To illustrate this, a representative transient dataset from the Lower Birs Valley (Switzerland) was investigated. The main focus of this work was to evaluate effects of river-groundwater interaction and artificial groundwater recharge. Results showed that the evaluation of a hundred year flood significantly contributed to the understanding of the transient character of river-groundwater interaction. An extended period without artificial recharge in the study area provided insights into the impact of planned changes in groundwater management. This investigation contributes to the better understanding of recharge processes in the groundwater system and provides a framework for discussion of goals for regional management of urban water resources.

10. Hydraulic conductivity distribution in crystalline rocks, derived from inflows to tunnels and galleries in the Central Alps, Switzerland

Inflow data from 23 tunnels and galleries, 136 km in length and located in the Aar and Gotthard massifs of the Swiss Alps, have been analyzed with the objective (1) to understand the 3-dimensional spatial distribution of groundwater flow in crystalline basement rocks, (2) to assess the dependency of tunnel inflow rate on depth, tectonic overprint, and lithology, and (3) to derive the distribution of fracture transmissivity and effective hydraulic conductivity at the 100-m scale. Brittle tectonic overprint is shown to be the principal parameter regulating inflow rate and dominates over depth and lithology. The highest early time inflow rate is 1,300 l/s and has been reported from a shallow hydropower gallery intersecting a 200-m wide cataclastic fault zone. The derived lognormal transmissivity distribution is based on 1,361 tunnel intervals with a length of 100 m. Such interval transmissivities range between $10^{(-9)}$ and $10^{(-1)}$ m²/s within the first 200-400 m of depth and between $10^{(-9)}$ and $10^{(-4)}$ m²/s in the depth interval of 400-1,500 m below ground surface. Outside brittle fault zones, a trend of decreasing transmissivity/hydraulic conductivity with increasing depth is observed for some schistous and gneissic geological units, whereas no trend is identified for the granitic units.

11. Bayesian experimental design of tracer studies to monitor wastewater leakage from sewer networks

Despite more than a decade of research, the magnitude of wastewater leakage from defective sewer systems into groundwater supplies is still largely unknown, partly because reliable measurement methods are lacking. Although recently suggested in-sewer tracer studies present a promising solution, it is unclear how to optimally design such studies in network settings. In this study we present a formal experimental design procedure, which uses Bayesian data analysis to improve the diagnosis of sewer leakage by combining tracer test data with prior knowledge on network topology and condition. From a simulation study, we show that (1) if a single sewer section is expected to have high leakage, that section should be distinguished in measurement layouts through isolated tests or appropriate overlapping of multiple tests; (2) if multiple sections are expected to have high leakage, layouts with tests that cover more than one high-leakage section should be avoided; and (3) if a robust experimental design is desired, a balanced layout of tests that overlap multiple sections of high leakage, yet minimizes stretch length, should be chosen. This design will have the additional benefit of inducing covariance in the posterior distribution of exfiltration estimates, which can be used to advantage in subsequent studies. We apply these guidelines to a case study of a catchment in Zurich, Switzerland, and find that optimal layout design can improve the anticipated gain of information substantially relative to designs based on practical considerations alone. Remaining concerns regarding the procedure include (1) the generally poor understanding of the mechanisms governing sewer leakage, which can hamper reliable prior information on exfiltration; (2) the currently low measurement precision of sewer tracer studies, which might only allow for the detection of large leaks; and (3) the need for numerical implementation of the Bayesian inference procedure, which requires careful tuning and long

computation times. In general, we were able to demonstrate that the incorporation of prior information through a Bayesian procedure adds significant value to experimental design, especially in situations with few "hard" data but good site-specific knowledge, which is common in water resources research.

12. Characterisation of virus transport and attenuation in epikarst using short pulse and prolonged injection multi-tracer testing

Attenuation processes controlling virus fate and transport in the vadose zone of karstified systems can strongly influence groundwater quality. This research compares the breakthrough of two bacteriophage tracers (H40/1 and T7), with contrasting properties, at subsurface monitoring points following application onto an overlying composite sequence of thin organic soil and weathered limestone (epikarst). Short pulse multi-tracer test results revealed that T7 (Source concentration, $C_0 = 1.8 \times 10^6$ pfu/mL) and H40/1 ($C_0 = 5.9 \times 10^6$ pfu/mL) could reach sampling points 10 m below ground less than 30 min after tracer application. Contrasting deposition rates, determined from simulated tracer responses, reflected the potential of the ground to differentially attenuate viruses. Prolonged application of both T7 ($C_0 = 2.3 \times 10^4$ pfu/mL) and H40/1 ($C_0 = 1.3 \times 10^5$ pfu/mL) over a five hour period during a subsequent test, in which ionic strength levels observed at monitoring points rose consistently, corresponded to a rapid rise in T7 levels, followed by a gradual decline before the end of tracer injection; this reflected reaction-limited deposition in the system. T7's response contrasted with that of H40/1, whose concentration remained constant over a three hour period before declining dramatically prior to the end of tracer injection. Subsequent application of lower ionic strength tracer-free flush water generated a rapid rise in H40/1 levels and a more gradual release of T7. Results highlight the benefits of employing prolonged injection multi-tracer tests for identifying processes not apparent from conventional short pulse tests. Study findings demonstrate that despite rapid transport rates, the epikarst is capable of physicochemical filtration of viruses and their remobilization, depending on virus type and hydrochemical conditions.

