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

Literaturzusammenstellung – Jahrgang 2016

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

Compilation de littérature pour l'année 2016

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Water Resources Research, 52/4, pp. 2647-2658

Übersichtspublikationen / Publications synoptiques

Der Schweizerische Bundesrat / Le Conseil fédéral suisse / Il Consiglio federale svizzero / The Swiss Federal Council

**Gewässerschutzverordnung (GSchV)
Ordonnance sur la protection des eaux (OEaux)
Ordinanza sulla protezione delle acque (OPAc)
Waters Protection Ordinance (WPO) [41]**

vom 28. Oktober 1998, Stand am **02. Februar 2016**

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV / Ufficio federale dell'ambiente UFAM / Federal Office for the Environment FOEN

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map.geo.admin.ch: [Hydrogeologische Karte der Schweiz 1:100000](#)

Schweizerisches Institut für Speläologie und Karstforschung SSKA / Institut Suisse de Spéléologie et de Karstologie ISSKA

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV / Ufficio federale dell'ambiente UFAM / Federal Office for the Environment FOEN

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Hydrological Yearbook of Switzerland 2015 [50]**

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Investigating sedimentation processes in the karstic system of Milandre (Jura, Switzerland) [94]

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BAFU – OFEV / 30.01.2017

Abstracts

Fachartikel national / Articles spécialisés nationaux

1. Behagliche Wärme aus 500 Metern Tiefe

In städtischen Gebieten mit dichter Bebauung stösst die Gewinnung von Erdwärme für Heizung und Warmwasser mitunter an Grenzen. Denn hier ist der Platz für die Verlegung von Erdwärmesonden knapp. Die Industriellen Werke der Stadt Lausanne beschreiten einen neuen Weg: Sie setzen weniger Sonden ein, verlegen sie aber tiefer.

2. Wasserqualität - Wissens-Plattform des VSA

Die Erfassung der Wasserqualität stellt, insbesondere im Bereich Mikroverunreinigungen in den Schweizer Fliessgewässern, eine grosse Herausforderung dar. Um diese zu meistern, ist ein verstärkter Wissens- und Erfahrungsaustausch zwischen Forschung, Behörden und Privatunternehmen nötig. Zu diesem Zweck gründeten Eawag, BAFU und VSA die Plattform «Wasserqualität».

3. Online-Durchflusszytometrie in der Praxis – Fenster in die Welt mikrobiologischer Dynamiken in Wasser - von der Quelle bis zum Wasserhan

Der Einsatz der Online-Durchflusszytometrie eröffnet neue spannende Einblicke in mikrobiologische Dynamiken auf kurzen Zeitskalen in natürlichen sowie technischen Wassersystemen. In Trinkwassersystemen treten solche Dynamiken sowohl im Rohwasser als auch am Wasserhahn auf. Das mit solchen neuen Methoden generierte Wissen über kurzzeitige Schwankungen der mikrobiologischen Wasserqualität eröffnet eine neue Dimension im gezielten Management von Wasserressourcen.

4. Mikroplastik in Abwasser u. Gewässern

Das Amt für Abfall, Wasser, Energie und Luft des Kantons Zürich (AWEL) hat erstmals die Abflüsse von Abwasserreinigungsanlagen (ARA), Oberflächengewässer sowie Grund- und Trinkwasser im Kanton Zürich auf Mikroplastik untersucht. Auf ARA werden durch die biologische Reinigung, Nachklärung und Filtration über 90% des Mikroplastiks aus dem Abwasser entfernt. Trotzdem tragen Zürcher ARA pro Tag insgesamt 30 Milliarden Teilchen Mikroplastik, umgerechnet 600 Gramm, in das Gewässersystem ein. Mikroplastik konnte in Oberflächengewässern, jedoch nicht im Grund- und Trinkwasser nachgewiesen werden.

5. Chronik der Basler Trinkwasserproduktion – Von der ersten Haus-Wasserversorgung zur künstlichen Grundwasseranreicherung

Vor 150 Jahren begann in Basel eine neue Ära: Die «neuzeitliche Haus-Wasserversorgung» wurde in Betrieb genommen. Von dort bis zum heutigen System der künstlichen Grundwasseranreicherung mit filtriertem Rheinwasser in den Langen Erlen war es jedoch ein weiter Weg. Einerseits galt es, nachhaltige Lösungen für die ständig wiederkehrende Wassernot in Basel zu finden, und andererseits war dem bis in die 1970er-Jahre steigenden Wasserbedarf mit Kapazitätserweiterungen beizukommen.

6. WVRB AG – Ein Erfolgsmodell

2007 konnten mit der organisatorischen und materiellen Zuweisung der Aufgabenbereiche Primär- und Sekundärversorger die Gemeinden im Grossraum Bern die jahrelangen Diskussionen über die Nutzung gemeinsamer und eigener Wassergewinnungsanlagen beenden. Zehn Jahre nach der Umstrukturierung fällt die Erfolgskontrolle durchwegs positiv aus. Die finanziellen und versorgungstechnischen Ziele wurden schneller als erwartet erreicht, auch haben sich weitere Gemeinden dem Verbund angeschlossen.

7. Grundwasserregime an Quellen – Typisierung für die Schweiz

Die für Grundwasserstände in Lockergesteins-Grundwasserleitern identifizierten Grundwasserregime (pluvial, pluvio-nival und nivo-glazial) lassen sich auch an Quellen oberflächennaher Locker- und Festgesteine erkennen. Grundwasserregime beschreiben einen charakteristischen Jahresgang, der sich für den Quellabfluss durch den mittleren Verlauf des Pardé-Koeffizienten über die einzelnen Monate ausdrücken lässt. Die Grundwasserregime können an Quellen nach ihrer Variabilität anhand des langjährigen Schwankungsbereichs des Pardé-Koeffizienten weiter differenziert werden.

8. Grundwasserqualität in Pumpwerken – Entwicklung nach Umsetzung von Massnahmen in der Landwirtschaft - am Beispiel von Nitrat

Gebiete der Grundwasserneubildung werden oft landwirtschaftlich genutzt. Entsprechend häufig treten dort Nitratkonzentrationen sowie Metaboliten von Pflanzenschutzmitteln auf. Wie rasch sich die Grundwasserqualität nach Umsetzung von Massnahmen in der Landwirtschaft verbessert, und welches Konzentrationsniveau erreicht werden kann, ist abhängig von diversen Faktoren. Die wichtigsten werden in diesem Artikel diskutiert. Auch wird darauf eingegangen, welche Lehren aus Nitratprojekten für andere Stoffe aus diffusen Quellen, insbesondere für Metaboliten von Pflanzenschutzmitteln, gezogen werden können.

9. Schadstoffbelastungen – Gefährdungen des Grundwassers

Die Schweiz ist das Wasserschloss Europas, und die Trinkwasserqualität ist allgemein sehr gut. Zudem können wir, gerade was die Wasserqualität von Flüssen und Seen betrifft, auf bemerkenswerte ökologische Fortschritte blicken. Vor 40 Jahren wollte und konnte niemand ohne Gesundheitsgefährdung im Rhein baden. Heute ist das wieder möglich. Allerdings gibt es auf den zweiten Blick etliche Befunde von Grundwasseruntersuchungen, die aufhorchen lassen. Der folgende Beitrag gibt einen wissenschaftlichen Überblick.

10. GeoQuat: Developing a system for sustainable management, 3D modelling and application of Quaternary deposit data

A large part of the shallow subsurface in Switzerland consists of Quaternary deposits. About 90% of the underground uses take place in the mainly unconsolidated rock layers. These sediments accommodate more than half of Switzerland's drinking water resources and they represent significant deposits of raw materials (gravels and sands). Furthermore, they are a source for shallow geothermal energy production and a significant part of housing and transport infrastructure takes place on and inside these geological bodies.

Due to the increased demand on these deposits, use conflicts in the shallow subsurface are unavoidable. To plan and coordinate the different uses in these rock layers, knowledge about their composition and spatial distribution is essential.

In Switzerland, numerous projects and studies have been conducted in the shallow subsurface over the last 100 years by private companies, municipalities, cantons, universities and by the confederation. By this, a huge amount of Quaternary deposit data has been generated. To date, guidelines and procedures for storing and managing geological data are missing for the shallow subsurface. In addition, currently no central data storage is available, that can manage the variety of existing document and data types in a uniform structure. Thus, at present existing data is difficult to compare and its use for efficient spatial data modelling is limited.

These challenges are tackled in the framework of the GeoQuat project conducted by the Federal Office of Topography swisstopo in cooperation with the Federal Office for the Environment FOEN and the Federal Office of Energy SFOE. Several cantons, private companies and universities are supporting GeoQuat by providing access to their Quaternary deposit data and/or by sharing their knowledge. The project lasts three years and should be completed by the end of 2017.

11. Stärken und Schwächen von Grundwassermodellen, anhand eines Fallbeispiels im Berner Seeland

Grundwassermodellrechnungen werden heute meist unter Zeitdruck und mit stark gekürztem Budget durchgeführt. Zur Auswahl stehen analytische und numerische Modelliermethoden. Analytische Modelle basieren dabei auf sehr vereinfachten Annahmen, welche einem kompliziert aufgebauten Grundwasserleiter nur näherungsweise gerecht werden. Numerische Modelle können komplexe

Verhältnisse theoretisch problemlos abbilden. Allerdings wird oft sowohl bei der Datenerhebung wie auch bei der Verfeinerung des Modells und der Anzahl an Rechendurchläufen gespart. In der Folge wird mit falschen Randbedingungen und zu groben Modellen gerechnet, was zu fragwürdigen Resultaten und Fehlinterpretationen führen kann. Die Ergebnisse fließen dann z. B. in Schutzzonenauscheidungen oder in Grundwassersanierungsprojekte ein, was zu falsch platzierten Filterbrunnen, abgelehnten Bauvorhaben etc. führen kann.

Korrekt angewendet und kalibriert können Grundwassermodelle interessante Einsichten in die Funktionsweise von Grundwasserleitern bringen. Sie erlauben z. B., künftige Vorhaben zu testen und Prognosen über daraus resultierende Veränderungen zu erstellen.

Der Artikel vergleicht anhand des Seelandgrundwasserleiters zwischen Kerzers im Südwesten und dem Nidau-Büren-Kanal im Nordosten verschiedene Berechnungsmodelle. Geprüft wird die Tauglichkeit der Modelle zur Prognose der Grundwasserneubildung aus Niederschlag und Infiltration von Aarewasser und damit zur Prognose des Aarewasseranteils in Filterbrunnen.

12. Nutzung und Schutz von Tiefengrundwasser im Spannungsfeld von Chancen, Risiken, Konflikten und regulatorischen Anforderungen

Die Schweiz besitzt ausgedehnte Tiefengrundwässer, welche sich in ihrem Chemismus regional stark unterscheiden und die bisher nur punktuell untersucht wurden. Jedes Tiefengrundwasser hat bezüglich Ausdehnung, Temperatur, Chemismus, Erneuerungsrate und Zirkulation (Fließverhalten) seine eigene Charakteristik. Diese Parameter entscheiden auch über die Nutzbarkeit. Eine nachhaltige Nutzung von Tiefengrundwässern nimmt Rücksicht auf deren meistens geringe Erneuerungsraten und setzt hydrogeologische Untersuchungen voraus.

Die bisher bekannten Tiefengrundwässer der Schweiz besitzen im obersten Kilometer nicht selten Trinkwasser-Qualität. Hauptnutzer sind die Mineralwasser-Industrie und die Thermalbäder. Künftig könnten weitere Nutzungen hinzukommen, insbesondere die hydrothermale Tiefengeothermie und die Landwirtschaft (saisonale Bewässerung in Trockenperioden). Ein erhöhter Nutzungsdruck sowie Bauvorhaben im tiefen Untergrund oder die Einlagerung von CO₂ in die Tiefengrundwässer können zu Nutzungskonflikten führen. Die Nutzung der Tiefengrundwässer erfolgt heute weitgehend unkoordiniert. Dies führt dazu, dass qualitativ hochwertige Grundwässer auch für Zwecke genutzt und „verbraucht“ werden können, für welche auch minderwertige Wässer genügen würden. Die koordinierte und planbare Nutzung der unterschiedlichen Tiefengrundwässer setzt grundlegende Ressourcen-Kenntnisse voraus, welche in den meisten Regionen der Schweiz noch nicht vorhanden sind. Eine regionale, wertebasierte Nutzungs-Priorisierung kann Nutzungskonflikte entschärfen, dazu müsste jedoch der gesetzgeberische Rahmen aktualisiert werden.

13. Schiefergasgewinnung durch Fracking – Plädoyer für eine ehrliche Debatte

Aus dem Grundwasser entweichendes Methan, Bohrplätze im Abstand von wenigen hundert Metern, Lastwagenkolonnen durch Kleinstädte im Stundenrhythmus, Konkurrenz um knappe Wasserressourcen auf dem Lande, von brennenden Gasfackeln erleuchtete Nachthimmel. Dies sind nur einige der Horrorszenerarien, die der Fracking-Technologie in Deutschland zugeschrieben werden und ihr das Attribut ‚umstritten‘ angeheftet haben. Nicht wenige Menschen glauben solchen Darstellungen oder sind zumindest verunsichert. Wer will es ihnen verdenken, da Medien alarmierende Berichte wirksamer verbreiten als nüchterne Sachinformationen. Unser Nachrichtenkonsumverhalten ist dadurch gekennzeichnet, dass wir aus der Fülle des Informationsangebotes oft das Aufregende und Kontroverse herausfiltern. Im Falle des Themas Fracking macht jedoch auch nachdenklich, dass viele Handelnde von Bürgerinitiativen, NGOs, Journalisten bis zu Entscheidungsträgern innerhalb weniger Jahre in Sachdebatten um Hydraulic Fracturing zu ‚Experten‘ geworden sind, ohne selbst elementare Grundkenntnisse in Hydrogeologie oder Gesteinsphysik zu besitzen.

14. Geothermienutzung mit Folgen

Im Rahmen einer Erdwärmesonden-Bohrung in Mumpf wurde 2009 ein Arteser angebohrt. Das artesisch gespannte, hochmineralisierte Tiefenwasser konnte aufgrund unzureichender Verschlussmassnahmen in die Niederterrassenschotter abfließen. Nach einem erneuten Verschluss der Bohrung wurde an zwei Stellen in Mumpf weiterhin ein Einfluss von Tiefenwasser festgestellt. Zur Klärung der Herkunft dieses Wassers wurden Geoelektrik- und Bodengasmessungen durchgeführt. Sie zeigen, dass Tiefenwasser entlang eines lokalen geologischen Störungssystems aufsteigt.

15. Effect of cave ventilation on karst water chemographs

The data briefly presented in this paper indicate that the degree of ventilation of underground flow paths, inducing more or less degassing of the CO₂ dissolved in water, can induce a significant variation in the water mineralization of a karst spring. The presented data also provides indications about further conditions controlling time variations of carbonate dissolution parameters: 1) variations in the mixing ratio of two or several waters (from distinct subcatchment areas) with distinct chemistry; 2) land-use with distinct soils (i.e. pCO₂) in the catchment area, which is also often related to the elevation of the various parts of the catchment area; 3) Localized and quick infiltration vs diffuse and slow infiltration through soils. It must be mentioned here that both concentrations and fluxes of CO₂ within all parts of karst systems must be considered in order to understand water chemographs. Both are mainly controlled by soil CO₂ production and by water-recharge flux. Further models and dedicated field data are required to better quantify CO₂ concentration and fluxes in karst systems.

16. Integrative passive samplers to detect chlorinated hydrocarbons contamination in karst

A large number of former industrial sites and landfills are responsible for aquifer contamination with chlorinated solvents in Switzerland. 16.7 % of them are located in karstic areas. But, the detection of such contaminations in springs or boreholes can be difficult because concentrations are often varying highly and rapidly. Measuring low concentrations during a few measurement campaigns is not sufficient to prove the absence of contamination. To overcome this difficulty, the performances of integrative passive samplers were investigated in the frame-work of the Chlorokarst project funded by the Swiss federal office for the environment. Three types of devices were tested. They allow measuring time weighted-average concentrations of pollutants over long periods. Experiments in karst springs show that the Sorbicell samplers developed by the Sorbisense company were capable of measuring average concentrations over a 2 months- period, matching the averages of the concentrations measured in daily snapshot samples collected with an automatic sampler taken as reference. Equipment of the springs with the Sorbicell devices was found to be easy. More difficulties were encountered when exposing the Sorbicell samplers in piezometers, because of the impact of the high fluctuations of the water column above the sampler on the filling rate. Adaptation of the device was thus carried out with the manufacturer, to reduce the effect of the water column, using air-vents and cartridges of high resistance. Satisfactory results were then obtained in terms of sampling rate. Uncertainty still remains on the estimated concentrations provided by the system since they can vary by a factor of two depending on how the volume of water that passed through the cartridge is estimated. Two other types of passive samplers were tested, the ceramic dosimeters developed at the Uni-versity of Tübingen and commercialized by IMW, and the Tips developed by the AGI company. They were both found to be inappropriate to estimate reasonably well the mean concentrations in chlorinated solvents in these types of environment, even if they can still be used to detect the presence of contamination.

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

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

ecosystem properties vary substantially among headwater streams likely in relation to annual/daily changes in flow and water source. Such headwaters may contribute strongly to the production, processing and transport of organic matter to downstream waters, especially in light of the expected increase in intermittent streams in alpine catchments experiencing rapid glacial recession.

18. Deep microbial life in high-quality granitic groundwater from geochemically and geographically distinct underground boreholes

Deep granitic aquifer is one of the largest, but least understood, microbial habitats. To avoid contamination from the surface biosphere, underground drilling was conducted for 300m deep granitic rocks at the Mizunami underground research laboratory (URL), Japan. Slightly alkaline groundwater was characterized by low concentrations of dissolved organic matter and sulfate and the presence of >100nM H-2. The initial biomass was the highest (approximate to 10^5 cells ml⁻¹) with the dominance of *Hydrogenophaga* spp., whereas the phylum *Nitrospirae* became predominant after 3 years with decreasing biomass (approximate to 10^4 cells ml⁻¹). One week incubation of groundwater microbes after 3 years with C-13-labelled bicarbonate and 1% H-2 and subsequent single-cell imaging with nanometer-scale secondary ion mass spectrometry demonstrated that microbial cells were metabolically active. Pyrosequencing of microbial communities in groundwater retrieved at 3-4 years after drilling at the Mizunami URL and at 14 and 25 years after the drilling at the Grimsel Test Site, Switzerland, revealed the occurrence of common *Nitrospirae* lineages at the geographically distinct sites. As the close relatives of the *Nitrospirae* lineages were exclusively detected from deep groundwaters and terrestrial hot springs, it suggests that these bacteria are indigenous and potentially adapted to the deep terrestrial subsurface.

19. Occurrence of the herbicide glyphosate and its metabolite AMPA in surface waters in Switzerland determined with on-line solid phase extraction LC-MS/MS

Glyphosate is currently one of the most important herbicides worldwide. Its unique properties provide for a wide range of uses in agriculture but also in non-agricultural areas. At the same time, its zwitterionic nature prevents the inclusion in multi-residue analytical methods for environmental monitoring. Consequently, despite its extensive use, data on occurrence of glyphosate in the aquatic environment is still scarce. Based on existing methods, we developed a simplified procedure for the determination of glyphosate and its main metabolite aminomethylphosphonic acid (AMPA) in water samples using derivatization with fluorenylmethyl chloroformate FMOCCl, combined with on-line solid phase extraction and liquid chromatography-tandem mass spectrometry (LC-MS/MS) detection. This method was extensively tested on over 1000 samples of surface water, groundwater, and treated wastewater and proved to be simple, sensitive, and reliable. Limits of quantification of 0.005 µg/L were routinely achieved. Glyphosate and AMPA were detected in the vast majority of stream water samples in the area of Zurich, Switzerland, with median concentrations of 0.11 and 0.20 µg/L and 95th percentile concentrations of 2.1 and 2.6 µg/L, respectively. Stream water data and data from treated wastewater indicated that non-agricultural uses may significantly contribute to the overall loads of glyphosate and AMPA in surface waters. In the investigated groundwater samples, selected specifically because they had shown presence of other herbicides in previous monitoring programs, glyphosate and AMPA were generally not detected, except for two monitoring sites in Karst aquifers, indicating that these compounds show much less tendency for leaching.

20. Sediment mobilization deposits from episodic subsurface fluid flow – A new tool to reveal long-term earthquake records?

Subsurface fluid flow can be affected by earthquakes; increased spring activity, mud volcano eruptions, groundwater fluctuations, changes in geyser frequency, and other forms of altered subsurface fluid flow have been documented during, after, or even prior to seismic shaking. Recently discovered giant pockmarks on the bottom of Lake Neuchatel, Switzerland, are the lake-floor expression of subsurface fluid flow. They discharge groundwater from the Jura Mountains karstic aquifers and experience episodically increased subsurface fluid flow documented by subsurface sediment mobilization deposits at the levees of the pockmarks. In this study, we present the spatio-temporal distribution of event deposits from these phases of sediment expulsion and of multiple time-correlative mass-transport deposits. We report five striking instances of concurrent multiple subsurface sediment deposits and multiple mass-transport deposits since late glacial times, for which we propose past earthquakes as a trigger. Comparison of this new event catalogue with historic earthquakes and other independent paleoseismic records suggests that initiation of sediment expulsion requires a minimum macroseismic intensity of VII. Thus, our study presents for the first time sedimentary deposits resulting from increased subsurface fluid flow as a paleoseismic proxy.

