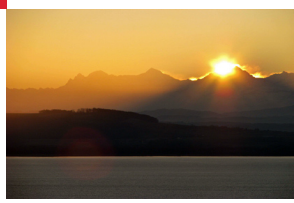

Abstract Volume
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1. Water across (scientific) boundaries

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1. Water across (scientific) boundaries

Eduard Hoehn, Adrian Jakob, Ronald Kozel, Urs Mäder, Bruno Schädler, Mario Schirmer

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1.1

Caractérisation hydrodynamique des principaux types de sol

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La caractérisation hydrodynamique des principaux types de sol suisses n'est pas encore appréhendée. Elle dépend non seulement du type du sol et de ses propriétés physiques mais surtout de sa structure fonctionnelle. L'aspect hydrodynamique du sol n'est abordé que par un angle théorique ou numérique. Dans cette perspective, nous avons oeuvré pour mettre au point une méthode robuste et fiable pour estimer quantitativement le flux à travers la zone non saturée et définir le risque lié au type d'écoulement (Alaoui et al., 2003).
Le but de cette étude est la caractérisation hydrodynamique des principaux types de sol à potentiel agricole pour l'estimation du flux d'eau transitant vers les eaux souterraines permettant de procéder à une évaluation de leur degré de vulnérabilité.
La méthode utilisée dans cette étude est jugée robuste pour deux principales raisons: i) les mesures de la teneur à partir desquelles le modèle MACRO (Jarvis, 1994) a été calibré sont très précises (intervalle de temps de mesure varie entre 1 et 5 minutes) et très denses (effectuées le long du profile du sol tous les 10 cm) et ii) le modèle utilisé est basé sur les principes physiques du sol. De ce fait, les calculs de simulation sont fiables et peuvent être extrapolés à d'autres sols similaires (de même type et même texture).
Les sols étudiés présentent un risque de pollution certain en cas d'application de pesticides ou herbicides quand ils sont humides ou très humides comme c'est le cas des sols bruns et sols bruns acides.
Les sols bruns lessivés peuvent présenter ce risque en état sec et humide.
Quant aux sols à gley, ils présentent un risque de pollution relatif s'ils sont secs. Le risque augmente avec l'humidité. Quand ces sols sont sur des nappes phréatiques fluctuantes, les eaux souterraines peuvent être contaminées par ruissellement vers les rivières si le sol est en pente ou par percolation verticale vers l'eau de la nappe qui remonte rapidement en surface dans le cas d'une plaine.
Ces résultats montrent en général que les sols ne présentent pas de risque majeur quand ils sont très secs. Le cas échéant, les pesticides et herbicides pourraient être appliquées durant ces périodes pour autant que ces sols ne subissent pas d'averses durant les jours qui suivent cette application.
Il est urgent d'établir une carte pédologique au niveau suisse qui tiendra compte du type de sol, de sa texture et du risque de pollution qu'il présente en cas d'utilisation d'herbicides ou de pesticides. Cette carte servira aux pratiquants dans les domaines du sol et de l'hydrologie. La présente étude est en faite à la base de cette cartographie et devra s'étendre aux sols agricoles de culture différente. L'impact de la culture sur la structure du sol devrait être alors évalué

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1.2

Insights from coupled thermal-hydraulic-chemical modelling of geochemical processes in carbonate and silicate-dominated reservoirs within deep geothermal systems

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We use coupled thermal-hydraulic-chemical models patterned after the geothermal systems at Bad Blumau, Austria, and Basel, Switzerland to track the fate of fluids that originate from a carbonate and a silicate-dominated geothermal reservoir,

respectively, on their passage through the geothermal system. We use numerical simulations to explore 1) geochemical conditions in the undisturbed reservoir, 2) chemical and hydrological implications of reinjecting the used fluid into the reservoir, 3) mineral scaling and the rate at which it occurs and 4) borehole corrosion and geochemical fingerprints indicating incipient corrosion.

The composition of the fluid in the reservoir is buffered by the mineralogy of the aquifer rock at local temperature and pressure conditions. Changes in pressure and conductive temperature during ascent and descent of the fluid induce changes in mineral solubilities. Oversaturated minerals may cause scaling within the borehole. The precipitation of mineral phases in the borehole is primarily dictated by the composition of the reservoir fluid. The distribution of minerals is a function of the flow and reaction rates. Mineral scaling within the borehole changes the fluid composition and may gradually clog the borehole, thereby obstructing fluid flow. Because different minerals exhibit different solubilities as a function of temperature, the mineral assemblages that precipitate in the production well are distinct from those in the injection well. For instance, if the fluid in the reservoir is saturated in silica, then the prograde solubility behaviour of silica favours its precipitation in the production well. Conversely, carbonate minerals tend to precipitate in the injection well owing to their retrograde solubility behaviour. However, calculating the distribution of mineral phases is complicated by the fact that the precipitation of some minerals is kinetically controlled, such that they may continue to precipitate far into the injection well (e.g. amorphous silica)

Any modification of the fluid composition caused by mineral precipitation along the fluid's pathway means that the reinjected fluid is no longer in equilibrium with the reservoir rock. Consequently, rock-water interaction and fluid mixing at the base of the injection well drive chemical reactions that cause changes in porosity and permeability of the reservoir rock, potentially compromising the efficiency of the geothermal system.

One concern during geothermal energy production is that of chemical corrosion of the borehole casing. For a range of "what-if" scenarios we explore the effect of corrosion on the fluid composition and on mineral precipitation to identify chemical fingerprints that could be used as corrosion indicators. Once suitable indicators are identified, incipient corrosion could be detected early on during regular chemical monitoring. Corrosion of the casing is typically associated with the release of Fe and H_2 into the circulating fluid. However, the implications of this release depend on the local chemical conditions where corrosion occurs. For instance, elevated H_2 in the fluid is a corrosion indicator only if it is not involved in subsequent redox reactions. Similarly, low H_2 concentrations do not rule out possible corrosion.

In general, the interpretation of a fluid or a mineral sample requires the understanding of chemical processes that occur along the flowpath throughout the geothermal system. If direct observations are not possible, then this understanding can only be achieved through numerical simulations that integrate and couple fluid flow, heat transport and chemical reactions within one theoretical framework. Our simulations demonstrate that these models are useful for quantifying the impact and minimizing the risk that chemical reactions may have on the productivity and sustainability of a geothermal system.

1.3

Transfer of solutes under forested watersheds

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The ALPEAU project aims to strengthen the protecting role of forests when it comes to sustainable water resource management and quality. Thus, several forested watersheds were chosen. The Gorges de l'Areuse watershed is located over the Swiss Jura mountains karstik system, whereas the Jorat forest and the Mont Gibloux are situated on the Swiss Plateau, mainly characterized by sandstone formations.

The main goal of this study is to assess the fate of contaminants, such as nitrates and pesticides, on their way down from the forest soil, which physico-chemical features are strongly linked to phytosociological combinations, through the unsaturated and saturated zone down to the system outlet.

In karstic areas, it is important to discriminate between water coming from the soil reservoir, the epikarst (interface between soil and karst), the low permeability volumes (the rock volume between the epikarst and the system outlet) and the

freshly infiltrated rainwater. To do so, gases produced in the soil and dissolved in rainwater will be used. A combined radon, CO_2 and TDGP (total dissolved gas pressure) measurements will be carried out in a water adduction tunnel at the Gorges de l'Areuse test site. Conductivity, temperature, turbidity, DOC (dissolved organic carbon), nitrogen and carbon isotopic composition and dissolved ions will also be part of the survey (Figure 1). Additional artificial tracing experiments will allow to get insight into the travel time, the storage location and the degradation kinetic of dissolved compounds.

Even though the Mont Gibloux test site is set on top of a sandy aquifer, the same method will be applied, if travel times are proved to be under a week. Indeed, radon decays with a half live of about 4 days, whereas CO_2 reacts with carbonate on its way down to the saturated zone.

The main focus on the Jorat forest test site is the environmental fate of cypermethrin, a synthetic insecticide used in timber treatment, oil products used in forest management and their metabolites.
First of all, it is essential to understand the hydrogeological behaviour of the watershed. Thus, a classical physico-chemical follow-up will be established at some chosen water harnessing, completed with comparative tracer tests. Then, wooden piles will be set on treatment sites, treated with cypermethrin (within the range of legal concentrations) and spring water watched over. The experiment will occur under artificial steady state conditions and during heavy rain events, as it is assumed to cause significant infiltration into the aquifer.

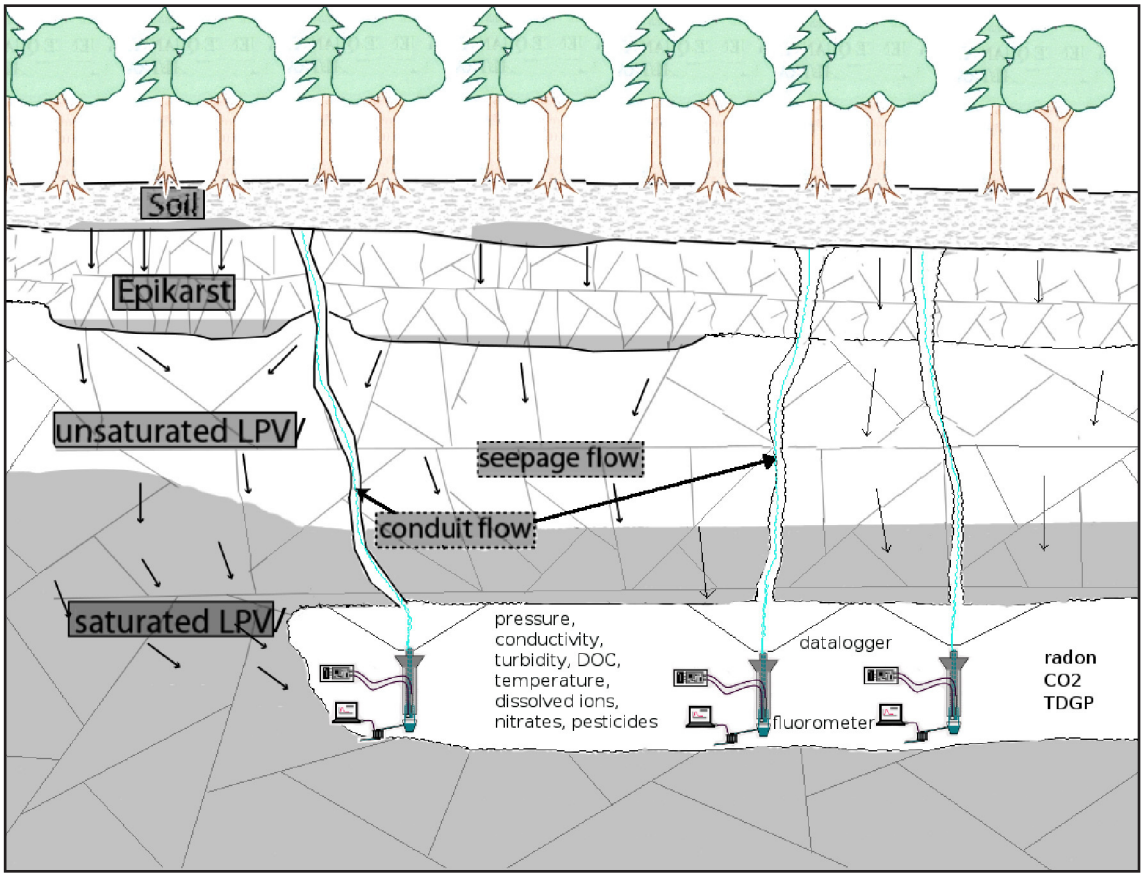

Figure 1. Schematic view of the Gorges de l'Areuse test site (modfied after Savoy L. 2007)

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1.4

Well-head capture zones delineation in transient flow conditions: the use of equivalent steady-state approximations

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The delineation of well-head protection areas S1, S2 and S3 as well as contribution zones Z_u aims to prevent groundwater resources from instantaneous and perennial pollutions. Due to the stress they induce on the land use, these so-called protection schemes cause socio-economic impacts, that becomes non negligible in high-density population area, such as the Swiss Plateau. Therefore the delineation of such protection schemes must be done with care in order to guaranty the protection of the resource on the one hand, while minimizing the overestimation of their size on the other hand.

Aquifers are natural systems that vary with space and time. Such variability will directly influence the way contaminant migrates through the aquifer and indirectly the design of the protection schemes. In practice, characterizing the resource by integrating this variability requires much more effort than using a simple homogeneous medium with steady-state flow conditions. Consequently the delineation of protection schemes is often done using low water steady-state flow conditions, assuming this constitutes a safer approach. However, by applying this simplified methodology, the size of the protection schemes is overestimated and the related socio-economic impacts enhanced.

A new methodology has been developed to identify flow conditions where steady-state approximation is justified or where this approximation should be avoided (Badoux 2007). The ratio between the mean transit time and the fluctuation period appears to be a good criterion to distinguish between these two cases. When this ratio is smaller than 0.5, the size of the protection schemes can be rigorously obtained using high and low water flow conditions. When this ratio is big enough - the exact number is site specific - the protection schemes can be approximated by mean steady-state flow conditions. In between, protection schemes cannot be obtained by any steady-state flow conditions, except if some transport parameters are adapted in an appropriate way.

This methodology has been applied to the Seeland aquifer in Canton Bern.

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1.5

Particles in reservoir waters affected by pump storage operations

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Pumped storage hydroelectricity is used to even out the daily and weekly fluctuations in energy consumption by pumping water to a higher altitude reservoir during low-peak periods, using the excess base-load capacity from coal and nuclear sources. This project investigates the effect of this pump storage operations on particle characteristics in the water column and on resulting sedimentation processes.

Grimselsee (1908 m) and Oberaarsee (2303 m), two reservoirs located in the Bernese Alps, are connected since 1980 by a pump storage unit which exchanges an annual amount of water amounting to several times the volume of the reservoirs. The impact of initial damming was studied recently for downstream areas and in the reservoirs themselves. The partially glaciated

catchments feeding the reservoirs lead to an enormous inflow of inorganic particles during snowmelt in spring, resulting in high turbidity in the reservoirs. Compared to pre-dam conditions, reservoirs retain particles of larger grain size which were previously released to downstream areas (Anselmetti et al., 2007). In addition, it was demonstrated that the shift of runoff from summer to winter affects the light regime and, consequently, the primary production in Lake Brienz (Finger et al. 2007; Jaun et al. 2007).

In order to understand the effect of the increasing pump storage operations on water turbidity and on particle size, water sampling campaigns were performed seasonally in both reservoirs as well as in the power station connecting them. Turbidity seems to correlate strongly with weather conditions and catchment characteristics in summer and with pump storage activity in winter. In summer, Grimselsee was found to be more turbid than Oberaarsee, which has a stronger thermal stratification and whose catchment is less glaciated. In winter, Grimselsee and Oberaarsee show similar conditions. However, turbidity was higher close to the in-/outlets, where both reservoirs are continuously exchanging water.

Hydraulic machines such as turbines cause shear stress and turbulence, which are known to induce flocculation of particles (Blaser & Boller, 1998; Serra et al., 2008). In order to investigate whether this effect occurs in the Grimsel reservoirs, water samples were taken upstream and downstream of the turbines during pump storage and power production regimes. To date, SEM image analyses and particle-counter analyses did not discover any aggregation effect, suggesting that the there is not significant change in particle characteristics from turbine passages.

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1.6

Sustainable management of urban water: substance flow analysis as a tool

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Pollutants released by cities into water are of more and more concern as they are suspected of inducing long-term effects on both aquatic organisms and humans (for example, hormonally active substances). The substances found in the urban water cycle have different sources in the urban area and a different fate in the cycle. For example, the pollutants emitted from traffic get to surface water during rain events often without any treatment, and are partially removed from the water cycle by sedimentation; pharmaceuticals resulting from human medical treatments get to surface water mainly through wastewater treatment plants, where they are partly taken out from water. The residual concentrations can re-enter the cycle through drinking water. It is therefore crucial to study the behavior of xenobiotics in the urban water cycle and to get flexible tools for urban water management.

The substance flow analysis (SFA), an extension of the classical material flow analysis originally developed by Baccini & Brunner, has recently been proposed as instrument for phosphorous management in urban water system. SFA is based on the principle of mass balance: a substance enters a closed system and may be transported or transformed in the system and may also leave the system.
To be used as management tool, SFA should be coupled with environmental quality criteria. These values express the maximum concentration, which is tolerable for a given substance in order to protect both human and the environment. Having this limit in mind, one can detect the most problematic flows and take action to diminish them.
In our study, we tested the application of SFA for a large number of classes of xenobiotics, i.e. heavy metals, pharmaceuticals, biocides and cosmetics, to evaluate its use for urban water management. We chose the city of Lausanne as case study as many data were available, on both the sewer system and the water quality.

The city of Lausanne, which is around 42 km^2 with 130'000 inhabitants. Lausanne is near lake Geneva and its effluents mainly reach this ecosystem, which is a recreational area as well as a source of drinking water for the city. The system itself is described in Figure 1 and illustrated for copper. We considered thirteen inputs of this heavy metal in the water system: drinking water (I_1), roofs (I_2) and houses sides (I_3) runoff, road runoff collecting car brakes (I_4), tires abrasion (I_5), motor oil residues (I_6) and dry deposition (I_{12}), particles from catenaries from trolleybuses (I_7), inputs through trains, i.e. particles from catenaries (I_8), brakes (I_9) and wheels (I_{10}) abrasion, input through boats (I_{11}) and rainwater (I_{13}). Transfer coefficients were estimated based on measurement or hypotheses. For copper, the water quality criterion was given by the Swiss legislation and the sediment quality criterion proposed elsewhere.

The SFA of copper showed that the city of Lausanne releases about 600Kg and 900Kg per year of this heavy metal in respectively the water and the sediments of lake Geneva. These estimations were validated by measurements of copper in the Lake near Lausanne. In the sediments, the continuous enrichment induces high concentrations of this heavy metal, which are above the recommended quality criterion. By using the SFA, we could identify that copper mainly reaches the Lake with stormwater, i.e without being removed by any treatment. The major sources are the catenaries of the trolleybuses and the roofs runoff. A reduction of the contamination of the water system would therefore include actions at this level (for example the treatment of the roofs runoff). SFA was also applied to biocides and pharmaceuticals with interesting results (not shown here).

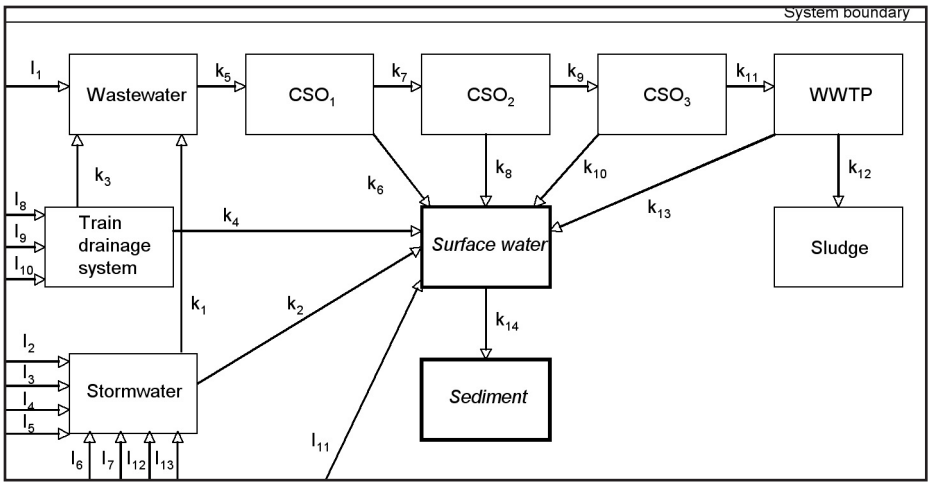

Figure 1: Description of the urbain drainage system of Lausanne and application to copper. The "I" flows stay for "Input". The "k" flows for the transfer coefficients.