13. Real-Time Management of an Urban Groundwater Well Field Threatened by Pollution

We present an optimal real-time control approach for the management of drinking water well fields. The methodology is applied to the Hardhof field in the city of Zurich, Switzerland, which is threatened by diffuse pollution. The risk of attracting pollutants is higher if the pumping rate is increased and can be reduced by increasing artificial recharge (AR) or by adaptive allocation of the AR. The method was first tested in offline simulations with a three-dimensional finite element variably saturated subsurface flow model for the period January 2004-August 2005. The simulations revealed that (1) optimal control results were more effective than the historical control results and (2) the spatial distribution of AR should be different from the historical one. Next, the methodology was extended to a real-time control method based on the Ensemble Kalman Filter method, using 87 online groundwater head measurements, and tested at the site. The real-time control of the well field resulted in a decrease of the electrical conductivity of the water at critical measurement points which indicates a reduced inflow of water originating from contaminated sites. It can be concluded that the simulation and the application confirm the feasibility of the real-time control concept.

14. Long-Term and Long-Range migration of radioactive fallout in a Karst system

Mountainous areas are often covered by little evolved soils from which deposited radionuclides can potentially leak into the vadose zone. In the Swiss Jura mountains, we observed unusual isotopic ratios of nuclear weapon test (NWTs) fallout with an apparent loss of NWTs plutonium relative to Cs-137 of Chernobyl origin in thinner soils. Here, we studied the karstic watershed of a vauculian spring to determine the residence times of plutonium, Am-241, and Sr-90 deposited by global fallout and their respective mobility in carbonaceous soils. The results show that Sr-90 is washed most efficiently from the watershed with a residence time of several hundred years. The estimated plutonium residence time is more than 10 times higher (in the range of 5000-10 000 years), and the Am-241 residence time is double that of plutonium. The spring water Am-241/Pu239+240 isotopic ratio is lower (0.12-0.28) than found in watershed soils (0.382 +/- 0.077). Similar differences are found in aquatic mosses (Am-241/Pu239+240 isotopic ratio 0.05-0.12), which are permanently submerged in spring waters. In contrast to plutonium, Sr-90 is leached from these mosses with 0.5 M HCl, demonstrating that strontium is probably associated with calcium carbonate precipitations on the mosses. The higher plutonium to americium isotopic ratio found in the samples of spring

water and mosses at the outlet of the karst shows that plutonium mobility is enhanced.

15. Technological advances and applications of geothermal energy pile foundations and their feasibility in Australia

Geothermal energy pile foundations are an alternative energy source for heating and cooling needs. Utilising this source of energy has great potential due to the environmental, economic and social benefits. This paper looks at an extensive amount of literature on the technology behind the system including the overall process, primary considerations for each of the main components including latest developments as well as design implications such as the integration of ground energy systems into structural piles of buildings. Environmental considerations including performance-dependent parameters of the subsurface are described. Main parameters include thermal conductivity, thermal diffusivity, specific heat capacity and moisture content. Temperature and groundwater effects are also discussed and design considerations are provided. Mathematical models are available to aid in the design of these systems but there are various other issues and complex parameters that need to be considered qualitatively. Furthermore, the design of these systems is governed by various standards and government legislation. Case studies are presented to show the application of these systems in practise including assessments of system performance. Examples originate from countries such as Austria, Switzerland, Germany, UK, USA, Japan, Iran, Sweden and Norway. Benefits and limitations of implementing these systems are summarised and finally, the feasibility of geothermal energy pile foundations in Australia is explored. This paper found that these systems, although exhibiting some limitations and possible challenges, are a viable option in terms of an alternative energy source.

16. Karst pools in subsurface environments: collectors of microbial diversity or temporary residence between habitat types

We studied bacterial diversity and community composition in three shallow pools of a Swiss karst cave system with contrasting hydrological and hydrochemical properties. The microbial assemblages in the pools were remarkably different, and only one operational taxonomic unit of 16S rRNA genes (OTU, 97% similarity) was shared between the three of them (total OTU number in all pools: 150). Unexpectedly high microbial phylotype richness was found even in the two pools without groundwater contact and with low concentrations of organic carbon and total cell numbers ($< 10^4$ ml⁻¹). One of these seepage water fed systems harboured 15 distinct OTUs from several deeply branching lineages of the candidate phylum OP3, whereas representatives of this group were not detected in the other two pools. A tentative phylogeographic analysis of available OP3-related sequences in the context of our data set revealed that there was generally little agreement between the habitats of origin of closely related sequence types. Two bacterial clades affiliated with the obligate methylamine utilizer *Methylotenera mobilis* were only found in the pool that was exposed to repeated flooding events. These bacteria formed relatively stable populations of up to 6% of total cell counts over periods of several months irrespective of inundation by groundwater. This suggests that karst water may provide a means of transport for these bacteria from terrestrial to freshwater habitats.