21. Streamflow sensitivity to water storage changes across Europe

Terrestrial water storage is the primary source of river flow. We introduce storage sensitivity of streamflow (E-S), which for a given flow rate indicates the relative change in streamflow per change in catchment water storage. E-S can be directly derived from streamflow observations. Analysis of 725 catchments in Europe reveals that E-S is high in, e.g., parts of Spain, England, Germany, and Denmark, whereas flow regimes in parts of the Alps are more resilient (that is, less sensitive) to storage changes. A regional comparison of E-S with observations indicates that E-S is significantly correlated with variability of low ($R^2=0.41$), median ($R^2=0.27$), and high flow conditions ($R^2=0.35$). Streamflow sensitivity provides new guidance for a changing hydrosphere where groundwater abstraction and climatic changes are altering water storage and flow regimes.

22. Extracting past atmospheric warming and urban heating effects from borehole temperature profiles

Borehole temperature logs in urban areas often show deviation from the regional geothermal gradient that increases towards the land surface in the top 100 m. This deviation is the sum of two effects: atmospheric global warming and urban heating. To invert the temperature profiles (T-logs), a novel analytical model is presented to distinguish effects of global warming and of urban structures on the ground thermal regime. The inversion is demonstrated on four characteristic T-logs measured in the city and suburbs of Zurich, Switzerland. The logging was performed in borehole heat exchanger U-tubes by an innovative, wireless measuring technique. Detailed information on past climatic and land use changes enabled the focus on two main urban heat sources, buildings and asphalt. For three of the locations, the T logs could be reproduced with a plausible heating of the asphalt by 3-3.5 degrees C, and an average temperature of 15-16 degrees C below the basement of buildings. However, the other location within the highly urbanized area, is influenced by additional heat sources. In most of the cases, the increased subsurface temperatures and the associated stored additional geothermal energy, mainly originate from urban structures, while climate change is secondary.

23. Neue Norm zur thermischen Nutzung des Grundwassers in der Schweiz

Die Nutzung von Grundwasser zum Heizen und Kühlen ist nach den Erdwärmesonden die zweithäufigste Anwendung oberflächennaher oder untiefer Geothermie. Anders als bei den Erdwärmesonden haben die Änderung der Grundwassertemperatur und der Förderbetrieb relativ weiträumige Auswirkungen, welche oft weit über die Grundstücksgrenzen hinausreichen. Die begrenzten Ressourcen einerseits und der berechnete Schutz des Grundwassers andererseits macht die Normierung seiner Nutzung erforderlich.

Der Schweizerische Ingenieur- und Architektenverein SIA hat nach der Norm 384/6 „Erdwärmesonden“ aus dem Jahr 2010 im April 2015 die Norm 384/7 „Grundwasserwärmenutzung“ publiziert. Die Autoren – die Sachbearbeiter und der Vorsitzende der Kommission der vorliegenden Norm – behandeln in diesem Beitrag die spezifischen Anforderungen, die sich aus der Interdisziplinarität und den unterschiedlichen Ansprüchen der Beteiligten ergeben. Sie zeigen auf, wie die verschiedenen Ansprüche an Qualitäts- und Funktionssicherung und Umweltschutzaspekte bei der Erstellung und Verabschiedung der Norm im breiten Konsens von Planern, Ausführenden und Behörden in der neuen Norm berücksichtigt werden.

24. Temperature patterns and factors governing thermal response in high elevation springs of the Swiss Central Alps

Temperature monitoring in 41 springs in different parts of the Swiss Central Alps revealed individual patterns, which seem to be determined by different factors. Geology plays an important role since karst springs in limestone rock often show temperatures below 3°C during winter. They are paralleled to the formation of ice and/or a strong decrease in discharge. In karst springs with permanent flow, temperature did not differ from springs of other geological formations. The water temperature of springs depends on thermal exchanges with the rock during the recharge process. Therefore, elevation, exposure, and permafrost location in the catchment area are expected to be the key factors governing water temperatures in alpine springs. The temperature showed a significant decrease of 0.37°C per 100 m of elevation. The water in springs facing north and west was significantly colder than in south-exposed springs. The temperature significantly increased with the distance to regions of permafrost in the catchment. Understanding the factors governing the thermal patterns will help predict the implication of climate change on springs.

25. Is groundwater response timing in a pre-alpine catchment controlled more by topography or by rainfall?

Groundwater levels in steep headwater catchments typically respond quickly to rainfall, but the timing of the response may vary spatially across the catchment. In this study, we investigated the topographic controls and the effects of rainfall and antecedent conditions on the groundwater response timing for 51 groundwater monitoring sites in a 20-ha pre-alpine catchment with low permeability soils. The median time to rise and median duration of recession for the 133 rainfall events were highly correlated to the topographic characteristics of the site and its upslope contributing area. The median time to rise depended more on the topographic characteristics than on the rainfall characteristics or antecedent soil wetness conditions. The median time to rise decreased with Topographic Wetness Index (TWI) for sites with $TWI < 6$ and was almost constant for sites with a higher TWI. The slope of this relation was a function of rainfall intensity. The rainfall threshold for groundwater initiation was also a function of TWI and allowed extrapolation of point measurements to the catchment scale. The median lag time between the rainfall centroid and the groundwater peak was 75min. The groundwater level peaked before peak streamflow at the catchment outlet for half of the groundwater monitoring sites, but only by 15 to 25min. The stronger correlations between topographic indices and groundwater response timing in this study compared to previous studies suggest that surface topography affects the groundwater response timing in catchments with low permeability soils more than in catchments with more transmissive soils.

26. A novel approach for estimating karst groundwater recharge in mountainous regions and its application in Switzerland

A pragmatic and simple approach for estimating the groundwater recharge of karst aquifers in mountainous regions by extrapolation of the hydrological regimes of gauged and well-documented systems is presented. Specific discharge rates are derived using annual precipitation and spring measurements by taking into account catchment size and elevation, which are assumed to be the dominant factors. Reference sites with high data reliability are used for calibration and regional extrapolation. This is performed with normalized values employing spatial precipitation deviations and correlation with the elevation of the catchment areas. A tiered step procedure provides minimum and maximum normalized gradients for the relationship between recharge quantity and elevation for karst regions. The normalized recharge can therefore be obtained and extrapolated for any location using the spatial precipitation variability to provide an estimate of annual groundwater recharge. The approach was applied to Switzerland (approximately 7500km² of karst terrain situated between 200 and over 4000ma.s.l.) using annual precipitation data from meteorological stations for the years 2000 to 2011. Results show that the average recharge rates of different Swiss karst domains range from 20 to 46L/km²s, which corresponds to an infiltration ratio between 0.6 and 0.9 of total precipitation. Despite uncertainties inherent in the approach, these results provide a benchmark for renewable karst groundwater resources in Switzerland of about 8.4km³/year. The approach can be applied to any other mountainous karst region, that is, where a clear relationship between elevation, precipitation and recharge can be assumed.

27. Importance of maximum snow accumulation for summer low flows in humid catchments

Winter snow accumulation obviously has an effect on the following catchment runoff. The question is, however, how long this effect lasts and how important it is compared to rainfall inputs. Here we investigate the relative importance of snow accumulation on one critical aspect of runoff, namely the summer low flow. This is especially relevant as the expected increase of air temperature might result in decreased snow storage. A decrease of snow will affect soil and ground-water storages during spring and might cause low streamflow values in the subsequent warm season. To understand these potential climate change impacts, a better evaluation of the effects of inter-annual variations in snow accumulation on summer low flow under current conditions is central. The objective in this study was (1) to quantify how long snowmelt affects runoff after melt-out and (2) to estimate the sensitivity of catchments with different elevation ranges to changes in snowpack. To find suitable predictors of summer low flow we used long time series from 14 Alpine and pre-Alpine catchments in Switzerland and computed different variables quantifying winter and spring snow conditions. In general, the results indicated that maximum winter snow water equivalent (SWE) influenced summer low flow, but could expectedly only partly explain the observed inter-annual variations. On average, a decrease of maximum SWE by 10% caused a decrease of minimum discharge in July by 6-9% in catchments higher than 2000 ma.s.l. This effect was smaller in middle-and lower-elevation catchments with a decrease of minimum discharge by 2-5% per 10% decrease of maximum SWE. For higher-and middle-elevation catchments and years with

below-average SWE maximum, the minimum discharge in July decreased to 70-90% of its normal level. Additionally, a reduction in SWE resulted in earlier low-flow occurrence in some cases. One other important factor was the precipitation between maximum SWE and summer low flow. When only dry preceding conditions in this period were considered, the importance of maximum SWE as a predictor of low flows increased. We assessed the sensitivity of individual catchments to the change of maximum SWE using the non-parametric Theil-Sen approach as well as an elasticity index. Both sensitivity indicators increased with increasing mean catchment elevation, indicating a higher sensitivity of summer low flow to snow accumulation in Alpine catchments compared to lower-elevation pre-Alpine catchments.

28. Multiple sulphur and oxygen isotopes reveal microbial sulphur cycling in spring waters in the Lower Engadin, Switzerland

Highly mineralized springs in the Scuol-Tarasp area of the Lower Engadin and in the Albula Valley near Alvaneu, Switzerland, display distinct differences with respect to the source and fate of their dissolved sulphur species. High sulphate concentrations and positive sulphur ($\delta^{34}\text{S}$) and oxygen ($\delta^{18}\text{O}$) isotopic compositions argue for the subsurface dissolution of Mesozoic evaporitic sulphate. In contrast, low sulphate concentrations and less positive or even negative $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ values indicate a substantial contribution of sulphate sulphur from the oxidation of sulphides in the crystalline basement rocks or the Jurassic sedimentary cover rocks. Furthermore, multiple sulphur ($\delta^{34}\text{S}$, $\Delta^{33}\text{S}$) isotopes support the identification of microbial sulphate reduction and sulphide oxidation in the subsurface, the latter is also evident through the presence of thick aggregates of sulphide-oxidizing *Thiothrix* bacteria.

29. Reactive transport of uranium in fractured crystalline rock: Upscaling in time and distance

Batch adsorption and breakthrough column experiments were conducted to evaluate uranium transport through altered material that fills fractures in a granite rock system at the Grimsel Test Site in Switzerland at pH 6.9 and 7.9. The role of adsorption and desorption kinetics was evaluated with reactive transport modeling by comparing one-, two-, and three-site models. Emphasis was placed on describing long desorption tails that are important for upscaling in time and distance. The effect of increasing pH in injection solutions was also evaluated. For pH 6.9, a three-site model with forward rate constants between 0.07 and 0.8 $\text{ml g}^{-1} \text{h}^{-1}$, reverse rate constants between 0.001 and 0.06 h^{-1} , and site densities of 1.3, 0.104, and 0.026 p.mol g^{-1} for 'weak/fast', 'strong/slow', and 'very strong/very slow' sites provided the best fits. For pH 7.9, a three-site model with forward rate constants between 0.05 and 0.8 mL g^{-1} reverse rate constants between 0.001 and 0.6 h^{-1} , and site densities of 1.3, 0.039, and 0.013 $\mu \text{mol g}^{-1}$ for a 'weak/fast', 'strong/slow', and 'very strong/very slow' sites provided the best fits. Column retardation coefficients (R_d) were 80 for pH 6.9 and 10.3 for pH 7.9. Model parameters determined from the batch and column experiments were used in 50 year large-scale simulations for continuous and pulse injections and indicated that a three-site model is necessary at pH 6.9, although a K-d-type equilibrium partition model with one-site was adequate for large scale predictions at pH 7.9. Batch experiments were useful for predicting early breakthrough times in the columns while column experiments helped differentiate the relative importance of sorption sites and desorption rate constants on transport.

30. An integrated spatial snap-shot monitoring method for identifying seasonal changes and spatial changes in surface water quality

Integrated catchment-scale management approaches in large catchments are often hindered due to the poor understanding of the spatially and seasonally variable pathways of pollutants. High frequency monitoring of water quality at random locations in a catchment is resource intensive and challenging. A simplified catchment-scale monitoring approach is developed in this study, for the preliminary identification of water quality changes - Integrated spatial snap-shot monitoring (ISSM). This multi-parameter monitoring approach is applied using the isotopes of water ($\delta \text{O-18-H}_2\text{O}$ and δD) and nitrate ($\delta \text{N-15-NO}_3^-$ and $\delta \text{O-18-NO}_3^-$) together with the fluxes of nitrate and other solutes, which are used as chemical markers. This method involves selection of few sampling stations, which are identified as the hotspots of water quality changes within the catchment. The study was conducted in the peri-alpine Thur catchment in Switzerland, with two snap-shot campaigns (representative of two widely varying hydrological conditions), in summer 2012 (low flow) and spring 2013 (high flow). Significant spatial (varying with elevation) and seasonal changes in the sources of water were observed between the two seasons. A spatial variation of the sources of nitrate and the solute loads was observed, in tandem with the land use changes in the Thur catchment. There is a seasonal shift in the sources of nitrate, it varies from a strong treated waste water signature during the low flow season to a mixture of

other sources (like soil nitrogen derived from agriculture), in the high flow season. This demonstrates the influence of other sources that override the influence of waste water treatment plants (WWTPs) during high flow in the Thur River and its tributaries. This method is expected to be a cost-effective alternative, providing snap-shots, that can help in the preliminary identification of the pathways of solutes and their seasonal/spatial changes in catchments.

31. Modeling cross-hole slug tests in an unconfined aquifer

A modified version of a published slug test model for unconfined aquifers is applied to cross-hole slug test data collected in field tests conducted at the Widen site in Switzerland. The model accounts for water-table effects using the linearized kinematic condition. The model also accounts for inertial effects in source and observation wells. The primary objective of this work is to demonstrate applicability of this semi-analytical model to multi-well and multi-level pneumatic slug tests. The pneumatic perturbation was applied at discrete intervals in a source well and monitored at discrete vertical intervals in observation wells. The source and observation well pairs were separated by distances of up to 4 m. The analysis yielded vertical profiles of hydraulic conductivity, specific storage, and specific yield at observation well locations. The hydraulic parameter estimates are compared to results from prior pumping and single-well slug tests conducted at the site, as well as to estimates from particle size analyses of sediment collected from boreholes during well installation. The results are in general agreement with results from prior tests and are indicative of a sand and gravel aquifer. Sensitivity analysis show that model identification of specific yield is strongest at late-time. However, the usefulness of late-time data is limited due to the low signal-to-noise ratios.

32. Multicomponent statistical analysis to identify flow and transport processes in a highly-complex environment

A combined approach of multivariate statistical analysis, namely factor analysis (FA) and hierarchical cluster analysis (HCA), interpretation of geochemical processes, stable water isotope data and organic micropollutants enabling to assess spatial patterns of water types was performed for a study area in Switzerland, where drinking water production is close to different potential input pathways for contamination. To avoid drinking water contamination, artificial groundwater recharge with surface water into an aquifer is used to create a hydraulic barrier between potential intake pathways for contamination and drinking water extraction wells. Inter-aquifer mixing in the subsurface is identified, where a high amount of artificial infiltrated surface water is mixed with a lesser amount of water originating from the regional flow pathway in the vicinity of drinking water extraction wells. The spatial distribution of different water types can be estimated and a conceptual system understanding is developed. Results of the multivariate statistical analysis are comparable with gained information from isotopic data and organic micropollutants analyses. The integrated approach using different kinds of observations can be easily transferred to a variety of hydrological settings to synthesise and evaluate large hydrochemical datasets. The combination of additional data with different information content is conceivable and enabled effective interpretation of hydrological processes. Using the applied approach leads to more sound conceptual system understanding acting as the very basis to develop improved water resources management practices in a sustainable way.

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

Chemistry of karst groundwater is related to conditions prevailing within the karst underground as well as at the land-surface within the recharge area. It is dominated by the dissolution of calcite and/or dolomite, which is strongly triggered by the presence of high $p\text{CO}_2$ in soils at the top of the bedrock. Dissolution (water mineralization) is clearly influenced by soil $p\text{CO}_2$, i.e. by global changes such as land-use, agriculture practices and climate change. However, the dissolution of carbonates is considered as a quite significant carbon sink for the Earth Atmosphere. Assessing the evolution of carbonate water mineralization can thus help characterizing the evolution of the carbon sink related to carbonate dissolution.

The main goal of the study is to check the presence of trends with a high statistical relevance in groundwater quality data along the past 20 years. Causes potentially explaining the observed trends, such as land-use, agriculture practices and global warming are analyzed and discussed. The long term evolution of parameters related to carbonate dissolution are discussed and extrapolated as they may have consequences for the Global Carbon Cycle.

The analysis is based on three independent data-sets stretching over more than 20 years each, coming from more than 40 sources. Statistical tests (Mann–Kendall trend test) indicate clear trends for

compounds related to groundwater mineralization: increase in temperature (by about 0.5°C/25 years), decrease in pH, increase in bicarbonate (by about 5%), and positive or negative trends for major ions directly related to human practices. Data and analysis suggest that carbonate dissolution is quickly increasing as a consequence of climate warming. Considering the largely accepted fact that carbonate dissolution acts as carbon sink for the atmosphere, it can be postulated that the observed increase could act as a negative feedback mechanism, tending to slowdown the atmospheric increase in CO₂.

34. Pore water colloid properties in argillaceous sedimentary rocks

The focus of this work is to evaluate the colloid nature, concentration and size distribution in the pore water of Opalinus Clay and other sedimentary host rocks identified for a potential radioactive waste repository in Switzerland. Because colloids could not be measured in representative undisturbed porewater of these host rocks, predictive modelling based on data from field and laboratory studies is applied. This approach allowed estimating the nature, concentration and size distributions of the colloids in the pore water of these host rocks. As a result of field campaigns, groundwater colloid concentrations are investigated on the basis of their size distribution quantified experimentally using single particle counting techniques. The colloid properties are estimated considering data gained from analogue hydrogeochemical systems ranging from mylonite features in crystalline fissures to sedimentary formations. The colloid concentrations were analysed as a function of the alkaline and alkaline earth element concentrations. Laboratory batch results on clay colloid generation from compacted pellets in quasi-stagnant water are also reported. Experiments with colloids in batch containers indicate that the size distribution of a colloidal suspension evolves toward a common particle size distribution independently of initial conditions. The final suspension size distribution was found to be a function of the attachment factor of the colloids. Finally, calculations were performed using a novel colloid distribution model based on colloid generation, aggregation and sedimentation rates to predict under in-situ conditions what makes colloid concentrations and size distributions batch- or fracture-size dependent. The data presented so far are compared with the field and laboratory data. The colloid occurrence, stability and mobility have been evaluated for the water of the considered potential host rocks. In the pore water of the considered sedimentary host rocks, the clay colloid concentration is expected to be very low (<1 ppb, for 10-100 nm) which restricts their relevance for radionuclide transport.

35. Online flow cytometry reveals microbial dynamics influenced by concurrent natural and operational events in groundwater used for drinking water treatment

Detailed measurements of physical, chemical and biological dynamics in groundwater are key to understanding the important processes in place and their influence on water quality – particularly when used for drinking water. Measuring temporal bacterial dynamics at high frequency is challenging due to the limitations in automation of sampling and detection of the conventional, cultivation-based microbial methods. In this study, fully automated online flow cytometry was applied in a groundwater system for the first time in order to monitor microbial dynamics in a groundwater extraction well. Measurements of bacterial concentrations every 15 minutes during 14 days revealed both aperiodic and periodic dynamics that could not be detected previously, resulting in total cell concentration (TCC) fluctuations between 120 and 280 cells μL^{-1} . The aperiodic dynamic was linked to river water contamination following precipitation events, while the (diurnal) periodic dynamic was attributed to changes in hydrological conditions as a consequence of intermittent groundwater extraction. Based on the high number of measurements, the two patterns could be disentangled and quantified separately. This study i) increases the understanding of system performance, ii) helps to optimize monitoring strategies, and iii) opens the possibility for more sophisticated (quantitative) microbial risk assessment of drinking water treatment systems.

36. Long-term pockmark maintenance by fluid seepage and subsurface sediment mobilization – sedimentological investigations in Lake Neuchatel

Pockmarks and mud volcanoes from marine and lacustrine environments are thought to be the surface expression of focused fluid flow (gas and/or water). However, the control fluid flow exerts on the sediment dynamics and rates of activity of such features, especially the maintenance and growth of pockmarks, is not well understood. This study suggests that variable fluid flow is the driving process that has maintained two lacustrine pockmarks over thousands of years. In Lake Neuchatel (western Switzerland), the currently active Chez-le-Bart Pockmark (diameter ca 160m, depth ca 10m) and the Treytel Pockmark (diameter ca 100m, depth ca 4m) indicate 'quiescent' fluid flow as well as past, 'eruptive', events of subsurface sediment mobilization. This study aims to test the hypothesis that phases of increased fluid flow through the pockmarks have led to the remobilization and spilling of sediment over the pockmark

rims, and that different modes of activity phases are responsible for their maintenance and growth. So termed 'subsurface sediment mobilization deposits' are visible in seismic profiles and correlate to specific, sedimentary intervals in Kullenberg-type long piston cores. In a detailed analysis, different modes of transport are recognized, which are attributed to high-density flows that correspond to multiple pulses of activity. The pockmark morphology, seismic stratigraphy and core correlation with pre-existing data reveals that the two pockmarks have been maintained throughout the Holocene and underwent several switches between 'quiescent' and 'eruptive' mode activity.

