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Bundesamt für Umwelt BAFU
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Veröffentlichungen zu angewandt-wissenschaftlichen Studien mit Bezug zum Grundwasser der Schweiz

Literaturzusammenstellung – Jahrgang 2020

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

Compilation de littérature pour l'année 2020

Inklusive Links zu Artikel-[Abstracts] (Um dem Link zu folgen: **[klicken]**)
Liens vers les [Abstracts] inclus (Pour suivre le lien : **[cliquer]**)

Fachartikel national / Articles spécialisés nationaux

Jordi, B.

Kontrolle der Entwässerunganlagen [1]

Aqua & Gas, 3/20, S. 52-57

Buechli, M.

Stefan Mürner, Paul Borer: "Es braucht eine Diversifizierung der Wasserbezugsorte" [2]

Aqua & Gas, 4/20, S. 10-13

Bryner, A., Angst, M., Fischer, M., Vollenweider, S.

Wasserpolitischer Jahresrückblick 2019 [3]

Aqua & Gas, 5/20, S. 58-63

Pronk, M., Urfer, D., Bonnet, C.

Etat microbiologique de l'eau potable. Etude par cytométrie en flux des eaux alimentant la région d'Yverdon-les-Bains - Grandson [4]

Aqua & Gas, 6/20, S. 22-29

Müller, S., Schärer, M., Jenny, A., Schwab, C., Muralt, R., Reinhardt, M., Leu. C., Beer, M.

Grundwasserschutz muss Qualität des Trinkwassers sichern [5]

Aqua & Gas, 7/20, S. 28-34

Alther, R., Bongni, N., Borko, S., Fiser, C., Altermatt, F.

Reiche Grundwasserfauna [6]

Aqua & Gas, 7/20, S. 36-42

Buechli, M.

Pierre-Yves Jeannin: "Les régions karstiques représentent une ressource en eau alternative" [7]

Aqua & Gas, 12/20, S. 10-12

Fachartikel international / Articles spécialisés internationaux

Muller, B., Meyerz, J., Gachter, R.

Nitrogen fertilization of soils fuels carbonate weathering and translocation in calcareous watersheds [8]

Aquatic Sciences, Volume 82, Issue 2, Article Number 37

DOI: 10.1007/s00027-020-0712-6

Iannella, M., Fiasca, B., Di Lorenzo, T., Biondi, M., Di Cicco, M., Galassi, D

Jumping into the grids: mapping biodiversity hotspots in groundwater habitat types across Europe [9]

Ecography, Volume 43, Issue 12, p1825-1841

DOI: 10.1111/ecog.05323

Wirth, S., Bouffard, D., Zopfi, J.

Lacustrine groundwater discharge through giant pockmarks (Lake Neuchatel, Switzerland) [10]

Frontiers in Water, Volume 2

DOI: 10.3389/frwa.2020.00013

Beria, H., Larsen, J., Michelon, A., Ceperley, NC., Schaefli, B.

HydroMix v1.0: a new Bayesian mixing framework for attributing uncertain hydrological sources [11]

Geoscientific Model Development, Volume 13, Issue 5, p2433-2450

DOI: 10.5194/gmd-13-2433-2020

Epting, J., Baralis, M., Kunze, R., Mueller, M., Insana, A., Barla, M., Huggenberger, P.

Geothermal potential of tunnel infrastructures - development of tools at the city-scale of Basel, Switzerland [12]

Geothermics, Volume 83, Article Number 101734

DOI: 10.1016/j.geothermics.2019.101734

Moeck, C., Molson, J., Schirmer, M.

Pathline Density Distributions in a Null-Space Monte Carlo Approach to Assess Groundwater Pathways [13]

Groundwater, Volume 58, Issue 2, p189-207

DOI: 10.1111/gwat.12900

Milanovic, P., Stevanovic, Z.

Fifty years of history of the Karst Commission of the International Association of Hydrogeologists [14]

Hydrogeology Journal, Volume 29, Issue 1, p7-19, Special Issue

DOI: 10.1007/s10040-020-02261-4

Arnoux, M., Halloran, L., Berdat, E., Hunkeler, D.

Characterizing seasonal groundwater storage in alpine catchments using time-lapse gravimetry, water stable isotopes and water balance methods [15]

Hydrological Processes, Volume 24, Issue 22, p4319-4333

DOI: 10.1002/hyp.13884

Kiewiet, L., van Meerveld, I., Stahli, M., J.

Do stream water solute concentrations reflect when connectivity occurs in a small, pre-Alpine headwater catchment? [16]

Hydrology and Earth System Sciences, Volume 24, Issue 7, p3381-3398

DOI: 10.5194/hess-24-3381-2020

Lucas, D., Herzog, R., Iten, M., Buschor, H., Kieper, A., Askarinejad, A., Springman, S.

Modelling of landslides in a scree slope induced by groundwater and rainfall [17]

International Journal of Physical Modelling in Geotechnics Volume 20, Issue 4, p177-197

DOI: 10.1680/jphmg.18.00106

Gramiger, L., Moore, J., Gischig, V., Loew, S., Funk, M., Limpach, P.

Hydromechanical Rock Slope Damage During Late Pleistocene and Holocene Glacial Cycles in an Alpine Valley [18]

Journal of Geophysical Research-Earth Surface, Volume 125, Issue 8, Article Number e2019JF005494

DOI: 10.1029/2019JF005494

Wanner, C., Waber, H., Bucher, K.

Geochemical evidence for regional and long-term topography-driven groundwater flow in an orogenic crystalline basement (Aar Massif, Switzerland) [19]

Journal of Hydrology, Volume 581, Article Number 124374

DOI: 10.1016/j.jhydrol.2019.124374

Arnoux, M., Brunner, P., Schaefli, B., Mott, R., Cochand, F. and Hunkeler, D.

Low-flow behavior of alpine catchments with varying quaternary cover under current and future climatic conditions [20]

Journal of Hydrology, Volume 592, Article Number 125591

DOI: 10.1016/j.jhydrol.2020.125591

Preisig, G.

Forecasting the long-term activity of deep-seated landslides via groundwater flow and slope stability modelling [21]

Landsilides, Volume 17, Issue 7, p1693-1702

DOI: 10.1007/s10346-020-01427-1

Epting, J., Bottcher, F., Mueller, M., Garcia-Gil, A., Zosseder, K., Huggenberger, P.

City-scale solutions for the energy use of shallow urban subsurface resources - Bridging the gap between theoretical and technical potentials [22]

Renewable Energy, Volume 147, p751-763, Part 1

DOI: 10.1016/j.renene.2019.09.021

Spiess, E., Humphrys, C., Richner, W., Schneider, M., Piepho, HP., Chervet, A., Prasuhn, V.

Does no-tillage decrease nitrate leaching compared to ploughing under a long-term crop rotation in Switzerland? [23]

Soil and Tillage Research, Volume 199, Article Number 104590

DOI: 10.1016/j.still.2020.104590

Kiefer, K., Bader, T., Minas, N., Salhi, E., Janssen, E., von Gunten, U., Hollender, J.