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1.7

Calcite-celestite veins and related past fluid flow through the Mesozoic sedimentary cover at Oftringen, near Olten

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The study is based on core samples from the recently drilled, 719 m deep borehole at Oftringen (near Olten), located in the northwestern Molasse basin, at 1.5 km from the frontal thrust of the Folded Jura (Waber, 2008). Veins of calcite (±celestite, pyrite) occur in the whole Malm sequence (up to 8 veins/m), including the more clay-rich Effingen Member. To date, such an intensity of veining in the Effingen Member has not been found in other deep boreholes located in the Molasse basin. Most of the veins are related to tectonic activity, but clay-filled karst structures are recognized in the upper Geissberg Member

limestone, and a few structures probably related to the diagenetic processes are documented in the Effingen Member. Fluid inclusions show average salinities between 3.3 and 4.4 wt% eq. NaCl in celestite and 2.7 wt% eq. NaCl in calcite. Average homogenization temperatures in calcite fluctuate between 56 and 68 °C, with a broad increase with depth and no correlation with salinity.

Malm whole-rock carbonates have $\delta^{18}O$ values fluctuating within a narrow range, probably determined by equilibrium with seawater (Fig. 1A). Their $^{87}Sr/^{86}Sr$ ratios follow a well-defined depth profile with minimum values in the middle part of the Effingen Member, fitting with Oxfordian seawater (McArthur et al., 2001; Fig. 1B). No correlation is observed between $^{87}Sr/^{86}Sr$ and clay content, and values higher than contemporary seawater might be related to the incorporation of radiogenic detrital carbonate.

The $\delta^{18}O$ values of vein calcite are systematically lower than the corresponding whole rock carbonate (Fig. 1A), consistent with precipitation from seawater at 50 - 70 °C. The $\delta^{34}S$ and $\delta^{18}O$ values of vein celestite follow a bacterial reduction trend pointing to Miocene seawater sulfate. Two vein pyrites gave negative $\delta^{34}S$ values consistent with bacterial sulfate reduction. Calcite and celestite of diagenetic origin have $^{87}Sr/^{86}Sr$ ratios that are indistinguishable from the corresponding whole rock carbonate fraction. In contrast, the $^{87}Sr/^{86}Sr$ ratios of epigenetic vein calcite and celestite show a systematic enrichment in radiogenic Sr compared to the corresponding whole-rock carbonate and require an external Sr source. Only Burdigalian seawater, at the time of Upper Marine Molasse (OMM) deposition, had an $^{87}Sr/^{86}Sr$ ratio high enough to explain the highest value obtained (Fig. 1B).

The rocks of the Malm-Dogger sequence were not pervasively affected by fluids post-dating burial diagenesis, and the influence of such fluids was restricted to open structures. The Molasse basin subsided in the Burdigalian (Kuhlemann and Kempf, 2002; Mazurek et al., 2006), and the veins might record tectonic activity related to this process. Calcite and celestite precipitated from descending seawater due to heating to 50-70°C, while precipitation of pyrite resulted from bacterial reduction of part of the seawater sulfate.

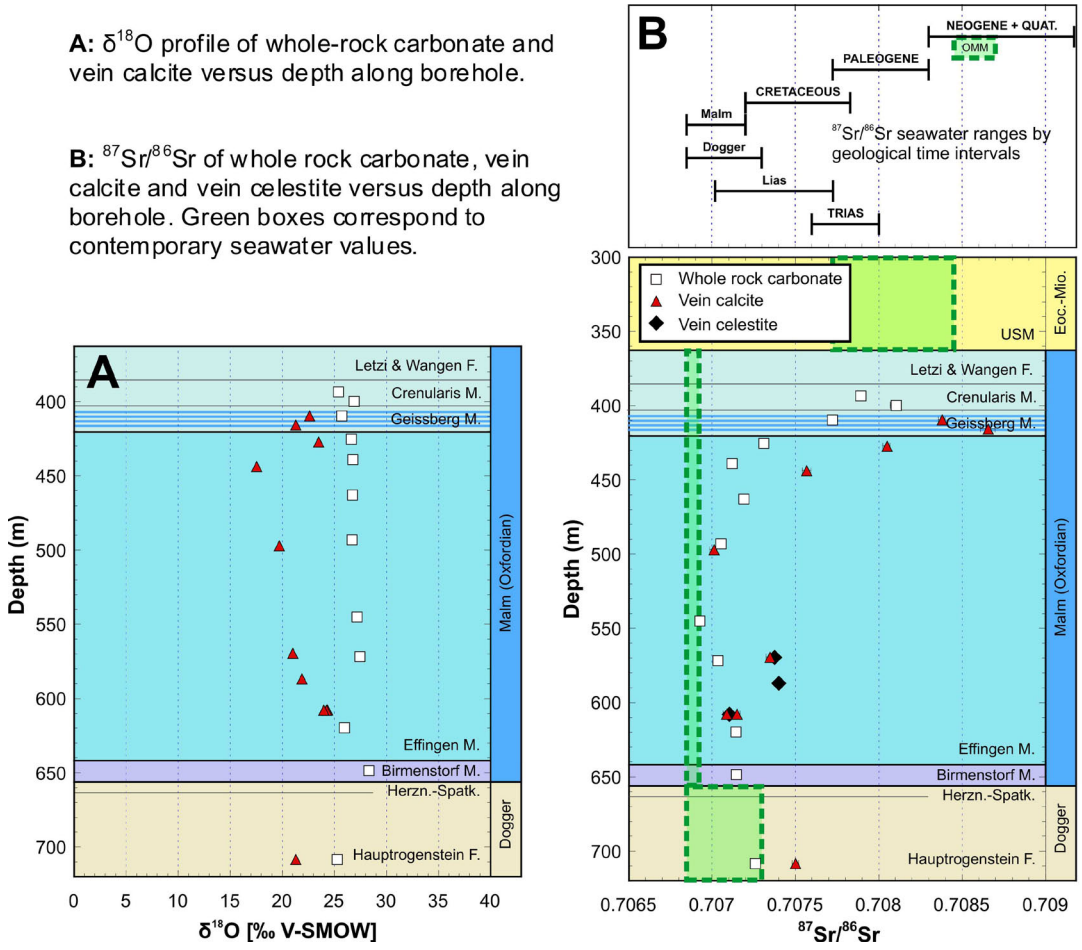

Figure 1. Oxygen and strontium isotopic data.

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1.8

Spatial characterization of hydraulic conductivity of the Thurtal-aquifer at the test site Widen

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For many hydrogeological and modeling problems on a scale of the order of 10-100 m, an assessment of the spatial distribution of hydraulic conductivity (h.c.) is of great importance. This is one of the tasks of the ReCorD project (Restored Corridor Dynamics) of CCES (Competence Center Environment and Sustainability of the ETH Domain). This project aims at understanding, how river restoration measures affect river - river corridor - groundwater systems in hydrologic and ecologic terms. The river Thur and the alluvial gravel-and-sand aquifer of the perialpine Thur valley flood plain were chosen for field investigations. In this aquifer, the distribution of h.c. at the required scale has not yet been investigated. Thus, the aim of this Master Thesis is to characterize the hydrogeology of the aquifer at a test site in the central part of the valley (Widen, Felben-Wellhausen/TG), which extends to about 10x20 m (aquifer thickness, 7 m), by using different methods on different scales. Work included logging of core drillings, sieving of the gravel samples (decimeter scale) and the conduction and analysis of a pumping test (decameter scale), flowmeter logs and slug tests (meter scale), with appropriate methods. Except for the slug tests (14 wells), four fully penetrating wells with piezometers of a diameter of 4.5" were used. The analysis of these tests resulted in values of h.c.

The *sieve analyses* (vertical intervals of samples: 0.5 m) were performed with the core material of the four wells. The values of h.c. calculated after Casati (1959) led to small absolute values and a narrow distribution (n=53, μ=-2.73 m/s, σ^2=0.01; where $\mu=\log_{10}$ geometric mean, $\sigma^2=\log_{10}$ variance). The small variability can be explained by the approach of the formula of Casati (1959), taking into account five grain size fractions and assuming absence of the secondary porosity of the material. The small absolute values originate from the calibration of the formula to a specific aquifer. Sieve analyses are well suited for a rough estimate of h.c. of perialpine alluvial gravel-aquifers, with an accuracy of a factor of about 2.
The *pumping test* (pumping well is one of the four wells, head observations in nine additional wells) involves a large aquifer volume. As for all pumping tests, the resulting value of h.c. (here calculated after Neuman (1972, in Kruseman & De Ridder 1991)) is biased by highly conductive zones and corresponds to the upper limit of the spectrum of the natural variability (μ=-1.83 m/s). This value is adequate for large scale investigations.
Flowmeter measurements were carried out at intervals of 0.25 m in the four 4.5"-piezometers. As for all flowmeter tests, an analysis with the method of Javandel & Witherspoon (1969, in Molz 1989) resulted in vertical profiles of relative values of h.c. The relative values can be calibrated to absolute values: Here they are calibrated relative to the mean h.c. of the pumping test, which integrates a large aquifer volume (total of n=29, μ=-1.83 m/s, σ^2=0.14; calculated for an average of 0.5 m intervals). The bias of the result of the pumping test is thus transferred to the results of the flowmeter measurements. The relative profile of h.c. should rather be calibrated with the result of tests that involve only a small aquifer volume, e.g. slug tests in fully penetrating wells, which are hard to realize in a highly conductive aquifer. So flowmeter logs are the adequate method, if the relative vertical distribution of h.c. is of primary importance.
Slug tests. For detailed information about the spatial distribution of h.c. in the order of 10-100 m, which is needed in the ReCorD project for the modeling of groundwater flow, solute and heat transport at small scales, pneumatic multi-level slug tests (with a system of double packers) were applied in 117 intervals of 0.5 m length of 14 piezometers (analyzed after Bouwer and Rice 1979, Springer and Gelhar 1991, in Butler 1998). These experiments resulted in the following distribution of h.c.: n=117, μ=-2.38 m/s, σ^2=0.11.

A statistical evaluation of the values of h.c. from the above methods showed that the results can not be compared. Thus, the choice of the method to assess the distribution of h.c. has to be done according to the problem and the required level of

detail. The slug tests resulted in the best absolute and relative representation of the distribution of h.c., compared to the other three methods: The absolute values of h.c. do not have to be calibrated with the result of a different method, the values of h.c. are accurate and cover most of the natural range of h.c. A statistical comparison of sieve analyses of the Widen test site with those of the whole Thur valley has shown that the distribution of d_{10}, d_{50} and d_{60} grain size fractions are similar in the western part of Thur valley. Probably, the distribution of h.c. assessed for the Widen test site can also be used for the western part of the valley, as this site seems to belong to the same facies. To decrease the work load required for slug tests and to increase the level of detail in h.c. assessments, I recommend a combination of hydraulic testing with high resolution geophysics and the use of tracers. The development of geophysical and tracer methods are an integral part of the ReCorD project.

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1.9

Metal partitioning in aquatic systems: from interdisciplinary research to environmental practice.

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Knowledge of partitioning of metals is fundamental for understanding their transport and their availability to aquatic organisms. Furthermore, a considerable fraction of metals in rivers, lakes and coastal ocean may be of anthropogenic origin with concentrations approaching the levels considered harmful for aquatic ecosystems. Measuring and, when possible, predicting metal partitioning therefore becomes essential for environmental risk assessment and associated management plans.

Current European and Swiss legislations fix environmental quality standards (EQSs) on metals for the filterable phase; defined as the metal fraction passing through the pores of a 0.45μm filter. A large fraction of "filterable" metals is actually associated with small-size colloids and thus is not truly in solution. Unlike metals in true solution, colloidal metals can be removed from the water column via coagulation and/or aggregation and sedimentation processes. Moreover, metals bound to colloids are not available to some organisms (e.g., algae), but might be available for others (e.g., zooplankton). These discrepancies between fundamental knowledge and current environmental practices raise two major questions: a) Is it possible, and useful, to determine metal partitioning in monitoring programs? b) How can the knowledge of metal partitioning between colloidal and truly dissolved phases be used in environmental assessment?

The published data indicate that metals of low solubility in oxic conditions (e.g., Cr(III), Fe, Mn, Ti, Pb) are predominantly associated with colloids, while metals preferentially forming anionic complexes occur mostly in true solution (e.g., Cr(VI), Mo, U, V). Partitioning of elements occurring as divalent cations (e.g., Cu, Zn, Cd, Ni, Hg) depends largely on physico-chemical conditions of ambient water and on the quantity and quality of colloids.

For the priority elements mentioned in European legislation, the literature data indicate that, in general, Ni and Cd have lower affinity for colloids than Pb and Hg (fig. 1). Note however that a part of the observed variability is caused by persisting technical limitations; i.e. tangential flow filtration (the most widely used technique to separate colloidal and truly dissolved fraction in partitioning studies) not being standardized and prone to artifacts. In such situation, measurement of metal partitioning between colloids and true solution in routine monitoring programs remains unlikely and probably not advisable. Nevertheless, inferring the percentage of truly dissolved fraction from the total filterable fraction has proven to be feasible for some elements (Vignati et al. 2005). Such information can be used to refine models on elements' environmental fate and also provide a more realistic evaluation of toxicity at primary producer level; which is highly relevant to the assessment of ecological risk. Indeed, algal bioassays carried out in the presence of organic colloids, demonstrated decreasing toxicity with increasing fraction of metals bound to colloids (Koukal et al. 2003, 2007).

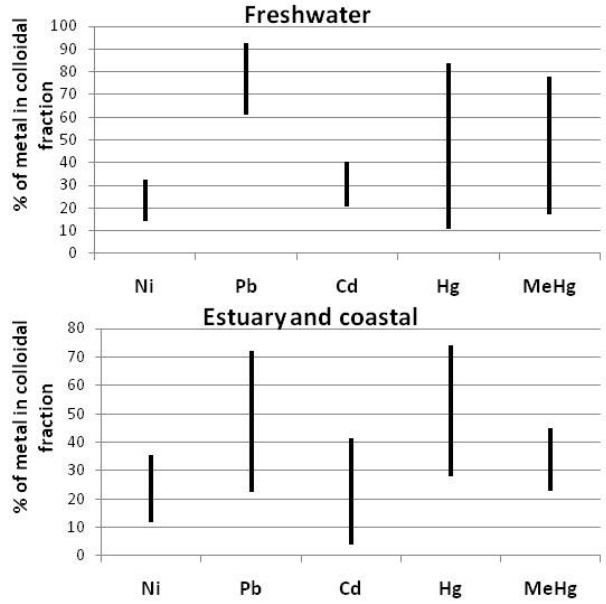

Fig. 1. Percentage of toxic metals associated with the colloidal fraction according to published data from freshwater and estuarine or coastal systems (compiled in Vignati et al. 2009). Bars represent the range between the means of the lower and the upper limits in each study.

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1.10

How water properties control the behaviour of continental and seafloor hydrothermal systems

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The flow patterns and thermal evolution in hydrothermal systems are of prime interest to a variety of basic and applied geoscience disciplines ranging from biogeoscience research on life in extreme environments through economic geology to geothermal energy exploration. Due to the extreme temperature-pressure conditions as well as the difficult access to many of these systems (e.g. those at mid-ocean ridges), insight has mostly been gained from numerical simulation.

In the case of continental hydrothermal systems heated by magmatic intrusions, numerical simulation has shown that the system-scale permeability structure is a prime order control on how much the convecting hydrothermal fluid may be heated. This is a result of the different rates with which convection (with the fluid flow rate primarily being controlled by permeability) transports heat away from the source and conduction (in the essentially impermeable hot magmatic source) delivers heat to the fluid (Hayba&Ingebritsen, 1997; Driesner&Geiger, 2007). On the other hand, fluid properties such as the position of the water boiling curve in temperature-pressure space are a major control on the style of hydrothermal fluid flow in the upflow zone.

For mid-ocean ridge hydrothermal systems, recent developments in numerical simulation techniques have revealed that the temperature-pressure-composition dependence of fluid properties such as viscosity, density, and heat capacity is a first order control on hydrothermal system behaviour. For example, by heating water from ambient temperature to to 200°C, viscosity drops by one order of magnitude. This increases the mobility of water by the same amount as a one order of magnitude increase in permeability. Hence, hot water can essentially "by itself" create corridors of high hydraulic conductivity in environments of otherwise homogenous permeability. As a result, strong self-organization effects may occur, the prime example being the recent prediction of pipe-like hydrothermal plumes underlying "black smoker" hydrothermal systems and being surrounded by narrow cylindrical zones of intense, warm recharge (Coumou et al., 2008). Current research focuses on the question to what degree these effects interfere with those resulting from the permeability structure of the crust (see Weis et al., this volume).

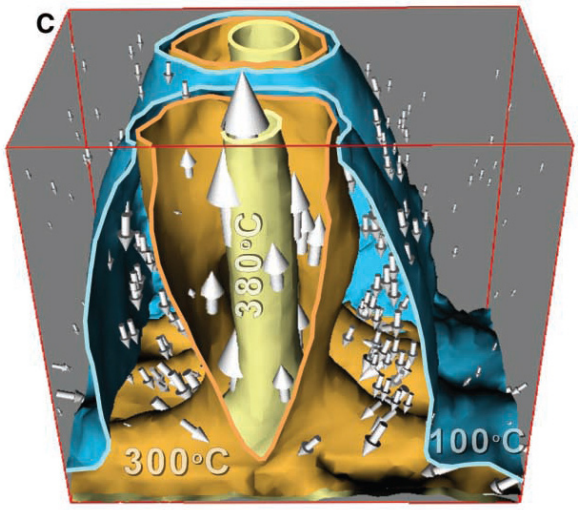

Figure 1. Thermal structure of the hydrothermal plume underlying a mid-ocean ridge black smoker field. A hot central upflow zone with temperatures up to 380°C is surrounded by a narrow recharge zone with temperatures between 100 and 200°C. From Coumou et al. (2008)

For oceanic systems with a homogenous permeability distribution, it can be shown that there is a strong interplay of fluid properties and permeability that determines the system's temperature as well as its ability to convect the incoming heat. Numerical simulations, verified by semi-analytical calculations, show that typical black smoker temperatures can only be achieved when permeability is LESS than about $3x10^{-14}$ m^2. At higher permeabilities, the temperatures are lower since fluid flow rates are too fast to allow stronger heating near the magmatic heat source. Below this permeability, fluid properties limit the maximum temperature of the system to ca. 400°C. Similarly, for typical heat flow rates at the bottom of the system, not all incoming heat can be convected away, and magma eruptions to the seafloor may potentially be the only way to balance the total heat input.