37. Inherited structural controls on fault geometry, architecture and hydrothermal activity: an example from Grimsel Pass, Switzerland

Exhumed faults hosting hydrothermal systems provide direct insight into relationships between faulting and fluid flow, which in turn are valuable for making hydrogeological predictions in blind settings. The Grimsel Breccia Fault (Aar massif, Central Swiss Alps) is a late Neogene, exhumed dextral strike-slip fault with a maximum displacement of 25–45 m, and is associated with both fossil and active hydrothermal circulation. We mapped the fault system and modelled it in three dimensions, using the distinctive hydrothermal mineralisation as well as active thermal fluid discharge (the highest elevation documented in the Alps) to reveal the structural controls on fluid pathway extent and morphology. With progressive uplift and cooling, brittle deformation inherited the mylonitic shear zone network at Grimsel Pass; preconditioning fault geometry into segmented brittle reactivations of ductile shear zones and brittle inter-shear zone linkages. We describe 'pipe'-like, vertically oriented fluid pathways: (1) within brittle fault linkage zones and (2) through along-strike-restricted segments of formerly ductile shear zones reactivated by brittle deformation. In both cases, low-permeability mylonitic shear zones that escaped brittle reactivation provide important hydraulic seals. These observations show that fluid flow along brittle fault planes is not planar, but rather highly channelised into sub-vertical flow domains, with important implications for the exploration and exploitation of geothermal energy.

38. Migration of contaminants in fractured-porous media in the presence of colloids: Effects of kinetic interactions

The presence of colloids in groundwater can enhance contaminant migration by reducing retardation effects. The field experiments performed in a water-conducting feature of a shear zone at the Grimsel Test Site in Switzerland indicate that the sorption processes for contaminants on mobile and immobile colloids are kinetically controlled and that colloid filtration occurs. To enable the modelling of those experiments, an appropriate model of colloid-facilitated contaminant transport in fractured-porous media is developed. The physical system is modelled as a single planar fracture with adjacent fully saturated porous rock matrix. Contaminants can diffuse into the rock matrix but colloids cannot. In the mathematical model, the 1D advective contaminant transport along the fracture is coupled with contaminant diffusion into the rock matrix perpendicular to the fracture. Radioactive decay and sorption processes for contaminants in the rock matrix (linear equilibrium), on the fracture surface (linear equilibrium and linear kinetic reactions) and on mobile and filtered colloids (linear kinetic approach), are considered. The model for colloid transport includes filtration of colloids in the fracture and their remobilization. A useful approach is developed that can be applied to adequately describe a natural system (crystalline rock) with our double-porosity model (single fracture integrated into porous rock). Numerical solutions are obtained using an implicit finite difference scheme and realized in the transport code COFRAME. The transport code is validated by the comparison of calculated results with field experiment data. Some sets of simulations are performed to study the effect of kinetics for interaction processes.

39. Contribution of alluvial groundwater to the outflow of mountainous catchments

Alluvial aquifers in mountainous regions cover typically a limited area. Their contribution to catchment storage and outflow is rarely isolated; alluvial groundwater discharge under gauging stations is generally assumed negligible; and hydrological models tend to lump alluvial storage with other units. The role of alluvial aquifers remains therefore unclear: can they contribute significantly to outflow when they cover a few percent of catchment area? Should they be considered a dynamic storage unit or merely a transmission zone? We address these issues based on the continuous monitoring of groundwater discharge, river discharge (one year), and aquifer storage (6 months) in the 6 km² alluvial system of a 194 km² catchment. River and groundwater outflow were measured jointly through "coupled gauging stations." The contribution of alluvial groundwater to outflow was highest at the outlet of a subcatchment (52 km²), where subsurface discharge amounted to 15% of mean annual outflow, and 85% of outflow during the last week of a drought. In this period, alluvial-aquifer depletion supported 75% of the

subcatchment outflow and 35% of catchment outflow—thus 3% of the entire catchment supported a third of the outflow. Storage fluctuations occurred predominantly in the aquifer's upstream part, where heads varied over 6 m. Not only does this section act as a significant water source, but storage recovers also rapidly at the onset of precipitation. Storage dynamics were best conceptualized along the valley axis, rather than across the more conventional riparian-channel transect. Overall the contribution of alluvial aquifers to catchment outflow deserves more attention.

40. Rapid identification of transience in streambed conductance by inversion of floodwave responses

Streambed conductance controls the interaction between surface and groundwater. However, the streambed conductance is often subject to transience. Directly measuring hydraulic properties in a river yields only point values, is time-consuming and therefore not suited to detect transience of physical properties. Here, we present a method to continuously monitor transience in streambed conductance. Input data are time series of stream stage and near stream hydraulic head. The method is based on the inversion of floodwave responses. The analytical model consists of three parameters: x , the distance between stream-bank and an observation well, a , the aquifer diffusivity, and α the retardation coefficient that is inversely proportional to the streambed conductance. Estimation of a is carried out over successive time steps in order to identify transience in streambed conductance. The method is tested using synthetic data and is applied to field data from the Rhone River and its alluvial aquifer (Switzerland). The synthetic method demonstrated the robustness of the proposed methodology. Application of the method to the field data allowed identifying transience in streambed properties, following flood events in the Rhone. This method requires transience in the surface water, and the river should not change its width significantly with a rising water level. If these conditions are fulfilled, this method allows for a rapid and effective identification of transience in streambed conductance.

Übersichtspublikationen / Publications synoptiques

41. Gewässerschutzverordnung (GSchV) Ordonnance sur la protection des eaux (OEaux) Ordinanza sulla protezione delle acque (OPAc) Waters Protection Ordinance (WPO)

Diese Verordnung soll ober- und unterirdische Gewässer vor nachteiligen Einwirkungen schützen und deren nachhaltige Nutzung ermöglichen. Zu diesem Zweck müssen bei allen Massnahmen nach dieser Verordnung die ökologischen Ziele für Gewässer berücksichtigt werden.

La présente ordonnance a pour but de protéger les eaux superficielles et les eaux souterraines contre les atteintes nuisibles et de permettre leur utilisation durable. A cet effet, toutes les mesures prises en vertu de la présente ordonnance doivent tenir compte des objectifs écologiques fixés pour les eaux.

Scopo della presente ordinanza è di proteggere le acque superficiali e sotterranee da effetti pregiudizievoli e di consentirne l'utilizzazione secondo il principio dello sviluppo sostenibile. A tal fine, per tutte le misure adottate ai sensi della presente ordinanza, si deve tenere conto degli obiettivi ecologici fissati per le acque.

This Ordinance shall facilitate the protection of surface and underground waters from harmful effects and enable their sustainable use. For this purpose, all measures taken under this Ordinance must take account of the ecological goals for waters.

42. Hydrogeologische Karte der Schweiz 1:100'000 Carte hydrogéologique de la Suisse 1:100'000 Carta idrogeologica della Svizzera 1:100'000 Hydrogeological map of Switzerland 1:100'000

Herausgegeben vom Bundesamt für Umwelt BAFU, der zuständigen Fachstelle der Landesgeologie für die Hydrogeologie. Die Hydrogeologische Karte 1:100'000 zeigt den Untergrund aus der Sicht von drei Fachbereichen: der Geologie, Hydrologie und Hydrogeologie. Der Untergrund ist nach lithologisch-petrografischen Kriterien und der Durchlässigkeit klassiert. Punkt- und Liniendaten (Quellen, Brunnen, hydraulische Verbindungen, Grundwasservorkommen etc.) zeigen die Zirkulationswege des Grundwassers und dessen Nutzung an Förderbrunnen und Quelfassungen. Die Darstellung im Massstab 100'000 gibt Einblick in die regionalen hydrogeologischen Gegebenheiten. Folgende Karten sind verfügbar: 1. Bözberg/Beromünster, 1972; 2. Bodensee, 1980; 3. Panixerpass, 1985; 4. Biel, 1991/92; 5. Toggenburg, 1993/94; 6. Saane, 1999; 8. Vallorbe - Léman nord, 2006; 7. Basel, 2014. Für die NW-Schweiz wurde ein blattschnittfreier Vektordatensatz der Kartenblätter 4, 6, 7, 8 erstellt. Die Daten können beim BAFU bezogen werden (www.bafu.admin.ch Daten, Karten, Indikatoren).

Publiée par l'Office fédéral de l'environnement (OFEV), office compétent du Service géologique national pour l'hydrogéologie. La carte hydrogéologique 1:100 000 présente le sous-sol dans la perspective des trois domaines spécialisés : géologie, hydrologie et hydrogéologie. Le sous-sol est classé d'après des critères lithologiques-pétrographiques et de perméabilité. Les données ponctuelles et linéaires (sources, puits, liaisons hydrauliques, nappes phréatiques, etc.) montrent les voies de circulation des eaux souterraines ainsi que l'utilisation actuelle de ces eaux et des eaux de source. La représentation à l'échelle 1:100 000 donne une vue d'ensemble des caractéristiques hydrogéologiques régionales. Voici les cartes disponibles : 1. Bözberg/Beromünster, 1972; 2. Bodensee, 1980; 3. Panixerpass, 1985; 4. Biel, 1991/92; 5. Toggenburg, 1993/94; 6. Saane, 1999; 8. Vallorbe - Léman nord, 2006; 7. Basel, 2014. Un jeu de données vectorielles, indépendant du découpage en feuilles, a été créé à partir des feuilles 4, 6, 7 et 8 pour le Nord-ouest de la Suisse. Les données peuvent être commandées à l'OFEV (www.bafu.admin.ch Données, indicateurs, cartes).

Publicata dall'Ufficio federale dell'ambiente (UFAM), il servizio specializzato del Servizio geologico nazionale competente per l'idrogeologia. La carta idrogeologica 1:100 000 rappresenta il sottosuolo dalla prospettiva di tre discipline: la geologia, l'idrologia e l'idrogeologia. Il sottosuolo è classificato secondo criteri litologico-petrografici e in funzione della permeabilità. I dati lineari e puntiformi (sorgenti, pozzi, relazioni idrauliche, falde freatiche ecc.) mostrano le vie di circolazione delle acque sotterranee come pure la loro utilizzazione in pozzi di pompaggio e captazioni di sorgenti. La rappresentazione in scala 1:100 000 fornisce una panoramica delle caratteristiche idrogeologiche regionali. Sono disponibili le seguenti carte: 1. Bözberg/Beromünster, 1972; 2. Bodensee, 1980; 3. Panixerpass, 1985; 4. Biel,

1991/92; 5. Toggenburg, 1993/94; 6. Saane, 1999; 8. Vallorbe - Léman nord, 2006; 7. Basel, 2014. Per la Svizzera nord-occidentale è stato creato un set di dati vettoriali senza suddivisioni a partire dai fogli 4, 6, 7, 8. I dati possono essere richiesti all'UFAM (www.bafu.admin.ch Dati, carte, indicatori).

Published by the Federal Office for the Environment FOEN, the specialist office of the Swiss Geological Survey responsible for hydrogeology. The hydrogeological map 1:100,000 shows the subsurface from the perspective of three disciplines: geology, hydrology and hydrogeology. The subsurface is classified according to lithological-petrographical criteria and permeability. Point and line data (springs, wells, hydraulic connections, groundwater resources, etc.) indicate the flow paths of groundwater and its exploitation at wells and tapped springs. The representation at a scale of 100,000 provides insight into the regional hydrogeological conditions. The following maps are available: 1. Bözberg/Beromünster, 1972; 2. Lake Constance, 1980; 3. Panixerpass, 1985; 4. Biel-Bienne, 1991/92; 5. Toggenburg, 1993/94; 6. Saane, 1999; 8. Vallorbe - Léman nord, 2006; 7. Basel, 2014. For North West Switzerland, a seamless vector data set of maps 4, 6, 7 and 8 was created. The data can be obtained from the FOEN (www.bafu.admin.ch Data, indicators, maps).

43. Ausdehnung der Grundwasservorkommen in Karstgebieten
Extensions des nappes souterraines en régions karstiques
Estensione delle falde freatiche in regioni carsiche
Extent of groundwater resources in karst regions

Der Layer Karstwasservorkommen zeigt die an die Oberfläche projizierte Ausdehnung des wassergesättigten Bereichs eines Karst-Grundwasserleiters. Diese wird bestimmt durch den Karstwasserspiegels und damit die Höhenlage der Hauptaustrittsstelle (Quelle) des jeweiligen Karstsystems. Dargestellte Informationen zu Karstgebieten bzw. Karstgrundwasser basieren auf hydrogeologischen 3D-Modellen (KARSYS-Ansatz). Sie wurden mit Unterstützung der jeweiligen Kantone durch das Schweizerische Institut für Speläologie und Karstforschung SSKA erarbeitet, herausgegeben durch das Bundesamt für Umwelt BAFU.

La couche Nappes d'eau souterraines karstiques représente la projection à la surface de l'extension de la zone saturée dans les aquifères karstiques. Cette dernière est déterminée par le niveau piézométrique karstique et donc par l'altitude de l'exutoire principal (source) de chaque système karstique. Les informations présentées dans les catégories Régions karstiques et Eaux souterraines karstiques sont déduites des modèles hydrogéologiques 3D (approche KARSYS). Elles ont été établies par l'Institut Suisse de Spéléologie et de Karstologie ISSKA avec le soutien des cantons et sont éditées par l'Office fédéral de l'environnement OFEV.

Il livello Falde freatiche carsiche consiste nella proiezione in superficie dell'estensione della zona satura di un acquifero carsico. Quest'ultima è determinata dal livello piezometrico carsico e quindi dall'altitudine dell'emissario principale (sorgente) del relativo sistema carsico. Le informazioni presentate nelle categorie Regioni carsiche e Acque sotterranee carsiche si basano su modelli idrogeologici 3D (approccio KARSYS). Sono state elaborate dall'Istituto svizzero di speleologia e carsologia ISSKA con il sostegno dei Cantoni e vengono pubblicate dall'Ufficio federale dell'ambiente UFAM.

The Karst water resources layer shows the extent of the water-saturated zone of a karstified aquifer projected to the surface. It is determined by the karst water level and therefore the elevation of the main point of emergence (spring) of that karst system. The information in the categories Karst regions and Karst groundwater, respectively, is based on hydrogeological 3D models (KARSYS approach). It was developed, with the support of the cantons, by the Swiss Institute for Speleology and Karst Studies SSKA and is published by the Federal Office for the Environment FOEN.

44. Einzugsgebiete in Karstgebieten
Bassins d'alimentation en régions karstiques
Bacini di alimentazione in regioni carsiche
Catchments in karst regions

Der Layer Karst-Einzugsgebiete bildet diejenigen Flächen ab, an denen versickerndes Wasser einer bestimmten Quelle zufließt und diese speist. Mitunter können sich Einzugsgebiete überlappen, nämlich wo Teilbereiche davon zugleich in Richtung verschiedener Karstquellen entwässern (Diffluenz). Die Karst-Einzugsgebiete sind mit den Karstquellen verknüpft: Wird ein Einzugsgebiet angewählt, werden die von ihm gespeisten Karstquellen markiert. Dargestellte Informationen zu Karstgebieten bzw. Karstgrundwasser basieren auf hydrogeologischen 3D-Modellen (KARSYS-Ansatz). Sie wurden mit

Unterstützung der jeweiligen Kantone durch das Schweizerische Institut für Speläologie und Karstforschung SSKA erarbeitet, herausgegeben durch das Bundesamt für Umwelt BAFU.

La couche Bassins d'alimentation karstiques représente la surface pour laquelle la recharge rejoint une certaine source. Il arrive que les bassins d'alimentation se superposent, une partie des eaux d'infiltration alimentant ainsi plusieurs sources (zone de diffluence). Les bassins d'alimentation karstiques sont reliés aux sources karstiques: si un bassin d'alimentation est sélectionné, les sources karstiques y étant rattachées le seront également. Les informations présentées dans les catégories Régions karstiques et Eaux souterraines karstiques sont déduites des modèles hydrogéologiques 3D (approche KARSYS). Elles ont été établies par l'Institut Suisse de Spéléologie et de Karstologie ISSKA avec le soutien des cantons et sont éditées par l'Office fédéral de l'environnement OFEV.

Il livello Bacini di alimentazione carsici corrisponde alle superfici dove la ricarica raggiunge una determinata sorgente. I bacini di alimentazione possono sovrapporsi se una parte delle acque di infiltrazione alimenta più di una sorgente (zona di diffluenza). I bacini di alimentazione carsici sono collegati alle sorgenti carsiche: selezionando un bacino di alimentazione vengono visualizzate anche le sorgenti carsiche corrispondenti. Le informazioni presentate nelle categorie Regioni carsiche e Acque sotterranee carsiche si basano su modelli idrogeologici 3D (approccio KARSYS). Sono state elaborate dall'Istituto svizzero di speleologia e carsologia ISSCA con il sostegno dei Cantoni e vengono pubblicate dall'Ufficio federale dell'ambiente UFAM.

The Karst catchments layer depicts those areas where seepage water flows into a specific spring and feeds it. Catchments can occasionally overlap, namely where sections of them drain towards different karst springs simultaneously (diffluence). The karst catchments are linked to the Karst springs: when a catchment is selected, the karst springs fed by it are highlighted. The information in the categories Karst regions and Karst groundwater, respectively, is based on hydrogeological 3D models (KARSYS approach). It was developed, with the support of the cantons, by the Swiss Institute for Speleology and Karst Studies SSKA and is published by the Federal Office for the Environment FOEN.

45. Einzugsgebietseinheiten in Karstgebieten
Unités de bassin d'alimentation en régions karstiques
Unità di baccino di alimentazione in regioni carsiche
Catchment units in karst regions

Der Layer Karst-Einzugsgebietseinheiten besteht aus denjenigen Teilflächen, von denen ausgehend jeweils ein ähnliches Fliessverhalten des Grundwassers hin zur Karstquelle zu erwarten ist. Dies trägt insbesondere dem für Karstgebiete typischen Phänomen Rechnung, dass eine Gebietseinheit je nach hydrologischen Bedingungen in unterschiedliche Richtungen entwässern und damit mehrere Karstsysteme respektive Karstquellen speisen kann (Diffluenz). Dargestellte Informationen zu Karstgebieten bzw. Karstgrundwasser basieren auf hydrogeologischen 3D-Modellen (KARSYS-Ansatz). Sie wurden mit Unterstützung der jeweiligen Kantone durch das Schweizerische Institut für Speläologie und Karstforschung SSKA erarbeitet, herausgegeben durch das Bundesamt für Umwelt BAFU.

La couche Unités de bassin karstique est constituée des surfaces pour lesquelles un écoulement similaire des eaux souterraines de la zone de recharge à la source karstique est attendu. Ceci tient notamment compte d'un phénomène typique des régions karstiques qui permet, selon les conditions hydrologiques, qu'une partie du bassin d'alimentation soit drainée vers plusieurs directions et alimente ainsi différents systèmes karstiques et les sources respectives (effet de diffluence). Les informations présentées dans les catégories Régions karstiques et Eaux souterraines karstiques sont déduites des modèles hydrogéologiques 3D (approche KARSYS). Elles ont été établies par l'Institut Suisse de Spéléologie et de Karstologie ISSKA avec le soutien des cantons et sont éditées par l'Office fédéral de l'environnement OFEV.

Il livello Unità di baccino carsico corrisponde alle superfici per le quali è previsto un deflusso idrico sotterraneo simile dalla zona di ricarica alla sorgente carsica. Consente di tenere conto in particolare di un fenomeno tipico delle regioni carsiche che, a seconda delle condizioni idrologiche, può far sì che una parte del bacino di alimentazione sia drenata in direzioni diverse e alimenti così sistemi carsici e le relative sorgenti carsiche differenti (diffluenza). Le informazioni presentate nelle categorie Regioni carsiche e Acque sotterranee carsiche si basano su modelli idrogeologici 3D (approccio KARSYS). Sono state elaborate dall'Istituto svizzero di speleologia e carsologia ISSCA con il sostegno dei Cantoni e vengono pubblicate dall'Ufficio federale dell'ambiente UFAM.

The Karst catchment units layer consists of the unit areas from which similar groundwater flow behaviour towards the karst spring can be expected. In particular, it allows for the phenomenon typical of karst

regions that a subunit of the catchment can drain in different directions according to the hydrological conditions and therefore can feed several karst systems or springs (diffluence). The information in the categories Karst regions and Karst groundwater, respectively, is based on hydrogeological 3D models (KARSYS approach). It was developed, with the support of the cantons, by the Swiss Institute for Speleology and Karst Studies SSKA and is published by the Federal Office for the Environment FOEN.