Chlorothalonil transformation products in drinking water resources: Widespread and challenging to abate [24]

Water Research, Volume 183, Article Number 116066

DOI: 10.1016/j.watres.2020.116066

Klages, S., Heidecke, C., Osterburg, B., Bailey, J., Calciu, I., Casey, C., Dalgaard, T., Frick, H., Glavan, M., D'Haene, K., Hofman, G., Leitao, IA., Surdyk, N., Verloop, K., Velthof, G.

Nitrogen Surplus-A Unified Indicator for Water Pollution in Europe? [25]

Water, Volume 12, Issue 4, Article Number 1197

DOI: 10.3390/w12041197

Wirth, S., Carlier, C., Cochand, F., Hunkeler, D., Brunner, P.

Lithological and Tectonic Control on Groundwater Contribution to Stream Discharge During Low-Flow Conditions [26]

Water, Volume12, Issue 3, Article Number 821

DOI: 10.3390/w12030821

18th Swiss Geoscience Meeting

Zurich, 6th November – 7th November 2020
https://geoscience-meeting.ch/sgm2020/

Beria H., Benoit L., Mariethoz, G., Schaefli, B.

Improving hydrologic model realism by using stable water isotopes [27]

Epting, J., Michel, A., Affolter, A., Huggenberger, P.

Climate change effects on groundwater recharge and temperatures - status and development for Swiss aquifers [28]

Lanz, K.

From hydrological forecasts to adapted water management [29]

Thornton, J., Mariethoz, G., Brunner, P.

Fully-integrated surface-subsurface hydrological modelling in steep, snow-dominated, geologically complex Alpine terrain [30]

Wanner, C., Ingold, P., Cardenas, M., Furrer, G.

Elevated concentrations of toxic elements in high-alpine streams of the Eastern Alps: a manifestation of climate change? [31]

Vinnå, L., Wirth, S.

Assessing pockmark activity in lakes under influence of drainage area processes [32]

Scheidler, S., Dresmann, H., Huggenberger, P., Auckenthaler, Ad., Epting, J.

Regional groundwater flow systems in the context of karst development - an example from north-western Switzerland [33]

Weatherl, R., Henao-Salgado., Schirmer, M.

Changing Groundwater Dynamics in Urbanizing Catchments: A Swiss Case Study [34]

HYDRO-CH2018 Forschungsprojekte

https://www.nccs.admin.ch/
https://www.nccs.admin.ch/forschungsprojekte

Holzkämper, A., Cochand, F., Rössler, O., Brunner, P., Hunkeler, D.

AgriAdapt – Modellgestützte Untersuchung der Einflüsse von Klima- und Landnutzungsänderungen auf Grundwasserressourcen im Berner Seeland [35]

Projektbericht

Arnoux, M., Hunkeler, D., Cochand, F., Brunner, P., Schaefli, B.

Dynamiques du stockage en eau souterraine et du régime hydrologique des bassins versants Alpins face aux changements climatiquesMagazin «die umwelt» 4/2020 - Wird in der Schweiz das Wasser knapp? [36]

Projektbericht

Epting, J., Huggenberger, P., Affolter, A., Michel, A.

Ist-Zustand und Temperatur-Entwicklung Schweizer Lockergesteins-Grundwasservorkommen [37]

Projektbericht

Übersichtspublikationen / Publications synoptiques

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Hydrologisches Jahrbuch der Schweiz 2019

https://www.bafu.admin.ch/bafu/de/home/themen/wasser/publikationen-studien/publikationen-wasser/hydrologisches-jahrbuch-der-schweiz.html

Annuaire hydrologique de la Suisse 2019 [38]

https://www.bafu.admin.ch/bafu/fr/home/themes/eaux/publications/publications-eaux/annuaire-hydrologique.html

Umwelt-Zustand - État de l'environnement, UZ-2019-D / UZ-2019-F, 40 p

Bundesamt für Umwelt BAFU / Office fédéral de l'environnement OFEV

Magazin «die umwelt» 4/2020 - Wird in der Schweiz das Wasser knapp?

https://www.bafu.admin.ch/bafu/de/home/themen/wasser/publikationen-studien/publikationen-wasser/magazin-die-umwelt-4-2020-wird-in-der-schweiz-das-wasser-knapp.html

Magazine «l'environnement» 4/2020 - La Suisse bientôt à court d'eau ? [39]

https://www.bafu.admin.ch/bafu/fr/home/themes/eaux/publications/publications-eaux/magazin-die-umwelt-4-2020-wird-in-der-schweiz-das-wasser-knapp.html

Magazin Umwelt - Magazine Environnement, MAG-2004-D / MAG-2004-F, 64

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BAFU – OFEV / 31.01.2021

Abstracts

Fachartikel national / Articles spécialisés nationaux

1. Kontrolle der Entwässerunganlagen

In der Schweiz sind in der Regel die Gemeinden für die Kontrolle der Entwässerungsanlagen zuständig. Weil viele von ihnen diese Aufsichtspflicht jahrzehntelang vernachlässigt haben, lässt vor allem der Zustand privater Abwasserleitungen häufig zu wünschen übrig. Nun setzt sich zunehmend das Modell eines systematischen Unterhalts durch. Dabei koordinieren die Gemeinden die Zustandserhebung sämtlicher Abwasseranlagen und erarbeiten quartierweise Sanierungsprojekte, die neben dem öffentlichen auch das private Leitungsnetz umfassen. Dieses Vorgehen schlägt auch die 2018 veröffentlichte Empfehlung des VSA zur Grundstücksentwässerung vor.

2. Stefan Mürner, Paul Borer: "Es braucht eine Diversifizierung der Wasserbezugsorte"Ist-Zustand und Temperatur-Entwicklung Schweizer Lockergesteins-Grundwasservorkommen