To what degree the influence of fluid properties may play a role in the formation of ore deposits or in the operation of geothermal systems is subject to ongoing research.

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1.11

Tracer tests in urbanised sites: a tool for a better characterisation of groundwater vulnerability in urban areas

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Vulnerability assessments and mapping methods (Vrba & Zaporozec 1994) are principally designed for natural areas. However, in urban zones, the groundwater recharge is strongly modified, due mainly to sealing of surface and/or presence of subsurface water mains and sewer pipes, which can contribute to recharge, or inversely act as drains for water in saturated and unsaturated zones (Lerner 2002; Thomas & Tellam 2006). As recharge can be considered as a key parameter for vulnerability evaluation (e.g., Aller, Bennett et al. 1987), urban processes which modify groundwater recharge have to be included in any vulnerability assessment of given urban groundwater resources.

In this perspective, multi-tracer tests were carried out at local scale in two urban test sites in Switzerland: Colombier and Neuchâtel. The Colombier test site is located in a low urbanised area, on quaternary glacial sediments forming the Plateau de Planeyse, where a small shallow aquifer is present in the silty formations. The Neuchâtel test site, at the shore of Lake Neuchâtel (Maladière area), is located in a high urbanised area, on highly heterogeneous anthropogenous backfill material and quaternary glacio-lacustrine sediments. The artificial conservative tracers (uranine, sulforhodamine B, duasyne and naphtionate) were injected in sealed and unsealed surfaces, or directly in subsurface rainwater pipes. In both test sites, tracer recovery was monitored in underlying urban aquifers (wells and drainage collectors), and in the downstream part of pipes where the tracer injections were performed.

The recovery results in Colombier and Neuchâtel (example of breakthrough curve in figure 1) pointed out dual role of pipes on recharge (increasing or decreasing recharge), an increase in recharge due to runoff concentration at the boundaries of sealed surfaces, and an increase in recharge due to the presence of artificial backfill materials in the uppermost part of the unsaturated zone. Not surprisingly, increased rates of tracer recovery during wet hydrological periods were observed during the performed tests.

Effects of these various parameters on recharge were further interpreted from a local urban-adapted groundwater vulnerability perspective. Consequently, key factors like the presence of underground pipes (in association with pipe parameters: material, age, hydraulic head, etc), or the local modifications of hydraulic conductivity of soil/subsoil formations by human activity, have to be integrated in urban groundwater vulnerability assessments and mapping methods.

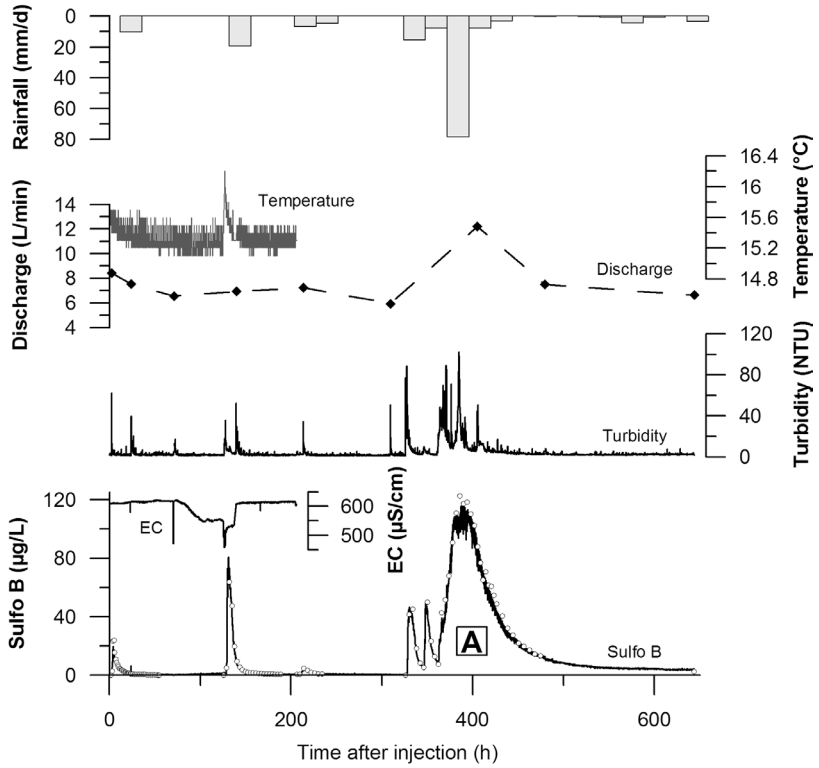

Figure 1. Breakthrough curve for sulforhodamine B (sulfo B) and time-series for electrical conductiity (EC), turbidity, discharge, and water temperature at the Colombier drainage outlet (summer 2007). The major rainfall event (A) and its noticeable related tracer response are indicated.

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1.12

A spectral analysis of rainfall-runoff variability for select Swiss catchments

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Time series analysis can provide useful insight into the complex relationships between variables of interest. In particular, analysis of precipitation and runoff for a particular hydrological catchment allows the physical complexity of the system to be better understood, both spatially and temporally. The Fourier transform is often used to analyse the frequency domain of time series, however, due to the non-stationarity of climatological and hydrological variables, wavelets have been introduced to analyse the spectral properties over time by transforming a time series into two-dimensional time-frequency space.

Wavelets have been used to understand the temporal and spatial variability in complex hydrological systems through an analysis of rainfall and runoff (for e.g., Labat et al., 2000) and to characterise remote watersheds based on runoff data only (Gaucherel, 2002). Cross-wavelet analysis between variables gives further insight into the temporal variability of the relationship (Grinsted et al., 2004) and insight into physical processes governing the system, in particular, the basin response to rainfall, which may help to classify catchments.

Here, we use wavelets to analyse daily precipitation and runoff time series from the Rietholzbach and the Töss catchments in Switzerland to better understand temporal relationships, with a focus on extremes during the past 30 years. We further investigate the spatial relationship between precipitation and runoff and quantify the precipitation contribution from different meteorological stations to total runoff for each catchment. We also discuss the minimal time-scales needed to adequately represent the physical relationships between rainfall and runoff (and hence the climatological signal), which could be applied, for e.g., in order to constrain hydrological impact studies (Bosshard et al., 2009).

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1.13

Gravity-driven Poiseuille-flow in the lithosphere

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Hydro-mechanical concepts of flow in permeable media (like fissured rocks, karst formations, unconsolidated sediments, and soils) are based on laminar flow that is driven by some force (i.e., any combination of the gradients of gravity, density, pressure, osmosis, capillarity, and other potentials), and that encounters resistance (usually expressed as its inverse like permeability or conductivity). Typical length and time intervals are up to kilometres and months in fissured rocks and groundwater systems, tens to hundreds of meters and weeks to days in karst formations and hillslope soils, tens of meters and hours to days in unsaturated and unconsolidated sediments, and single meters and minutes to hours in unsaturated soils. Depending on the problem and the system at hand the dimensionality may vary from one to three, and flow directions may reverse as infiltration/capillary rise in soils may illustrate. In addition, the flow-driving force may alter, for instance, from gravity-dominated infiltration to capillarity-dominated rise of soil moisture and to pressure-dominated flow when the medium becomes water saturated. In view of the many groups of professionals dealing with various kinds of flow and transport in various kinds of permeable media, a variety of concepts and methods have evolved that adapted to the needs of the respective groups. Group-specific adaptations include methods and protocols, time and length scales, system boundaries, and degree of intensity in dealing with spatial variability. For instance, capillarity in the non-saturated root zone of soils is so dominant that soil hydrologists and soil physicists relate water contents, hydraulic gradients and hydraulic conductivities to it. On the other side, the vadose zone (i.e., the non-saturated zone) of unconsolidated sediments between soils and groundwater tables is usually sort of hydraulic and hydrological no-man's land, whereas research on water flow in karst systems and groundwater systems follow their own rules.

A concept of infiltration will be presented that assumes gravity as dominant driving force which is balanced by viscosity. A set of equations evolves that describes the constant velocities of wetting and draining fronts, and that deals with trailing waves. The approach is linear but discontinuous; it does not require a representative elementary volume which is consider as obstacle to the up-scaling of most models. The approach allows for superimposing flows in time and space. Flow fore-casting is easy, however, hind-casting is impossible after flows have joined. From neutron radiography comes experimental evidence that the approach applies to sand layers that are thinner than 1 mm: From sand tank experiments we know that it applies to layers as thick as 2 m. The propagation of wetting front s across 20 m of unconsolidated sediments and across 2 km of fissured granite indicate the applicability of the approach to larger systems. Moreover, it explains conceptually the formation of finger flow in unsaturated porous media.

1.14

A synthesis of available data to analyze the interaction between the Rhône River and its alluvial aquifer

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Before the first (1863-1894) and second (1930-1960) Rhone corrections, the floods produced by the Rhone River had regularly disastrous effects for the inhabitants. Recent events (1987, 1993 and 2000) revealed major deficiencies in flood protection, which confirmed the necessity of the third regulation project of the Rhône. In addition to flood protection, the project aims at enhancing the ecological aspects of the river (OFEFP/OFEG 2003).

The general approach followed is to widen the riverbed by a factor of at least 1.6. This implies in some sections a lowering of the water level in the river. As the groundwater table of the Rhone alluvial aquifer is partly controlled by the exchanges between the aquifer and the Rhone, the widening of the riverbed may influence the alluvial aquifer. The correction will also modify the geomorphology of the riverbed. This may affect the permeability of the riverbed and thus have an effect on the exchange between the river and the groundwater. For example, a lowering of the groundwater table might induce land

subsidence or cause the drying out of agricultural terrains and involve enhanced irrigation. On the opposite, a rise of the groundwater table might lead to a rise of groundwater in buildings or by swamp formation.

To forecasts those potential impacts, it is necessary to characterize the present situation and to analyse the current state of the exchanges between the river and the aquifer. In a second stage, a numerical groundwater flow model will be used to simulate the main observation and to investigate the possible effects of a modification of the riverbed.

The characterization of the aquifer and the design of the conceptual aquifer model is based on a broad range of sources information such as seismic surveys, boreholes, piezometric head measurements, water analysis, hydraulic tests, etc. So far, the analysis of these data have shown some important aspects.

First, the continuous measurements of piezometric data show that the water table of the alluvial aquifer is highly influenced by the water level of the Rhône river. More precisely, the piezometric maps show that in a large portion of the region, the level of the Rhône is higher than the piezometry. This indicates either recharge conditions or disconnection.The assumption of recharge is in agreement with new maps (e.g. Fig. 1) of the hydrochemical data that were interpolated for this study. Those maps show that low concentrations of the different chemical species are most often measured near the low mineralized Rhône River.

In addition, the comparison of the hydrochemical data with the lithology of the valley slopes indicates places with a groundwater inflow from karstic aquifers.

Finally, the importance of the drainage ditches on the groundwater flow is revealed by the maps of the water chemistry. On those maps, the ditches form clearly recognizable barriers between two types of water (e.g. higher and lower mineralized waters, on both sides of the Canal du Syndicat, Fig. 1).

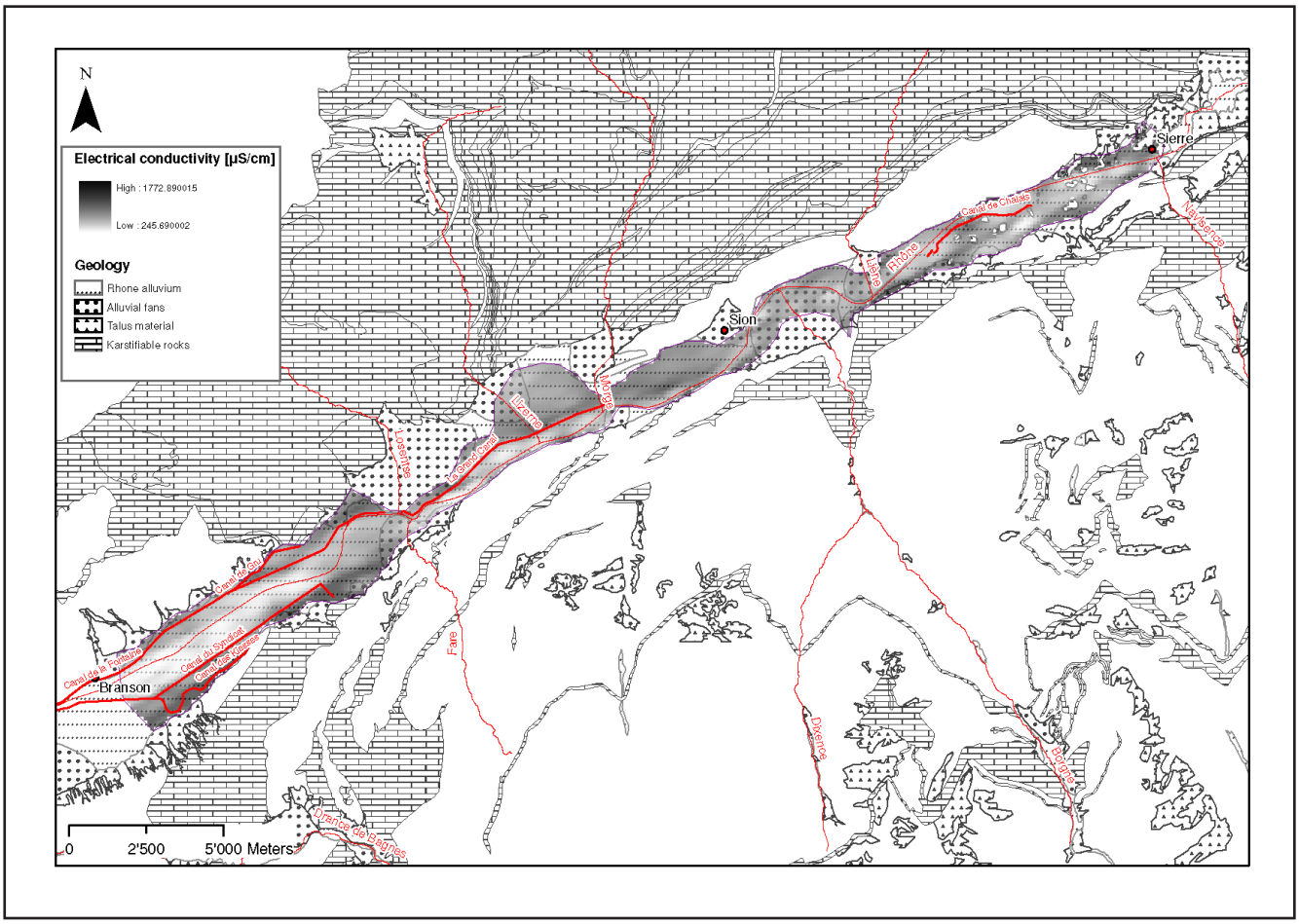

Figure 1. Interpolated map (kriging) of electrical conductivity in the Rhone aquifer between Sierre and Branson (Data: High water levels 1985).

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1.15

Impacts climatiques sur la recharge d'un système karstique englacé, Tsanfleuron-Sanetsch, Alpes suisses

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Les glaciers de haute montagne accumulent une grande quantité d'eau en hiver, contribuant ainsi à la recharge des eaux souterraines durant les saisons chaudes. Actuellement les glaciers alpins sont globalement en retrait et certains vont disparaître dans les 50 prochaines années sous les effets des changements climatiques. La région de Tsanfleuron-Sanetsch dans les Alpes de Suisse occidentale est un site expérimental idéal pour étudier les interactions glacier-aquifère. En effet un glacier au recul très rapide et présentant un risque de disparition prochaine surmonte un aquifère karstique drainé principalement par la source de Glarey et utilisée pour l'approvisionnement en eau potable. De larges surfaces de l'aquifère sont exposées aux précipitions et à la fonte des neiges entre le glacier et ce captage. Ainsi, entre le glacier de Tsanfleuron et sa moraine de 1855 (petit âge glaciaire) la surface du karst a été polie par l'écoulement glaciaire, alors que des lapiaz typiques sont présents sous le cordon morainique. Géologiquement la zone est formée de roches sédimentaires jurassiques à paléogènes, plissée selon un large anticlinal limité au sud par un étroit synclinal au niveau du captage de Glarey. Les relations entre stratigraphie, tectonique, processus de recharge et drainage souterrain de l'aquifère karstique a été étudié par de multiples méthodes, en particulier des essais de traçage et certains paramètres physiques mesurés en continu. La géométrie et structure du glacier de Tsanfleuron ont été étudiées par plusieurs campagnes géophysiques (méthode radio magnétotellurique RMT). Le volume de glace a été estimé à 102 millions de m^3, correspondant à ~93 millions de m3 d'eau liquide disponible pour recharger l'aquifère karstique et le soumettant à une variabilité journalière et saisonnière. L'eau de fonte produite par le glacier influence la géométrie des courbes de restitution et, par conséquent, les flux et le transport dans l'aquifère. Basé sur les prévisions climatiques, un modèle de disponibilité saisonnière de l'eau a été établi. L'hiver et le printemps présenteront un surplus d'eau alors que des périodes de manque d'eau seront à craindre lors de longues périodes sèches en été et automne, l'eau glaciaire étant absente. De plus les précipitations seront plus fortes mais plus rares et la demande en eau plus importante, particulièrement pour l'irrigation.

1.16

Partitioning of total mercury and methylmercury between colloids and true solution in overlying and interstitial waters (Lake Geneva).

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Mercury is one of the priority metals on the list established by the EU legislation due to its bioaccumulation in the food chain (Morel et al., 1998). Mercury bioaccumulation and biomagnification (i.e., increasing concentrations across trophic levels) are mainly caused by the transformation of inorganic Hg into the organic form methylmercury (MeHg) (Fitzgerald and Lamborg, 2003). As it is the case for many other elements (Vignati et al., 2005), the partitioning of mercury and MeHg largely controls their bioavailability and transfer to the trophic chains. Furthermore, formation of MeHg is particularly active at the sediment water interface thus making the study of Hg and MeHg partitioning in interstitial waters a topic of utmost interest for Hg/MeHg biogeochemical cycles and the associated risk assessment.
In this study, we used tangential flow filtration (TFF) to determine the partitioning of Hg and MeHg between operationally defined colloidal (0.45 μm – 3 kDa) and truly dissolved (< 3 kDa) fractions. Using ultraclean techniques (Cossa and Gobeil, 2000), blank values of 0.1–0.8 ng L^{-1} and < 0.01 ng L^{-1} were obtained for total Hg (HgT) and MeHg, respectively. We also adapted the TFF methodology to process volumes of 60 – 80 mL; corresponding to the amount of interstitial water (IW) recovered from 4 cm of sediment after centrifugation and filtration.
Sediment cores and overlying waters were collected at two sites with contrasting characteristics in Lake Geneva (Switzerland/France). Cores were sliced under nitrogen atmosphere to recover interstitial water. Interstitial water was filtered (0.45 μm) and then ultrafiltered. Total filterable Hg and MeHg concentrations were in the range 3.5–11 ng L^{-1} and 0.061–0.082 ng L^{-1}, respectively. The percentage of Hg and MeHg associated with colloids were similar: 20–35% of total filterable concentrations.