46. Quellen und Schwinden in Karstgebieten
Sources et pertes en régions karstiques
Sorgenti e perdite in regioni carsiche
Springs and swallow holes in karst regions

Der Layer Karstquellen und Schwinden zeigt die Hauptaustrittsorte von Grundwasser aus dem Karstsystem sowie relevante punktuelle Infiltrationsstellen. Es wird zwischen gefassten und ungefassten sowie zwischen temporären und permanenten Quellen unterschieden. Die Karstquellen sind mit den dazugehörigen Karst-Einzugsgebieten verknüpft: Bei Auswahl einer Quelle wird das Einzugsgebiet markiert, aus welchem diese gespeisen wird. Dargestellte Informationen zu Karstgebieten bzw. Karstgrundwasser basieren auf hydrogeologischen 3D-Modellen (KARSYS-Ansatz). Sie wurden mit Unterstützung der jeweiligen Kantone durch das Schweizerische Institut für Speläologie und Karstforschung SSKA erarbeitet, herausgegeben durch das Bundesamt für Umwelt BAFU.

La couche Sources karstiques et pertes représente les exutoires principaux des eaux souterraines dans un système karstique ainsi que des infiltrations ponctuelles majeures. Une distinction est faite entre les sources captées et non-captées ainsi qu'entre les sources temporaires et pérennes. Les sources karstiques sont reliées aux bassins d'alimentation karstiques: en sélectionnant une source, son bassin d'alimentation sera indiqué. Les informations présentées dans les catégories Régions karstiques et Eaux souterraines karstiques sont déduites des modèles hydrogéologiques 3D (approche KARSYS). Elles ont été établies par l'Institut Suisse de Spéléologie et de Karstologie ISSKA avec le soutien des cantons et sont éditées par l'Office fédéral de l'environnement OFEV.

Il livello Sorgenti carsiche e perdite rappresenta i principali emissari delle acque sotterranee in un sistema carsico e i principali punti d'infiltrazione. Vengono distinte le sorgenti captate e quelle non captate come pure le sorgenti temporanee e quelle perenni. Le sorgenti carsiche sono collegate ai bacini di alimentazione carsici: selezionando una sorgente viene visualizzato anche il bacino di alimentazione corrispondente. Le informazioni presentate nelle categorie Regioni carsiche e Acque sotterranee carsiche si basano su modelli idrogeologici 3D (approccio KARSYS). Sono state elaborate dall'Istituto svizzero di speleologia e carsologia ISSKA con il sostegno dei Cantoni e vengono pubblicate dall'Ufficio federale dell'ambiente UFAM.

The Karst springs and swallow holes layer shows the main points where groundwater emerges from the karst system as well as important infiltration points. Distinctions are made between tapped and untapped as well as temporary and permanent springs. The karst springs are linked to the associated karst catchments: When a spring is selected, the catchment from which it is fed is highlighted. The information in the categories Karst regions and Karst groundwater, respectively, is based on hydrogeological 3D models (KARSYS approach). It was developed, with the support of the cantons, by the Swiss Institute for Speleology and Karst Studies SSKA and is published by the Federal Office for the Environment FOEN.

47. Unterirdische Fliesswege in Karstgebieten
Écoulements souterrains en régions karstiques
Vie di deflusso idrico sotterraneo in regioni carsiche
Underground flow paths in karst regions

Der Layer Unterirdische Fliesswege zeigt die wahrscheinliche Richtung an, die das Grundwasser in Karstgebieten innerhalb des Einzugsgebiets hin zur entsprechenden Quelle nimmt. Diese Interpretationen stützen sich auch auf Ergebnisse von Markierversuchen, die vermutete Fliessverbindungen belegen. Dargestellte Informationen zu Karstgebieten bzw. Karstgrundwasser basieren auf hydrogeologischen 3D-Modellen (KARSYS-Ansatz). Sie wurden mit Unterstützung der jeweiligen Kantone durch das Schweizerische Institut für Speläologie und Karstforschung SSKA erarbeitet, herausgegeben durch das Bundesamt für Umwelt BAFU.

La couche Écoulement souterrains montre le cheminement probable des eaux souterraines entre un bassin d'alimentation karstique et sa source. L'interprétation se base également sur les résultats d'essais de traçage, ces derniers prouvant les liens préalablement supposés. Les informations présentées dans les catégories Régions karstiques et Eaux souterraines karstiques sont déduites des modèles hydrogéologiques 3D (approche KARSYS). Elles ont été établies par l'Institut Suisse de Spéléologie et

de Karstologie ISSKA avec le soutien des cantons et sont éditées par l'Office fédéral de l'environnement OFEV.

Il livello Vie di deflusso idrico sotterraneo illustra le probabili vie seguite dalle acque sotterranee in un bacino di alimentazione carsico fino alla relativa sorgente. L'interpretazione si basa tra l'altro sui risultati di prove di tracciamento, grazie alle quali è possibile dimostrare i collegamenti ipotizzati in precedenza. Le informazioni presentate nelle categorie Regioni carsiche e Acque sotterranee carsiche si basano su modelli idrogeologici 3D (approccio KARSYS). Sono state elaborate dall'Istituto svizzero di speleologia e carsologia ISSKA con il sostegno dei Cantoni e vengono pubblicate dall'Ufficio federale dell'ambiente UFAM.

The Underground flow paths layer indicates the probable direction taken by the groundwater in karst regions within the catchments towards the relevant spring. These interpretations are also based on the results of tracer tests to verify presumed flow patterns. The information in the categories Karst regions and Karst groundwater, respectively, is based on hydrogeological 3D models (KARSYS approach). It was developed, with the support of the cantons, by the Swiss Institute for Speleology and Karst Studies SSKA and is published by the Federal Office for the Environment FOEN.

48. Umgang mit Wasserressourcen in Ausnahmesituationen Gestion des ressources en eau dans les situations exceptionnelles

Auch die Schweiz als Wasserschloss Europas kann von lokalen, vorübergehenden Wasserknappeitsproblemen betroffen sein, wie dies der Sommer 2003, der Frühling 2011 oder jüngst der Sommer 2015 gezeigt haben. Zum Umgang mit lokaler Wasserknappheit in der Schweiz werden die Kantone mit Expertenberichten im Auftrag des BAFU unterstützt. Die Berichte beinhalten Methoden und gute Beispiele sowohl für den präventiv-langfristigen Umgang mit Wasserknappheit als auch für den Umgang mit Ausnahmesituationen. Für den präventiv-langfristigen Umgang mit Wasserknappheit empfiehlt der Bund den Kantonen ein zweistufiges Vorgehen. Zunächst sollen Regionen mit Handlungsbedarf identifiziert werden. Für Regionen mit Handlungsbedarf sollen dann mit Hilfe einer regional vorausschauenden Planung Konflikte vermieden und die langfristige Verfügbarkeit der Wasserressourcen sichergestellt werden. Die entsprechenden Grundlagen werden in einem weiteren Expertenbericht zur Verfügung gestellt. Diese vorausschauenden Planungsinstrumente tragen dazu bei, dass Ausnahmesituationen von Wasserknappheit längerfristig seltener respektive weniger gravierend ausfallen.

Comme l'ont montré les sécheresses de l'été 2003, du printemps 2011 et tout dernièrement de l'été 2015, même la Suisse, pourtant considérée comme le château d'eau de l'Europe, peut être touchée par des pénuries d'eau localisées et passagères. Pour soutenir les cantons dans la gestion de ce type de situations, l'Office fédéral de l'environnement (OFEV) commande des rapports auprès d'experts reconnus de la gestion des ressources en eau. Regroupant suggestions méthodologiques et exemples de bonnes pratiques, ces rapports ont pour but d'accompagner les instances cantonales dans la gestion préventive et à long terme des pénuries d'eau et des situations d'exception. L'approche préconisée s'articule sur deux phases : tout d'abord, il s'agit d'identifier les régions présentant des besoins spécifiques. Une fois celles-ci identifiées, il convient d'élaborer une planification régionale à long terme, destinée à prévenir les conflits et à garantir la pérennité des ressources. Les bases correspondantes sont regroupées dans un deuxième rapport. Ces divers instruments de planification préventive visent d'une part à réduire la fréquence des pénuries et d'autre part à limiter leur degré de gravité.

49. Bestimmung von Regionen mit Handlungsbedarf bei Trockenheit Identifier les régions où des actions s'imposent en cas de sécheresse

Auch die Schweiz als Wasserschloss Europas kann von regionalen, vorübergehenden Wasserknappeitsproblemen betroffen sein, wie dies der Sommer 2003, der Frühling 2011 oder jüngst der Sommer 2015 gezeigt haben. Zum Umgang mit lokaler Wasserknappheit in der Schweiz werden die Kantone mit Expertenberichten im Auftrag des BAFU unterstützt. Die drei Berichte beinhalten Methoden und gute Beispiele sowohl für den präventiv-langfristigen Umgang mit Wasserknappheit als auch für den Umgang mit Ausnahmesituationen. Für den präventiv-langfristigen Umgang mit Wasserknappheit empfiehlt der Bund den Kantonen ein zweistufiges Vorgehen. Zunächst sollen Regionen mit Handlungsbedarf identifiziert werden: Der vorliegende Expertenbericht liefert die Grundlagen dafür. Für Regionen mit Handlungsbedarf sollen dann mit Hilfe einer regionalen vorausschauenden Planung Konflikte vermieden und die langfristige Verfügbarkeit der Wasserressourcen sichergestellt werden. Die entsprechenden Grundlagen werden im Bericht [0.1] zur Verfügung gestellt. Ein dritter Expertenbericht [0.2] bietet einen Werkzeugkasten zum kurzfristigen Umgang mit Ausnahmesituationen.

Bien qu'elle soit le château d'eau de l'Europe, la Suisse peut être confrontée à des pénuries d'eau locales et temporaires. Preuve en sont les situations qu'elle a connues en été 2003, au printemps 2011 et au cours de l'été 2015. La Confédération souhaitant aider les cantons à gérer les pénuries d'eau locales en Suisse, l'OFEV a commandé trois rapports d'experts. Ces rapports présentent des méthodes et des exemples de bonnes pratiques tant en matière de prévention à long terme que pour la gestion de situations exceptionnelles. Pour la prévention à long terme, la Confédération recommande aux cantons d'appliquer une démarche en deux étapes. Il s'agit d'abord d'identifier les régions où des mesures s'imposent : cette première étape est décrite dans le présent rapport. Pour les régions où il faut agir, il convient ensuite d'élaborer une planification régionale prospective afin d'éviter les conflits d'utilisation et de garantir la disponibilité à long terme des ressources en eau. Cette seconde étape est expliquée dans le rapport [0.1]. Un troisième rapport d'experts [0.2] contient un mode d'emploi et des instruments permettant de gérer à court terme des situations exceptionnelles.

50. Hydrologisches Jahrbuch der Schweiz 2015
Annuaire hydrologique de la Suisse 2015
Annuario idrologico della Svizzera 2015
Hydrological Yearbook of Switzerland 2015

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

Publié par l'OFEV, l'Annuaire hydrologique donne une vue d'ensemble des événements hydrologiques de l'année en Suisse. Il présente l'évolution des niveaux et des débits des lacs, des cours d'eau et des eaux souterraines. Des informations sur les températures de l'eau ainsi que sur les propriétés physiques et chimiques des principaux cours d'eau suisses y figurent également. La plupart des données proviennent des relevés de l'OFEV.

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

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

51. Hitze und Trockenheit im Sommer 2015. Auswirkungen auf Mensch und Umwelt.
La canicule et la sécheresse de l'été 2015: impacts sur l'homme et l'environnement

Der Sommer 2015 ist in der Schweiz nach 2003 der zweitwärmste Sommer, der je gemessen wurde. Er ist geprägt durch niedrige Pegelstände und geringe Abflussmengen in den Gewässern, starken Gletscherschmelze und eine rekordhohe Erwärmung von Permafrostböden. Hitze und Trockenheit haben Auswirkungen auf Gesundheit, Landwirtschaft, Wald, Biodiversität, Luftqualität und Stromproduktion. Wegen der Sommerhitze sind 2015 rund 800 Todesfälle mehr zu beklagen, als in einem normalen Jahr. Bei der Wasserversorgung ist die Lage 2015 weniger angespannt als 2003. Bis Mitte des 21. Jahrhunderts dürften Verhältnisse wie im Sommer 2015 zum Normalfall werden.

L'été 2015 est, après celui de 2003, le deuxième été le plus chaud jamais enregistré en Suisse. Il se distingue par les bas niveaux d'eau et les faibles débits des cours d'eau, par une forte fonte des glaciers et par un réchauffement record des terrains à pergélisol. Canicule et sécheresse ont des impacts sur la santé, l'agriculture, le risque d'incendie de forêt, la biodiversité, la qualité de l'air et la production d'électricité. La canicule de l'été 2015 a provoqué quelque 800 décès de plus que ce qui aurait été attendu lors d'une année normale. En matière d'approvisionnement en eau, la situation s'est révélée moins tendue en 2015 qu'en 2003. Les conditions météorologiques de l'été 2015 devraient devenir la norme d'ici le milieu de ce siècle.

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52. Tools for the State of Geneva to manage its subsurface resources

The use of GIS, database, web interface or OpenData services is increasingly used by geological surveys to manage their data. Until today, management of subsurface data was often regarded as less important than the interpretation and understanding of the data themselves. However, State institutions need more and more strong and secure infrastructure where surface and subsurface data are collected and stored to ensure a better understanding and management of the subsurface resources of their territory. The State of Geneva was confronted to this situation with the GEothermie2020 program. Piloted by the State of Geneva and implemented by the Services Industriels de Genève (SIG), this program aims to rework with old data, collect new one and gives, thus the opportunity to improve subsurface knowledge. Nevertheless, the actual IT infrastructure is not complete enough to centralize these data.

In the context of this program, my project consists on finding the balance between comprehensiveness and relevance of the data to integrate to the future complete database system. Geological data are numerous, various and often very heterogeneous and incorporate all data is often difficult or even impossible. One of the main challenges is to find the limit between archiving and valorising the information. The first step is, therefore, the understanding and the harmonization of regional stratigraphy. This is also a key issue to appreciate lateral variation and to design properly sedimentary body distribution through the subsurface to allow 3D modelling.

To constrain and understand better the stratigraphy and lateral variabilities of the Great Geneva Basin (GGB), nearly 50 diplomas and 10 PhD theses of the University of Geneva were consulted, enhanced by an extensive published literature search. A large work on collecting and digitizing these data was accomplished and numerous correlations sheets and stratigraphic logs were generated. In Geneva, we have a great opportunity to understand better the subsurface units by studying them in the numerous surrounding outcrops (Charollais et al., 2007, Meyer, 2000). Thus, different field campaigns on the Jura, Saleve and Vuache, were also made to complete the study.

Done over several generations, it is a real challenge to connect the different definitions, interpretations and stratigraphic associations peculiar to each author. Heterogeneities and discrepancies of the data are the main issue. Mesozoic and the Cenozoic time period form the major part of the sedimentary succession in the GGB and are principally composed of an alternation of carbonates and marls. The thicknesses and facies vary laterally across the basin. The Upper Jurassic and lower Cretaceous are the main series studied in the outcrops surrounding Geneva. However, Middle Jurassic and Lower Jurassic and Triassic series are weaker in terms of data in the area. Direct correlations with the HARMOS program, the new official Swiss stratigraphic framework (Morard, 2014, Strasser et al., 2016) are not exhaustive for all geological periods, in particular for the Jurassic and for the Triassic. Significant differences between local stratigraphic nomenclature and this new system exist and further investigations are necessary to fit to the needs. Different composite logs and a stratigraphic catalog are in progress to help the State of Geneva and the SIG in their subsurface prospections. Therefore, a clear stratigraphic framework will be available for the GGB and it will be possible to integrate homogenized data in the new IT system.

The GEothermie 2020 Program has raised the importance of harmonizing and correlating data in order to understand better the GGB subsurface geology. The future database, build on a clear geological context with relevance of the data to integrate and the accurate stratigraphic framework, will offer tools to the State of Geneva to easily find data, create correlations, modelisation and requests. Furthermore, an easier management of its subsurface resources will be possible. The development of this intelligent and interactive system for data management holds an important place, especially for such large-scale projects involving growing numbers of stakeholders.

53. FREEWAT: Open source water resource management platform

FREEWAT (FREE and open source tools for WATer resource management) is an HORIZON 2020 project financed by the EU Commission whose principal result will be an open source and public domain GIS integrated modelling platform for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module.

FREEWAT aims at promoting water resource management by simplifying the application of the Water Framework Directive and other EU and national water related Directives.

Specific objectives of the FREEWAT project are:

- to coordinate previous EU and national funded research to integrate existing software modules for water management in a single environment into the GIS based FREEWAT;
- to support the FREEWAT application in an innovative participatory approach gathering technical staff and relevant stakeholders (in primis policy and decision makers) in designing scenarios for the proper application of water policies.

From a technical point of view the FREEWAT platform is a complex QGIS plug-in which integrates the USGS MODFLOW “suite” of open source numerical models together with other tools, libraries and software to offer a seamless environment with a large number of functions and tools accessible with specific interfaces, which facilitate the model creation, calibration, running and result analysis.

The open source characteristics of the platform allow to consider FREEWAT an initiative “ad includendum”, as further research institutions, private developers etc. may contribute to the platform development was chosen to guarantee the sustainability of the platform. The development of 14 case studies in Europe and Africa that has been preceded by one week training and that will be implemented with a participatory approach will assure a large number of stakeholder involvement and software validation.

Free training courses are foreseen the next year in each case study country, including Switzerland, to further disseminate the platform.

54. Groundwater and low flows in Switzerland – Part 3: Assessment of water resources vulnerability to droughts using synthetic hydrogeological models

Climate models tend to predict more frequent and intense periods with limited water availability. Even temperate and relatively humid regions like Switzerland are affected by issues related to low-flows. It is thus essential to characterise the vulnerability of watersheds to droughts in order to manage water supply. Aquifers, as a major fresh water reservoir, greatly impact hydrological catchment dynamics. Especially river low-flows are strongly dependent on the surrounding hydrogeological settings. Numerous studies have analysed watershed processes under dry conditions. However, they have mainly concentrated on stream flows.

We thus propose an integrated quantification of the impact of droughts on water resources by considering the sensitivity of both rivers and groundwater to prolonged dry periods. To achieve this, the hydrogeological and topographical controls on storage processes are characterised. The relationship between the physical properties of the catchment and its low-flow dynamics is highly complex, and no straightforward correlation can be obtained by analysing real catchment data. A modelling approach is therefore developed to systematically and independently quantify the control mechanisms of catchment parameters on river and groundwater dynamics. The physically based numerical model HydroGeoSphere is used, which simulates surface water and groundwater in a fully coupled way. Numerous synthetic models are designed with systematically varying geometry and hydrogeological parameters. Indicators describing drought vulnerability of stream flows, groundwater heads and storage volumes are proposed. A clear correlation between catchment porous storage volume and resilience to drought is observed. An attempt to link these results to real watersheds is made, analysing the flows and the geology of a selection of catchments. The validation of the synthetic results with observations would allow the development of drought sensitivity indicators based solely on physical properties of watersheds.

55. Groundwater and low flows in Switzerland – Part 1: Comparative physically based modelling of two Swiss catchments for assessing their low flow dynamics

In the context of a large BAFU project, we aim to understand the behaviour of two Swiss river catchments during low flow periods. Specifically, we aim to identify key catchment characteristics and processes which control low flow catchment response. The Roethenbach and the Langete catchments are characterized by the same meteorological conditions because of their geographical proximity, but have completely different river flow dynamics. The Roethenbach is characterized by high peak flows and low mean flows. Conversely, the Langete is characterized by relatively low peak flows and high mean flow rates. To understand the fundamentally different behaviour of the two catchments under future and current climate conditions, a fully-integrated surface-subsurface flow model for each catchment was developed and calibrated.

The 3D models of each catchment were developed using HydroGeoSphere (HGS). HGS is a physically-based, fullyintegrated variably-saturated surface-subsurface flow model. The main advantage of an integrated model is its ability to realistically reproduce processes which play a key role during low flow

periods such as surface-subsurface interactions or evapotranspiration. Calibration results showed that models were able to represent measured groundwater heads and the surface flow dynamics of each catchment. The calibrated models were then run with climatic scenarios consisting of a succession of historically observed dry periods.. Finally, the comparative analysis was carried out by comparing groundwater heads, stream flow rates and by indentifying resevoirs which maintain river flow rates during low flow. The study allows identifying the spatial and temporal dynamics of the different water storages such as bedrock, alluvial aquifer, soil or snow.

56. GeoQuat project: From harmonization of unconsolidated rock data to 3D geological and parametric modelling

In Switzerland, Quaternary deposits have been explored for hydrogeological, geotechnical or geothermal purposes. About 90 % of the underground uses take place in the mainly unconsolidated rock layer. These sediments accommodate about half of Switzerland's drinking water resources and they represent significant deposits of raw materials (gravels and sands). Furthermore, they are a source for shallow geothermal energy production and a significant part of housing and transport infrastructure takes place on and inside these rock bodies. Due to the increased demand on these deposits, use conflicts in the shallow subsurface are unavoidable. To plan and coordinate the different uses in these rock layers, knowledge about their composition and spatial distribution is essential. The GeoQuat project has been therefore launched by the Federal Office of Topography swisstopo in cooperation with the Federal Office for the Environment FOEN and the Federal Office of Energy SFOE in order to:

- i) Develop a system for structured storage of unconsolidated rock data (QLG database).
- ii) Realize 3D geological and parametric models (voxel models) of Quaternary deposits (Preisig et al., 2016).
- iii) Make them accessible to users working in the different fields of applied geology.