Der Klimawandel wird sowohl quantitative als auch qualitative Auswirkungen auf Grundwasservorkommen haben. Diese Auswirkungen unterscheiden sich für Grundwasservorkommen im Fels- und Lockergestein, urban oder ländlich geprägten Standorten sowie den vorherrschenden Prozessen der Grundwasserneubildung. Für ein Verständnis der Entwicklung zukünftiger Grundwassernutzungen und -temperaturen bedarf es einer differenzierten Betrachtung der geologischen Standortbedingungen und relevanten hydrogeologischen Prozesse, einschliesslich der Prozesse der Grundwasserneubildung, „positiver und negativer Rückkoppelungen“ sowie direkter anthropogener Einflüsse. Diese Grundlagen sind wesentlich, um die Reaktion von Grundwasservorkommen auf anthropogene Veränderungen und Einflüsse des Klimawandels zu verstehen. Projektziel des HydroCH2018 Zusatzmoduls „Ist-Zustand und Temperatur-Entwicklung Schweizer LockergesteinsGrundwasservorkommen“ war eine differenzierte Betrachtung der Einflüsse, welche die Grundwassertemperaturen bestimmen. Hierzu sind einerseits Kenntnisse charakteristischer Eigenschaften von Grundwasservorkommen notwendig, einschliesslich räumlicher Dimensionen und Grundwassererneuerungsraten. Anderseits ermöglicht die Ableitung repräsentativer Schlüsselparameter (Aquifergeometrien, Speichereigenschaften, Grundwassererneuerungsraten und -verweilzeiten, etc.) sowie eine Kenntnis der Grundwasserneubildungsprozesse und der Temperaturprägung einen Vergleich aber auch Prognosen über die Sensitivität einzelner Grundwasservorkommen auf den Klimawandel. Ein Vergleich der charakteristischen hydraulischen und thermischen Randbedingungen verschiedener repräsentativer Schweizer Lockergesteins-Grundwasservorkommen im Mittelland, dem Jura und dem Alpenraum ist Grundlage für die Ableitung der Übertragbarkeit auf Schweizer Grundwasservorkommen im Allgemeinen. Eine Auswahl, der im Rahmen von Hydro-CH2018 erarbeiteten Klimaprojektionen (CH2018, 2018), ermöglichte es die Sensitivität von Grundwassertemperaturen in Zusammenhang mit den wesentlichen Grundwasserneubildungsprozessen zu beschreiben. Für nicht-urbane und ländliche Gebiete wird erwartet, dass der Klimawandel insgesamt einen starken Einfluss auf die Grundwassertemperaturen hat. Hingegen dürften in urbanen Gebieten direkte anthropogene Einflüsse weiterhin dominieren (Epting und Huggenberger 2013). So resultiert die vermehrte thermische Nutzung des Untergrundes und die Abwärme von Untergrundstrukturen als auch Anpassungsstrategien in Zusammenhang mit der Klimaerwärmung („positive Rückkopplung“) in erhöhten Grundwassertemperaturen. Messdaten für Basel zeigen, dass Grundwassertemperaturen, allein für den Zeitraum von 1993 bis 2016, im Mittel um 3.0 ± 0.7 K stiegen und in stark urbanisierten Gebieten sogar über 18 °C erreichen können. Bei flachgründigen Grundwasservorkommen mit geringer Mächtigkeit, wie z.B. in Davos, ist damit zu rechnen, dass die Temperaturen des Grundwassers stark beeinflusst werden. Dagegen sind Temperaturveränderungen bei tiefgründigen Grundwasserressourcen, wie z.B. in Biel, oder teilweise grossen Flurabständen, wie z.B. Winterthur, nur stark gedämpft und über lange Beobachtungszeiträume zu erwarten. Auswirkungen auf die Grundwassertemperaturen hängen vor allem mit saisonalen Verschiebungen der Grundwasserneubildung zusammen. So geht eine Verlagerung von Niederschlags- und Hochwasserereignissen vom Sommer in die Wintermonate einher mit einer Zunahme der

Grundwasserneubildung in vergleichsweise „kühlen Jahreszeiten“ („negative Rückkopplung“). Wie schon in vorausgehenden Arbeiten (z.B. CH2014-Impacts (2014)) konnte aufgezeigt werden, dass die Interaktion mit Oberflächengewässern und eine verstärkte Grundwasserneubildung während hoher Wasserführung der Fliessgewässer die Temperaturprägung des Grundwassers stark beeinflussen werden. Mit den Resultaten der Forschungsarbeit konnten Grundlagen geschaffen und Wissenslücken im Zusammenhang mit der Variabilität hydraulischer und thermischer Grundwasserregime Schweizer Lockergesteins-Grundwasservorkommen geschlossen werden. Adäquate Monitoring-Konzepte und quantitativer Analysemethoden (Modellierung, GIS), erlauben es dabei den Spielraum für lokale Anpassungsstrategien, wie z.B. vermehrte Nutzung der „Abfallwärme“ aus urbanen Grundwasserleitern mit gleichzeitig Reduktion erhöhter Grundwassertemperaturen, zielgerichteter und effizienter zu nutzen.

Le changement climatique aura des effets à la fois quantitatifs et qualitatifs sur les ressources en eaux souterraines. Ces effets diffèrent selon le type d’aquifère d’une roche meuble ou dure, dans une zone urbaine ou rurale et selon les processus dominants de recharge des nappes. Afin de comprendre l’évolution des changements futurs de l'utilisation et la et température des eaux souterraines, il nécessite au préalable une étude différenciée des conditions géologiques des sites, des processus hydrogéologiques et des recharges des nappes, des "rétroactions positives et négatives", ainsi que l’influence anthropique directe. Ces bases sont essentielles afin de comprendre la répercussion des ressources des eaux souterraines aux changements anthropiques et aux effets du changement climatique. L’objectif du projet du module complémentaire Hydro-CH2018 "État actuel et évolution de la température des ressources en eau souterraine des roches meubles" était une prise en compte différenciée des influences déterminant la température des eaux souterraines de la roche meuble. Pour ce faire, il nécessite une connaissance des propriétés caractéristiques des ressources en eau souterraine, ainsi que les dimensions spatiales et les taux de renouvellement. D’une autre part, la dérivation des paramètres clés représentatifs (géométrie de l’aquifère, propriétés de stockage, taux de renouvellement des eaux souterraines et temps de rétention, etc.), ainsi que les processus essentiels de la recharge des eaux souterraines et de la formation de la température permettent de comparer, mais aussi de pronostiquer sur la sensibilité des différentes ressources des eaux souterraines du changement climatique. Une comparaison des contraintes hydrauliques et thermiques caractéristiques des diverses aquifères en roche meuble représentatifs du Plateau Suisse, Jura et de la région alpine sert de base afin d’estimer la transférabilité des ressources en eaux souterraines suisses. Pour les zones rurales, le changement climatique dans son ensemble devrait avoir un impact considérable sur la température des eaux souterraines. Concernant les zones urbaines, les influences directes d’origine anthropique continueront de primer (Epting et Huggenberger 2013). L’augmentation de l’utilisation thermique du sous-sol, de la chaleur résiduelle des structures souterraines, ainsi que des stratégies d’adaptation liée au réchauffement climatique (« rétroaction positive ») entraînent une augmentation des températures de la nappe. Durant la période de 1993-2016, des mesures ont été effectuées dans la ville Bâle. Ces derniers montrent que la température des eaux souterraines a augmenté en moyenne de 3,0 ± 0,7 K. En particulier dans les zones de haute densité, la température peut atteindre les 18°C. Dans le cas des eaux souterraines peu profondes et à faible épaisseur, par exemple à Davos, il faut s’attendre à ce que la température soit davantage influencée. Au contraire pour les eaux souterraines profondes, par exemple à Bienne, ou dans certains cas avec des grandes distances par rapport à la surface, par exemple à Winterthur, les changements de température sont atténués et peuvent être observés sur une longue période. Les effets sur les températures des eaux souterraines sont principalement liés aux changements saisonniers de sa recharge. Ainsi, un déplacement des précipitations et des inondations d’été vers les mois d’hiver est accompagné d’une augmentation de la recharge des eaux souterraines en comparaison des "saisons fraîches" ("rétroaction négative"). Comme dans les études précédentes (par ex. CH2014-Impacts (2014)), il a pu être démontré à nouveau, que l’interaction avec les eaux de surface et l’augmentation de la recharge des eaux souterraines lors des périodes de grandes crues influenceront fortement les caractéristiques des nappes. Les résultats des travaux de recherche ont permis d’apporter de nouvelles connaissances sur la variabilité des régimes hydrauliques et thermiques des nappes phréatiques de roche en meuble de la Suisse. Des concepts de surveillance adéquats et des méthodes d'analyse quantitative (modélisation, SIG) permettent une utilisation plus ciblée et plus efficace des possibilités de stratégies d'adaptation locales, par exemple une utilisation accrue de la "chaleur résiduelle" des aquifères urbains résultant une réduction des températures élevées des eaux souterraines.