To verify if truly dissolved concentrations of Hg/MeHg could be estimated from the more easily measured total filterable concentrations, we combined our results with data available from literature. No significant correlation between filterable vs. truly dissolved concentrations were found for MMHg. On the other hand, significant Spearman correlations ($R^2 = 0.56$; $N = 30$; $p < 0.01$ for freshwater data and $R^2 = 0.92$; $N = 23$; $p < 0.001$ for oceanic water data) were obtained for total Hg. Our data superimposed rather well to the regression obtained for oceanic waters, rather than to the regression for freshwaters. We therefore surmise that the ligands controlling total Hg partitioning in IW are similar to those in oceanic coastal waters. The validity of this model should obviously be confirmed by future studies, but it opens an intriguing possibility to estimate Hg partitioning in IW and thus to refine the existing biogeochemical models.

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1.17

Trends in streamwater chemistry at the Damma glacier, Switzerland

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The contribution of silicate weathering to global cationic denudation rates is not known precisely due to the difficulty of separating the weathering from silicate and carbonate minerals. Accurate quantification of in situ silicate mineral weathering rates is required to constrain the carbon cycle. Small, mono-lithological catchments are ideal for elucidating the processes by which silicate rocks weather and how these processes change under varying seasonal conditions.

This work forms part of the multi-disciplinary BigLink Project which is investigating the 10.7 km^2 granitic Damma catchment (Switzerland). The glacier has retreated rapidly, exposing fresh mineral surfaces allowing the initial stages of granite weathering to be studied. Stream waters were sampled for one year, with higher frequency sampling during the summer, in five different locations, in conjunction with high resolution hydrological and meteorological measurements. Selected isotope ratios were analysed in addition to the overall chemical composition to characterise spatial and temporal variations in stream water chemistry.

After correction for atmospheric inputs, daily and seasonal cycles were clearly observed in the cation concentrations. The cyclic trends were independent of dilution and indicated the mixing of at least two distinct sources whose relative proportions changed over seasonal and daily timescales. In order to identify potential end-member sources, porewater and groundwater samples were also analysed. Our data show that these potential end-members are highly variable spatially and temporally.

The different sources reflect differing water-rock interaction times as evinced by variable elemental ratios (e.g. Na/Ca) which were offset from bulk rock ratios. A groundwater contribution with Na/Ca ratios close to bulk rock values is dominant in winter. During increased surface discharge in summer, groundwater contributions are smaller and Na/Ca ratios are offset from those of bulk rock.

This study shows that even in a lithologically well-constrained watershed, large variations in cation flux occur over daily and seasonal timescales, primarily due to changing hydrological conditions. Thus, knowledge of the hydrology of a catchment is essential to quantify cyclic cationic denudation rates, and to estimate silicate weathering rates.

1.18

Processes at and across the interface: Lessons lerned from river groundwater interactions under different hydrologic conditions

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Canalization of many rivers in the 19th century strongly influenced the economic development and urbanization of most European countries. Together with technical developments in agriculture, a series of environmental problems such as flooding, groundwater pollution and ecological changes, including the decrease of characteristic habitats of riverine landscapes, were created. Most of the river valleys are important groundwater reservoirs, in particular in central Europe. These reservoirs are often highly endangered due to intense agricultural and industrial activities and a dense network of urban areas connected by numerous traffic lines. Additionally, the high permeability of fluvial sediments (esp. fluvial shaped aquifer types of alpine type), the frequently observed lack of a thick protective cover layer and the exchange processes with surface waters result in a high vulnerability of groundwater resources.

Formulated goals for a sustainable development of water resources guide mitigation strategies and consider defined standards, i.e. natural composition of surface waters. Major efforts for future transdisciplinary research, with respect to hydrological regimes (low and high flow) or groundwater flow regimes, will concentrate on the knowledge of the structural dynamics of the river and related groundwater systems. To identify hydrological and hydrogeological system profiles, methodologies to quantify and control these profiles must be developed and applied. This can be achieved by the implementation of management systems that include observation systems and the development of numerical models combined with specific field experiments and scenario development.

The integral of changes in river structures in the catchment (i.e. lack of retention space) has already demonstrated serious consequences during major floods. Due to the experience gained from the hazardous flood events in the last twenty years, the pollution problems and the loss of characteristic riverine landscapes, most countries have adopted a more comprehensive view of rivers. It is recognized that the consideration of processes of river-groundwater interactions are important, which significantly differ for natural and channelized states.

Within this context, positive and negative aspects of river-groundwater interaction for channelized and non-channelized surface waters are investigated. The interaction of surface and subsurface waters is subject to continuous dynamics involving water budgets, water quality and flow patterns. When considering quantitative hydrological aspects of river-groundwater interaction, the transient character of riverbed permeability is an essential factor. Sediment erosion as well as transport and deposition processes are influenced by rivers that are able to exert their natural dynamics. As a consequence, the variance of the riverbed permeability is increased temporarily, influencing infiltration rates and groundwater mixing ratios, as well as residence times for groundwater from different provenance.

To understand the dynamics of river-groundwater interaction, our investigations focus on: (1) the evaluation of transient hydraulic boundary conditions, including the transient character of riverbed permeability and (2) qualitative aspects of surface waters and groundwater. Results from experiments of selected river-reaches are presented, including: (1) adequate observation systems that facilitate the measurement of groundwater parameters at different depths, as well as the definition of sampling strategies, (2) non-destructive geophysical methods (Georadar, Geoelectrics) within the river bed and the riparian zone, as well as (3) subsequent high resolution groundwater flow and transport modeling, including scenario techniques, model calibration and sensitivity analyses. Interaction processes are studied at a regional and a local scale (e.g. Upper Rhine Graben, individual catchment areas, river-reaches and capture zones of extraction wells).

1.19

The fate of organic contaminants at the groundwater-surface water interface

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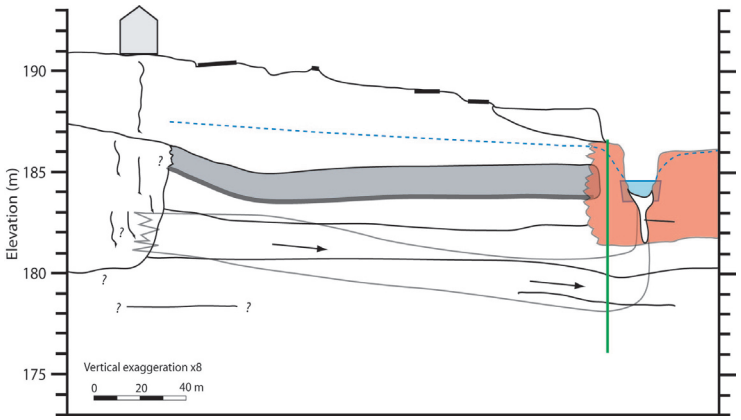
Persistent groundwater contaminants with little tendency to sorb to the matrix often travel over extended distances in aquifers and can eventually reach surface water bodies or other groundwater dependent ecosystems. In the vicinity of surface water bodies, sediment quality and redox conditions frequently change and biological activity is enhanced creating additional possibilities for contaminant retention and degradation. To what extent these altered conditions affect the contaminant fate strongly depends on groundwater flow paths, which are often highly complex in vicinity of surface water bodies, and the residence time of groundwater in zones with geochemical conditions suitable for contaminant degradation or retention.

In the presentation, results from two field sites are discussed where a tetrachloroethene (PCE) and a trichloroethene (TCE) plume, respectively discharges to a stream. PCE and TCE are well suited compounds to evaluate the effect of changing geochemical conditions on the contaminant fate since their degradation is highly dependent on the redox conditions. PCE and TCE degrade by reductive dechlorination under moderately reducing conditions, while their degradation products cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC) require strongly reducing conditions for further reductive transformation. Alternatively, cDCE and VC can also be oxidized to CO2 under aerobic and moderately reducing conditions. At the two sites, contaminant transformation was characterized using high resolution sampling and analysis of redox sensitive species, dissolved contaminants, stable isotope ratios of contaminants and microbial parameters.

At the PCE site (Abe et al., 2009), the contaminant plume travelled through a sandy aquifer under confined conditions and discharged into the stream through an approximately 2m thick layer of silty-clayey streambed sediment rich in organic matter (Figure 1a). While no degradation occurred in the sandy aquifer, highly variable degradation was observed in the streambed sediments related to small scale heterogeneities. The degree of degradation reached from no degradation in sandier zones where rapid groundwater discharge occurred to complete reductive dechlorination in clay-rich zones where highly reducing conditions prevailed. The TCE site consisted of an unconfined sandy aquifer (Chapman et al., 2007). In the upgradient part of the site, groundwater travelled at a depth of several meters below ground surface while in the downgradient zone, the water table was close to the surface and contaminants partly migrated through organic carbon rich floodplain sediments where reductive dechlorination occurred (Figure 1b). However, the shallow water table conditions favored groundwater discharge into ponds and creeks. Hence, while the aquifer showed a substantial capacity for contaminant degradation, most of the contaminants traveled via these small creeks to the main stream.

The studies demonstrate that in order to gain insight into the contaminant fate at groundwater-surface water interfaces a good understanding of the geochemical variability and groundwater flow paths is essential. At both sites, zones with favorable conditions for contaminant degradation occurred. However, these zones were partly by-passed and overall only partial elimination of the contaminants occurred. Finally, the study also illustrates the need for high resolution sampling to develop a consistent conceptual model of contaminant migration and degradation at groundwater-surface water interfaces.

a) PCE site



b) TCE site

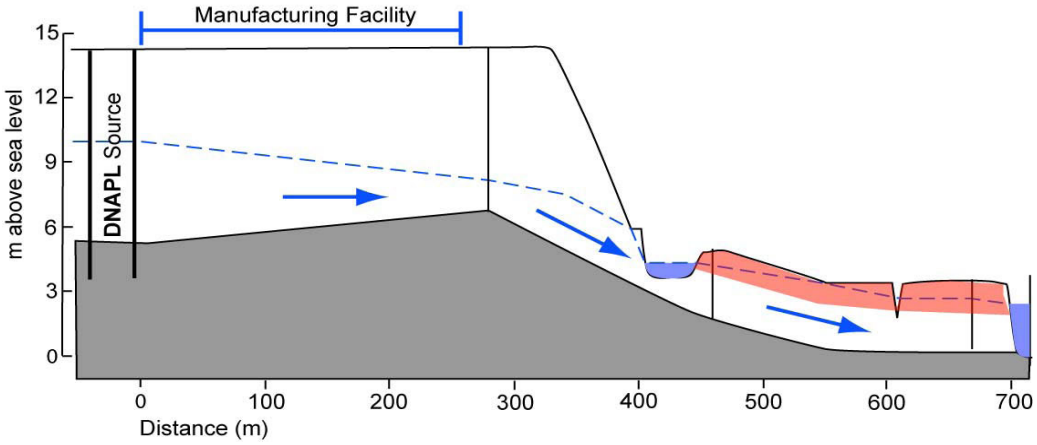


Figure 1: Schematic cross section of the field sites where contaminant plumes discharge into a stream under confined (a) and unconfined (b) conditions.

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1.20

Thoron as a possible marker tracing surface water / groundwater interaction

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Radon (^{222}Rn, half-life 3.6 d) and thoron (^{220}Rn, half-live 55.6 s) are the most long lived isotopes of the noble gas radon. As part of the two natural radioactive decay series of ^{238}U and ^{232}Th, respectively, they are released from minerals to fluids (e. g. soil gas, ground water) by α-decay from their precursors ^{226}Ra and ^{224}Ra, respectively (emanation process). Both radon-isotopes can be found in soil gas. ^{222}Rn has been subject to research for a long time and is well known to occur in aquatic systems, especially in ground water. It is often used as a tracer for assessing residence times of surface waters infiltrating to ground water. In contrast, studies on thoron in aquatic systems are rare. However, thoron is expected to be found in groundwater, too, where it could be used for an assessment of mixing. Also, for assessing upwelling/downwelling processes in the river bed, thoron is a potentially promising tracer.

Up to now, we did not find any thoron in ground water. This is most probably related to the fast decay of thoron, which result in a restricted mobility, and the time-consuming detection system to determine thoron. Further more, the geophysical and geochemical character of the radionuclides of the ^{238}U series is different from that of the ^{232}Th series and, therefore, the appearance of radon in aquatic systems does not necessarily reflect the occurrence of thoron.

In order to conceptually describe the thoron emanation we formulated the following working hypothesis: The precursors of radon and thoron ($^{224, 226, 228}$Ra) are known to be slightly more soluble in anoxic than in groundwater (in oxic water, Ra is only hardly soluble and remain essentially in the solid phase). If such anoxic ground water gets into contact with oxygen, radium tends to co-precipitate with Mn and Fe oxide/hydroxides. As a result, the emanation of thoron to the water phase may be enhanced by radium, which is attached to surface coatings of the precipitates. In order to enhance the sampling procedure, we modulated a conventional sampling system (RAD7, coupled with commercial degassing unit RAD AQUA) by interconnecting an additional closed air loop with adjustable diaphragm pump to decrease the residence times of water and air between sampling and measurement.

Primary results confirm the feasibility of thoron analysis in oxygen-poor springs, especially if iron and manganese precipitates are present. Gamma-spectroscopy of precipitates at the springs's outlet showed the relative high content of thoron precursors and daughter products in the Fe and Mn oxides/hydroxides. Moreover, α-spectrometric analysis showed that thoron precursors and daughters are concentrated on the surface of the precipitates, which further add evidence to our conceptual view of thoron emanation.

1.21

Variability of in situ biodegradation of chlorinated ethenes in a constructed wetland

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The spatial and temporal biogeochemical development of a model wetland supplied with cis- and trans-1,2-dichloroethene contaminated groundwater was characterized over 430 days by hydrogeochemical and compound-specific isotope analyses (CSIA). The hydrogeochemistry dramatically changed over time from oxic to strongly reducing conditions as emphasized by increasing concentrations of ferrous iron, sulfide, and methane since day 225. δ13C values for transand cis-DCE substantially changed over the flow path and correlated over time with DCE removal. The carbon enrichment factor values (ε) retrieved from the wetland became progressively larger over the investigation period, ranging from -1.7 ± 0.3‰ to -32.6 ± 2.2‰. This indicated that less fractionating DCE oxidation was progressively replaced by reductive dechlorination, associated with a more pronounced isotopic effect and further confirmed by the detection of vinyl chloride and ethene since day 250. This study demonstrates the linkage between hydrogeochemical variability and intrinsic degradation processes and highlights the potential of CSIA to trace the temporal and spatial changes of the dominant degradation mechanism of DCE in natural or engineered systems.

In parallel, the dynamics and composition of microbial communities in the aqueous phase of the model wetland was characterized. PCR-DGGE analysis of water sample obtained from different part of the wetland revealed that changes of the bacterial community structures coincided with a succession of the hydrogeochemical conditions in the wetland, from oxic towards anoxic conditions. During this transition phase, the appearance of vinyl chloride and ethene correlated with the presence of putative dechlorinating bacteria (Dehalococcoides spp., Geobacter spp. and Dehalobacter spp.). Additionally, shift of DCE isotopic composition indicated the progressive prevalence of reductive dechlorination in the wetland. Although the DCE degradation processes varied over time, biodegradation activity was maintained in the wetland system. 16S rRNA gene libraries revealed that Proteobacteria accounted for > 50 % of 16S rRNA genes clone libraries, whereas ~17 % of the sequences from the wetland were related to sulphate reducers. Based on an multiple-method approach, this study illustrates the linkage between microbial community dynamics and composition, changes of hydrochemical conditions and processes of DCE degradation in a wetland system.

1.22

Role of land-atmosphere interactions for climate extremes and trends

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Processes acting at the interface between the land surface and the atmosphere have a strong impact on the European summer climate, particularly during extreme years. These processes are to a large extent associated with soil moisture. This presentation provides an overview on recent analyses investigating the role of soil moisture-atmosphere coupling for the European summer climate over the period 1959-2006 using simulations with a regional climate model.

The set of experiments consists of a control simulation with interactive soil moisture, and sensitivity experiments with prescribed soil moisture. Soil moisture-climate interactions are found to have significant effects on temperature extremes

in the experiments, and impacts on precipitation extremes are also identified. Case studies of selected major summer heat waves reveal that the intraseasonal and interannual variability of soil moisture account for 5–30% and 10–40% of the simulated heat wave anomaly, respectively. In addition, is also found that soil moisture has a significant effect on heat wave persistence through soil moisture memory. For extreme precipitation events on the other hand, only the wet day frequency is impacted in the experiments with prescribed soil moisture.

Finally, trends in climate extremes in current climate-change projections, such as an increase in temperature over the whole European continent, as well as a Southern European decrease and Northern European increase in precipitation extremes, can already be detected in simulations for the past decades, and appear at least partly linked to soil moisture-atmosphere feedbacks.

1.23

Swissrivers.ch – Online river forecast prediction

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Discharge prediction in river basins has become a pluridisciplinary and high-technology topic. The needs for such systems are related to flood management, hydroelectricity market or leisure activities. In this context, swissrivers.ch has been developed to provide everyone, using internet, information about the future discharge in all the main rivers of Switzerland.

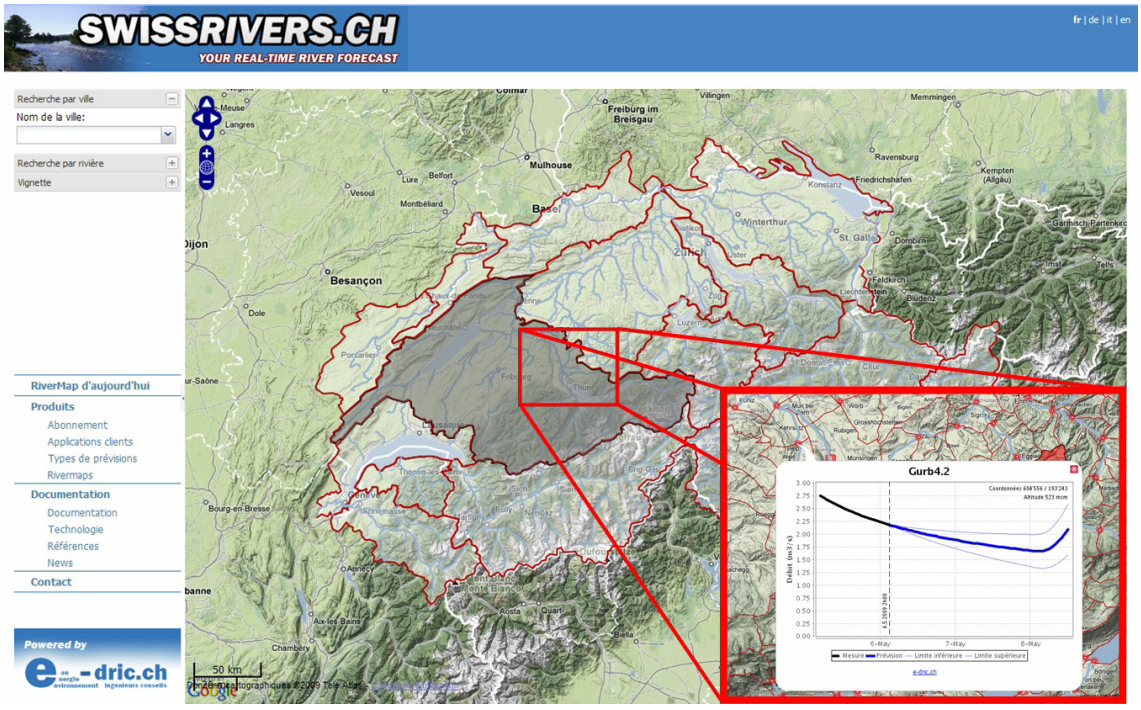

Figure 1. The new web platform www.swissrivers.ch, with a direct geographical access to river discharge predictions.