The focus is given on the development of a system, for homogeneous and structured storage of unconsolidated rock data in Switzerland, which constitute the basis of 3D geological and parametrical modelling. Indeed, the unused potential of existing Quaternary deposit data needs to be made accessible to interested users working in the different fields of applied geology related to the shallow subsurface. In order to test the practicality of the currently developed GeoQuat infrastructure, four pilot regions (Birrfield, Lake Lucerne, Upper Aar Valley and Visp) were defined. The variety of data sources and data owners complicate the development and deployment of a central storage for Quaternary deposit data. Due to their different origin, the data is characterized by a large heterogeneity in their format, type and content, leading to a large variation of data quality. To make the data comparable a well-structured Quaternary deposit data model is needed. The QLG data model is currently implemented at the Swiss Geological Survey (SGS) in conjunction with the setup of the national borehole database that is based on the Borehole data model (Brodhag & Oesterling 2014). Topographic maps (GA25), Geological vector datasets (GeoCover), top bedrock and digital elevation model (swissALTI3D) are also implemented in the QLG data model.

Wells, geological cross-sections and geophysical data are the main components of the QLG database. The original lithological description in the «Layers» table is followed by the «Classifications» which integrates material properties based on Swiss and European standards: VSS, SIA, EN, ISO. The table «Computations» integrates computed values from the «Classifications», such as hydraulic conductivity. Another group of relevant data is the «Field and laboratory measurement» group, which considers in situ measurements and laboratory analyses. Observed, measured and analyzed data in the QLG database are a good basis for the characterization of Quaternary deposits and history, as well as for the elaborations of 3D geological and parametric models.

57. Time lag of trend reversal after nitrate reduction measures determined by tracer measurements in the Dünnerngäu, Solothurn

Rising nitrate concentrations due to intense agriculture threaten the quality and safety of drinking waters in many places in Switzerland and around the world. In the Dünnerngäu between Balsthal and Olten, nitrate concentrations surpassed the quality target value for nitrate concentrations of 25 mg/L (GschV) in the 1980s at several of the production wells. Although nitrate concentrations did not yet exceed the tolerance value of 40 mg/L at the end of the 1990s, the "Nitratprojekt" was founded in 2000 to establish measures to reduce the input of nitrate to the groundwater. A 2D particletracking model was implemented to determine contributing areas of production wells, groundwater travel times, and to predict reaction times to nitrate reduction measures (Biaggi et al., 1999). In the first few years after the initiation of the

“Nitratprojekt”, nitrate concentrations decreased as predicted but then they stagnated or even increased again in some of the wells.

To better understand this discrepancy, we quantified residence times in the saturated and unsaturated zone based on time series of nitrate measurements from the pumping wells and measurements of environmental tracers (^3H , ^3He , ^4He , ^{39}Ar , and ^{85}Kr). These measurements are interpreted by means of a lumped-parameter model that explicitly considers the unsaturated zone. Model parameters are estimated using a Bayesian inference scheme based on the Markov-Chain Monte-Carlo method (Alikhani et al., 2016). We also assess the usefulness of both the nitrate time series and the tracer data in constraining residence times and predicting nitrate concentrations. Finally, models with and without an explicit unsaturated zone were compared to identify the effect of including the unsaturated zone on estimated residence times and predicted nitrate concentrations.

We find that residence times of water and nitrate in the subsurface are longer than previously thought. The main reason is relatively long transfer times in the unsaturated zone of 2 to 10 years, which were neglected in the particle-tracking study. Generally, combining tracer data and nitrate time series leads to smaller uncertainties in nitrate predictions for wells, especially where the available nitrate time series are relatively short. For some wells, however, including tracer data results in a poorer agreement with the measured nitrate time series. Including the tracer data results in hydrogeologically more realistic parameter sets, even if predicted nitrate concentrations look very similar to predictions from using nitrate time series alone. Finally, using nitrate time series alone, parameters of the model with an explicit unsaturated zone cannot be estimated due to high parameter correlation. Thus, environmental tracer measurements are indispensable to allow for a separation of residence times in the saturated and unsaturated zones.

58. Use of Isotope data to quantify the interaction between the river Rhine and the groundwater at Oberriet, CH

A groundwater model has been built up to quantify the influence of the planned flood protection measures along the Alpenrhein. One of the most important questions building up the model has been the interaction between Rhine and groundwater, especially near the existing drinking water wells. The drinking water quality directly depends upon the fraction of infiltrated Rhine water.

For model calibration purposes, the electrical conductivity (EC) measures at the drinking water well “Balanggen” near Oberriet have been used. EC is quite a good tracer for quantifying the river infiltration into wells near the river, because the river water values are considerably lower than the background values in groundwater. If the well is positioned further away from the river, as this is the case at Oberriet, a mineralization takes place during the travel path to the well. This introduces a new unknown parameter to the calibration process. To omit this problem, the ^{18}O concentrations have been used for model validation. ^{18}O measurement values are provided by the NAQUA National Groundwater Monitoring at the “Balanggen” well. ^{18}O concentration remains stable during groundwater passage.

Two methods were applied to validate the model. The first method is derived from a path line method developed by Cordes and Kinzelbach (1992). Because the method is based on a continuous flow field, the water balance can be calculated along the flow paths (Gmünder 2008). The method can be used to quantify the age and fraction of river water arriving at the well. 100 flow paths have been started at the well every five days during the simulation period and were tracked back in time. At the nodes where river water enters into the model, the measured ^{18}O concentration of the river Rhine was applied to the infiltrating water.

As a second method, a mass transport model has been setup. Along the river Rhine, the measured ^{18}O concentration was assigned to the water infiltrating into the groundwater. The ^{18}O concentration at all other boundary nodes was set to a background value. At the Alpenrhein valley, background ^{18}O values of 10.3 have been measured (Kralik et al. 2011).

A good match between simulated and measured ^{18}O concentrations could be achieved. The simulations showed a strong time dependency of river water fraction and travel times. The mean fraction of river water is about 25%. The travel time of water infiltrated during the high-water season is between 90 and 120 days. As a by-product of the calibration process, the mineralization speed of EC could be quantified. It could be shown that ^{18}O time series are well suited for the quantification of river infiltration to wells with a travel time of some months. The ^{18}O concentrations should be measured monthly to detect the minimum and maximum values of the annual fluctuations.

59. Challenges of groundwater management and protection in urban areas – Examples from the Basel area

The urban agglomeration of Basel, located on the border with France and Germany, is one of the most dynamic economic regions in Switzerland and also constitutes an international and national transport hub. The groundwater resources of the region are located in aquifers made up of unconsolidated fluvial sediments in the valleys of the rivers Rhine, Birs and Wiese as well as in the vulnerable karst areas of the Tabular and Folded Jura. Among other impacts, the quality and quantity of groundwater is affected by the ongoing urbanization and the development of subsurface infrastructures. The densification of land use affects the availability of water resources and also leaves measurable traces in the groundwater.

Urban subsurface resources and especially urban groundwater bodies are particularly vulnerable to environmental impacts and their rational management is of major importance. Therefore, the development of optimization strategies should consider simultaneously the numerous impacts on urban subsurface resources, such as infrastructure development or groundwater and geothermal subsurface use.

Important issues of urban hydrogeology is the understanding of the changes due to the realization and operation of infrastructure projects in the underground, the use of groundwater for cooling or as a heat resource. Urban areas are also confronted with permanent use changes. This increasingly requires instruments that allow understanding and predicting the development of quantitative and qualitative issues concerning ground water resources, to recognize the impact of the various uses in a larger context and derive measures of resource protection.

Generally, infrastructure development in urban environments and associated alterations in land use only consider the benefits for the improved infrastructure itself and planning largely takes the pragmatic form of engineering for short-term economic objectives. This often leads to adverse effects concerning quantitative and qualitative issues of subsurface resources including groundwater flow regimes, induced natural hazards and use conflicts in general. Alternative approaches include the implementation of adaptive management schemes. Such schemes start with the definition of particular profiles of systems (i.e. water supply). Together with the identification of system profiles, specific targets can be defined that lead to overall goals for particular subsurface resources, in the case of groundwater i.e., the desired short and long-term development of urban groundwater resources. The conceptual approach we propose includes the combination of instruments that allow to adequately identifying influences of the various single impacts on the complete environmental system. Thereby, both impacts that only affect the system in its immediate vicinity and impacts with influence on the system on a regional scale are considered.

In recent years, the Applied and Environmental Geology group of the Basel University has developed, in cooperation and on behalf of the cantonal authorities BS and BL and in the context of transnational projects, a system of tools that make it possible to understand the current state of the different groundwater bodies in the Basel area. These tools are applied, tested and further developed in the context of the construction of subsurface transport infrastructure, thermal management of groundwater resources or scenarios techniques for the evaluation of river revitalisation measures in a transnational context.

60. Geostatistical inversion of subglacial drainage system

Water flow at the glacier and bedrock interface plays an important role in understanding alpine catchment hydrology, glacier motion, erosion processes, as well as potential hazards such as glacial outburst floods. In general, the subglacial drainage system (channelized and distributed water flow) is not directly accessible and measurable. In addition, the transient processes of melt, freezing and the advance of the glacier, make it a very complex system. Numerical models that aim to represent the physics of this system have been built, however, existing models require to know a number of physical parameters that are usually impossible to uniquely determine based on the available data (Flowers 2015). This work focuses on identifying ranges of parameters for a subglacial system based on inverse modeling. As such, it investigates for the first time the use of inverse geostatistical modeling for identifying inaccessible subglacial features. To this end, two innovations are proposed.

The first innovation is a methodology where subglacial features are generated using a combination of stochastic and physics-based processes. The methodology includes the generation of discrete elements such as channels incised to the ice (Röthlisberger channels) and a linked cavity system represented by distributed diffuse flow. We use a finite element groundwater model to represent pressurized flow and mass transport (Cornaton 2007).

The second innovation is the use of an inverse framework that iteratively modifies the subglacial drainage network to match the observed discharge at the outlet of the glacier and breakthrough curves from tracer

experiments in moulines. At each iteration, the channel network and model parameters are perturbed to search for an ensemble of suitable solutions. This technique ensures a hydrologically coherent connectivity of the channelized elements and allows the generation of different network structures.

Overall, the proposed methodology is able to represent and identify the type of connected patterns that drive subglacial dynamics and allows conditioning to observed data. As such, this work is a step towards rigorous assessment of parameters uncertainty in subglacial modeling.

61. Solute mixing and chemical reactions in multiphase systems: from pore- to field-scale

Flow and transport processes in multiphase systems remain a grand scientific and engineering challenge in industrial (e.g., CO₂ sequestration, unconventional oil and gas extraction, enhanced oil recovery) as in natural systems. As a particular case, the soils and vadose zone, where air and water coexist, play a key role in the transport of chemical substances from the surface to groundwater resources. Mixing processes in porous media is a major control on fluid-fluid and fluid-solid chemical reactions. However, conventional continuum-scale theories and models oversimplify and/or ignore many important pore-scale processes. Multiphase flows, with the creation of highly heterogeneous velocity fields (i.e., regions of fluid of very low velocities, also called stagnation zones, and connected principal paths of high velocity), makes transport more complex, both conservative and reactive. We discuss recent experimental developments and theoretical approaches at different scales to quantify transport, including mixing, and reaction and their coupling with multiphase flows.

62. Visual KARSYS – a web-tool for the documentation of karst aquifers

Visual KARSYS is a web-tool being developed for the documentation of karst aquifers and the management of groundwater resources. The tool is developed by SSKA and i4ds with inputs from various cantons and Confederation. The project is supported by the grant for Innovation and Technologic development provided by the Swiss Federal Office for Environment. The tool will help users to apply the KARSYS approach (Jeannin et al. 2013) by themselves through an intuitive web-based interface. It will also include a 3D-Web viewer dedicated to end-users (e.g. water authorities), who are interested in viewing and interrogating the data/results, for instance as maps for decision-making, etc. Innovations regarding the developments concern the online (hydro)geological 3D viewer, the 3D tools to process the 3D models and the connection of models and viewer to a geological data base. The talk intends to present the architecture of Visual KARSYS data base and the expected functionalities of the tool, which is still at the beginning of its development.

63. The effects of model complexity and calibration period on groundwater recharge predictions

Numerous groundwater recharge models exist that vary in terms of model complexity and structure (Crosbie et al., 2011; von Freyberg et al., 2015). Complex physically based models are often considered to be more robust in the predictions, however, the computational expenses might constrain their use for certain applications (e.g., long-term predictions of climate change scenarios). A few studies indicate that model robustness in more simple models can be enhanced with longer calibration periods that contain climatically contrasting conditions (Moeck et al., 2016). In that context, an implicit assumption is made that model parameters calibrated over historical periods are also valid for the predictions. However, non-stationarity of model parameters can occur, suggesting that certain historic time periods might be more useful for the identification of the parameter space while others might be less informative. Very few studies exist which investigate the effect of chosen model complexity and calibration period on performance and robustness of groundwater recharge models. Therefore, we systematically compared four groundwater recharge models (soil-water balance equation, lumped models and physically-based models) within a stochastic framework by using a long-term data set from a large-scale weighting lysimeter in northern Switzerland. To evaluate model robustness, all models were calibrated on lysimeter recharge data with six different calibration periods that cover a wide range of contrasting climatic conditions, i.e. from very wet to very dry. We then analysed the models' performance for climatic conditions that were very different to those during the calibration periods (differential split sample test).

We demonstrate that an acceptable model performance during the calibration period does not ensure reliable groundwater recharge predictions under contrasting climatic conditions. The deviations between simulated and observed groundwater recharge, however, is a function of the chosen model complexity. We also show that the more complex, physically-based models best reproduced observed recharge, even when calibration and prediction periods had contrasting climatic conditions. In contrast, the performance of the soil-water balance model and the lumped model depended strongly on the chosen calibration

period. Our analysis suggests that the uncertainty in model parameters was less important than the model structure itself, so that the robustness of each individual model followed the degree of model complexity. It can be argued that physically-based models have a greater potential to obtain predictions beyond the range of conditions during calibration. It is however, still difficult to provide general guidelines on how to choose an optimal calibration period, since model performance seems to depend more on the model complexity and structure rather than on the calibration period. The results obtained here have important implications when using recharge models as decision-making tools in a wide range of applications (e.g. water availability, climate change impact studies, water resource management, etc.).

64. Multi-parameter low enthalpy geothermal mapping of Cantone Ticino

Low enthalpy geothermal energy is a type of renewable energy that is continuously growing in terms of exploitation within Europe, especially through the use of closed-loop systems. Currently the authorisation process for closed-loop systems in Cantone Ticino is based on maps taking into account the presence of restrictions arising from the enforcement of the water protection act and ordinance. It states that new closed-loop systems can not be installed within S groundwater protection zones, while they are always allowed in üB(“übriger Bereich”= remaining territory) sectors. Within the Au (usable groundwater) sector, a “sacrifice area” approach is adopted, allowing the installations of such systems in specific areas where the presence of conflicts precludes groundwater exploitation for drinking purposes. The described procedure, however, does not consider the subsurface potential. Therefore developing a multi-parameter geothermal mapping could give precious planning indications from both an energetic and socio-economic standpoint while fulfilling environmental protection requirements. Furthermore, an overall estimate of shallow geothermal potential in Canton Ticino is important due to the progressive diffusion of these kind of systems in the next years, since at least the 20% of energy requirements for new buildings will have to be provided from renewables (RUEn, 2008). The mapping procedure started with the realization of a ground surface temperature (GST) map using mean annual air temperature (MAAT) data retrieved by MeteoSwiss stations and a 25m DEM. Firstly we correlated MAAT measured in different stations with altitude in order to find a regression equation, then we applied it to the DEM to create a MAAT map. The GST map was then obtained by applying the formulas contained in SIA 384/6 regulation:

$$GST = \text{Mean Annual Air Temperature} + 1.55 \quad \text{for altitude} < 1000 \text{ m.a.s.l.}$$

$$GST = \text{Mean Annual Air Temperature} + 1.55 + \frac{(\text{Altitude} - 1000)}{800} * 2.45 \quad \text{for altitude} > 1000 \text{ m.a.s.l.}$$

Results were compared with real measured data of ground temperature coming both from IDAWEB database and undisturbed ground temperature values obtained by TRT tests executed in 6 spots. A digitalized geological map (Geologische Karte der Schweiz 1:500000, 2005) was used in order to define the main outcrop lithologies, while part of the sedimentary portion of the Canton Ticino region was characterized using hydraulic conductivity values extracted from pumping tests, interpolated using ordinary kriging and classified accordingly into gravels, sands and clays. A reference set of thermal properties was then assigned to each lithological unit (both rocky and sedimentary) according to SIA 384/6 regulation and a thermal conductivity map (for outcrops and equivalent Quaternary deposits) was realized. 128 simulations with EED varying λ , GST, heat flux and volumetric heat capacity were performed in order to calculate the total borehole length required to satisfy a hypothesized annual heat demand of 30 MWh/year. This value was estimated taking into account a residential unit composed of 5 flats of 100 m² each, with an equivalent operating annual time of 1200 hours, a heat pump peak power of 25 kW and an energetic index of 60 kWh/m² year (MINERGIE® standard for refurbished buildings). Maps of required borehole length and estimated extraction rate (W/m) were developed for Canton Ticino. Usually the most suitable areas match the most densely populated ones however, within Au sectors, most of the areas where closed-loops are authorised show lower potential as they are placed in alluvial fans, where the higher depth to the groundwater table results in lower λ values.

65. GeoQuat project: realization of groundwater volumes and vulnerability maps based on 3D parametric modeling

In Switzerland, Quaternary deposits have been widely explored for hydrogeological, geotechnical or geothermal purposes, in particular by means of boreholes. For instance, about half of drinking water supply comes from aquifers located in Quaternary formations. The GeoQuat project has been therefore launched by the Federal Office of Topography swisstopo in cooperation with the Federal Office for the Environment FOEN and the Federal Office of Energy SFOE in order to i) develop a system for structured storage of unconsolidated rock data (QLG database), ii) realize 3D geological and parametric models (voxel models) of Quaternary deposits, and iii) make them accessible to users working in the different

fields of applied geology. The first task mainly consists in data harmonization and pre-processing, while the second and third include data processing (modeling) and post-processing. Specifics about data harmonization, pre-processing and modeling are detailed in Volken et al. (2016). In this abstract, the focus is given on the post-processing of 3D parametric models for deriving exemplified maps of groundwater volumes and groundwater vulnerability.

3D parametric models aim to simulate the heterogeneity of material properties, such as the spatial distribution of hydraulic conductivity (K). One of the simplest and straightforward method for realizing 3D parametric models is geostatistical processing coupled with voxel modeling. In this framework, a volume is subdivided into regular cells (voxels) and geostatistical algorithms, e.g. kriging, are subsequently used to interpolate available raw data to each voxel. In GeoQuat, all lithological layers in the QLG database are classified through the Unified Soil Classification System (USCS). On the basis of a norm (e.g. SIA SN 670'010) or on a methodology taking into account the grain size characteristics of soil materials, it is then possible to link the USCS of each lithological layer to a numeric value representative of the layer hydraulic conductivity (Fig. 1a). In the pilot region Birrfeld (AG) of the project GeoQuat 1'581 boreholes for a total of 19'794 lithological layers have been captured and classified. All layers have been linked to a value of hydraulic conductivity, expressed as $\log_{10}(K[m/s])$ and used as input data for building a 3D hydraulic conductivity model of the pilot region. Fig. 1b illustrates a cross section through the 3D parametric model which consists of 6'050'254 voxels of size 25x25x2m. An anisotropic searching ellipsoid has been used to favor the ordinary kriging along the direction of the glacial flow. The modeling has been realized with the software SGeMS (Remy 2004).

Once the 3D voxel model is constructed, it can be used to post-process maps whose elaboration depends on subsurface characteristics. A good example are maps of groundwater volumes and groundwater vulnerability (Fig. 1c). For the derivation of maps of groundwater volumes, the 3D hydraulic conductivity model is merged with the surfaces representing average groundwater table levels of Birrfeld aquifers. A python code (Python Software Foundation 2016) scans each vertical column of the 3D voxel model and for the permeable voxels (i.e. $K > 10^{-5}$ m/s) situated below the groundwater level, the code converts the voxel hydraulic conductivity in porosity and calculates the voxel groundwater volume. By means of a summation along the vertical column of voxels the groundwater volume is obtained for a cell of size 25x25m and the map is generated by plotting the volume of each cell (Fig. 1c). For the elaboration of maps of groundwater vulnerability, the vulnerability concept detailed in Philipp et al. (2006) has been adapted for 3D voxel models. Based on the 3D parametric model and on the average groundwater table level, a python code scans each vertical column, considers only voxels situated above the groundwater level and applies the concept of Philipp et al. (2006) to evaluate the protective effect of the top layer and of the unsaturated zone and subsequently estimates the vulnerability of a given aquifer to surface contamination.