Die Wasserstrategie 2010 des Kantons Bern ist Richtschnur für den nachhaltigen Umgang mit der Ressource Wasser und orientiert sich am Ansatz der integralen Wasserwirtschaft. Für die Teilbereiche Wassernutzung, Wasserversorgung und Siedlungsentwässerung wurden Umsetzungsziele und Massnahmen formuliert. Im Interview beschreiben Stefan Mürner und Paul Borer vom Amt für Wasser und Abfall AWA des Kantons Bern die Aktivitäten im Bereich Wasserversorgung, die unter dem Motto

«Moderne Infrastruktur und nachhaltige Bewirtschaftung» stehen. Selbstverständlich darf dabei die im letzten Jahr aufgekommene Chlorothalonil-Problematik nicht fehlen.

3. Wasserpolitischer Jahresrückblick 2019

Vor dem Hintergrund der Pestizidverbots- und der Trinkwasserinitiative, aber auch nach Bekanntwerden neuer Resultate zum ungenügenden Grundwasserschutz, standen 2019 vor allem Fragen zur Qualität der Wasserressourcen und des Trinkwassers im Zentrum der Wasserpolitik. Fortgesetzt wurde das Ringen um mehr Stromproduktion aus Wasserkraft durch Lockerungen beim Gewässer- und Landschaftsschutz und um mehr Ausnahmen beim Ausscheiden des Gewässerraums.

4. Etat microbiologique de l'eau potable. Etude par cytométrie en flux des eaux alimentant la région d'Yverdon-les-Bains – Grandson

La cytométrie en flux est une technique moderne et rapide permettant de définir l'état microbiologique d'un réseau d'alimentation en eau potable. L'étude détaillée des réseaux d'eau de la région d'Yverdon-les-Bains - Grandson a permis de déterminer les communautés microbiennes des principales ressources en eau et de suivre leur évolution spatio-temporelle dans le réseau d'adduction, de stockage et de distribution. Une telle caractérisation de l'état microbiologique à l'échelle du réseau d'eau constitue un outil de gestion supplémentaire pour les distributeurs d'eau.

5. Grundwasserschutz muss Qualität des Trinkwassers sichern

Aufgrund von Belastungen des Grundwassers mit unerwünschten Substanzen – meist Nitrat und Abbauprodukte von Pflanzenschutzmitteln – mussten in der Schweiz bereits viele Trinkwasserfassungen aufgegeben werden. Weil es in unserem dicht besiedelten und intensiv genutzten Land kaum mehr geeignete Ausweichmöglichkeiten gibt und unbelastete Standorte folglich rar sind, muss künftig die Nutzung der Flächen in den Zuströmbereichen angepasst werden. Zur langfristigen Sicherung einer guten Trinkwasserqualität ist ein besserer Schutz des Zuströmbereichs, aus dem das geförderte Grundwasser mehrheitlich stammt, unabdingbar.

6. Reicher Grundwasserfauna

Eine Pilotstudie der Eawag hat an über 300 Standorten im Schweizer Mittelland die Grundwasserfauna untersucht, wobei die Rohwässer in Brunnenstuben durch die Wasserversorgungen selbst beprobt wurden. Anschliessend wurden die gefundenen Organismen morphologisch und teils genetisch bestimmt. An über 60% der Stellen wurden Organismen aus 18 biologischen Ordnungen gefunden. Bei den Grundwasserflohkrebsen wurden neue Arten für die Schweiz und auch für die Wissenschaft entdeckt.Paraglacial history and structure of the Moosfluh Landslide (1850-2016), Switzerland

7. Pierre-Yves Jeannin: "Les régions karstiques représentent une ressource en eau alternative"

L’Institut suisse de spéléologie et de karstologie (ISSKA) a été fondé il y a plus de 20 ans pour offrir une compétence scientifique spécifique dans le domaine du karst. L’ISSKA modélise et développe des méthodes pour mieux comprendre et représenter le sous-sol en termes de géologie et d’hydrologie. Sur cette base, il est possible de proposer des solutions pour la recherche, l’exploitation, la gestion et la protection des eaux souterraines en milieu calcaire. Dans l’interview, Pierre-Yves Jeannin, directeur de l’ISSKA, décrit le travail de l’Institut et souligne l’importance des eaux souterraines karstiques en Suisse aujourd’hui et ce qu’elles pourraient signifier à l’avenir.
Slope Stability of a Scree Slope Based on Integrated Characterisation and Monitoring

Fachartikel international / Articles spécialisés internationaux

8. Nitrogen fertilization of soils fuels carbonate weathering and translocation in calcareous watersheds

In calcareous watersheds, groundwater alkalinity results largely from dissolution of carbonate minerals in soils. The alkalinity increases initially approximately in proportion to nitrate (NO3-) concentration and eventually approaches an apparent maximum of approximately 8 mmol L-1 at high NO3- concentrations. This close positive relationship between alkalinity and NO3- concentration appears to be predominantly a result of three processes: (i) mineralization of organic nitrogen fertilizer, (ii) exchange of OH- and H+ during the uptake of NO3- or ammonium by crop plants, and (iii) CO2 released by roots as a result of fertilizer-stimulated plant growth. We suggest that the asymptotic approach to a maximum groundwater alkalinity at NO3- concentrations exceeding 0.25 mmol L-1 may be caused by (i) a maximum possible areal crop production at excessive N fertilization and (ii) an increasing CO2 loss to the atmosphere due to the increasing CO2 production in the soil. Our analysis provides a general understanding and quantitative prediction of steady-state groundwater NO3- concentration, alkalinity, pH, the degree of CO2 supersaturation in the soil, and soil CO2 emissions to the atmosphere. The positive correlation between alkalinity and NO3- concentration observed in groundwaters persists in rivers and lakes. We conclude that an economically efficient agricultural practice that avoids over-fertilization might accelerate the in-soil carbonate weathering rate up to approximately threefold compared to unfertilized soils, but it will not jeopardize the use of aquifers for drinking water.