The new online platform works as follows: numerical weather predictions are provided by the Federal Office for Meteorology and Climatology (Meteoswiss), twice a day and up to 72 hours ahead. Their precipitation and temperature predictions issued from the COSMO-7 model (Schättler, Barbu, 2008) with a 6.6 km horizontal grid mesh are used for an extract over the whole country to calculate the predicted discharges in the sub-basins and in the rivers. In order to optimize the quality of the predicted discharges, the hydrological model is updated 4 times a day: the continuous simulation is automatically modified by comparison between discharge measurements and computed discharges based on meteorological observations over the last 24 hours for each one of the 280 automatic federal gauging stations of Switzerland (BAFU). The objective of this model update is to ensure that the model always simulates realistic discharges in rivers.

The information provided by swissrivers.ch can be freely accessed for 2500 sub-basins and 1500 locations in the swiss rivers. For every selected location, the updated simulation of the last 24h, as well as the discharge prediction for the next 30 hours are presented as a plot.

The system is based on the RS3.0 technology, which allows the automatic data acquisition and storage in a database (weather and discharge observations, numerical weather forecasts), the rainfall-runoff simulation including snowmelt, glacier melt, evaporation, infiltration, surface runoff, river routing as well as flow routing in hydraulic structures (reservoirs, power plants, water diversions, etc...). RS3.0 also allows an automatic publication of the results in a web platform or in a GIS. This technology is based on previous developments realized for the MINERVE Project at the Ecole Polytechnique Fédérale de Lausanne (Jordan et al., 2007, Garcia et al., 2008, Jordan et al., 2008).

The performance of the system has been optimized by a calibration-validation procedure using more than 15 years of hourly data, over 300 control points in Switzerland. However, the model could be improved by integration of new historical and real-time control points, in basins located upstream of large dams and reservoirs.

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1.24

The influence of climate change on the water balance of mesoscale catchments in Switzerland

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Recent research shows that the anticipated climate change in Switzerland will result in changing precipitation patterns and increasing temperatures during the first half of the 21st century. Amongst others, the temperature increase will cause an upward shift of the snowline, and precipitation will fall more often as rain than as snow. The combination of these changes will provoke a change in the runoff regime such as an earlier yearly peak flow. While evapotranspiration will generally increase in a future climate, the changes in precipitation amounts will differ seasonally, with increases in winter and decreases in summer (OcCC 2007). The yearly volume of discharge is likely to decrease with the exception of alpine catchments where glaciers will function as reservoirs during the next years (Schädler 2008).

Our main interest lies in the question when and in particular where the system starts tipping over and abovementioned changes show through in the hydrological response of catchments. This issue will be addressed in the framework of the joint research project "Climate Change in Switzerland – Hydrology" (CCHydro) which was initiated by the Federal Office for the Environment (FOEN) and seeks to assess possible effects of climate change on hydrological systems in Switzerland. The heterogeneity of complex mountainous landscapes, however, forbids general statements. Therefore, a multidisciplinary and holistic approach was chosen and the scenarios in use are of high temporal and spatial resolution.

As a first step, hydrological modelling is used to identify and examine catchments that exhibit sensitivity towards a change in climate. For this, we use the process-oriented hydrological modelling system PREVAH (Viviroli et al. 2007). The mesoscale catchments under investigation have a mean area of about 150 km^2. After calibration of the catchments for which measured

discharge records are available, a regionalisation scheme (Viviroli 2007) is used to arrive at a comprehensive set of model parameters for the entire area of Switzerland. Spatially and temporally highly resolved scenarios of the projected climate change until 2050 will then be used to force the model. The scenarios will be scaled down to station data by the Institute for Atmospheric and Climate Science (IAC) at ETH Zurich using the Delta Approach.

As a result, regions exhibiting climate sensitivity in the period 2021 to 2050 will be specified, and possible causal relationships between sensitivity and specific catchment characteristics will be evaluated.

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1.25

Palaeoenvironmental mapping of the Swiss Rhone river

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As many European rivers, the Swiss Rhone river and its floodplain have known several morphological variations after the Little Ice Age that ended around 1850. Based on the concept of the palaeoenvironmental atlas built on the French Rhone river by J.-P. Bravard et al. (2008), palaeoenvironmental mapping has been carried out in the Swiss Rhone river watershed (Laigre 2009). Comparison of historical maps from 1835 to 1996 (Dufour map, Siegfried Atlas, and several editions of national map of Switzerland) shows several events of fluvial metamorphosis (Bravard 1989) of the channel. Until the 1860's, numerous gravel bars, extensive islands and large active zone can be observed. The braided style is the dominant fluvial pattern. Since the end of the 19th century, most of channels are straight, excepted one area – the Finges Forest zone – where a large part of the valley is occupied by an important braided system. Since the 1940's, a channel constriction is observed as well and incision of the present straight channel is progressing.

Analysis of the metamorphosis factors emphasises principally one external variable, which modified the system: human intervention. Channelization of the Rhone river and its tributaries from the late 19th century and gravel extractions have completely modified the natural sedimentary functioning and balance, in a period of reduced sedimentary supply that characterises the end of the Little Ice Age. Moreover, morphological modifications of the fluvial system had impacts on the floodplain landscape evolution and land use in the valley, which was characterised by large woodland and wetland areas until the end of 19th century. Understanding functioning of past environments may be a precious help to anticipate eventual future flood events that cause large damages in the Alpine range.

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1.26

Storage and release of water and chemical species in glaciers

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Glaciers accumulate solid precipitation in form of ice, and with it materials ranging from chemical species to dust and stones. Only under steady climate conditions the release rate of these materials, and water, is constant. Under a varying climate there exist cold periods with reduced release of accumulated water and chemical species, as well as warm periods when water is released at high rate. During the warm periods, high concentrations of chemicals and sediments are released from the glacier. We present results from a transient flow line model of a glacier which allows us to quantify these processes. In a case study on Oberaargletscher we show that persistent organic pollutants (POPs) emitted to the atmosphere in the 1950-1960s were stored in the glacier and are released at high rate during the last decade. Consequently, the concentration of toxic POPs in the proglacial lake are as high as during the time of atmospheric impact, which agrees with measurements in a sediment core.

1.27

Groundwater and tunneling: implementation of a geochemical monitoring network in the southern Switzerland

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The interaction of tunneling with groundwater is a problem from the environmental as well as the engineering point of view. In fact, tunnel drilling may cause a drawdown of piezometric levels and inflows in tunnels can be a problem during excavation steps. In fractured rock water circulation is strongly influenced by structural elements, such as fault zones, fractures and other discontinuities, and numerical solutions are frequently used in literature (NAGRA since 1985, Ofterdinger et al 1999, Löw et al. 2007). To this purpose various conceptual approaches has been performed to describe and model the groundwater flow through fractured rock masses, ranging from equivalent continuum models to discrete fracture network simulation models. However their application needs many preliminary investigations on the behavior of the groundwater system; moreover these models request a correct calibration, that is very complex, even impossible without a collection of necessary structural and hydrochemical data.

To study large-scale flow systems in fractured rocks of mountainous terrains, a comprehensive study is ongoing close to Lugano using the data produced in one of the main infrastructures actually in construction, the Alptransit Monte Ceneri base tunnel. The main goal of this work is the understanding of how the collection of isotopic and geochemical data, and geophysical techniques (VLF profiles and 2D resistivity surveys), combining with structural and hydrogeological informations, can be used in order to develop hydrogeological conceptual and perhaps numerical models.

In the region surrounding the Monte Ceneri base tunnel there are about 750 springs actually registered in the cantonal database. On the basis of criteria of *(i)* relevance (use and discharge) and *(ii)* distance from the tunnel, a number of springs are be selected for monthly measurements of discharge, electric conductivity, *pH*, and temperature, and water samples are taking to monitor stable isotopes of hydrogen and oxygen (^{2}H, ^{18}O) and tritium (^{3}H), perhaps combined with helium-3.

Furthermore these data will be compared with tunnel inflows informations to perform, within reason, a validation of the model that will be designed taking advantages of these techniques.

In particular, the analysis of stable isotope composition of springs, will reflect their water origin, because spatial (recharge altitude, topography, etc.) and temporal (seasonal) effects in precipitations strongly affect the isotopic composition of meteorological water and consequently of groundwater reservoirs (fig. 1). The analysis of tritium, that is a radioactive isotope, will be used for groundwater dating (fig. 2); using only tritium we will obtain a qualitative indication of water age (young or old groundwater), while tritium combined with helium-3, in case of modern water, will provide us, a “discrete age” for the sampled water.

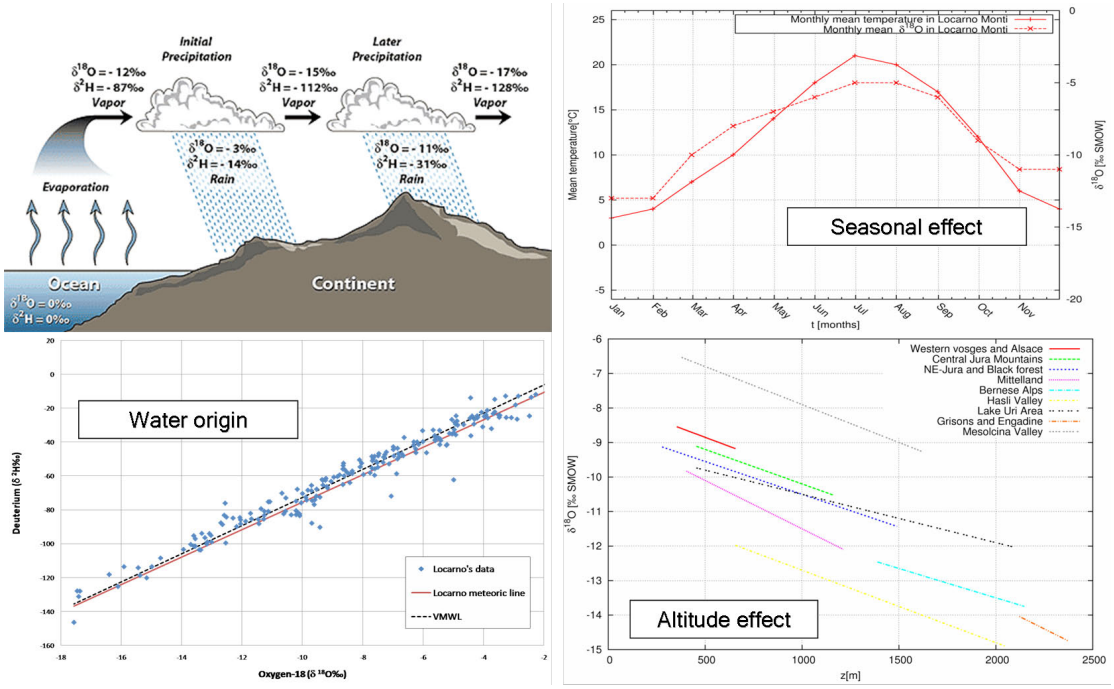

Figure 1. Stable isotopes fractionation: physical processes and relevant registered effects.

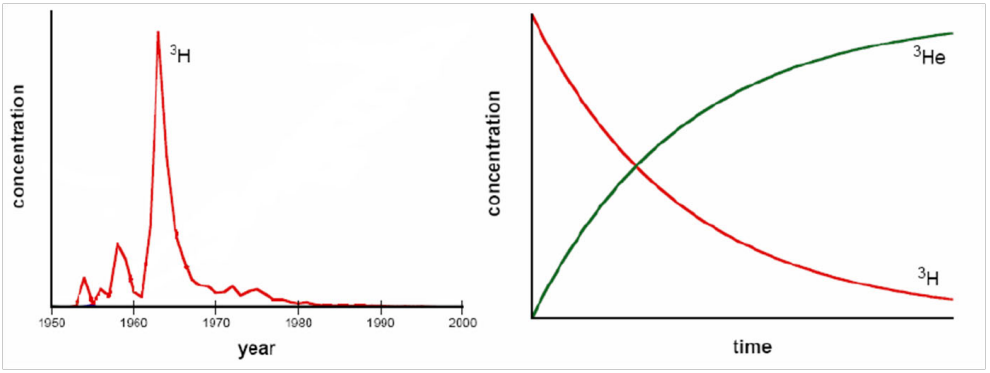

Figure 2. Basic principles of the dating methods with tritium. On the left the registered tritium concentration during last decades, that allows to qualitative distinction between young and old groundwaters. On the right the using of tritium combined with helium-3.

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1.28

Dynamics of colloid concentrations in a small river related to hydrological conditions and land use.

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Colloids play a major role in the transport and bioavailability of contaminants in aquatic environments. Their dynamics in an ecosystem (erosion, transport, aggregation and subsequent settling) is a key parameter to understand the fate and potential impacts of colloid-associated pollutants such as metals or organic pollutants (e.g. Benoit et al. 1994, Irace-Guigand and Aaron 2003). In river systems, colloidal particles are mainly of detrital origin and derived from the erosion of soils and impermeable surfaces in the watershed.

In the present study, the watershed of the Versoix River (France, Switzerland), a tributary of Lake Geneva, has been investigated by sampling water at different sites along the river course, and under various hydrological conditions (low flows, snow melting, small floods). The watershed main characteristics (slope, land use) have been determined at each sampling point and quantified through a GIS-based study. Colloid and particle number and size distributions have been measured in the range 0.05 – 20 μm using a single particle counter (Rossé and Loizeau 2003).

Results show that the size distributions (expressed in number of particles) follow a power law, with very similar slopes, independently of the concentration. At the river mouth, colloid concentrations during small flood conditions were 10 to 100 times higher than during low flows, while suspended matter was only 2 to 3 times higher, and the discharge increased just by a factor two. These large discrepancies in the amplification factors between suspended particles and colloids concentrations reflect the preferential mobilization of easy erodible colloidal particles during rain events. In addition, colloid concentrations also generally increase with the distance from the head waters, for both high and low flows. This likely reflects a continuous colloid source from the river bed itself. However some variations exist in the colloid concentration that may be related to differences in the land cover. The Versoix River watershed is complex, comprising forest, meadows, cultivated fields, industrial and urban surfaces, and wetlands. A careful examination of the colloid concentration evolution along the river course during rain events shows that proportion of urban surfaces and cultivated field are positively correlated to increased colloid concentrations in the river.

As the capacity of colloidal particles to scavenge and subsequently transport contaminant is largely related to their specific surface, the large increase of colloid concentrations during flood implies a much larger potential contaminant load to the receiving water body than that generally observed with pollutant inputs related to suspended particle matter.

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1.29

Water disturbance as the organizer of riparian vegetation

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The flow regime plays an important role in the organization of riparian vegetation in natural rivers by creating suitable germination sites, eroding plants and changing the river morphology. An important aspect of the flow regime is the disturbance element, i.e. the seasonal distribution, timing and magnitude of floods. The interactions between water, sediment, and riparian vegetation are most evident in natural unregulated rivers, such as gravel-bed braided streams and sand-bed meandering rivers. Restoration projects in regulated rivers often aim to make room for these natural interactions to take place. Therefore we need to continuously improve the scientific basis to understand the fundamental water-sediment-vegetation interactions and develop new tools and methods to simulate and test them. In this paper we present two new approaches (numerical and laboratory-based) which we are developing in our group and which look at water disturbance as an organizing element of riparian vegetation.

The first numerical approach is a stochastic model for water-sediment-vegetation interactions in a braided gravel-bed stream. This is an approach that models the expansion and contraction of the exposed sediment area in a braided river driven by stochastic flood disturbances and by a deterministic colonization of the exposed sediment banks and bars by riparian vegetation in the time between the floods. The basic model allows us to develop an analytical solution for the probability density function of the exposed sediment area as a function of the flood disturbance parameters and vegetation growth rate (Fig 1) (Perona et al., 2009).

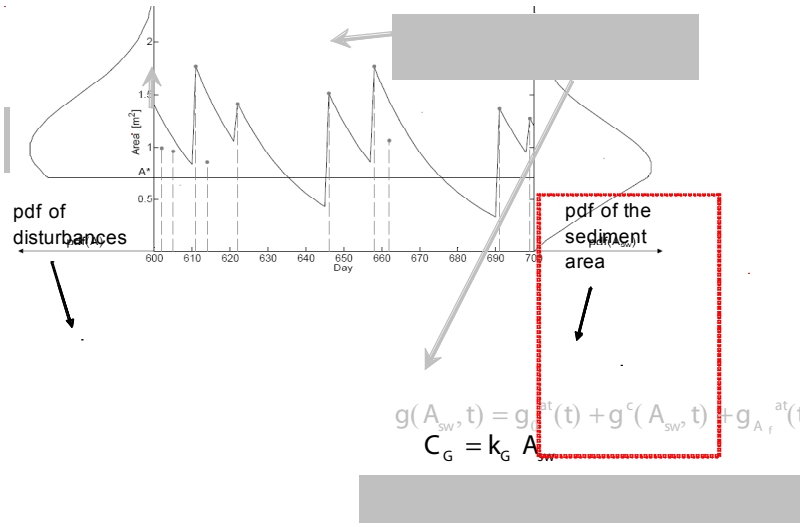

Figure 1. Setup of the process equation for the exposed sediment area A_{sw} and an illustration of the solution for the pdf of A_{sw}.

This simple model may be extended to include successive vegetation stages and their competition for available space on the floodplain (Perona et al., 2008).

The second laboratory approach is an experiment which studies the role of hydrological disturbances on biomass erosion dynamics in a sand-bed flume which is seeded by a fast growing grass. This experiment was conducted at the Total Environment Simulator of the University of Hull under the Hydralab3 EU Programme (Molnar et al., 2009, in preparation). In the experiment we studied the interactions between the disturbances and the growth rate of the vegetation roots and stems. Preliminary results show that the action of fluvial erosion removes systematically plants that are not able to withstand the applied stress, while the non-eroded community continues to grow and develop (Fig 2).

The two presented approaches both illustrate that the water disturbance regime plays an important role in the organization of braided river morphologies and sand bed streams, riparian vegetation, and plant communities. The water disturbance regime and vegetation growth interact and result in a dynamic riparian community. We advocate that this is not a deterministic problem and that the effect of water-sediment-riparian vegetation interactions should be examined in a probabilistic framework both at a large field and small laboratory scale.