66. Integrated water management approaches – new paradigms

The quality of the receiving waters, lakes and rivers has improved overall in Switzerland since the 60s with the development of sewage systems, despite the demographic development and the proliferation of synthetic substances. More “soft” decisions such as substitution or prohibition of hazardous substances have also contributed to this situation. Nevertheless, many challenges are still present and are emerging in global water management. These challenges include climate change, constant increase of imperviousness on watersheds, multiplication of persistent synthetic substances, lack of financial resources ... There is a need to constantly develop new approaches, concepts and management tools.

Historically, different water sectors, directly related, were developed independently, in conjunction with the Swiss political organization. Thus, sewage system, wastewater treatment plants, and finally receiving waters are too often managed independently. This division has certainly helped in optimizing each sector, but conducted to lose the overview of the system as a whole. An integrated approach, promoting links between sectors, is necessary.

An integrated sewer network-receiving water approach was for example developed in Switzerland, related to the General Plan for Water Management (PGEE), mandatory for each commune. As part of the PGEE, urban wet-weather water management is based on the immission concept (Rossi et al, 2009), through the STORM directive (Brenni et al, 2007). For its implementation, we first need to set expectations and goals for the receiving waters and, depending on these objectives (immission), the acceptable emissions are defined.

The receiving environment is somehow again at the center of discussions. This approach requires nevertheless skills in multiple areas, whether in urban hydrology, hydrobiology, ecotoxicology, etc. Thus, a transdisciplinary approach is necessary for its implementation.

STORM Directive is applied mainly for small streams. Only recently developments have focused on discharges in lakes. The Léman21 project (www.leman21.ch), based on the case of the Bay of Vidy in Lake Geneva, is focused on the link between micropollutants and their impacts on the lake environment. The project Elemo (www.elemo.ch) also allowed to better understand the lake environment and the link between the urban watershed and the potential impacts of substances released by human activities. Discussions are underway to define a “STORM Lake” approach, designed to better identify the impacts of urban wet-weather discharges to lake environments.

In these developments, the currents plays an essential role in estimating the impacts of discharges. 3D modeling tools in lacustrine environments, validated by field measurements, help in advancing towards a better understanding of implicated processes, but at the cost of a major effort for data acquisition and modeling. Hopefully, all lakes in Switzerland will be modeled, thus facilitating a better understanding of potential impacts.

In terms of water management, many projects are going in the direction of integrated management, including also sectors such as drinking water, hydrogeology, agriculture, recreational activities ... The main obstacle to this integrated vision, encouraged by the Confederation (Schaffner et al. 2009), is not related to technologies, but more institutional. Participants in a conference like the SGM can play a key role in integrated approaches, developing multidisciplinary research and analysis outside their research comfort zone.

Through various examples, this presentation will illustrate some case studies and will suggest ways to promote and develop an interdisciplinary and integrated approach for water management.

67. Bacterial transport in saturated porous media

Understanding the transport of bacteria in saturated porous media is crucial for many applications ranging from the management of pumping wells subject to bio-clogging to the design of new bioremediation schemes for subsurface contamination. However, little is known about the spatial distribution of bacteria at the pore scale, particularly when smallscale heterogeneities – always present even in seemingly homogeneous aquifers – lead to preferential pathways for groundwater flow. In particular, the coupling of flow and motility has recently been shown to strongly affect bacterial transport, and this leads us to predict that subsurface flow may strongly affect the dispersal of bacteria in saturated aquifers. We present here an upscaling framework for the transport of motile bacterial in saturated porous media by combining detailed numerical simulations with controlled laboratory experiments.

Bacteria are ubiquitously exposed to fluid flow in natural environments, the human body, and artificial systems. However, the influence of flow on the transport and attachment of bacteria to surfaces and the formation of biofilms remains poorly investigated and understood. We have used microfluidic technology and mathematical modelling to study the role of fluid shear on surface colonization by pathogenic bacteria, such as *Pseudomonas aeruginosa* and *Escherichia coli*, under clinically relevant flow rates. In a first set of experiments, we discovered a novel and counterintuitive phenomenon by which the coupling of motility and shear results in a higher cell concentration near the walls of a channel and consequently in a strong enhancement of bacterial surface attachment compared to quiescent conditions. A crucial step in obtaining these results was the use of a multi-channel microfluidic device, which allowed the simultaneous monitoring of bacterial surface coverage under different shear conditions while avoiding potential confounding factors stemming from variability among cell cultures. In a second set of experiments, we studied the coupling of flow and surface topography by observing the attachment of bacteria to corrugated surfaces. In particular, we show how the topological features of the flow can promote the attachment of bacteria to specific regions of the corrugated surface, which will ultimately influence the formation of biofilms. These results highlight the intimate link between small-scale biological processes and transport in porous media.

68. Mass flux of micropollutants in cities – Challenges in urban hydrogeology

Urban areas are a focus of increasing conflict with regard to water use and water protection. More than half of the world's population (54%) and about 73% of Europeans live in cities (UN 2014). As a direct and/or indirect consequence of human activity, urban water systems are frequently polluted with organic contaminants. Many of those are related to human behaviour and activity, such as pharmaceuticals, personal care products (collectively PPCPs) and endocrine-active substances, and are increasingly found

in urban water systems (Schirmer & Schirmer 2008). However, the fate and the effects of these contaminants in the environment have been widely unknown until now. Consequently, an interdisciplinary project on the assessment of risk of urban water pollution, focussing on PPCPs and endocrine-active substances, has been performed at the UFZ in collaboration with Eawag and other research partners. The aim was to explore new integrated methodologies (including flux calculations as well as chemical and biological investigations) for determining the impact of human activities on urban water systems and on processes within the urban watershed. The overall goal was to assess the risks to humans and the ecosystem, and to support the development of suitable management strategies.

Our research on urban water in large cities like Leipzig and Halle/Saale (Germany) focused on the source, distribution and transport behaviour of micropollutants as indicator substances for the anthropogenic impact on the urban water system (Schirmer et al. 2013). The micropollutants reported here are low concentrations of highly eco-toxic micropollutants including PPCPs and industrial chemicals, most of them can be endocrine disrupters. The concepts presented required a new methodology for assessing human activities on the urban water system and processes among urban watersheds. To this end, we used different approaches in relation to the hydrogeological and hydrodynamic situation of the cities of Leipzig and Halle.

In Leipzig in a first approach, we used a concept of various urban land uses and their influence on the urban water system. At both sites investigated, we demonstrated the use of indicators consisting of hydrological parameters and compoundspecific patterns of complex organic substances. These indicators helped to balance urban substance fluxes and assess urban effects on surface water quality (Musolff et al. 2009).

In a further study, a new methodology to estimate mass flux from leaky sewers was developed. Using average concentrations derived by Integral Pumping Tests (IPT) up- and downstream of a leaky sewer, we calculated two mass flow rates. The difference between mass flow rates up- and downstream yields the mass flow rate per length of the sewer. For chloride, e.g., as wastewater indicator a mass flow rate $7.8 \text{ g m}_{\text{sewer}}^{-1} \text{ d}^{-1}$ was estimated.

The new methodology can be used in field studies to give average exfiltration rates from leaky sewers into groundwater for desired target substances under specific conditions. The results are more reliable than point sampling, because the heterogeneity of the exfiltration from the leaky sewer is overcome by this approach. The obtained values can be used as input for transport models in urban areas. The methodology is not suitable to obtain mass fluxes from a complete sewer network, because the effort for the operation of the pumping wells and the sample analysis in the laboratory is too large to realize it on a larger scale. The applicability of the new methodology also depends on background concentrations and exfiltration rates from the sewer. Due to dilution during pumping, a strong concentration difference between upstream groundwater and the potential source is needed to obtain reliable mass flow rates. Effects of sorption and biodegradation on the concentration distribution downstream of the leaky sewer have to be considered in future work on micropollutants.

In conclusion, identification of anthropogenic impacts on urban waters is often not easy by means of concentration measurements. In many cases, the concentration input is too low and retardation as well as degradation processes mask this influence. More promising is the investigation of the contaminant mass fluxes, although these methods are, by far, more extensive, especially as the water fluxes have to be determined using a model that integrates groundwater, surface water and soil water.

69. Groundwater and low flows in Switzerland – Part 2: Efforts to consider the spatial component of groundwater surface water exchange in a bucket-type hydrological model

Longer dry spells can become critical for water supply and groundwater dependent ecosystems. During these dry spells groundwater is often the most relevant source for streams. Hence, the hydrological behavior of a catchment is often dominated by groundwater surface water interactions, which can vary considerably in space and time. While classical hydrological approaches hardly consider this spatial dependence, quantitative, hydrogeological modeling approaches can couple surface runoff processes and groundwater processes. Hydrogeological modeling can help to gain an improved understanding of a catchment during low flow. However, due to their complex parametrization such hydrogeological models are not applicable for larger catchments or a set of several catchments. In these cases bucket-type hydrological models remain a practical alternative. In our project we try to combine the strengths of both the hydrogeological and bucket-type hydrological models to better understand low flow processes and ultimately to use this knowledge for low flow projections. Bucket-type hydrological models have traditionally not been developed with focus on low flow simulation. One consequence is that interactions

between surface and groundwater are not explicitly considered. Water in bucket-type hydrological models is commonly simulated to flow only in one direction from the groundwater to the stream but not from the stream to the groundwater. This latter flux, however, can become important during low flow situations. We thus further developed the bucket-type hydrological model HBV to simulate low flow situations by allowing for exchange in both directions i.e. also from the stream to the groundwater. The HBV exchange box is developed by using a variety of hydrogeological models as training set. In this way processes that occur in different spatial settings within the catchment are translated to functional relationships and effective parameter values for the conceptual exchange box can be extracted. We show the development as well as the application of the HBV exchange box and compare the simulations to benchmark models without groundwater surface water interaction.

70. 3D geological modelling as a basis for hydrogeological investigations in complex mountain terrain

Physically-based hydrogeological models demand the a priori specification of a large number of uncertain parameters distributed in 3D space. Making reasonable estimations of their values at the outset helps to constrain any subsequent, automated calibration to the realm of physical plausibility. Thus, within a probabilistic framework, the parameter sets deemed “acceptable” are more likely to be useful for prediction than if no prior had been specified, assuming the selected performance criteria are appropriate. Developing predictive capability with respect to mountain hydrology is particularly pressing given the sensitivity of such regions to climatic change. Here, the ongoing development of a 3D geological model for the Nant / Anzeindaz region (Vaud Alps, Switzerland) is described. First, terrain and geological data (surface mapping and interpretive vertical cross-sections) were compiled. Then, in the GeoModeller software, the geological units were interpolated between the known reference points using geostatistics and geological rules. In the forthcoming phase, hydrological parameters shall be assigned to each unit in order to construct a physically-based, fully-coupled groundwater-surface water representation of the catchment using the HydroGeoSphere code. The presence of karstic systems in the region is expected to provide an additional challenge. Ultimately, the hydrogeological model will be employed to explore the data worth of spatially-distributed field measurements obtained using novel techniques (drone surveys of water temperature, dissolved gas concentration measurements to estimate water ages) in the processes of model parameter estimation, calibration and evaluation.

71. Pockmarks in Lake Neuchâtel

Numerous pockmarks were discovered in Lake Neuchâtel in 2012 during the acquisition of new swath bathymetric data (Reusch et al. 2015; Reusch et al. 2016). Most prominent are four ‘giant’ pockmarks (80 to 160 m in diameter) located along the northern lake shore in the extension of NW-SE or NE-SW oriented faults of the Jura Mountains. In addition, numerous (>200) smaller pockmarks (up to 40 m in diameter) are present on the Molasse ridge in the central part of the lake.

One of the giant pockmarks was more closely investigated (Reusch et al. 2015). The temperature and the water oxygen isotopic composition of the sediment suspension filling the ~60 m deep pockmark crater indicates that the water originates from the karst system of the Jura Mountains. Tertiary deposits are absent or minor at the positions of the giant pockmarks, probably allowing vertical flow of artesian groundwater from the Malm aquifer through karstified Cretaceous units into the overlying Quaternary sediments (Pasquier et al. 1999; Ndiaye et al. 2014). Up to now, however, it is unknown if karst water indeed discharges into the lake via the pockmarks and how big that water volume would be. We are therefore installing a monitoring system with temperature, conductivity and pressure probes, as well as an ADCP (Acoustic Doppler Current Profiler) for continuously recording the hydro(geo)logical and sedimentological behavior of the pockmark in relation with meteorological events in the Jura Mountains. This setup should allow assessing potential vertical water flow within the pockmark crater and just above the pockmark surface.

Little is so far known about the origin and characteristics of the numerous smaller pockmarks located on an about 500 m thick package of Molasse covered by 30–40 m of Quaternary deposits (Sommaruga et al. 2012; Reusch 2016; Reusch A. and Gorin G., unpubl. seismic data). Their formation might be related to glacial erosion since some pockmark groups are aligned in a SW-NE orientation consistent with scour marks observable in the swath bathymetric data. Alternatively, fractures in the Molasse could give way to fluid and/or gas flow into the overlying Quaternary deposits. These hypotheses as well as the degree of activity of the pockmarks will be investigated in the future.

25. Tagung der FH-DGGV

72. Die Bedeutung regionaler Betrachtungsweisen für das Verständnis urbaner Grundwassersysteme und lokaler Interaktionsprozesse

Ein nachhaltiger Schutz urbaner Grundwasserressourcen erfordert ein umfassendes Verständnis der lokalen und regionalen, quantitativen und qualitativen sowie geologischen und hydrogeologischen Zusammenhänge. Aufgrund von Nutzungskonflikten im Zusammenhang mit dem Grundwasser- und Trinkwasserschutz konzentriert sich die Forschung stark auf Untersuchungen von lokalen Interaktionsprozessen zwischen Fließgewässern und dem Grundwasser. Die Dynamik regionaler Grundwasserfließregime, welche einen starken Einfluss auf die räumliche Verteilung der Austauschraten zwischen Grundwasserkörpern und den Fließgewässern haben, wird dabei oft vernachlässigt.

Am Beispiel von verschiedenen Forschungsprojekten in der Region Basel (Schweiz) wird die Relevanz von regionalen Grundwasserfließregimen aufgezeigt. Aufgrund der geologischen Gegebenheiten (Falten- und Tafeljura) werden Grundwasserkörper häufig durch Felsstufen getrennt. Dadurch entsteht eine komplexe Abfolge von Flussabschnitten, in denen entweder Grundwasser-exfiltrierende oder Flusswasser-infiltrierende Prozesse dominieren. Der zeitlich und räumlich instationäre Charakter der Interaktionsprozesse kann sich während Hochwasserereignissen entlang der Flussabschnitte verschieben, wobei nicht zwangsläufig vermehrt Flusswasser infiltriert, sondern regionale Prozesse der Druckübertragung und Grundwasserexfiltration dominieren können. Auch kann die Interaktion mit Karst- und Kluftsystemen, insbesondere in den Schottergrundwasserleitern im Bereich des Falten- und Tafeljuras, die Qualität des Grundwassers wesentlich beeinflussen.

Ein erweitertes Verständnis über die regionalen und lokalen Grundwasserverhältnisse liefert Grundlagen bei der Lösungsfindung von Nutzungskonflikten und für eine Festlegung von lang- mittel- und kurzfristigen Zielen hinsichtlich der regionalen Bewirtschaftung von Wasserressourcen.

73. Verwendung radioaktiver Edelgasisotope zur Bestimmung der Austauschdynamik zwischen Grundwasser und Oberflächengewässern

Die Interaktion zwischen Oberflächenwasser (OW) und Grundwasser (GW) ist ein wichtiger hydrologischer Prozess. Sie bestimmt die Abflussdynamik von Fließgewässern und, im Fall von Flusswasserinfiltration, Menge und Qualität des neu gebildeten Grundwassers. Zur Analyse der Austauschdynamik von OW und GW sind Datierungstracer notwendig. Wie schnell GW-OG Systeme auf Klimaveränderungen oder mehrjährige Wetterphänomene reagieren, hängt im Wesentlichen von der mittleren Verweilzeit des Grundwassers ab.

Der GW-OW-Austausch kann mittels Abflussmessungen, Wassertemperatur, Leitfähigkeit oder Radonmessungen studiert werden. Damit lassen sich Ort und Menge von Grundwasserzuflüssen bestimmen. Zur Datierung des zuströmenden Grundwassers können ^3H , SF_6 , CFCs sowie ^4He Messungen herangezogen werden, welche Zeitskalen von einigen Monaten bis ca. 60 Jahren abdecken. Dazu müssen flussnahe GW Messstellen vorhanden sein. Einfacher ist eine in-situ Beprobung des Flusswassers. Hierbei müssen aber Gasaustauschprozesse mit der Atmosphäre berücksichtigt werden. Außerdem müssen bei allen diesen Tracern (außer ^3H) zusätzlich die Infiltrationsbedingungen des GWs bestimmt werden und besonders bei CFCs ist oft auch Kontamination ein Problem. Bei der Datierung von OW-Infiltration ins Grundwasser sind die relevanten Zeitskalen oft so kurz (Tage bis Monate), dass oben erwähnte Tracer nur beschränkt einsetzbar sind.

Diese Präsentation soll aufzeigen, wie ein Teil der angesprochenen Schwierigkeiten mit der Verwendung radioaktiver Edelgasisotopen umgangen werden kann. Dazu wird zuerst ein Überblick gegeben über die Palette an radioaktiven Edelgasisotopen zur Altersbestimmung von Grundwasser (^{222}Rn , ^{37}Ar , ^{85}Kr , ^{39}Ar , ^{81}Kr). ^{222}Rn mit einer Halbwertszeit von 3.8 Tagen ist zum Beispiel für Zeitskalen von einigen Tagen geeignet, während ^{37}Ar mit einer Halbwertszeit von 35 Tagen vielversprechend ist für Zeitskalen von einigen Monaten. Anschließend wird an konkreten Anwendungsbeispielen an der Fischa-Dagnitz bei Wien und Rötenbach und Emme in der Schweiz exemplarisch illustriert, wie diese Tracer zur Bestimmung der Austauschdynamik zwischen Oberflächengewässern und Grundwasser eingesetzt werden können.

74. Grundwassertemperaturen im Stadtgebiet von Basel (Schweiz) – Nutzungskonflikte und Lösungsansätze für urbane Wärmeinseln

Die Temperatur des oberflächennahen Untergrundes in urbanen Gebieten wird durch zahlreiche natürliche und anthropogene Faktoren beeinflusst. Hierzu zählen beispielsweise die Versiegelung von Flächen, offene oder geschlossene geothermische Anlagen, Tunnelbauten, Kellereinbauten, die ins Grundwasser reichen, Parkhäuser, Leitungsnetze und Abwasserkanäle im Untergrund (vgl. Benz et al., 2015; Epting et al., 2013). Aktuell steigt die Nachfrage nach thermischer Nutzung von oberflächennahem Grundwasser aus dem Schotteraquifer im Stadtgebiet von Basel stark an. Diese steigende Nachfrage kann zu Nutzungskonflikten mit anderen Grundwassernutzungen, Untergrundstrukturen, Altlasten und dem Grundwasserschutz führen und erfordert daher eine effiziente und nachhaltige (thermische) Bewirtschaftung des oberflächennahen Untergrundes. Gemäß der Gewässerschutzverordnung der Schweiz (GSchV, 2015) und der „Wegleitung Grundwasserschutz“ (BUWAL, 2004) darf die Grundwassertemperatur durch die thermische Nutzung 100 m im Abstrom des Rückgabestandortes um höchstens 3 K im Vergleich zum „natürlichen“ Zustand verändert werden. Im Kanton Basel-Stadt wird hierbei momentan von einer „natürlichen“ Grundwassertemperatur von 12 °C ausgegangen. Derzeit werden aber in stark urbanisierten Regionen von Basel bereits Grundwassertemperaturen von bis zu 18 °C im Jahresmittel gemessen. Etwa 50% der Messstellen, die im städtischen Gebiet liegen, wiesen in den Jahren 1994 bis 2013 eine Grundwassertemperatur von über 12,9 bis 14,4 °C im Jahresmittel auf.

Es werden daher Instrumente benötigt, die den Ist-Zustand der Grundwassertemperaturen erfassen, sowie Szenarien zu verschiedenen Einflüssen auf die Temperaturentwicklung in urbanen Grundwasserkörpern abbilden können (z.B. Temperatur-Monitoring-Systeme und numerische Modelle der Grundwasserströmung und des Wärmetransportes). Analytische Modelle werden in Kombination mit tiefendifferenzierten Temperatursensoren verwendet, um den Einfluss des Wärmeeintrags über die Atmosphäre in den Untergrund abzuschätzen. Die Simulationsergebnisse von regionalen, numerischen Wärmetransportmodellen ermöglichen es den Einfluss von bestehenden oder zukünftigen thermischen Grundwassernutzungen oder Einbauten ins Grundwasser auf das thermische Grundwasserregime unter instationären Bedingungen und mit räumlich variablen Aquiferparametern abzuschätzen oder für verschiedene Teilgebiete Jahresbilanzen des Wärmetransportes zu berechnen.