9. Jumping into the grids: mapping biodiversity hotspots in groundwater habitat types across Europe

Biodiversity hotspots are routinely identified by grid-based analyses, despite grids encompassing different habitats, thus hindering the potential to assess which habitat type accounts for the conservation priority assigned to a grid. In this study, we aimed at identifying the main hotspots for the conservation of the European stygobitic Crustacea Copepoda Harpacticoida at the groundwater habitat scale. A multi-metric approach was used, based on six biodiversity indicators: species richness, endemicity, evolutionary origin, phylogenetic rarity, taxonomic distinctness, habitat specificity. The Hot Spot Analysis, based on the statistics Getis-Ord Gi*, was used to compare the local to the global average values of each indicator to identify hotspots of conservation. The operational units used to perform the analyses were the groundwater habitat types, in order to gather all the possible patterns of spatial occupancy in terms of habitat variability. Eight biodiversity hotspots of stygobitic Crustacea Harpacticoida were highlighted: 1) the Pyrenees (Spain and France), 2) the Jura Massif (France), 3) the Alpine arc (France, Switzerland and Italy) embracing southward the River Po alluvial plain and the Slovenian External Dinarides, 4) the Central Apennines (Italy), 5) the Carpathian and Balkan mountains in Romania and at the boundary between western Bulgaria and north-west Macedonia, 6) the Dinaric Alps (from Croatia to Albania), 7) the Sardinia Island, 8) an area in central-northern Europe embracing Denmark, the Netherlands and Germany. The hotspots showed a clear spatial distribution in southern Europe where they were distributed predominantly south to the 45th parallel, in line to what reiteratively observed in previous studies. Many hotspots embraced more than one habitat type. The adoption of discrete groundwater habitat types as working spatial units rather than grids provided a higher resolution of where the stygobitic harpacticoid species effectively live, with the possibility of intervening more precisely to preserve them and their habitats.

10. Lacustrine groundwater discharge through giant pockmarks (Lake Neuchatel, Switzerland)

Pockmarks are circular depressions on the floor of oceans and lakes and constitute potential hot spots of gas ebullition and/or groundwater discharge. Marine pockmarks are well-studied, whereas lacustrine pockmarks are virtually unexplored. In Lake Neuchatel (Switzerland) four giant pockmarks of 80 to 150 m in diameter are located along the northern shore and adjacent to the karst system of the Jura Mountains. Two pockmarks have a ~60 m-deep chimney filled with mud; two are funnel-shaped 12 and 29 m deep holes. We present evidence for the presence of groundwater in the pockmark chimneys and active lacustrine groundwater discharge (LGD) at both pockmark types. Temperature, electrical conductivity and calcium concentrations of the pore water in the chimneys show values typical for karst water (maximal

sampling and profiling depth: 41 m into the pockmark) and contrast strongly with the properties of the lake water. TOC and TIC indicate that the chimney mud is homogenized and composed of liquefied sediments from the entire deglacial to Holocene lacustrine sediment succession. Mini mud volcanoes apparent on the suspension surface imaged with a remotely operated vehicle (ROV) localize the groundwater exit points and confirm LGD. LGD is further corroborated by electrical conductivity anomalies detected above the lutoclines and within a funnel-shaped pockmark during the ROV survey. We conclude that the giant pockmarks in Lake Neuchatel represent a type of subaquatic springs that connect the water body of the lake with the karst system. A next essential research step will be to quantify LGD via the pockmarks in order to assess their lake-wide relevance. This study underlines the existing need for research on the connectivity of lakes and oceans with groundwater systems for completing our understanding of the hydrological cycle.

11. HydroMix v1.0: a new Bayesian mixing framework for attributing uncertain hydrological sources

Tracers have been used for over half a century in hydrology to quantify water sources with the help of mixing models. In this paper, we build on classic Bayesian methods to quantify uncertainty in mixing ratios. Such methods infer the probability density function (PDF) of the mixing ratios by formulating PDFs for the source and target concentrations and inferring the underlying mixing ratios via Monte Carlo sampling. However, collected hydrological samples are rarely abundant enough to robustly fit a PDF to the source concentrations. Our approach, called HydroMix, solves the linear mixing problem in a Bayesian inference framework wherein the likelihood is formulated for the error between observed and modeled target variables, which corresponds to the parameter inference setup commonly used in hydrological models. To address small sample sizes, every combination of source samples is mixed with every target tracer concentration. Using a series of synthetic case studies, we evaluate the performance of HydroMix using a Markov chain Monte Carlo sampler. We then use HydroMix to show that snowmelt accounts for around 61% of groundwater recharge in a Swiss Alpine catchment (Vallon de Nant), despite snowfall only accounting for 40 %-45% of the annual precipitation. Using this example, we then demonstrate the flexibility of this approach to account for uncertainties in source characterization due to different hydrological processes. We also address an important bias in mixing models that arises when there is a large divergence between the number of collected source samples and their flux magnitudes. HydroMix can account for this bias by using composite likelihood functions that effectively weight the relative magnitude of source fluxes. The primary application target of this framework is hydrology, but it is by no means limited to this field.

12. Geothermal potential of tunnel infrastructures - development of tools at the city-scale of Basel, Switzerland

This work presents preliminary evaluation elements for geothermal potential assessment and thermal influences of planned tunnel infrastructures for the urban agglomeration of Basel (Switzerland). In dependence of the tunnel type (motorway or railway) as well as its location related to the geological and hydrogeological settings different solutions for shallow geothermal energy systems (SGE) are investigated. 'Passive' and 'active' SGE have been evaluated, including heat-exchanging segments installed in tunnel lining structures and thermal exploitation of water circulating in culvert systems.

First results suggest that thermal activation of a planned railway tunnel is most efficient where it is located within groundwater-saturated zones of the unconsolidated rock deposits. In summer, thermal power of 3.7 and 1.4 MW can be exchanged from two 736 and 284 m-long tunnel sections, respectively. Accordingly, in standard heat pump operating conditions a thermal energy of 10.4 and 3.8 GWh can be delivered for 'cooling'. In winter, thermal power of 1.9 and 0.7 MW can be exchanged, respectively, and a thermal energy of 5.2 and 1.9 GWh can be delivered for 'heating'.

SGE within culverts reveals to be favorable in heating mode only and for sections where the motorway tunnel runs perpendicular to the regional groundwater flow field and where ambient groundwater temperatures are high. Under such conditions along a 320 m-long tunnel section thermal power of up to 0.4 MW can be provided in summer and 0.8 MW in winter, respectively, and thermal energy of 1.1 GWh in summer and 2.1 GWh in winter, can be delivered.