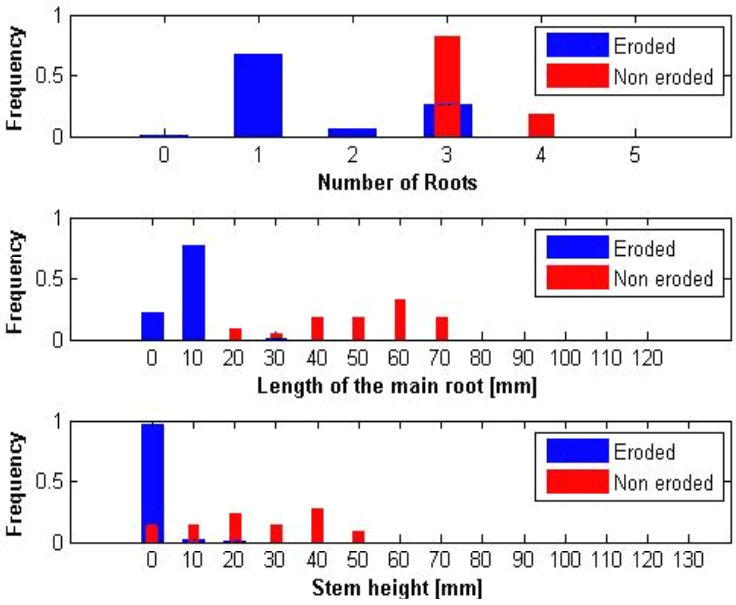

Figure 2. Example of a simulation run with the histograms of the number of roots (top), length of the main root (center) and stem height (bottom) for eroded and non-eroded plants.

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1.30

Calculating bedload transport rates in Swiss mountain streams using new roughness approaches

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Most methods for predicting bedload transport do not take into account typical roughness elements of small, steep mountain streams, like step-pool sequences, large boulders or woody debris. However, flow resistance due to such form roughness elements appears to be an important control on bedload transport rates in mountain streams.

Recently, new approaches based on laboratory experiments were proposed to assess flow resistance due to form roughness. They quantify the effects of generalized models of roughness elements to flow resistance. Furthermore, several empirically derived formulae to calculate bedload transport rates including a respective roughness parameter have been published.

The objective of our study is to systematically test these approaches with field observations. For this purpose, we measured the required roughness parameters for seven Swiss mountain streams, with local channel gradients ranging from 1.5 to 16.5 %, and catchment areas from 12 to 43 km^2. We calculated flow resistance and bedload transport for sediment transport events in 2000 and 2005. By comparing calculated and observed data of bedload transport we identified whether and in which range the examined approaches are suitable for application in natural stream conditions.

1.31

Pollution des eaux: la santé est-elle un levier pour mettre en place une gestion intégrée à l'échelle du basin versant?

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La problématique des polluants comme les pesticides, médicaments, cosmétiques, dans les eaux de surface est de plus en plus actuelle. Non pas que ces micropolluants soient des substances nouvelles, mais plutôt que les techniques d'analyse chimique se perfectionnant, on découvre de plus en plus de substances chimiques dans le milieu aquatique. Il semble également que ces substances ne soient pas sans conséquences sur l'homme et l'environnement puisqu'on leur attribue des effets cancérigènes ou de diminution de la fertilité.

Dans une optique de gestion durable des ressources en eau, il est donc indispensable de prendre en compte l'aspect des micropolluants. Cependant, cette pollution est très difficile à maîtriser car elle n'est pas confinée dans un endroit clos. Les substances sont souvent transportées sur de longues distances et peuvent ainsi engendrer des effets loin de leur source d'émission. A titre d'exemple, des rejets industriels dans le Valais ont conduit à une contamination du Léman par certains pesticides et médicaments qui se retrouvaient ensuite dans les eaux brutes des stations de pompage autour du Léman. Cette pollution est aussi difficile à limiter car si des quotas peuvent êtres définis par secteurs, la somme globale des substances de tous les secteurs peut vite donner lieu à une pollution ayant des conséquences importantes sur l'environnement. Enfin, cette pollution est complexe car l'association entre différentes substances peut aussi donner lieu à des cocktails détonants.

Pour minimiser le risque pour l'homme et l'environnement des micropolluants, il est donc indispensable de passer à une gestion « intégrée» de l'eau qui prenne en compte les acteurs et leur organisation à une échelle régionale. Au travers d'un jeu de rôle organisé dans le cadre d'une formation post-grade, nous avons tenté d'explorer comment la santé pourrait être (ou ne pas être) un levier pour mettre en place cette gestion intégrée et en quoi cela pourrait conduire à revisiter les pratiques de l'aménagement du territoire.

La brève analyse que nous avons mené du jeu de rôles nous permet de mettre en exergue trois conclusions principales:
La première, c'est que la santé est un levier particulièrement pertinent pour déclencher une prise de conscience du problème et permet d'amorcer de façon très rapide une démarche visant à le résoudre. En cela, la santé semble être un élément déclencheur et catalyseur du processus.

La seconde, c'est que la santé est un thème sensible dont il est très difficile de déterminer et d'assumer la responsabilité. Pour autant, cette complexité engendre aussi la prise de conscience de la nécessitée de mettre en place un processus collectif. La santé permet donc de rassembler et de dynamiser une démarche collective, globale et intégrée.

Enfin, la troisième, c'est que le processus entier ne peut entièrement reposer sur l'argument de la santé. En effet, il semble que la santé, même si elle représente un enjeu fort, peut être vite en concurrence avec d'autres enjeux, particulièrement avec les enjeux économiques. Il en résulte alors souvent la mise en place de solutions réduites, « end of pipe », qui ne correspondent plus à l'objectif de départ, à savoir : une solution globale et intégrée.

Pour conclure, il nous parait important de souligner à nouveau que si le jeu de rôle est un outil très intéressant pour analyser des processus, il ne remplace en aucun cas l'étude de cas réels. En effet, il s'agit d'une situation simplifiée, accélérée dans le temps et avec des acteurs factices. Néanmoins, il est intéressant de constater que les situations décrites dans le jeu de rôles se retrouvent souvent dans des cas réels.

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1.32

Effective stress and fracture permeability in regional groundwater flow: numerical comparison of analytical formulas

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The dependency of fracture permeability on effective stress is a subject well known and has been intensively studied last decades. In regional and deep groundwater flow system underground draining structures as tunnels, cause a diminution of pore pressure leading to an increasing effective stress and a decreasing permeability. One approach consists to insert constitutive laws relating effective stress to permeability in Darcy's law, which is used to evaluate 3D regional simulations of discharge rates, pressure distributions and flow paths. This approach gain in accuracy as compared to the classical ones which consider constant permeability field. However, the type and parameterization of the constitutive law influence the final result.

In this work, three different model functions relating effective stress to permeability are implemented in the tensor form of Darcy's law, and compared by means of numerical experiments. Two of these functions were derived from experimental works (Louis 1969; Walsh 1981), the other one was theoretically derived from Hooke's law. Numerical simulations are all based on an initial fractured hydrostatic system where an underground draining structure is activated, causing a steady-state saturated flow from the upper boundary condition (surface) to the lower boundary condition (underground structure). The governing non linear equations are solved using the finite element method.

In the three cases, results show that the introduction of stress-dependent permeabilities in Darcy's law leads to discharge rates significantly lower than those calculated with the classical approach. This is explained by a decreasing permeability due to an increasing effective stress, particularly in the vicinity of the deep draining structure. Louis' experimental model yields the largest difference and has the deficiency of not considering the vertical stress term, while Walsh's model is difficult to solve numerically due to higher order non linearities. The elasto-statistical model analytically derived from Hooke's law seems to be better adapted for solving such problems and yields differences which are somewhat smaller than the two others.

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1.33

Debris flows, landslides, and sediment transport in mountain catchments

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In mountain headwater catchments with steep channels and hillslopes, floods are often associated with sediment transport and/or with debris flows. Possible interactions between debris flows, shallow landslides and fluvial sediment transport in steep streams are illustrated Figure 1. These processes often occur during high-intensity or long-duration rainstorms, possibly combined with snowmelt, resulting in slope instabilities, sediment transporting flows and floods. These processes are often associated with damage to houses or infrastructure, particularly along the channel network, and may involve also casualties.

Debris flows typically occur in steep headwater catchments. A torrent catchment is characterised by sporadic and sudden high discharges of both water and sediments, and it typically comprises a catchment area less than about 25 km2. The channel gradient may vary from more than 60 % to a few % in the fan area. The torrent system and debris-flow occurrence can be characterised by three main zones: The headwater area or initiation zone where the flow is triggered, the transit zone (gully and channels) where entrainment of more solid material may occur, and the debris fan area where often major deposition takes place. Debris flows in the Alps may involve total sediment volumes of up to some hundred thousand cubic metres. The sediment may be supplied from point sources such as landslides or from incision of the torrent bed by vertical and lateral erosion. The total event magnitude is often used as a rough indication to characterise the intensity of a debris flow. This parameter largely influences the flow behaviour in the channel and – in the case of overtopping - the extent of the affected areas on the fan. Debris flows may deliver important quantities of sediment to the receiving mountain river.

In contrast to lowland gravel bed rivers, relatively few studies were made on sediment transport in steep headwater channels, with stream gradients steeper than about 5 %. Sediment transport dynamics in these channels may be quite different from low-gradient channels. There is often a strong interaction between hillslope processes and the channel network. Sediment transport may be supply limited rather than controlled by the sediment transport capacity for a given discharge and channel conditions. Steep headwater streams are characterised by a wide range of sediment sizes and temporally- and spatially-variable sediment sources. Bed morphology and channel structures may be influenced by the presence of large boulders, woody debris and bedrock constrictions. This can result in large variations in channel geometry, streamflow velocity and roughness, and thus the application of theoretical sediment transport equations may be problematic. Also, quantitative measurements of sediment and bedload transport in steep streams are very limited.

In this presentation an overview will be given on the processes debris flows, shallow landslides and fluvial sediment transport. A particular focus will be the discussion of interactions between these processes. Although a number of methods have been proposed to predict and describe the initiation and flow behaviour of debris flows and sediment transporting flows in mountain streams, quantitative predictions for hazard assessment are still difficult in many cases. The application of some methods will be illustrated using some examples from past flood and rainstorm events.

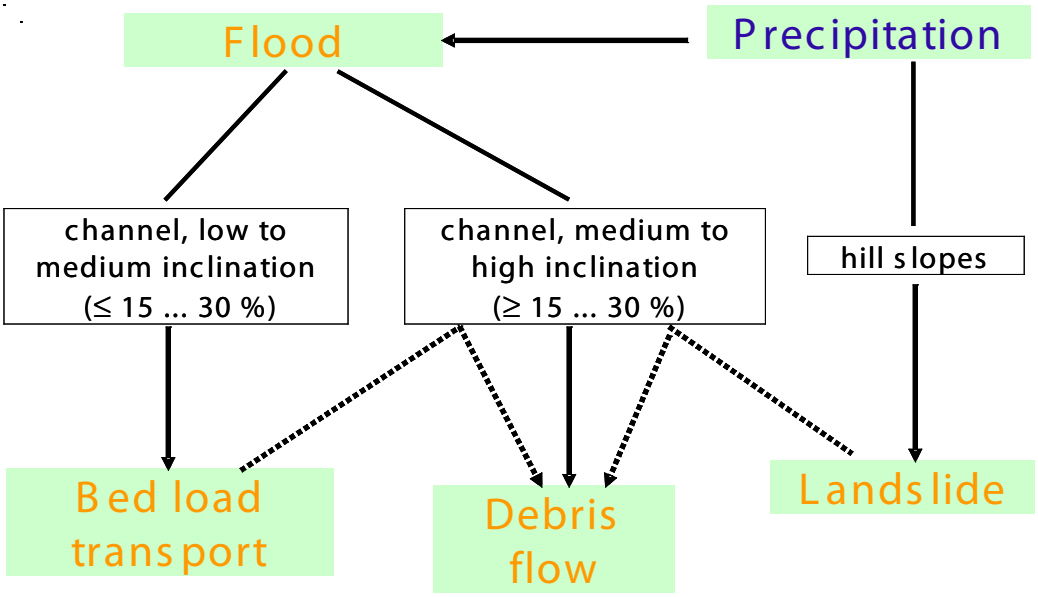

Figure 1: Occurrence of debris flows, shallow landslides and fluvial sediment transport in steep mountain streams.

1.34

Characterisation of geothermal reservoirs using 3D geological modelling and gravity

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The productivity of geothermal resources depend on different parameters mainly the reservoir temperature, the hydraulic conductivity and the stress field. It has been realized in different studies that the hydraulic conductivity of the reservoir is the dominant factor (e.g. Best Practice Handbook for the Development of Unconventional Geothermal Resources with a Focus on Enhanced Geothermal Systems, 2008). This study is part of the long-term research of the Laboratory of Geothermics at Neuchâtel with the objective to develop a methodology to investigate permeability from geophysical exploration. The aim of this study is to develop a method to characterize the porosity from gravity inversion combined with 3D geological modeling.

Gravity measurements provide information on the density of subsurface units either by forward modeling or inversion. And it is well known that the density of the subsurface can be either controlled by lithological changes or changes in porosity (Pruis & Johnson 1998). Furthermore, when the geological area is well known, the 3D gravity inversion is well constraint so it provides accurate result and best densities values are obtained. For porosity, one among the relationships which exist between the density and porosity can be used (e.g. Johnson et al., 2000).

In the geothermal area of Soultz the combination of 3D geology and gravity inversion has revealed density changes in the granitic basement (Figure 1) which can be related to both changes in the granitic facies to the North of the geothermal site and to porosity in the horst structure, where the reservoir is located (Schill *et al.*, subm). Synthetic models for other deep geothermal reservoirs such as St. Gall (Switzerland) provide further indication on the possibilities to deduce porosity from gravity forward modeling. The example from Soultz shows, however, that only if the geological structures are well known and can be assumed as fix in the gravity inversion, the estimation of density changes caused by porosity are possible.

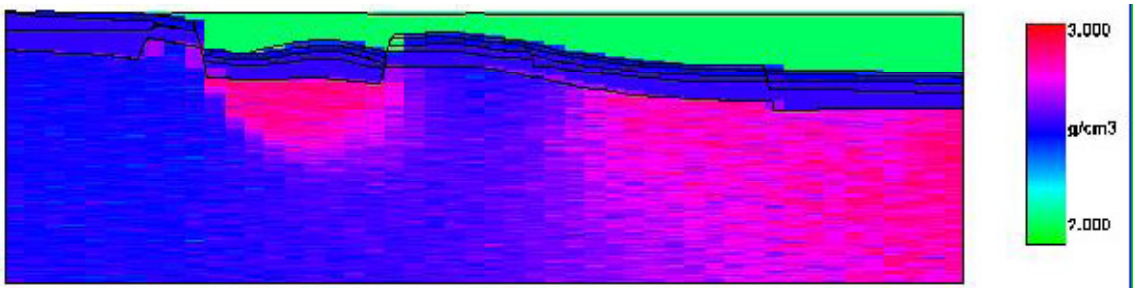

Figure 1: Mean density distribution resulting from inversion of gravity data for a representative E-W profile across the geothermal reservoir of Soultz-sous-Forêts. (E-W extension 29 km, altidude a.s.l.: -8000 to 250 m).

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1.35

Field Fluorometer for Simultaneous Detection of 3 Colourless Tracers

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We have designed flow-through field fluorometers for simultaneous detection of two or three invisible, colourless tracers, since there is an increasing interest for “blind” tracer tests.

Although most dye tracers used in hydrogeology are harmless to the environment (Behrens et al. 2001, FOEN Report 2002) their visible and indiscreet impact on the population remains a source of annoyance for the field hydrogeologist.

The recent appearance of small, inexpensive LEDs radiating UV light made it possible the excitation of colourless tracers of the naphthalene family.

A few years ago, companies could not always afford multi-tracer tests because laboratory expenses increase with the number of tracers. Today, thanks to the field fluorometer, multi-tracing is the rule (Schnegg and Doerfliger 1997). However, a successful separation of tracers by the field fluorometer presupposes dissimilar spectral characteristics of each tracer (Schnegg 2003). Careful selection of the set of tracers remains mandatory.

The field fluorometer conveniently replaces the water sampler. With this instrument there is no need for frequent sample collection and subsequent laboratory analysis of the samples. Very high time resolution is also of great interest. However, the separation of two or three different dye tracers cannot be performed at the resolution achievable in the laboratory with a spectro-fluorometer. The optics of the field fluorometer is characterized by pass-band filters. To separate 2 or 3 dyes in a multi-tracer test, the fluorometer requires as many light sources (usually LEDs) as tracers, and detectors. Each optical channel is equipped with adequate optical filters. The unknown concentrations of each tracer are obtained by resolving in real-time a system of 2 or 3 linear equations (Schnegg 2003).

For optimal tracer separation, the determinant of the system of equations must be as large as possible. Low values of the determinant indicate inadequate association of tracers of similar excitation/emission spectra. For example, there is no chance to separate a cocktail of rhodamine B, G or WT. Even the sophisticated laboratory instrument will have trouble performing the separation.

Most frequently dye tracers used are: Uranine, eosine, naphtionate, sulforhodamine B, amidorhodamine G, rhodamine WT, duasyne, tinopal, amino G acid (Käss 1998). The problem with most of them is the visual impact in surface or drinking water, particularly near the point of injection (disappearance at concentrations below 10 μg/L). Two of them, naphtionate and amino G acid are much more discreet in the environment. This is because their excitation band is located in the UV part of the spectrum, and their emission is close to the short wavelength limit of visible light.
A field test was carried out in a surface stream (100 L/s) over a distance of 300 metres. Yellow duasyne, a third, hardly visible tracer, was used jointly with the two other tracers. Quantities of 1 and 10 mg of each tracer were injected in turn at 2 minutes interval, so that the breakthrough curves would overlap, allowing thus for testing the separation method. The figure shows the three breakthrough curves after mathematical separation. As expected, they display the same shape and height. Careful calibration of the fluorometer is important for achieving perfect separation.

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1.36

Recent Research on the Remote Retrieval of Soil Moisture from Space with Microwave Radiometry

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L-band (1 - 2 GHz) microwave radiometry is a remote sensing technique to monitor soil moisture over land surfaces. The European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) radiometer mission aims at providing global maps of soil moisture, with accuracy better than 0.04 m3m-3 every 3 days, with a spatial resolution of approximately 40 km. Monitoring the large scale moisture dynamics at the boundary between the deep bulk soil and the atmosphere provides essential information both for terrestrial and atmospheric modellers. Performing ground based radiometer campaigns before the mission launch, during the commissioning phase and during the operative SMOS mission is important for validating the satellite data and for the further improvement of the used radiative transfer models.
This presentation is an example of research at the boundary between soil hydrology and remote sensing. It starts with an overview of the SMOS mission followed by an outline of the basic concepts behind remote moisture retrieval from passive L-band radiation. Then the results from a selection of ground based microwave campaigns performed within the ETH domain during the last 7 years are presented. Furthermore, the design of an L-band radiometer is shown which was built for ESA to perform further ground based experiments during the SMOS commissioning and operative phase.

1.37

Groundwater resources in Switzerland

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Groundwater is an invisible but crucial component of the water cycle. It feeds surface streams as well as aquatic ecosystems, and is the main drinking water resource in many countries. Switzerland is rich in groundwater due to favourable climatic, hydrological and hydrogeological conditions, i.e. high recharge. More than 80% of Swiss drinking water requirements are met by groundwater, and groundwater therefore represents a social and economic asset of national importance. Knowledge about the extent of the resource is essential for sustainable groundwater management. This is of particular interest given the pressure on groundwater resources due to increasing water demand, intense underground engineering activities, and climate change.