17. Subsurface exploration and transient pressure testing from a deep tunnel in fractured and karstified limestones (Lotschberg Base Tunnel, Switzerland)

This paper summarizes the results from a subsurface exploration campaign carried out in fractured and karstified limestones and marls of the Lotschberg Base Tunnel in the Swiss Alps. The exploration program in the 3.2 km long Doldenhorn Section consisted of 50 cored and 13 destructive horizontal predrillings of 250-300 m length each (in total 14,853 m of predrillings). These boreholes were used to locate possible tunnel in flows and characterize their hydraulic properties. A new efficient hydrogeological test protocol has been developed and was systematically and successfully applied. The test protocol consists of short constant rate out flow and recovery tests in open boreholes. The onsite test analysis allowed reliable predictions of the hydrogeological conditions ahead of the advancing tunnel face in brief period of time, leading to decisions regarding further reconnaissance drillings, tunnel driving or sealing measures. Detailed analysis of the transient pressure responses of the hydrogeological tests carried out after tunnel completion led to important new findings regarding flow model identification (type and orientation of conductive fractures), aquifer parameters and boundary effects. Even though the hydrogeological tests had to be carried out within a short time frame (a few hours) they allowed characterization of

large scale aquifer properties relevant for long term tunnel inflow behavior.

18. New insights into the transport of sediments and microorganisms in karst groundwater by continuous monitoring of particle-size distribution

Mobile particles play crucial roles for contaminant transport in karst aquifers, but few studies have investigated the relationships between sediment dynamics and contaminants. This is partly due to the difficulty in monitoring suspended particles: Turbidity is easy to measure but does not deliver detailed information on the size and type of particles; mineralogical laboratory analyses are laborious and not suitable for continuous monitoring. A portable particle counter was used for the study presented here. The instrument delivers time-series of particle-size distribution (PSD), i.e. the number and diameter of suspended particles, grouped into different size-classes ranging from 0.9 to 139 μm . The test site is a karst system near the city of Yverdon-les-Bains, Switzerland. A swallow hole draining agricultural land is connected to two karst springs, 4.8 and 6.3 km away, which are occasionally contaminated by faecal bacteria at highly variable levels. Turbidity alone turned out not to be a reliable indicator for microbial contamination. To obtain more insight into bacteria and particle transport towards the springs, a comprehensive research program was carried out, including tracer tests and monitoring of PSD, turbidity, total organic carbon (TOC), faecal bacteria (*E. coli*) and various hydrologic and physicochemical parameters. Results show that there are two types of turbidity: A primary turbidity signal occurs shortly after rainfall during the rising limb of the hydrograph; a secondary signal typically occurs during spring flow recession. The first signal is explained by remobilization of conduit sediments due to a hydraulic pressure pulse (autochthonous or pulse-through turbidity). The second peak indicates the arrival of water from the swallow hole, often together with TOC and faecal bacteria (allochthonous or flow-through turbidity). PSD analyses revealed that autochthonous turbidity is composed of a broad mixture of fine and large particles, while allochthonous turbidity predominantly consists of very fine particles. This is explained by sedimentation of larger particles between the swallow hole and the springs. During allochthonous turbidity periods, very good correlation between the finest particles (0.9-1.5 μm) and *E. coli* was found ($R^2 = 0.93$). The relative increase of fine particles can consequently be used as an "early-warning parameter" for microbial contamination of karst spring water. Further applicability and limitations of this approach are also discussed.

19. Geometry and drainage of a retreating glacier overlying and recharging a karst aquifer, Tsanfleuron-Sanetsch, Swiss Alps

Alpine glaciers store large amounts of freshwater contributing to groundwater recharge during warmer periods, but the interactions between glaciers and aquifers have rarely been investigated in detail. The Tsanfleuron-Sanetsch area, Switzerland, is an ideal test site to study glacier-aquifer interactions. It consists of a rapidly retreating glacier (2.8 km^2) overlying a karst aquifer drained by a spring (mean discharge 600-700 L/s) used for drinking water supply and irrigation. The geometry and structure of the glacier were assessed by means of geophysical surveys, using radiomagnetotellurics (RMT). The estimated ice volume is $1.0 \times 10^8 \text{ m}^3$ ($0.92 \times 10^8 \text{ m}^3$ water equivalent), but the glacier currently loses 1.5 m ice thickness per year. Field observations, flow measurements and tracer tests allowed characterisation of glacier drainage and aquifer recharge. Three recharge pathways have been identified: 1) The main glacial stream sinks into the aquifer via swallow holes 3 km downstream of the glacier mouth; 2) Numerous small meltwater streams sink underground shortly below the glacier front; 3) Subglacial meltwaters and supraglacial streams sink into the glacier via moulins and contribute to aquifer recharge through fractures and swallow holes underneath the glacier. Recharge and spring discharge display strong diurnal and seasonal variability, with a general high-flow period during snow and glacier melt from spring to autumn. Preliminary predictions of the future availability of spring water after disappearance of the glacier suggest that the discharge may decrease by 20-30%. Nearly all of this loss will occur in summer and autumn, presumably resulting in temporary water shortage.