13. Pathline Density Distributions in a Null-Space Monte Carlo Approach to Assess Groundwater Pathways

A null-space Monte-Carlo (NSMC) approach was applied to account for uncertainty in the calibration of the hydraulic conductivity (K) field for a three-dimensional groundwater flow model of a major water supply system in Switzerland. The approach generates different parameter realizations of the K field using the pilot point methodology. Subsequently, particle tracking (PT) was applied to each calibrated model, and the resulting particles are interpreted as the spatial pathline density distribution of multiple sources. The adopted approach offers advantages over classical PT which does not provide a means for treating uncertainty originating from the incomplete description of subsurface heterogeneity. Uncertainty in the K field is shown to strongly influence the spatial pathline distribution. Pathline spreading is particularly evident in locations where the information content of the head observations does not sufficiently constrain the estimated parameters. Despite the predictive uncertainty, the pumped drinking water at the study site is most likely dominated by artificially-infiltrated groundwater originating from the local infiltration canals. The model suggests that within the well field, the central pumping wells could be extracting regional groundwater, although the probability is relatively low. Nevertheless, a rigorous uncertainty assessment is still required since only a few realizations resulted in flow paths that support the field observations. Model results should therefore not be based on only one model realization; rather, an uncertainty analysis should be carried out to provide a sufficiently large suite of equally probable simulations that include all potential sources and pathways.

14. Fifty years of history of the Karst Commission of the International Association of Hydrogeologists

The Commission on Karst Hydrogeology, also known as the Karst Commission (KC), was founded in 1970 in Neuchatel, Switzerland, and it is an important part of the International Association of Hydrogeologists (IAH). The general idea was to organise a group of hydrogeologists from different countries, with relevant experience in karst hydrogeology, to promote cooperation among scientists interested in karst topics, exchange experiences and, particularly, create an optimal strategy for groundwater resources development. From foundation until today, more than 40 formal meetings and many informal KC gatherings (including field trips) have been convened in different karst regions, and a number of papers and books have been published by KC members. The first publication in the IAH book series International Contributions to Hydrogeology (the "blue books") was on the subject of karst, presenting the experiences gleaned from a number of development projects from various karst regions, as well as bibliographic data on karst research of the time. Today, the KC is one of the most active IAH groups, with 70 permanent members from 6 continents and many young researchers, whose work is supported by funding and regular awards. The KC members have led or have been involved in many projects run with international cooperation. The two largest, completed in the course of the past decade, are the World Karst Aquifer Map (WOKAM) and the Dinaric Karst Transboundary Aquifer System (DIKTAS) projects. This paper summarizes the history of the KC to date.

15. Characterizing seasonal groundwater storage in alpine catchments using time-lapse gravimetry, water stable isotopes and water balance methods

Alpine areas play a major role in water supply in downstream valleys by releasing water during warm and dry periods. However, the hydrogeology of alpine catchments, which are particularly exposed to the effects of climate change, is currently not well understood. Increasing our knowledge of alpine hydrogeological processes is thus of considerable importance for any forward-looking hydrological investigations in alpine areas. The objectives of this study are to quantify seasonal groundwater storage variations in a small Swiss alpine catchment and to evaluate the capabilities of time-lapse gravimetry in the identification of zones of high groundwater storage fluctuations. Time-lapse gravimetric measurements enable rapid localisation of zones of dynamic groundwater storage changes and help to highlight aquifers with a higher storage decrease. Temperature sensors enable measurement of the temporal trend in stream and spring drying in the post-snowmelt period. Stable isotope measurements allow us to identify the origin of surface water exiting the catchment. The results improve our comprehension of a conceptual schema highlighting two different hydrogeological systems: (a) a shallow, rapidly depleted one fed directly by snowmelt and (b) a deeper one, with a slower recession, fed by main recharge during peak snowmelt and emerging at the lower part of the catchment below the talus and moraine of the catchment where bedrock is exposed. These dynamics confirm the high variability of storage in the talus and moraine aquifers and highlight the dominant role of Quaternary deposits and their connectivity to store water over seasonal and multi-year time-scales. The mechanisms explaining the importance of Quaternary deposits

are the combination of moraine and talus with different permeabilities allowing the storage of sufficient quantities of water permitting continuous release during drier periods of the year.

16. Do stream water solute concentrations reflect when connectivity occurs in a small, pre-Alpine headwater catchment?

Expansion of the hydrologically connected area during rainfall events causes previously disconnected areas to contribute to streamflow. If these newly contributing areas have a different hydrochemical composition compared to the previously connected contributing areas, this may cause a change in stream water chemistry that cannot be explained by simple mixing of rainfall and baseflow. Changes in stormflow composition are, therefore, sometimes used to identify when transiently connected areas (or water sources) contribute to stormflow. We identified the dominant sources of streamflow for a steep 20 ha pre-Alpine headwater catchment in Switzerland and investigated the temporal changes in connectivity for four rainfall events based on stream water concentrations and groundwater level data. First, we compared the isotopic and chemical composition of stormflow at the catchment outlet to the composition of rainfall, groundwater and soil water. Three-component end-member mixing analyses indicated that groundwater dominated stormflow during all events, and that soil water fractions were minimal for three of the four events. However, the large variability in soil and groundwater composition compared to the temporal changes in stormflow composition inhibited the determination of the contributions from the different groundwater sources. Second, we estimated the concentrations of different solutes in stormflow based on the mixing fractions derived from two-component hydrograph separation using a conservative tracer (delta H-2) and the measured concentrations of the solutes in baseflow and rainfall. The estimated concentrations differed from the measured stormflow concentrations for many solutes and samples. The deviations increased gradually with increasing streamflow for some solutes (e.g. iron and copper), suggesting increased contributions from riparian and hillslope groundwater with higher concentrations of these solutes and thus increased hydrological connectivity. The findings of this study show that solute concentrations partly reflect the gradual changes in hydrologic connectivity, and that it is important to quantify the variability in the composition of different source areas.

17. Modelling of landslides in a scree slope induced by groundwater and rainfall

Predicting the trigger of a slope failure of a steep Alpine scree slope in south-west Switzerland is challenging. The groundwater (GW) flow from snow-melting and rainfall infiltration during summer changes the susceptibility to surficial failure, which also depends on the slope angle, bedrock geometry, stratigraphy and the shear strength of the soil. Surficial failure mechanisms are investigated using prototype ground models that integrate input from field monitoring, geological observations and soil properties and account for relevant factors and constraints for physical and numerical modelling. Shallow scree deposits overlying various bedrock configurations (parallel to the slope, with and without a step) were tested under two hydrological regimes: GW flow, and GW combined with additional intense rainfall. Numerical modelling was used to study the parameter combinations that would lead to failure, and worst-case scenarios were defined in terms of the bedrock geometry and hydraulic perturbations. These results were verified using advanced physical modelling techniques in a geotechnical drum centrifuge. Physical modelling results indicated that, for a given GW condition, slope stability decreases (a) as the depth of the soil cover over the bedrock decreases and (b) the higher the bedrock step. Furthermore, a bedrock step impacts the volume and the location of the triggered failure. Rainfall exacerbates the situation.