The Groundwater Resources Map of Switzerland on a 1:500,000 scale presents the yield of near-surface groundwater resources in a qualitative manner. The map provides an inventory of hydrogeological units, subdivided according to high, moderate and low productivity, which is determined mainly by aquifer thickness and permeability. However, this map does not provide quantitative information in terms of the volume or the safe yield of groundwater resources. While the *groundwater volume* describes how much groundwater is available in the underground, the *safe yield* is defined as how much groundwater is renewable and can thus be used in a long-term and sustainable manner. Both parameters are crucial for managing groundwater resources. To date, however, they have not been assessed in Switzerland on a national basis.

A study was therefore conducted to evaluate the volume and safe yield of Swiss groundwater resources. Specific approaches were developed in order to provide estimates for both parameters for the main aquifer types encountered (i.e. porous, fissured and karstified rock) and based on the Groundwater Resources Map. This study was performed in co-operation with the Institute of Environmental Engineering and the Geological Institute of the ETHZ (Swiss Federal Institute of Technology Zurich), and the Swiss Institute of Speleology and Karstology SISKA.

Highly productive porous aquifers along large river valleys represent the main drinking water resources in Switzerland. The groundwater volume stored in such aquifers was assessed by considering aquifer geometry and porosity. Estimating safe

yields, however, is more problematic as these aquifers are fed to a large extent by the infiltration of river water. In this case, a modelling approach for an extraction scenario along a river with typical aquifer characteristics provided maximum withdrawal rates. For porous aquifers not connected to surface streams, estimates of safe yield were derived solely from recharge by precipitation.
In fissured aquifers, groundwater fills the pores and open fractures in the weathered part of consolidated rock. Estimates of groundwater volume in fissured aquifers were made from tunnel inflow measurements at selected sites in crystalline alpine rocks. As fissured and karstified aquifers are discharged naturally by springs, discharge data from representative spring inventories were used to evaluate the safe yield for both aquifer types. Finally, a geological-tectonic approach enabled estimates of the groundwater volume in the saturated zone of karstified aquifers, whereas this value is largely determined by the depth to which karst groundwater is regarded as suitable for water supply.

1.38

The role of the colloidal pool for transport and fractionation of the rare earth elements in stream water

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The rare earth elements (REE) are a powerful tool for the study of trace metal behavior in surface and groundwaters because of their specific atomic structure and their coherent chemical properties throughout the REE group. Fractionation of REE distribution patterns in water samples have in the past been used to monitor processes such as surface and solution complexation or to identify precipitation and dissolution of specific mineral phases (Gaillardet *et al.*, 2003 and cit. therein). Recent studies have shown that the REE of the <0.45 or <0.22 μm fraction of surface and groundwaters are mainly present in colloidal form rather than truly dissolved (Gaillardet *et al.*, 2003 and cit. therein). Colloids are organic or inorganic microscopic phases in a size range of about 0.1 nm to 0.2 μm. For the Kalix river in northern Sweden it has been demonstrated that colloids are more abundant in summer and that the REE-bearing colloidal fraction is composed of Fe/Mn-oxyhydroxides and organic matter (Andersson *et al.*, 2006). These authors furthermore show that in winter small (~ 3 nm) organic-rich colloids, and larger (~ 10-12 nm) Fe/Mn-oxyhydroxide colloids can be distinguished, whereas combined Fe/Mn-organic matter colloids of about 3 nm in size occur during spring and summer. The detailed analysis of the winter colloids reveals that the light REE (La-Sm, LREE) are preferentially associated with Fe/Mn colloids, whereas the heavy REE (Dy-Lu, HREE) have stronger affinity for organic colloids (Andersson *et al.*, 2006). This distinction of the colloidal REE fraction into a organic matter and a Fe/Mn-oxyhydroxide controlled pool is confirmed by experimental studies (Pourret *et al.*, 2007a).

Recently, Steinmann & Stille (2008) have reported for 0.45 μm filtered stream water samples from the french Massif Central a continuously growing depletion of the LREE from upstream to downstream over a flow distance of less than 10 km (Fig. 1). The authors furthermore showed that this evolution is linked with the saturation index (SI) for Fe-oxyhydroxide (goethite, Fig. 2): The stream waters have REE distribution patterns similar to the basaltic bedrock upstream, where the samples are strongly oversaturated with respect to goethite (SI up to 8). During downflow, the SI value for goethite diminishes and the LREE depletion develops. Steinmann & Stille (2008) have interpreted this evolution with the presence of Fe/Mn-bearing colloids that grow during downflow and finally precipitate as Fe/Mn-oxyhydroxide particles. The preferential scavenging of the LREE by these precipitates could explain the observed depletion of the LREE in the < 0.45 μm fraction.

The scope of the present study is to verify the hypothesis of Steinmann & Stille (2008) by direct analysis of the colloidal fraction on new samples sampled in September 2009 in the same field site by using the ultracentifugal procedure described by Pourret *et al.* (2007a) to separate the colloids. This new analytical approach has been completed with computer modeling in order to evaluate in more detail the competition between organic and inorganic colloids on REE transport and fractionation in stream water. Interactions with organic colloids were described using Model VI and the further refined REE parameters described by Pourret *et al.* (2007b). Adsorption of the REE onto oxyhydroxide colloids was modeled using a surface complexation model integrated into PHREEQC.

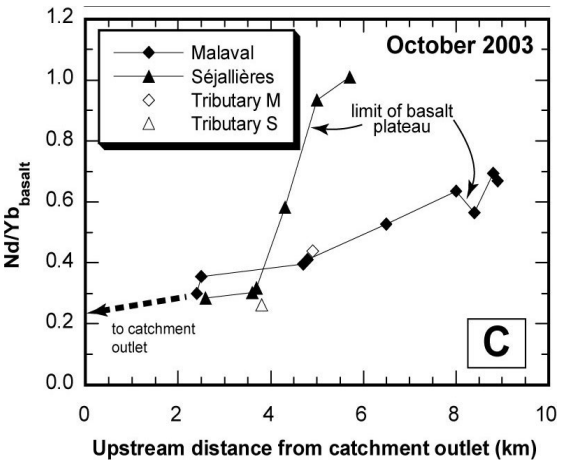

Fig. 1 : Evolution of LREE depletion with distance monitored by bedrock normalised Nd/Yb ratios in the < 0.45 μm stream water fraction (figure from Steinmann & Stille, 2008)

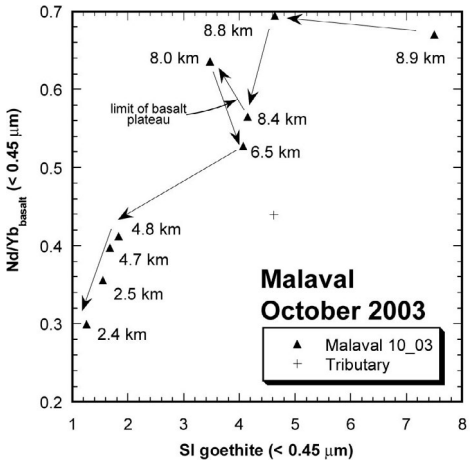

Fig. 2 : Link between Nd/Yb ratios the saturation index (SI) for goethite. Note the regular evolution with flow distance (figure from Steinmann & Stille, 2008)

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1.39

Microbial communities in the steep gradients of the meromictic lake Cadagno

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Lake Cadagno is a crenogenic meromictic lake located in the catchment area of a dolomite vein rich in gypsum in the Piora Valley in the southern Alps of Switzerland. This lake is characterized by a compact chemocline at 12 m depth with high concentrations of sulfate, steep gradients of oxygen, sulfide and light and a turbidity maximum that correlates to large numbers of bacteria mostly belonging to anerobic phototrophic sulfur bacteria and sulfate reducing bacteria. Population analyses in water samples obtained from the chemocline have been performed regularly during the last 20 years using molecular methods as well as cultivation techniques. The 16S rDNA based clone library obtained from samples of the monimolimnion and the anoxic sediments of the meromictic Lake Cadagno allowed for the development of specific oligonucleotide probes and accurate FISH (fluorescent *in situ* hybridization) distribution analysis of bacterial populations. Phototrophic sulfur bacteria (*Lamprocystis, Thiodictyon*) forming syntrophic aggregates with sulfate reducing bacteria (*Desulfocapsa*) dominated the chemocline whereas members of the genus *Desulfomonile* were prominent in the monimolimnion and in the first centi-

meters of the sediments. In deeper sediment layers methanogenic archaea and SRB were detected by FISH.
Moreover, in the chemocline, spatio-temporal analysis of bacterial populations over 2 decades revealed an initial dominance of Chromatiaceae (*C. okenii, Lamprocystis, Thiodictyon)*, after 2001, a clonal population of *Chlorobium clathratiforme* became dominant. This major change in community structure in the chemocline was probably due to extreme climatic events in autumn of the years 1999 and 2000 causing deep mixing of the waterbody which were accompanied by changes in profiles of turbidity and photosynthetically available radiation, as well as for sulfide concentrations and light intensity. Overall, these findings suggest that the temporary disruption of the chemocline may have altered environmental niches and populations in subsequent years.

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1.40

Dissolved inorganic carbon and its stable isotope composition as a tracer of geo-, bio-, and anthropogenic sources of carbon

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The concentration and carbon isotope composition of dissolved inorganic carbon (DIC), in addition to the oxygen and hydrogen isotope compositions of water as well as the major dissolved cations and anions have been analyzed seasonally for several rivers, lakes, dams used as sources for hydroelectric energy, and effluents from a number of waste water treatment plants (WWT) in Western Switzerland. The aim is to evaluate the DIC and its isotopic composition as a tracer for the geologic, biologic and anthropogenic contributions of carbon to the rivers and lakes.

The upper reaches of the Rhone and the Sarine typically have Alpine catchments characterized by thin or no soil covers with only sparse vegetation. Glacial melt waters and surface runoff make up the bulk of the water sources in their upper reaches. Further downstream other tributaries, themselves often being melt water fed but many also being exploited for hydroelectric power and thus with a number of dams along their course, join these rivers. In addition, the vegetation and soil cover increases downstream in parallel with the agricultural exploitation, population density, and the number of WWT plants that generally pass their treated waste waters directly into the rivers. In contrast, rivers draining the Jura mountains do not have a glacial melt water source, nor are there major hydroelectric systems coupled to the river systems investigated.

The difference in geology of the catchment as well as the soil cover thickness and hence biologic activity in the soil are reflected by the C isotope composition of the DIC. $\delta^{13}C$ values are as high as −2.5‰ in the upper source reaches of the Rhone and the Sarine, reflecting predominant uptake of carbon from atmospheric CO_2. Further downstream, $\delta^{13}C$ values decrease towards −5 to −11.5‰, compatible with a higher input of soil-, plant-derived CO_2. The $\delta^{13}C$ values of DIC are higher (−5 to −8.5‰) if carbonate relative to silicate rocks dominate the catchment, unless the agricultural activity is intense. The latter is the case for the rivers draining the largely carbonate-dominated Jura (for example the Venoge), which have $\delta^{13}C$ values of between −11 to −13‰. The $\delta^{13}C$ values are also higher for all lakes and dams along the rivers, indicating an additional exchange with atmospheric CO_2 for water masses exposed to the atmosphere for longer periods. For smaller lakes, the $\delta^{13}C$ values correspond to those of the riverine inputs though. For larger lakes the $\delta^{13}C$ values of the DIC may also be used as tracers of the mixing processes between riverine input and the lake (Fig. 1).

The $\delta^{13}C$ values in the rivers are generally lower in winter and spring compared to summer and fall, indicating a higher biological activity within the water column during the warmer periods. The differences are most notable in dams and lakes, where vertical profiles are also well-established within the upper 5 to 10 m of the water column as a result of increasing photosynthesis during the warmer periods (Fig. 1).

Contributions of organic carbon from WWT plants are clearly marked by 0.5 to 3‰ lower $\delta^{13}C$ values for DIC directly downstream of the effluents, with the treated waste waters having values that may be as low as −27‰. Such sources may also clearly be expressed by differences in H- and O-isotope compositions of the waters relative to the river or lake waters, as well as their sodium, potassium and nitrate contents, as well as the isotopic composition of the latter.

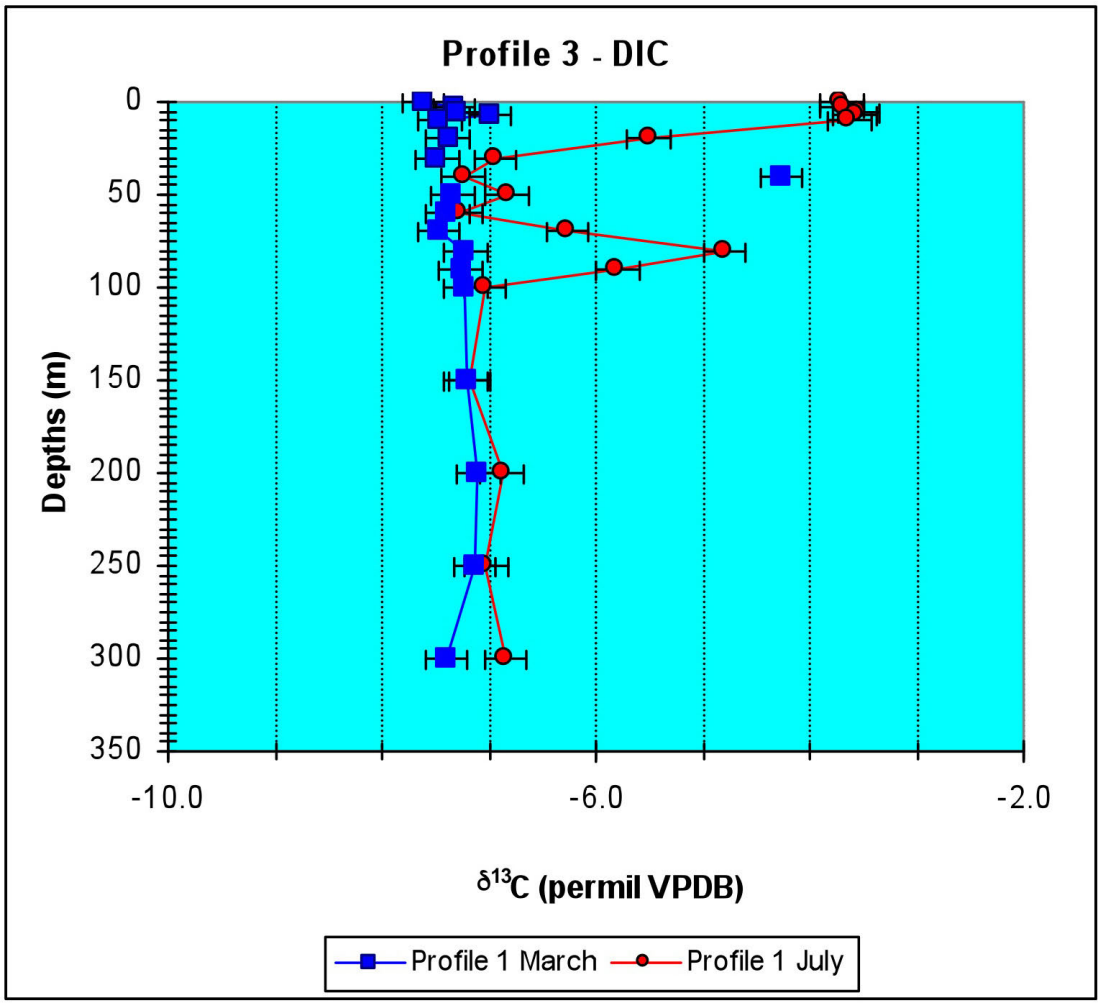

Figure 1: δ13C values of DIC in a depth profile in the deepest part of Lake Geneva (approximately in the center of the lake). Note the high values at the surface during the summer (July 2005 profile) compared to the winter (March 2005 profile) typically indicating the bioproductivity in the photic zone during summer. Higher values at depths of 50 to 100 m represent mixtures of the Rhone water rich in 13C descending to these depths within the lake, three months after a complete overturn of the lake at the end of February.

1.41

High-resolution temperature measurements at the river – groundwater interface: Quantification of seepage rates using fiber-optic Distributed Temperature Sensing

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In recent years, the transition zone between surface water bodies and groundwater, known as the hyporheic zone, has been identified as crucial for the ecological status of the open-water body and the quality of groundwater. The hyporheic exchange processes vary both in time and space. For the assessment of water quality of both water bodies reliable models and measurements of the exchange rates and their variability are needed.

A wide range of methods and materials exist to estimate water fluxes between surface water and groundwater. Due to advances in sensor technique and data loggers, work on heat as a tracer in hydrological systems has increased recently, especially with focus on surface water – groundwater interaction. A new promising method is Distributed Temperature Sensing (DTS). DTS is based on the temperature dependence of Raman scattering. Light from a laser pulse is scattered along an optical fibre of up to several km length, which is the sensor of the DTS system. By sampling the back-scattered light with high temporal resolution, the temperature along the fibre can be measured with high accuracy (0.1 K) and high spatial resolution (1 m). We used DTS at a test side at River Thur in North-East Switzerland (TG). Here, the river is losing.

For estimation of seepage rates we measured highly resolved vertical temperature profiles in the river bed. To this end, we wrapped an optical fibre around a piezometer tube and measured the temperature distribution along the fibre. Due to the wrapping, we obtained a vertical resolution of approximately 5 mm. We analyzed the temperature time series by means of Dynamic Harmonic Regression as presented by Keery et al. (2007). From the travel time and attenuation of the diurnal signal, we estimated the apparent velocity and diffusivity of temperature propagation, which then can be used to quantify infiltration rates. A particular strength of the new measurement technique lies in the high spatial and temporal resolution, enabling us to detect non-uniformity and temporal changes in vertical water fluxes.

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1.42

Natural springs – the living passage between groundwater and surface water

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Natural springs are unique ecosystems that provide specific abiotic conditions, and they are stepping-stones between groundwater and surface water. They appear in the landscape in various forms and are especially obvious in alpine regions. Springs are habitats for many freshwater organisms, which partly show a strong adaptation to the specific conditions in springs. As an alpine country Switzerland is rich of springs, but not many are still in a natural or at least near natural condition. Despite their importance as unique habitats and despite their endangered situation they were not well studied until a few years ago. At the Institute of Biogeography from the University of Basel we investigate natural springs in the northern part of Switzerland and adjacent regions. The distribution of the spring fauna and the influence of abiotic parameters, especially discharge, are the main topics of our research. A first approach to a faunistic spring typology shows differences between springs based on the dominant feeding habits of the macrozoobenthic species. They are related to abiotic parameters like substrate composition. Our goal is a spring typology for the whole country based on faunistic data. And also the colonisation of springs is an important part of our research. In a one-year field experiment in artificial springs we investigated the colonisation rate and the preferences of different substrates by macrozoobenthic organisms. Mesoscale analyses show that the colonisation occurs rapidly from the adjacent headwater and that the organisms prefer different substrate types for their settlement.