75. Stabile Wasserisotope als Tracer der Oberflächenwasser-Grundwasser-Interaktion

Die stabilen Isotope des Wassermoleküls, Deuterium und Sauerstoff-18, sowie der entsprechende Deuterium-Überschuss markieren den Wasserkreislauf und seine zeitlichen Veränderungen. Im Rahmen der Nationalen Grundwasserbeobachtung NAQUA, Modul Wasserisotope ISOT, erhebt das Bundesamt für Umwelt BAFU in der Schweiz seit 1992 Isotopendaten im Niederschlag (13 Stationen) und im Oberflächenwasser (9 Stationen). Die Isotope wurden 2007-2013 an den 50 Messstellen des NAQUA-Moduls TREND (Grundwasserqualität) analysiert.

Das Isotopensignal im Niederschlag überträgt sich auf die Oberflächengewässer und das Grundwasser. Anhand der stabilen Isotope lässt sich somit überprüfen, ob und wie die lokale Information einer Niederschlagsstation durch die unterschiedlichen Vorgänge bei der Abflussbildung eines Fließgewässers modifiziert wird. Dies hat Einfluss auf die saisonalen Schwankungen im Flusswasser. Die stabilen Wasserisotope stellen somit einen natürlichen Tracer dar, um in Flusstalebenen die Oberflächenwasser-/Grundwasser-Interaktion zu beschreiben. In Abhängigkeit von den Grundwasserverhältnissen kommt es zu jahreszeitlich und räumlich wechselnden In- bzw. Exfiltrations-Verhältnissen entlang der Flüsse mit jeweils charakteristischen Isotopensignaturen im Flusswasser und Grundwasser. Viele Flüsse in der Schweiz haben ein höher gelegenes Einzugsgebiet als das lokale Grundwasser, wodurch im Grundwasser anhand der stabilen Wasserisotope der Anteil des Flusswasser- und des Niederschlagswasserinfiltrats unterschieden werden kann.

Im Raum Bern zum Beispiel ist der Unterschied im Sauerstoff-18 ($d^{18}O$) zwischen dem Fluss Aare und dem Grundwasser mit 2 bis 3 ‰ gross genug, um den jahreszeitlichen Verlauf der Wechselwirkung zwischen Flusswasser und flussnahe Grundwasser verfolgen zu können. Die stabilen Wasserisotope werden hier im Grundwasser an der Messstelle Kiesen beobachtet. Der Förderbrunnen liegt in den Aareschottern mit hydraulischer Anbindung an den Fluss. Die den Grundwasserleiter bildenden Ablagerungen sind hier rund 30 Meter mächtig. Sie weisen eine mittlere Durchlässigkeit von $4,2 \cdot 10^{-3}$ m/s und eine Porosität von 15 % auf. Die mittlere Fließgeschwindigkeit des Grundwassers liegt zwischen 8 und 15 m/Tag. Die saisonale Dynamik im $d^{18}O$ ist in der Aare und im Grundwasser ähnlich, wobei die negativen d-Werte des Winterniederschlags durch die hohe Bedeutung von Schmelzwasser in den Sommer verschoben sind. Diese Übereinstimmung im Gang der Isotopensignatur zeigt, dass das

Grundwasser in diesem Bereich – v.a. im Sommer während der Schnee- und Gletscherschmelze – größtenteils durch Flusswasserinfiltration gespeist wird. Die anhand der stabilen Isotope bestimmten jahreszeitlichen Anteile an Fluss- und Niederschlagswasserinfiltrat stimmen gut mit den Ergebnissen eines grossangelegten Tracerversuchs überein. Während extremer Trockenperioden oder Hochwasserspitzen sind die Mischungsverhältnisse jedoch deutlich verändert, was sich dann auch in der abweichenden Isotopensignatur widerspiegelt.

76. Simulation des Transports organischer Schadstoffe mittels reaktiver Fluoreszenztracer

Fluoreszenztracer sind ein gängiges Mittel für die Untersuchung des Stofftransports im Untergrund. Allerdings werden dabei in den seltensten Fällen die tatsächlichen Stoffeigenschaften vermeintlich konservativer Tracer berücksichtigt. So kann es mitunter zu Fehlannahmen bei der Modellierung des Stofftransports kommen, wenn etwa Sorptionsprozesse nicht als solche erkannt und differenziert sind. Andererseits kann man sich das Manko nicht-konservativer Tracer zunutze machen, indem diese bewusst zur Simulation des Verhaltens reaktiver Schadstoffe herangezogen werden.

Für einen solchen Ansatz muss das Verhalten der eingesetzten Markierstoffe gut charakterisiert und mit dem des jeweiligen Schadstoffes abgeglichen werden. Dies geschieht mittels Laborversuchen unter Verwendung der relevanten Festphase. Der getestete Tracer kann dann im Gelände als Ersatz für einen spezifischen organischen Schadstoff fungieren. Die Ergebnisse eines Tracerversuchs liefern wiederum die nötigen Informationen, um im Rückschluss eine effektive Retardation des Schadstoffes im Untergrund zu modellieren.

Im vorliegenden Fall wurden verschiedene Fluoreszenztracer mit diversen Pflanzenschutzmitteln und Kohlenwasserstoffen verglichen. Dabei kamen v.a. solche Schadstoffe zum Einsatz, bei denen davon auszugehen ist, dass sie aufgrund ihrer nur mässigen Sorption mitunter bis ins Grundwasser verfrachtet werden. Nach einem ersten Screening auf Basis von Schüttelversuchen wurden ausgewählte Stoffe im Säulenversuch getestet und deren Retardationsfaktoren berechnet. In beiden Fällen wurde Aquifermaterial des Untersuchungsgebietes verwendet.

Die Retardation im Grundwasserleiter selbst wurde dann mittels Dipol-Tracerversuch auf lokaler Skala bestimmt. Untersucht wurde ein Lockergesteins-Grundwasserleiter im Schweizer Mittelland. Mehrere Fluoreszenztracer kamen zum Einsatz (u.a. Uranin, Rhodamin WT, Amidorhodamin G), welche simultan ins Grundwasser eingegeben und bei natürlichem Gradienten über eine Fließstrecke von 5 m in einem zweiten Piezometer beprobt wurden. Analog zum Säulenversuch zeigte sich – bei vergleichbarer dominanter Fließgeschwindigkeit von etwa 0,2 m/h – ein signifikant verzögerter Durchbruch der Fluoreszenztracer in Bezug auf den Referenztracer Bromid.

Anhand des Pflanzenschutzmittels Chloridazon kann beispielhaft aufgezeigt werden, wie auf diese Weise die Retardation als Folge der Wechselwirkung mit dem Aquifermaterial modelliert und quantifiziert werden kann. Dies geschieht in situ unter ungestörten Bedingungen, ohne dass die Schadstoffe für das Experiment eingebracht werden müssen – was sich im Hinblick auf den Gewässerschutz in der Regel auch verbietet. Auch können diese Ergebnisse auf andere, grösserskalige Markierversuche im selben Grundwasserleiter übertragen werden. Dieser Ansatz ermöglicht ein besseres Verständnis vom Transport spezifischer organischer Schadstoffe, für den gerade hinsichtlich Retardation innerhalb des Grundwasserleiters noch Wissensbedarf besteht.

77. Mikrobielle und faunistische Ansätze zur ökologischen und hydrodynamischen Charakterisierung der Grundwasserleiter

Ökologische Aspekte stellen nicht nur ein weiteres Element in der Charakterisierung von Grundwasserressourcen dar, sondern können auch hydrodynamische Prozesse abbilden oder als Indikator für die Wasserqualität herangezogen werden. So ist in der schweizerischen Gewässerschutzverordnung explizit festgehalten, dass die Biozönose unterirdischer Gewässer „naturnah und standortgerecht“ sowie „typisch für nicht oder nur schwach belastete Gewässer“ sein soll.

Vor diesem Hintergrund wurden in der Schweiz im Rahmen der Nationalen Grundwasserbeobachtung NAQUA zwei Pilotstudien durchgeführt. Damit sollte abgeklärt werden, wie sich der Zustand der Grundwasserbiozönose in Bezug auf natürliche Mikroorganismen und auf Grundwasserfauna (Makrozoobenthos) mit einfachen Ansätzen beschreiben lässt.

Bei den mikrobiologischen Untersuchungen an 50 für die Grundwasserverhältnisse des Landes repräsentativen NAQUA-Messstellen stellte sich heraus, dass insbesondere die Gesamtanzahl an Bakterienzellen in einer Grundwasserprobe – die mittels Durchflussszytometrie bestimmte Zellzahl – einen für die Art des Grundwasserleiters typischen Wertebereich aufweist. Insgesamt wurden

Größenordnungen von 10^3 bis 10^6 Zellen pro mL gemessen (Kötzsch & Sinreich 2014). Dabei weisen Lockergesteins-Grundwasserleiter in der Regel die geringeren, Kluft- und v.a. Karst-Grundwasserleiter eher höhere Zellzahlen auf. Insbesondere für Karst- Grundwasserleiter korreliert die Zellzahl mit dem generellen hydrodynamischen Verhalten, also auch der Vulnerabilität des Systems (Sinreich et al. 2014).

Für den faunistischen Ansatz wurden 8 ausgewählte NAQUA-Quellmessstellen zur Erfassung der Driffauna beprobt. Die Zusammensetzung der mit insgesamt 40 Arten reichhaltigen Grundwasserfauna spezifiziert nicht nur deutlich die einzelnen Grundwasservorkommen, sondern spiegelt auch die hydrodynamischen Eigenschaften der entsprechenden Festgesteins- Grundwasserleiter wider. Wenig vulnerable Systeme (geringe Schwankungen der Schüttung und der physiko-chemischen Parameter) zeichnen sich durch einen hohen Anteil an echter Grundwasserfauna – also an stygobionten Arten – und durch geringe Abundanzen aus. Vulnerable, dynamische Karst-Grundwasserleiter zeigen dagegen ein Übergewicht an nichtstygobionten Arten hoher Abundanz.

Mit beiden Ansätzen können die Grundwasserleiter ökologisch beschrieben und im Kontext der hydrodynamischen Verhältnisse klassifiziert werden. Abweichungen von den so definierten charakteristischen Typsituationen hinsichtlich Zellzahl und/oder Anteil stygobionter Arten weisen dabei auf eine Beeinträchtigung der naturnahen Grundwasserbiozönose hin. Ausserdem lassen die ökologischen Parameter in den durchgeführten Studien Rückschlüsse auf die hydrogeologischen Eigenschaften zu, insbesondere zum Grad des Oberflächeneinflusses bei Festgesteins-Grundwasserleitern. Inwieweit dies vorrangig von den hydrologischen oder den ökologischen Faktoren bestimmt wird, bedarf weiterer Abklärungen.

78. Particle retention on granite as a function of residence time and particle size using a synthetic fracture flow cell

The interaction of monodisperse fluorescent carboxylated polystyrene particles (25 nm and 1000 nm in diameter) with a cut granite surface (Grimsel granodiorite; Switzerland, (Schäfer et al. 2012) and with acrylic glass is investigated both experimentally and numerically focusing on the effect of residence time, colloid size, collector material and fracture orientation on particle retention. Long particle residence time between 1 h and 24 h are accomplished by stopflow experiments. Additionally to the colloid experiments, conservative solute tracer (Amino- G) experiments are performed to characterize the flow and transport conditions. A cylindrical parallel plate type fracture flow cell (diameter 38 mm; aperture 0.75 mm) has been designed for the transport experiments. The artificial fracture of the flow cell is sandwiched between the acrylic glass and/or the granite. At the flow cell outlet the breakthrough curves are obtained continuously by means of fluorescence spectroscopy. All experiments are conducted at pH 5 under low ionic strength (1 mM NaCl). Using colloid probe technique and atomic force microscopy (AFM) special surface information of the granite and acrylic glass discs are obtained in dependence of the particle size attached to the cantilever. Results show earlier first arrivals and more pronounced tailings in the measured breakthrough curves for both colloid types compared to the conservative tracer. A positive correlation between residence time and particle retention is observed in all experiments. Using 1000 nm particles, the results show that the fracture material has no significant effect on particle retention. For the same fracture orientation the increase in particle retention is similar for both acrylic glass and granite disc. However, in experiments with a horizontal fracture orientation the particle retention is higher than in experiments with vertical orientation. In contrast to that, results of experiments using 25 nm particles show an effect of the collector surface material on particle retention and no effect of fracture orientation, respectively. The increase of particle retention with time was higher in experiments with inserted granite disc than with inserted acrylic glass disc. These findings lead to the assumption that the 1000 nm particles undergo sedimentation and are not affected by the existent surface roughness due to the bigger particle size. On the contrary, 25 nm particles will not undergo sedimentation within 24 h but they are affected by surface inhomogeneity, such as surface roughness. For example, an increased roughness will direct enhance diffusivity of the smaller particles (25 nm) into scratches or cracks on granite/acrylic glass surface compared to bigger particle sizes (1000 nm). These experimental findings are corroborated by the results of AFM measurements and by 2-D numerical simulations using the software COMSOL.

79. Identifizierung des biologischen Abbaus von chlorierten Kohlenwasserstoffverbindungen in gering durchlässigen Schichten mittels Stoffspezifischer Isotopen Analyse (CSIA)

Durch die unsachgemäße Verwendung und Entsorgung von chlorierten Lösungsmitteln treten diese häufig als Schadstoffe im Untergrund auf. Aufgrund der hohen Dichte und der tiefen Viskosität sind chlorierte Lösungsmittel sehr mobil und migrieren oft bis in die gesättigte Zone. Dort akkumulieren sie

sich an gering durchlässigen Schichten und diffundieren in diese hinein, was zu einer langfristigen Kontamination der angrenzenden Grundwasserleiter führen kann. In gering durchlässigen Schichten treten jedoch häufig reduzierende Bedingungen auf. Dies kann zu einem biologischen Abbau der chlorierten Kohlenwasserstoffverbindungen führen, was die Gefahr einer langfristigen Kontamination der angrenzenden Grundwasserleiter vermindert. Die Stoffspezifische Isotopen Analyse (CSIA) wird zunehmend für die Quantifizierung des biologischen Abbaus von organischen Schadstoffen in Grundwasserleitern verwendet. Die Methode benutzt Isotopeneffekte, welche durch den biologischen Abbau verursacht werden. Im Gegensatz zu Aquiferen wurde jedoch noch nicht untersucht, ob CSIA auch in gering durchlässigen Schichten zur Quantifizierung des biologischen Abbaus verwendet werden kann. Um diese Wissenslücke zu schliessen wurden mehrere detaillierte Kohlenstoff (C) und Chlor (Cl) Isotopenprofile von chlorierten Kohlenwasserstoffverbindungen in einem tonigen Aquitard gemessen. Der Aquitard wurde vor 14,5 Jahren durch eine kontrollierte Lösungsmittelinjektion in das angrenzende Aquifer künstlich kontaminiert. Im Aquitard konnte eine starke Verschiebung der Isotopenverhältnisse hin zu mehr leichten Signaturen (z.B. 23‰ for C Isotopen in TCE) mit zunehmender Tiefe beobachtet werden. Dies lässt auf das Vorhandensein von biologischem Abbau im Aquitard schliessen. Weiter konnten, durch die Verwendung von numerischen Modellierungen, Abbauraten für die chlorierten Kohlenwasserstoffverbindungen bestimmt werden. Unsere Resultate zeigen, dass CSIA auch in gering durchlässigen Schichten zur Quantifizierung des biologischen Abbaus von organischen Verbindungen verwendet werden kann. Weiter zeigen unsere Ergebnisse, dass Isotopenprofile sensibler als Konzentrationsprofile auf unterschiedliche Abbaubedingungen in einem Aquitard reagieren. Deshalb sind Isotopeninformationen eine wichtige Ergänzung zu den Konzentrationsdaten, um den Abbau von chlorierten Kohlenwasserstoffverbindungen in gering durchlässigen Schichten nachweisen zu können.

80. Mehrwert von Stoffeinsatzerhebungen bei der Interpretation von Spurenbelastungen im Grundwasser

Spurenstoffe werden im Rahmen der regulären Messkampagnen der Nationalen Grundwasserbeobachtung NAQUA ein- bis viermal pro Jahr an den Messstellen analysiert. Damit wird die Grundbelastung im Grundwasser erfasst. In der Pilotstudie „Dynamik Pflanzenschutzmittel“ wurde untersucht, ob signifikante Konzentrationsspitzen von Pflanzenschutzmitteln zwischen den üblichen Beprobungszeitpunkten auftreten. Dazu wurden in zwei aufeinanderfolgenden Jahren vierzehn ausgewählte Messstellen in hoher zeitlicher Auflösung beprobt. Um die Herkunft der Pflanzenschutzmittel (PSM) im Grundwasser zu identifizieren, wurde zusätzlich der Stoffeinsatz an Pflanzenschutz- und Düngemitteln in den Einzugsgebieten dieser Messstellen erhoben.

In den Grundwasserproben wurden mehr als 80 PSM-Wirkstoffe und - Abbauprodukte analysiert, wovon ein Grossteil in keiner der Messstellen nachgewiesen wurde. Mithilfe der Stoffeinsatzerhebungen konnte unterschieden werden, in welchen Einzugsgebieten diese Stoffe im Untersuchungszeitraum gar nicht appliziert wurden und in welchen dies mit einem Abbau bzw. Rückhalt im Untergrund zusammenhängen muss. 25 Substanzen wurden in mindestens einer Probe nachgewiesen, wobei das Auftreten an den jeweiligen Messstellen je nach Substanz eher vereinzelt oder regelmässig erfolgte. Eine hohe Dynamik zeigten v.a. nicht-persistente Stoffe, die nur dann ins Grundwasser gelangten, wenn sie zeitnah vor der Beprobung bzw. in Verbindung mit Grundwasserneubildungsereignissen ausgebracht wurden (z.B. Bentazon, Diazinon). Andere Stoffe dagegen traten im Grundwasser auf, obwohl sie im Zeitraum der Untersuchungen in den Einzugsgebieten der Messstellen gemäss Stoffehebung gar nicht appliziert wurden. Diese Stoffe wurden vermutlich weit früher ausgebracht und zeigen, dass einzelne einmal ins Grundwasser gelangte PSM aufgrund ihrer Langlebigkeit über Jahre im Untergrund gespeichert und nachgewiesen werden können (z.B. Atrazin, Simazin, Abbauprodukte von Chloridazon).

Mithilfe der Ergebnisse der Stoffeinsatzerhebungen und unter Berücksichtigung der Stoffeigenschaften der PSM kann die Dynamik im Auftreten zum Teil erklärt sowie exemplarisch aufgezeigt werden, aus welchen Speichern des Systems die Spurenstoffe möglicherweise an die Messstelle gelangen. So konnten weniger mobile Substanzen (z.B. Glyphosat) an Messstellen in Lockergesteins-Grundwasserleitern nicht, wohl aber in Karst-Grundwasserleitern nachgewiesen werden. Dort spielt aufgrund der unterschiedlichen Vulnerabilität im Einzugsgebiet der Ort der Ausbringung eine entscheidende Rolle. Zudem gelangten manche Substanzen nur sporadisch nach Niederschlägen an die Messstelle, auch wenn sie nicht unmittelbar davor ausgebracht worden waren, was auf einen signifikanten Speicher in der ungesättigten Karstzone hinweist.

Stoffeinsatzerhebungen können so wichtige Informationen zu Eintragsort und -zeit einzelner Spurenstoffe in den Grundwasserleiter liefern und damit zu einem verbesserten System- und Prozessverständnis beitragen.

81. Projet Chlorokarst: des capteurs passifs intégratifs pour détecter les hydrocarbures chlorés de sites pollués en milieu karstique

La mise en évidence de l'effet de sites pollués implantés en milieu karstique sur la qualité des eaux souterraines constitue un véritable défi, compte-tenu des caractéristiques spécifiques de ce type d'aquifère. Les apports de substances sont par exemple soumis à de forts effets de dilution et de grandes fluctuations, difficiles à capter à partir de prélèvements ponctuels des eaux tels que classiquement réalisés. A la complexité des écoulements en milieu karstique s'ajoutent celle des substances chimiques transportées : les hydrocarbures chlorés sont en effet particulièrement difficiles à détecter, notamment en raison de leur densité plus grande que l'eau et de leur attitude à se volatiliser.

Comme les sites pollués aux hydrocarbures chlorés représentent 70% des sites potentiellement pollués recensés en Suisse, et parmi ceux-ci, 16,7% sont implantés en milieu karstique, L'Office fédéral de l'environnement (OFEV) finance un projet de développement méthodologique et technologique dédié spécifiquement à ce thème (projet Chlorokarst). Dans ce cadre, des expérimentations ont été menées pour tester la performance de capteurs passifs intégratifs.

L'intérêt de ces capteurs est de permettre d'analyser les concentrations en substances chimiques durant une longue période d'exposition, en s'affranchissant de l'effet des fluctuations observées classiquement en milieu karstique. Les capteurs constituent une alternative aux prélèvements ponctuels, dont les chances de réussite pour mettre en évidence une pollution sont faibles, et aux prélèvements automatiques d'échantillons, dont le coût est élevé.