18. Hydromechanical Rock Slope Damage During Late Pleistocene and Holocene Glacial Cycles in an Alpine Valley

Subglacial water pressures influence groundwater conditions in proximal alpine valley rock slopes, varying with glacier advance and retreat in parallel with changing ice thickness. Fluctuating groundwater pressures in turn increase or reduce effective joint normal stresses, affecting the yield strength of discontinuities. Here we extend simplified assumptions of glacial debuttressing to investigate how glacier loading cycles together with changing groundwater pressures generate rock slope damage and prepare future slope instabilities. Using hydromechanical coupled numerical models closely based on the Aletsch Glacier valley in Switzerland, we simulate Late Pleistocene and Holocene glacier loading cycles including long-term and annual groundwater fluctuations. Measurements of transient subglacial water pressures from ice boreholes in the Aletsch Glacier ablation area, as well as continuous monitoring of bedrock deformation from permanent Global Navigation Satellite Systems stations, help verify our model assumptions. While purely mechanical glacier loading cycles create only limited rock slope damage in our models, introducing

a fluctuating groundwater table generates substantial new fracturing. Superposed annual groundwater cycles increase predicted damage. The cumulative effects are capable of destabilizing the eastern valley flank of our model in toppling-mode failure, similar to field observations of active landslide geometry and kinematics. We find that hydromechanical fatigue is most effective acting in combination with long-term loading and unloading of the slope during glacial cycles. Our results demonstrate that hydromechanical stresses associated with glacial cycles are capable of generating substantial rock slope damage and represent a key preparatory factor for paraglacial slope instabilities.

19. Geochemical evidence for regional and long-term topography-driven groundwater flow in an orogenic crystalline basement (Aar Massif, Switzerland)

Detailed knowledge about the circulation of meteoric water in non-magmatic, orogenic belts is fundamental for assessing the potential of such settings for geothermal power production, as well as their use as potential groundwater resources. To get more general insight into these hydrological processes, we have conducted regional (20 x 10 x 9 km) thermal-hydraulic-chemical (THC) simulations of meteoric water circulation in the orogenic, crystalline basement of the Aar Massif in the Central Alps, Switzerland. Model results were compared to numerous geochemical and isotopic analyses of groundwater discharging into the longest and deepest tunnel of the world, the Gotthard railbase tunnel located within the model domain. Explicitly considering the surface topography in our model was sufficient to reproduce all key characteristics of the tunnel inflows (salinity, temperature, delta O-58 values, and up- and downward directed flow zones inferred from geochemical constraints). This quantitatively confirms that surface topography operates as the governing control on fluid flow in orogenic crystalline basements with meteoric water infiltration occurring at high altitude and resulting upward directed flow zones along major valleys. Owing to low flow rates below 2 m year(-1), computed residence times of the longest flow paths were above 100 k years, confirming that groundwater and/or porewater in orogenic crystalline basements may act as an archive for palaeohydrologic variations. Moreover, simulation results show that down to the lower model boundary at 9 km depth, penetration of meteoric water is not limited by the decrease in permeability with depth that is typically observed in granitic rocks. This suggests that advective fluid transport in orogenic crystalline basements may reach the brittle-ductile transition zone and that infiltrating meteoric water can attain temperatures well above 150 degrees C. We conclude that orogenic geothermal systems are promising plays for geothermal power production.

20. Low-flow behavior of alpine catchments with varying quaternary cover under current and future climatic conditions

Alpine environments are particularly vulnerable to climatic warming, and long term observations suggest a shift of snow-influenced river discharge towards earlier periods of the year. For water resources management, the seasonal patterns of discharge in alpine areas are particularly relevant, as the shift to lower flows in summer and autumn combined with increased water demand could lead to water shortage in downstream catchments. The storage of groundwater in alpine catchments could significantly modulate how changing climatic conditions influence the annual streamflow regime. However, groundwater storage and its buffering capacity in alpine areas remain poorly understood. Moreover, studies on how climate change will impact water resources in alpine areas rarely consider the influence of geology.

In this paper, catchment geology is used as a basis for the classification of future summer low flows behavior of several alpine catchments in Switzerland. Based on the analysis of the relationship between low-flow indicators and geology, the role of unconsolidated quaternary deposits is explored. We show that quaternary deposits play a critical role in the seasonal storage of groundwater, which can contribute to rivers during low-flow periods. Three climate change simulations based on extreme RCP 8.5 scenarios are fed into a conceptual hydrological model to illustrate the buffering role of groundwater. Past and future low flows normalized by mean past and future streamflows appear correlated with the percentage of unconsolidated quaternary deposits. These results highlight that catchments with high groundwater contribution to streamflow relative to precipitation will have a slower decrease in future summer discharge. Therefore, we propose two indicators that can be used to anticipate the response of future summers low flows in alpine areas to climate change: the current winter low flows and the percentage of unconsolidated quaternary deposits of the catchments.

21. Forecasting the long-term activity of deep-seated landslides via groundwater flow and slope stability modelling

Large (deep-seated) landslides present complex geometries, rock/soil properties, and kinematical behavior. Complex geometries are due to the presence of several sliding zones, while complex properties typically result from the dilation, compression, or fatigue of geologic materials. Kinematical behavior is often episodic, with periods of stability followed by periods of enhanced slope movements owing to shear strength reduction in response to groundwater pressure changes. These mechanisms complicate our capacity in forecasting the long-term activity and thus, the choice of a strategy for hazard management. This technical note introduces a method for predicting the long-term activity of deep-seated landslides based on one-way coupled hydromechanical numerical modelling. The method is applied to analyse the long-term stability of a deep-seated compound slide in the Swiss Jura Mountains. Results indicate that, under natural groundwater pressure changes, the analysed compound slide will continue to move in an episodic fashion in response to groundwater levels in the slope, without developing velocities greater than several centimeters per year. This example demonstrates how one-way coupled hydromechanical modelling constrained by field data is a reliable tool for assessing the long-term activity of deep-seated landslides and helping the management of associated hazards.

17th Swiss Geoscience Meeting

22. City-scale solutions for the energy use of shallow urban subsurface resources - Bridging the gap between theoretical and technical potentials

One solution for reducing the current consumption of fossil fuels is a more frequent use of shallow geothermal energy. However, particularly regarding urban subsurface resources, increased use conflicts are predictable. Consequently, reasonable exploitation of subsurface resources requires an assessment of technologically achievable energy potentials with scientific based tools. We present application-oriented management tools which target on deriving shallow subsurface energy potentials. 3D groundwater flow and heat-transport models are used to capture groundwater flow and heat-transport dynamics on the city- and quarter-scale, 2D box models are used to quantify technically feasible extraction rates of well doublets for groundwater heat pump systems.