1.43

Porewater as an archive of the palaeo-hydrogeology during the Holocene and Pleistocene

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Fractured rocks comprise two different hydraulic regimes: The first regime constitutes the water-conducting zones related to regional and/or local fracture networks where groundwater flow takes place. It is characterised by a hydraulic transmissivity of mostly above 10^{-9} m^2/s and solute transport takes place by advection. The second regime constitutes the low permeable rock matrix with the porewater residing in its connected pore space. Here, the hydraulic transmissivity is low to very low (<< 10^{-10} m^2/s) and solute transport is increasingly dominated by diffusion. The mass of porewater present in the rock matrix is, however, larger than in the fracture network even in crystalline rocks with a connected porosity of less than 1 Vol.%.

Porewater in the rock matrix and groundwater in the fracture network always tend to reach chemical and isotopic equilibrium. If solute transport in the rock matrix can be shown to occur by diffusion, then a chemical and isotopic signature established in the porewater at a certain time might be preserved over geologic time periods. Thus, porewater may act as an archive of the past fracture groundwater composition(s) and therefore of the palaeo-hydrogeological history of a site. The degree of the preservation of such signatures depends on: 1) the distance of the porewater sample from the nearest water-conducting fracture in three dimensions, 2) the solute transport properties of the rock (i.e. diffusion coefficient, porosity), and 3) the period of constant boundary conditions (i.e. constant fracture groundwater composition). The frequent climatic and hydrogeologic changes during the Holocene and Pleistocene and related compositional changes in the fracture groundwater resulted in superimposed signatures in the porewater. These can be unravelled to a large degree by the investigation of different, largely independent natural tracers in the porewater.

Porewater in granitic and monzodioritic rocks from Laxemar-Oskarshamn, central Sweden, are of different chemical and isotopic composition in bedrock characterised by high transmissivity and a high frequency of water-conducting fractures at shallow to intermediate depth (0-400 m b.s.l.), and bedrock characterised by low transmissivity and a low frequency of water-conducting fractures at greater depth (400 -1000 m b.s.l.). In the more transmissive, shallower interval, porewater is of a general Na-HCO_3 chemical type with a Cl^- concentration of less than 1 g/kgH_2O. The oxygen and hydrogen isotope composition indicates a formation from meteoric infiltration under different climatic conditions. Combined with the distance between porewater sample and nearest water-conducting fracture in the borehole and the quantitative modelling of the natural tracer profiles (Cl^-, $\delta^{18}O$, δ^2H) sampled at high resolution in one of the boreholes, the porewater signatures in the first few metres from a fracture may be explained in terms of exchange with Holocene fracture groundwater of present-day type, of Holocene

thermal maximum type (at about 7-4 ka BP) and of glacial (late Weichselian) or glacio-lacustrine (Baltic Ice Lake, 15-11.5 ka BP; Ancylus Lake, 10.8-9.5 ka BP) type. Exchange with fracture groundwater composed of present-day brackish water of the Baltic Sea is limited and absent for the earlier Baltic Sea stages (Yoldia, 11.5-10.8 ka BP; saline Littorina, 8.5-7 ka BP). Farther away from water-conducting fractures, Na-HCO_3 type porewater signatures with low Cl^- concentrations indicate an evolution from Pleistocene fracture groundwater of warm climate origin (possibly Eemian Interglacial) and cold climate periods (early Weichselian or older). Cold climate influence from the last glaciation with $\delta^{18}O$ values around -14‰ VSMOW occurs between about 135-350 m depth and down to about 500 m depth depending on borehole.

At intermediate depth levels below the Na-HCO_3 type porewater a change to higher mineralised porewater of a general Na-Ca-SO_4 and Ca-Na-SO_4 chemical type occurs. Depending on borehole location this porewater type occurs from about 430 m and 620m depth over a restricted interval of about 120 m. The change coincides with a marked decrease in transmissivity, in the frequency of water-conducting features and the transition zone from Ävrö granite to quartz monzodiorite. Highly variable Cl^- concentrations (2.5 to 7.6 g/kgH_2O) and water isotope compositions ($\delta^{18}O$ about -2‰ to -13‰ VSMOW) are associated with high concentrations of Ca^{2+} and SO_4^{2-} up to gypsum saturation. Chemical and isotopic composition of these porewater types cannot be explained by interaction with a known type of fracture groundwater and more advanced rock-water interaction. They appear to have formed from interaction with cryogenic brines that formed during permafrost conditions and which migrated downwards in the fractures by buoyancy effects. The large distance to the nearest water-conducting fracture of this porewater type suggests that these signatures have been established before the Last Glacial Maximum.

At greater depth there occur again more dilute porewaters of Na-HCO_3 type and Na-Ca-Cl-(HCO_3) type. Here, Cl- contents vary between about 0.5 to 3 g/kgH_2O and associated $\delta^{18}O$ values of between about -8‰ to -11‰ VSMOW. Porewaters below 820 m are then of a Na-Ca-Cl type with Cl^- concentrations of more than 8 g/kgH_2O, but low SO_4^{2-} concentrations and an oxygen isotope composition generally enriched in ^{18}O compared to the more shallow porewaters. At these low-transmissivity depths, the porewaters display complex, superimposed signatures that cannot be resolved based on the present data. In the deepest samples, however, a component of a deep saline brine seems to be present similar as observed in fractures at even greater depth.

The data indicate that the palaeo-hydrogeological evolution of a site indeed can be re-constructed based on porewater data. In addition, signatures no longer present in the fracture groundwaters can be identified. In the case of cryogenic brines that formed during permafrost conditions, this is of special importance within the framework of the long-term safety assessment of a deep geologic repository for radioactive waste.

1.44

In-situ Remediation of Polluted Groundwater: A Transdisciplinary Approach

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Careless handling of environmentally hazardous substances and wastes has left its mark in the geological underground. If substances like persistent organic compounds or heavy metals from contaminated sites migrate into the groundwater, an immediate and sustainable suppression of the source is required. However, in most cases the groundwater in its downstream flow will stay contaminated over a long time. On duty of the society and the environment to provide for safe water, the remediation of polluted groundwater is both an essential and ambitious task.

Consultant geologists in cooperation with chemical laboratories generally are keen now in assessing the type, amount and distribution of contaminants in groundwater. But after one decade of the commitment by law to remediate the "sins of yesterday", the scientific and technical knowledge on approved procedures to clean spoiled groundwater is still poor. On the one hand research institutes mostly experience at laboratory scale only. At the other hand, the party responsible for a contaminated groundwater plume is interested in fast solutions, and not in making expensive attempts without a guaranty of a long lasting achievement.
Researchers from the university and professionals from consulting companies can complement one another in creating new technologies. Research, development and implementation of new technologies can profit from "the Nine Laws of God governing the incubation of something from nothing" (Kelly, 1995). Taking as an example the project to reduce the charge of he-

xavalent chromium with permeable reactive walls (PRB), the way of a successful cooperation using a transdisciplinary approach (Hermanns-Stengele & Schenker, 2000) will be demonstrated.

In designing a PRB as a passive remediation method the crucial aspects are what to take as the reactive material and of course how well the contaminants are treated after the installation of such a PRB.
Batch and column experiments performed in order to chose the best available iron shavings for the PRB Thun showed that shavings with a carbon content of approximately 4% have very good properties concerning the reduction of hexavalent chromium. Interestingly large differences in the reaction rates among various types of iron shavings were observed. Looking at the various shavings under the scanning electron microscope we came up with the conclusion that reaction rates are highly correlated with the nature of the carbon inclusions within the iron matrix of the shavings.
In order to estimate the success of future barrier operations geochemical models are cheap and powerful tools (Steefel, 2005). Using the data of the lab experiments the geochemical reactive transport model and reaction network of Mayer et al. (2001) was calibrated using the modeling software Crunchflow (Steefel, 2005). The calibrated model was used to simulate the hydrodynamics and hydrogeochemistry within the double pile-array of the barrier in 2D. Examples of model outcomes are illustrated in figure 1.

The modelling work clearly points out that the limiting factors in the performance of the PRB are the groundwater flow velocity, the permeability of the piles and the groundwater chemistry.

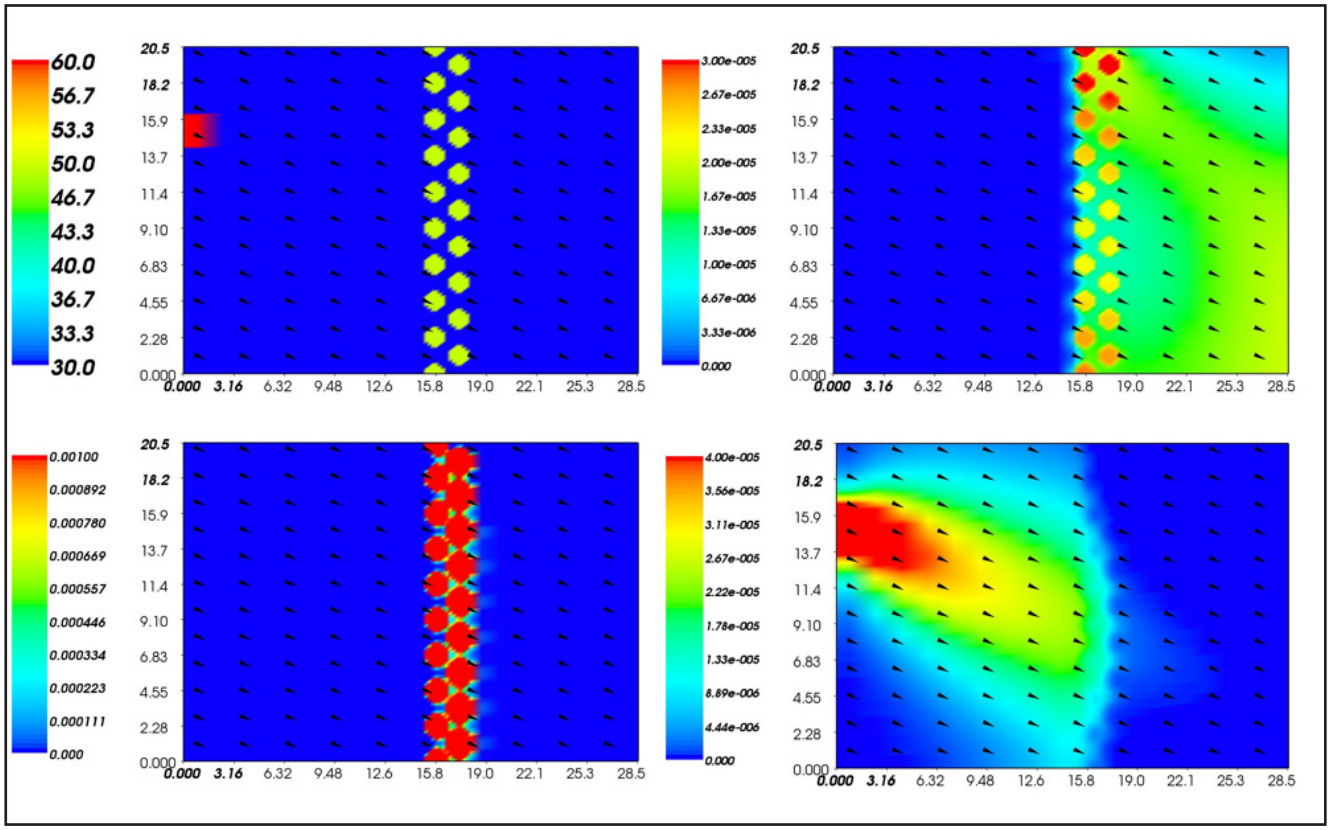

Figure 1. Illustrations of 2D model calculations of the PRB site Thun: Model setup in terms of porosity in the upper left picture, aqueous Fe^{2+} concentrations (mol/l) upper right, green rust precipitation volumes (vol%) bottom left and aqueous Cr^{VI} concentrations (mol/l) bottom right.

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On the physical hydrology of hydrothermal systems at mid-ocean ridges

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Fluid evolution and migration in magmatic hydrothermal systems strongly depend on the physical properties of water. Within the pressure and temperature range given by a specific geologic setting, fluid properties like density and viscosity vary non-linearly by orders of magnitude (Driesner and Heinrich, 2007).

Magmatism at mid-ocean-ridges is predominantly basaltic and acts as a heat source for hydrothermal convection cells. Seawater percolates through the ocean floor into the subsurface, is heated near the magma chamber, travels upward, and vents at the ocean floor, eventually forming black smoker fields.
Numerical simulations in 3D with pure water and a homogeneous permeability have shown that the system naturally forms regularly-spaced pipe-like upflow zones which is well-supported by measurements and observations (Coumou et al., 2008). These simulations further revealed that most of the downflow occurs in the immediate vicinity of the upflow zone where fluids are heated to about 200°C. Compared to the colder fluids at larger distance from the axis, their viscosity is lower by one order of magnitude while they are still relatively dense hence maximizing downward fluid transport. In combination with the ~400°C fluids of the upflow zone, this leads to a mass and energy flux optimization (see also Driesner et al., this volume).

Introducing geological structures to the model geometry adds further complexity to the system but preserves the first order principle described above. Figure 1 shows convection at a mid-ocean ridge system with a deeper gabbroic part overlain by a basaltic layer of higher permeability. The simulations show that a secondary convection cell establishes within the highly permeable basalt layer resulting in a more efficient cooling of the upper part of the upflow zone. Normal faults within the oceanic crust near the ridge axis are often referred to as conduits for enhanced up- or downflow (Fisher, 1998). First numerical simulations introducing normal faults as heterogeneities within the permeability structure of the model geometry have been conducted. Downflow velocities similar to the ones described above only developed in relatively wide normal faults (50m) that have a high permeability contrast to the surrounding rock (up to two orders of magnitude) and are located very close to the ridge axis.

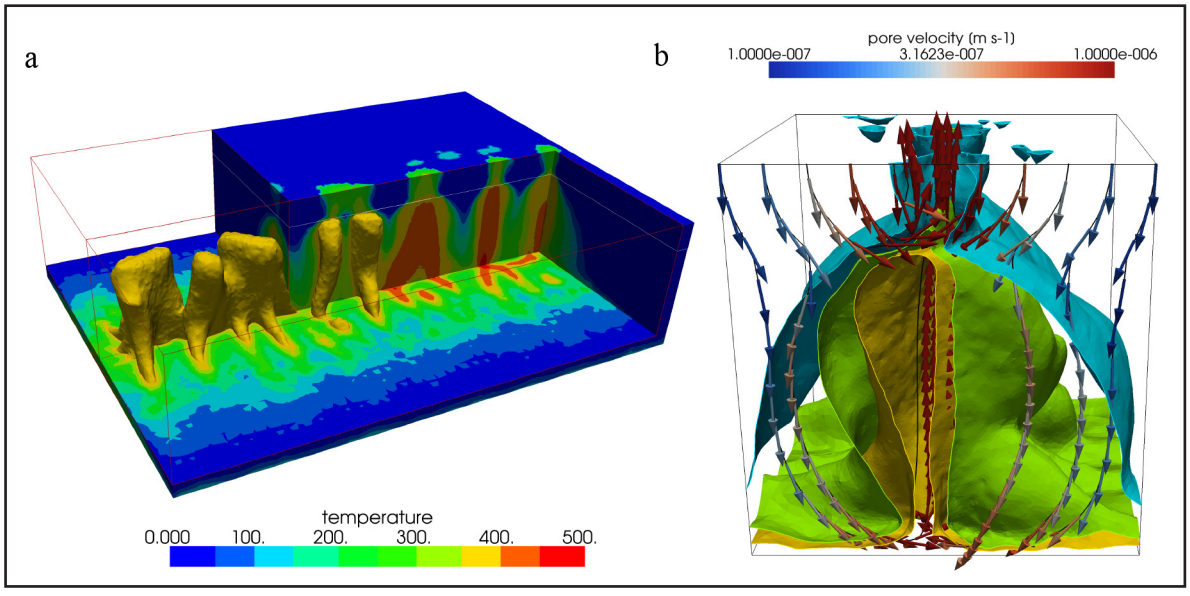

Figure 1. Convection at mid-ocean-ridges self-organizes into hot pipe-like upflow zones (a). Downflow concentrates in the immediate vicinity of the upflow zone as shown by the pore velocities of the selected streamlines (b). The model geometry describes a 1 km deep piece of oceanic crust (3x4 km^2). Constant fluid pressure at the top boundary represents a water depth of 2.5 km and a bell-shaped heat flux at the bottom boundary of a total of 350 MW/km represents an axial magma chamber at depth. The permeability structure consists of a lower gabbroic layer (k = 3 x 10^{-14} m^2) overlain by a 200 m thick basaltic layer (k = 10^{-12} m^2). Figure 1b is a 1 km^3 excerpt of Figure 1a.

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One lake, two countries and a lot of methane - the concept for a viable extraction of an unusual resource

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The 485 m deep Lake Kivu (Rwanda, DR Congo) is among the most fascinating lakes on earth. Not only does it host a spectacular temperature-salinity staircase of more than 300 interface-layers, it also contains ~60 km^3 of methane and ~300 km^3 of carbon dioxide and is permanently density-stratified by salty, carbon dioxide-rich water released by sub-aquatic springs. Those springs and their chemical composition affect the lake stratification. Especially, the lake-internal nutrient upwelling, strongly depending on the spring discharges, is crucial for algae growth and the subsequent methane production in the deep waters. Over the centuries, methane has accumulated to an amount, which can be economically exploited, but which also poses a risk (limnic eruption like in Lake Nyos) to the riparian ~2 million people. To avoid building-up of such a risk of gas eruption, the two governments have decided to exploit the methane, worth more than $20 billions.

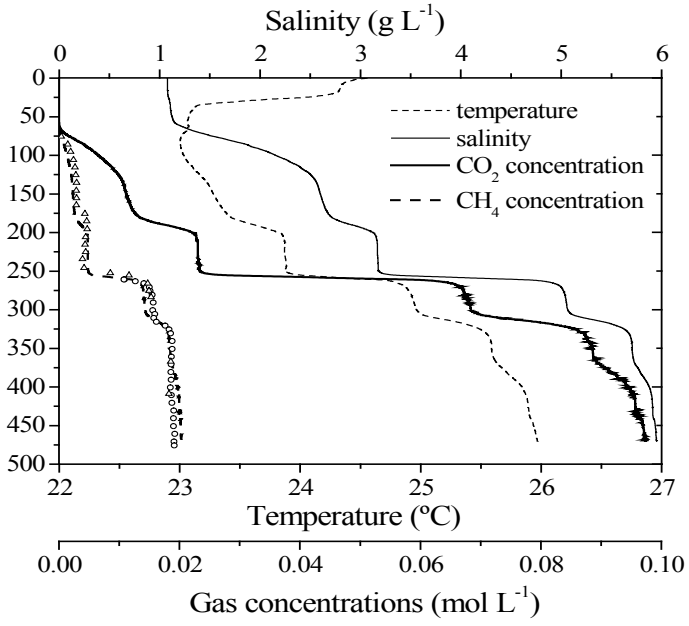

Figure 1. Vertical profiles of temperature, salinity, CH_4 and CO_2, as observed in February 2004 (Schmid et al. 2005). All major water constituents are increasing with depth due to the discharge of deep sub-aquatic springs.

The talk will focus on finding a extraction concept, which (i) lowers the risk of a gas eruption from the lake, (ii) is environmental-friendly and conserves the lake's ecological integrity and (iii) maximizes the economic benefit at the same time.

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