Trois types de capteurs ont été sélectionnés pour les besoins du projet Chlorokarst : des dosimètres en céramique, commercialisés par la société IMW (D), des TIPS, commercialisés par la société AGI (USA), et des Sorbicells commercialisés par la société Sorbisense (DK). Les critères de sélection appliqués étaient les suivants :

- Accumulation des hydrocarbures chlorés en priorité
- Exposition sur de longues périodes : 2 à 3 mois
- Détection de faibles et fortes concentrations
- Equipement de sources ou de forages piézométriques
- Résistance aux conditions d'écoulement des milieux karstiques
- Simplicité d'utilisation
- Dispositifs commerciaux (pas de nécessité de fabrication artisanale)

Les capteurs ont été testés dans des sources et des piézomètres de différents terrains d'essai karstiques, présentant des concentrations en hydrocarbures chlorés contrastées.

Durant l'exposé, les procédures expérimentales, les résultats d'analyses, les contraintes d'utilisation et les types de capteurs à retenir en fonction des caractéristiques des sites et des objectifs à atteindre seront présentés.

82. Projet Chlorokarst: investiguer et évaluer les sites pollués aux hydrocarbures chlorés implantés en milieu karstique

Les sites pollués aux hydrocarbures chlorés représentent 70% des sites potentiellement pollués recensés en Suisse, et parmi ceux-ci, environ 17% sont implantés en milieu karstique. L'investigation et l'évaluation de l'impact de ces sites sur les eaux souterraines posent de nombreux problèmes techniques et réglementaires.

Les sites pollués implantés en milieu karstique présentent en effet des caractéristiques très différentes de celles de sites pollués implantés en milieu poreux. Lorsqu'elles ont migrées, les sources de pollution sont très difficiles à localiser ; les concentrations en substances aux exutoires des bassins versants, points d'observation faciles d'accès de la qualité des eaux souterraines, sont soumises à de forts taux de dilution et de grandes fluctuations : la pollution observée en un exutoire peut provenir de plusieurs sites pollués du bassin versant : un même site pollué peut contribuer à la pollution de plusieurs exutoires.

Les moyens d'investigation classiques utilisés pour évaluer l'impact des sites pollués sur les eaux souterraines, tel que le prélèvement d'un échantillon ponctuel dans un forage situé en aval hydraulique proche d'un site pollué, s'avèrent inopérants dans ce contexte. La réglementation suisse relative à la gestion des sites pollués (ordonnance sur les sites contaminés du 26 août 1998), conçue initialement pour les milieux aquifères poreux, se révèle ainsi inadaptée.

Dans ce cadre, l'office fédéral de l'environnement (OFEV) finance un projet de développement méthodologique et technologique (projet Chlorokarst). Initié en 2014, le projet vise à 1) élaborer un processus d'évaluation des sites pollués sur karst dans le cadre réglementaire en vigueur, 2) élaborer une démarche d'investigation des sites pollués sur karst et 3) tester et déployer une sélection de moyens d'investigation sur 3 terrains d'essai. Le projet est suivi par un groupe de travail regroupant les Autorités cantonales et fédérales concernées par la problématique, et fait l'objet de rapports publics de restitution des résultats.

Les objectifs, l'état d'avancement du projet et les résultats attendus seront présentés dans le détail dans le poster.

83. Integrative passive samplers to detect chlorinated hydrocarbons contamination in karst

A large number of former industrial sites and landfills are responsible for aquifer contamination with chlorinated solvents in Switzerland. 16.7 % of them are located in karstic areas. But, the detection of such contaminations in springs or oreholes can be difficult because concentrations are often varying highly and rapidly. Measuring low concentrations during a few measurement campaigns is not sufficient to prove the absence of contamination. To overcome this difficulty, the performances of integrative passive samplers were investigated in the frame-work of the Chlorokarst project funded by the Swiss federal office for the environment. Three types of devices were tested. They allow measuring time weighted-average concentrations of pollutants over long periods. Experiments in karst springs show that the Sorbicell samplers developed by the Sorbisense company were capable of measuring average concentrations over a 2 months- period, matching the averages of the concentrations measured in daily snapshot samples collected with an automatic sampler taken as reference. Equipment of the springs with the Sorbicell devices was found to be easy. More difficulties were encountered when exposing the Sorbicell samplers in piezometers, because of the impact of the high fluctuations of the water column above the sampler on the filling rate. Adaptation of the device was thus carried out with the manufacturer, to reduce the effect of the water column, using air-vents and cartridges of high resistance. Satisfactory results were then obtained in terms of sampling rate. Uncertainty still remains on the estimated concentrations provided by the system since they can vary by a factor of two depending on how the volume of water that passed through the cartridge is estimated. Two other types of passive samplers were tested, the ceramic dosimeters developed at the University of Tübingen and commercialized by IMW, and the Tips developed by the AGI company. They were both found to be inappropriate to estimate reasonably well the mean concentrations in chlorinated solvents in these types of environment, even if they can still be used to detect the presence of contamination.

84. Hazard based water quality management of Karst springs – Combining the aquifer base gradient approach and the concept of dynamic vulnerability

Rapid changes in spring water quality in karst areas due to fast recharge of bacterially contaminated water are a major concern for drinking water suppliers and users. Karst aquifers have complex and distinct characteristics, which make them very different from other aquifers. They are extremely heterogeneous and anisotropic and therefore particularly vulnerable to contamination. In view of these special characteristics, some of the methods such as mapping methods used for vulnerability assessment have been specifically designed for karst environments. However, mapping approaches hardly consider the temporal variability (event and seasonal) and hydrological dependences of vulnerability. Previous studies (Butscher and Huggenberger, 2007) clearly show the non-stationary character of vulnerability, which cannot be shown on static vulnerability maps. Furthermore, the various indices used to generate vulnerability maps are largely conceptual, and thus subjective.

Butscher and Huggenberger (2007) related the concept of the aquifer base gradient approach and information on catchment characteristics derived from 3D geological models, as the geometry of aquifers and aquitards as well as their displacements along faults, to the general concept of vulnerability assessment. Furthermore, the temporal variation in the vulnerability, depending on rainfall events and overall recharge conditions, have been assessed and quantified using the Dynamic Vulnerability Index (DVI; (Butscher et al., 2011)). DVI corresponds to the ratio of conduit to diffuse flow contributions to spring discharge. To evaluate model performance with respect to predicted vulnerability the simulation

results are discussed together with high-resolution monitoring data of physical parameters and data of spring-water samples which were analyzed for *Escherichia coli*, enterococci, *Clostridium perfringens*, and heterotrophic plate count bacteria as well as data from high resolution flow cytometry during and after several rainfall events.

The objective of this work is to facilitate a sustainable regional planning of water resources in karst areas by providing a conceptual framework for an integrative vulnerability assessment. A combined 3D geological modelling, monitoring and lumped parameter modeling approach is proposed, taking into account both spatial and temporal aspects of karst groundwater vulnerability. The conceptual framework comprises the delineation of recharge areas, monitoring of physical and microbial parameters, numerical flow and transport modeling and the integration of information into a spring protection and management scheme.

For a series of Karst springs in northwestern Switzerland (tabular and folded Jura) the time series of physical and microbial parameters were compared with the calculated DVI's for different springs using basically the same model structure. For a number of springs we observed a good agreement between the calculated and monitored spring discharge. For those cases, where no good agreement between calculated and monitoring data could be achieved, the model structure could be revised to account for the larger complexity of certain Karst systems, e.g. considering further hydrological processes as infiltrating streams or karst system compartments which only actively contribute to spring discharge during certain hydraulic conditions.

To conclude, the results of the monitored parameters and modelling approaches generally allow accessing the time dependence of karst groundwater vulnerability. The DVI approach provides a quantitative basis for drinking water management and for regional planning. The approach is the basis for the application of more flexible and differentiated spring protection and management concepts. Water treatment can be optimized according to the specific hydrogeological conditions. Furthermore, the results and comparison of system behavior of different Karst springs allowed to derive the information relevant for setting up hazard-based spring-water protection concepts and to include the influence of catchment-scale activities. However, the variability of the hydrological data demonstrate, that for certain Karst springs longer time series, which also cover extreme hydrological events, are required to fully understand the system behavior.

85. Karst modelling challenge

Karst is known to be highly heterogeneous, i.e. one of the most difficult media to be modelled. Modelling techniques are getting more and more sophisticated. However, do they provide right results for the right reasons?

The idea of the Karst Modelling Challenge is to invite a selection of research groups and private companies to model various dynamics of the Milandre karst system (Swiss Jura), for which many data of various kinds are available, and to compare and discuss results given by the respective modelling tools and approaches. Review papers should result from the project. A KMC price (5'000 €) and distinction will be awarded every two years at Eurokarst Conferences.

Three main modelling targets are defined for starting the project: modelling the hydrology (i.e. the rain-discharge relationship), modelling the hydrodynamics (i.e. the evolution of flow and heads within the aquifer), and modelling solute transport (i.e. the evolution of mass-fluxes and concentrations of a tracer within the aquifer). Further aspects of karst modelling (e.g. particle transport, heat transfer, isotopes, speleogenesis, etc.) are not planned at that stage but could be added later on along the project.

A field trip to the test-site will be organized during Eurokarst 2016 for a presentation of different aspects. A basic set of data (e.g. 5 years of data) will be provided to each participant, who is expected to deliver his best model based on this set. The validation (or the consistency) of the delivered models will be made first by simulating three further years, and by comparing results to the measured data. We will also look at other data than the ones given in the basic dataset (e.g. heads in boreholes outside the dataset).

No funding is available for starting the project. Depending on participation, funding could be organized for meetings, for further field data acquisition or even for modelling development.

86. Effect of cave ventilation on karst water chemographs

The data briefly presented in this paper indicate that the degree of ventilation of underground flow paths, inducing more or less degassing of the CO₂ dissolved in water, can induce a significant variation in the water mineralization of a karst spring. The presented data also provides indications about further

conditions controlling time variations of carbonate dissolution parameters: 1) variations in the mixing ratio of two or several waters (from distinct subcatchment areas) with distinct chemistry; 2) land-use with distinct soils (i.e. pCO_2) in the catchment area, which is also often related to the elevation of the various parts of the catchment area; 3) Localized and quick infiltration vs diffuse and slow infiltration through soils. It must be mentioned here that both concentrations and fluxes of CO_2 within all parts of karst systems must be considered in order to understand water chemographs. Both are mainly controlled by soil CO_2 production and by water-recharge flux. Further models and dedicated field data are required to better quantify CO_2 concentration and fluxes in karst systems.

87. KARSYS, for a better management of karst groundwater in Switzerland

Thanks to the Swisskarst project, which was funded by the National Research Program 61 (2010-2013), the KARSYS approach was developed and promoted all over Switzerland. Several cantons were involved in the project and asked for an application over their karst territories to address various issues, i.e. evaluation of groundwater resources, regulation of geothermal heat-pumps, or evaluation of underground hydropower potential. Late 2015, nearly one third of the Swiss karst regions have been processed, providing the most complete documentation of karst hydrogeological systems in Switzerland. Nowadays, the documentation process is still ongoing and, in a parallel way, the resulting features and information are being transferred to the Geo-platform of the Swiss Confederation (map.geo.admin.ch). This documentation will be accessible for a wide audience and will contribute to consider specificities of karst in most management projects. The talk will present advantages of the KARSYS approach through various case-studies.

88. Karst groundwater vulnerability: quantitative definition of a protection unit by correlating standardized tracer test results and mapping criteria

Tracing experiments are recognized as an essential tool for validating vulnerability mapping in karst terrains. The proposed approach first includes the development of a standardized artificial recharge scenario for conducting and comparing tracer test in karst environments. Based on accurate discharge and tracer concentration monitoring at the karst system discharge area, non-reactive tracer attenuation, mass recovery and mean transit time over the duration of the main breakthrough curve is used for the quantitative assessment and validation of spatial groundwater vulnerability.

Comparative tracer tests performed at several Swiss karst systems typically illustrate that recovery rates differ significantly for injections within the same catchment even in case of limited contrast of a single vulnerability mapping criteria (e.g. a few decimeters of soil thickness). Multi-tracer tests focused successively on each sub-system controlling the water and contaminant flow in karst settings allowing a better quantification of conservative solute concentration attenuation from the soil surface to the discharge area. Storage in the soil and subsoil thereby showed to play the most important role in relation to intrinsic vulnerability in many karst systems.

A protection unit was defined based on the quantitative interpretation of numerous tracer experiments and classes of vulnerability criteria were assigned accordingly. This protection unit corresponds to the smallest protection effect or vulnerability class, respectively, that can be determined for a mapping criterion, and which generate a quantifiable influence on the tracer breakthrough curve (maximum concentration, mass recovery, transit time).

89. Seasonal trends in continuous physico-chemical spring data from karstified and fissured rocks in Switzerland

Continuous water temperature data of 16 springs in karstified carbonate rocks and of 17 springs in fissured rocks of the Swiss National Groundwater Monitoring NAQUA have been processed grouping for winter, spring, summer, and autumn measurements. Springs in the Jura, on the Plateau, and in the Alps have been studied. Three karst springs in the Alps are recharged in summer by glacier melting water. While some springs in karstified carbonate rocks show an overall increasing trend for groundwater temperature over the last 15 years, such a tendency is only observed in a specific season or not at all at springs in fissured rocks (crystalline, molassic and carbonate rocks). The increasing tendency of the groundwater temperature at karst springs can be attributed to climate change. Furthermore the groundwater temperature data have been compared with the NAQUA continuous measurements of spring discharge, electrical conductivity and turbidity. While spring discharge and turbidity do not follow the temperature's evolution with time, the electrical conductivity indicates a scarcely increasing tendency at specific karst springs. The results from Swiss aquifers are also compared with observations made in the neighboring countries. In the Austrian groundwater monitoring network, for example, an increasing

tendency of the groundwater temperature in more than 50% of the all aquifers for the period 1997-2009 has been observed.

90. Process-based modelling of contaminant attenuation in karst aquifers

Modelling of transport in karst groundwater must take into account the reaction processes of specific contaminants in addition to a variable and complex flow regime. The use of reactive artificial tracers as contaminant surrogates represents a powerful tool in this field. Results from tracing experiments in karst aquifers indicated that reactive solute and colloid tracers can interact with aquifer material despite the dominance of preferential and conduit flow components. Several attenuation processes were involved and could be identified. Examples from karst systems in Switzerland highlight the in-situ effectiveness of such processes.

The approach combines field and laboratory experiments for defining single and coupled transport and attenuation processes. This provides the information needed for modelling contaminant attenuation during transport, taking into account specific processes and reaction kinetics. Furthermore, tracing behavior was adjusted with real contaminants in order to obtain in-situ contaminant attenuation rates. The findings are not only used for transport modelling purposes but may also enhance the general comprehension of the processes involved in karst aquifers and should enable the development of conceptual models with a more quantitative basis.

91. Insight into origin and fate of the bacterial load in karst groundwater

The bacterial load of karst groundwater resources has shown to be significantly higher than for other aquifer types. This is assumed the result of a higher degree of recently infiltrated surface water components, which makes total cell count a reliable additional parameter for aquifer characterization and levels of global system vulnerability, respectively. The occurrence of microorganisms originating from fecal contamination represents only around 1/100'000 of the total bacterial load but may be of concern regarding drinking water supply. Knowledge about the origin and fate of both natural and fecal microorganisms is crucial for predicting microbial contamination at karst spring as well as for establishing adequate protection measures.

Field experiments at both catchment and local scales provided deepened insight into the relevant processes during microbial transport and storage, i.e. input, interaction and inactivation. Specific tracing tests as well groundwater monitoring particularly over recharge events and spring floods allowed for correlating with hydrodynamics and the proportion of the rapid recharge component. Furthermore, by means of the simultaneous employment of an array of differing microbiological techniques – going beyond conventional fecal indicator bacteria analyses – a distinction of the bacteria's origin in terms of autochthonous/allochthonous, fecal/natural and human/ruminant (i.e. microbial source tracking markers) could be made.

92. The Betteraz spring: an attempt to understand the origin of its contamination

The chlorokarst project aims at defining a general methodology to manage contaminated sites located in karstic environments in Switzerland. The project includes some general methodological aspects as well as testing various tools to analyze contaminant migration in such systems. It has a special emphasis on chlorinated solvent contaminations as they are potentially affecting a large number of sites (waste disposal and former industrial sites) in the Jura.

In this framework, the Betteraz spring has been chosen as one of the study sites for the Chlorokarst project because it has been very well studied and documented over the past decades. The spring is located in Porrentruy (canton of Jura, Switzerland). It is polluted by chlorinated solvents and because it is used as the main drinking water supply for the city, its water requires a costly treatment. Several potential contaminant sources have been identified in the catchment, but their respective influence is still unclear.

The present study aims at improving the general hydrogeological knowledge of the Betteraz catchment in order to provide basic data to possibly identify the contaminants paths and origins. For this purpose, the study includes several aspects.

First, all available geological data have been compiled and used to construct a 3D geological model with Geomodeler. This model allows to better constrain the extension of the karstic catchment and especially understand the role of several internal barriers related to the geometry of the impermeable layers at the bottom of the karstic aquifer. This permits to infer some possible flow paths in the system, even if the

relative flatness of the structures in the area (tabular Jura) makes the interpretation of those flow path more uncertain than in folded domains with strong structural control.

The geological investigation are completed with classical groundwater investigations (level monitoring in 8 wells in the catchment, dilution and tracer tests). All those data are then used to constrain a hydrogeological reservoir model. The aim is to demonstrate how simple tools can be used to better understand and define the hydrogeological system.

Finally, all the data collected during this study and the models that have been constructed are used to discuss the possible contributions of the various contaminant sources to the pollution of the Betteraz spring.

93. Hydraulics and sediment transport in the karstic system of Milandre (Jura, Switzerland)

Flood events at karstic springs are generally associated with intense turbidity peaks. Suspended particles arriving at a karstic outlet may come directly from soils and/or from the resuspension of intra-karstic sediments. In the Milandre cave, monitoring of sedimentation processes has been going on for about ten years. In particular, observations of flow, turbidity and sediment accumulation in the underground stream have been made. In this communication, we focus on the characterization of the remobilisation of intra-karstic sediments at the event scale.

As in most karstic catchments, the flow pulse following recharge events travels quickly (a few hours) through the Milandre system towards the springs. Epiphreatic zone hydraulics are key in understanding sediment resuspension - both in terms of hydraulic head and flow velocity variations. Thus, a hydraulic pipe-flow model (EPA SWMM) was built on the basis of the cave survey, flow paths inferred from tracer tests, and hydraulic head records in the underground stream. Simulated flow velocities were compared with observed turbidity peaks and sedimentation observations.

In the first stages of larger flood events, simulated flow velocities increase rapidly and substantially. When the outlet conduits can no longer accommodate the incoming flow rate, water level in the epiphreatic conduit rises, progressively filling it up. Thus, the flow section is greatly increased and the model indicates a drop in flow velocity. A secondary velocity peak during flow recession appears in simulations of large flood events.

Sedimentation observations in the active conduit agree well with these results: erosion processes are only observed in the lower part of the conduit. In the upper parts of the conduit, sediment accumulation is generally observed after major flood events. Turbidity records in the underground stream and at the springs also show evidence for distinct primary and secondary autochthonous turbidity peaks.

94. Investigating sedimentation processes in the karstic system of Milandre (Jura, Switzerland)

Observations of thick and evolving clay deposits in the epiphreatic zone of the Milandre system suggest sedimentation processes associated with flood events. These processes were investigated by means of twelve sedimentation plates distributed at different heights on one wall of the main active conduit. These 10 cm x 10 cm wooden plates, fixed horizontally by a metallic rod pressed into the sediment, allow the observation of sediment accumulation and/or erosion.

These observations were compared with contemporaneous flow and hydraulic head records within the cave system and at the outlets. Flow velocities simulated by a pipe-flow model were also analysed. Results suggest that erosion of intra-karstic sediments occurs in the early stages of a flood event, when the flow velocity is highest and the active conduit is only partially flooded. The progressive flooding of the conduit is associated with a decrease of flow velocity and concurrent sediment deposition, which is observed on the upper sedimentation plates. Evidence also suggests a secondary erosion phase when the conduit drains during flow recession.

95. Pesticides and microorganisms occurrence explained by karst hydrogeological fundamentals in conjunction with detailed agricultural land-use information

Intensified monitoring in rural karst catchments located in the Swiss Jura Mountains evidenced differing occurrence patterns for the diverse pesticides and microorganisms analysed. Whereas some of the substances were only detected sporadically, some occurred regularly at each sampling. Particularly microbial pollution could be linked to high discharge events, while spring monitoring data alone were not sufficient to explain the partly sporadic detection of some pesticides. A detailed assessment of land-use activities including information on the application of plant protection products was conducted and

provided more insight into the transport processes in this context. It permitted – in conjunction with a sound knowledge of the karst systems' hydrogeological characteristics assuming three different sub-domains – to explain sporadic and regular pesticides and microorganisms' occurrence at the related springs.

The study illustrates how detailed land-use information and concurrent sampling on diverse contaminants with differing properties and behavior can provide additional comprehension on both, micropollutant and microorganism fate and transport behavior. It also demonstrates the importance of this data in order to set-up an appropriate groundwater monitoring program particularly in karst systems.