For Basel (Switzerland), prospective large theoretical energy potentials can be derived for areas with high advective heat flux and high temperature gradients. Likewise, single city quarters are suitable for 'active' thermal use with well doublets, whereas thermal power potentials reach 1.2 MW. Regarding 'passive' installations of energy absorbers in subsurface structures located within the groundwater, energy potentials amount to 4 and up to 40 W m(-2).

The assessment results can be integrated into urban energy plans and support architects, city planners and potential users to acquire initial site-specific information on the technical feasibility of shallow geothermal energy systems.

23. Does no-tillage decrease nitrate leaching compared to ploughing under a long-term crop rotation in Switzerland?

The intensification of agriculture in the industrialized countries since the 1950s led to an increase not only in productivity but also in nitrate concentrations of ground and surface waters. In some countries, various policy measures aim at reducing agricultural nitrogen losses to waters. Still, nitrate concentrations of groundwater impair drinking water quality and nitrogen inputs to surface water are elevated in many areas. Since no-tillage (NT) is often promoted as a farming system that reduces nitrate leaching, we conducted a seven-year lysimeter trial at Berne-Liebefeld (Switzerland) to compare impacts of NT with mouldboard ploughing (MP) in a diverse crop rotation. Crop yields were 13 % lower and N removals by harvested products 5 % lower under NT than under MP. Seepage volumes under NT exceeded those under MP by 8 %. Larger seepage volumes under NT were found in nearly all crop-by-year combinations and months of the year. Mean nitrate concentrations of seepage water were 20 % lower under NT than under MP but still exceeded Swiss official limits for drinking water quality. On average, nitrate-leaching rates were more

affected by nitrate concentrations than by seepage volumes because nitrate concentrations varied much more between tillage systems, crop types and years than seepage volumes. Mean annual rates of nitrate leached exceeded 50 kg N ha(-1) in both tillage systems and crop rotations with a large range from 2 to 221 kg N ha(-1)in individual years. NT showed 14 % lower leaching rates than MP. The differences between the two tillage systems were not statistically significant due to elevated coefficients of variation and the small number of replicates. Improvements in experimental design are suggested to increase the statistical power in future trials.

24. Chlorothalonil transformation products in drinking water resources: Widespread and challenging to abate

Chlorothalonil, a fungicide applied for decades worldwide, has recently been banned in the European Union (EU) and Switzerland due to its carcinogenicity and the presence of potentially toxic transformation products (TPs) in groundwater. The spread and concentration range of chlorothalonil TPs in different drinking water resources was examined (73 groundwater and four surface water samples mainly from Switzerland). The chlorothalonil sulfonic acid TPs (R471811, R419492, R417888) occurred more frequently and at higher concentrations (detected in 65-100% of the samples, <= 2200 ngL(-1)) than the phenolic TPs (SYN507900, SYN548580, R611968; detected in 10-30% of the samples, <= 130 ngL(-1)). The TP R471811 was found in all samples and even in 52% of the samples above 100 ngL(-1), the drinking water standard in Switzerland and other European countries. Therefore, the abatement of chlorothalonil TPs was investigated in laboratory and pilot-scale experiments and along the treatment train of various water works, comprising aquifer recharge, UV disinfection, ozonation, advanced oxidation processes (AOPs), activated carbon treatment, and reverse osmosis. The phenolic TPs can be abated during ozonation (second order rate constant k(O3) similar to 10(4) M(-1)s(-1)) and by reaction with hydroxyl radicals ((OH)-O-center dot) in AOPs (k(OH) similar to 10(9) M(-1)s(-1)). In contrast, the sulfonic acid TPs, which occurred in higher concentrations in drinking water resources, react only very slowly with ozone (k(O3) <0.04 M(-1)s(-1)) and (OH)-O-center dot (k(OH) <5.0 x 10(7) M(-1)s(-1)) and therefore persist in ozonation and (OH)-O-center dot- based AOPs. Activated carbon retained the very polar TP R471811 only up to a specific throughput of 25 m(3)kg(-1) (20% breakthrough), similarly to the X-ray contrast agent diatrizoic acid. Reverse osmosis was capable of removing all chlorothalonil TPs by >= 98%.

25. Nitrogen Surplus-A Unified Indicator for Water Pollution in Europe?

Pollution of ground-and surface waters with nitrates from agricultural sources poses a risk to drinking water quality and has negative impacts on the environment. At the national scale, the gross nitrogen budget (GNB) is accepted as an indicator of pollution caused by nitrates. There is, however, little common EU-wide knowledge on the budget application and its comparability at the farm level for the detection of ground-and surface water pollution caused by nitrates and the monitoring of mitigation measures. Therefore, a survey was carried out among experts of various European countries in order to assess the practice and application of fertilization planning and nitrogen budgeting at the farm level and the differences between countries within Europe. While fertilization planning is practiced in all of the fourteen countries analyzed in this paper, according to current legislation, nitrogen budgets have to be calculated only in Switzerland, Germany and Romania. The survey revealed that methods of fertilization planning and nitrogen budgeting at the farm level are not unified throughout Europe. In most of the cases where budgets are used regularly (Germany, Romania, Switzerland), standard values for the chemical composition of feed, organic fertilizers, animal and plant products are used. The example of the Dutch Annual Nutrient Cycling Assessment (ANCA) tool (and partly of the Suisse Balance) shows that it is only by using farm-specific "real" data that budgeting can be successfully applied to optimize nutrient flows and increase N efficiencies at the farm level. However, this approach is more elaborate and requires centralized data processing under consideration of data protection concerns. This paper concludes that there is no unified indicator for nutrient management and water quality at the farm level. A comparison of regionally calculated nitrogen budgets across European countries needs to be interpreted carefully, as methods as well as data and emission factors vary across countries. For the implementation of EU nitrogen-related policies notably, the Nitrates Directive-nutrient budgeting is currently ruled out as an entry point for legal requirements. In contrast, nutrient budgets are highlighted as an environment indicator by the OECD and EU institutions.

26. Lithological and Tectonic Control on Groundwater Contribution to Stream Discharge During Low-Flow Conditions

Knowing how stream discharge in an ungauged catchment reacts to dry spells is a major challenge for managing water resources. The role of geology on these dynamics is poorly understood. For the Swiss Molasse basin, we therefore explored how the geology influences the groundwater contribution to stream flow during low-flow conditions. Using existing data from geological reports and maps as well as from deep boreholes, we constructed a basin-wide overview of the hydrogeological quality of the bedrock and investigated five catchments in 3D. We found that catchments with the most permeable sedimentary bedrock are least sensitive to low flows (marine sandstone, K = 10(-4) to 10(-5) m/s, P-eff = 5-10%). In contrast, if bedrock K is low (K < 10(-6) m/s), the presence of a productive Quaternary volume becomes decisive for groundwater contribution to stream flow. Limitations exist due to a restricted database for K and P-eff values of the Molasse and limited information on continuation of lithologies with depth. This emphasizes the need for more hydrogeologically relevant data for the future management of water resources. Our results highlighting what lithotypes favor groundwater contribution to stream flow are valid also in other regions for the assessment of a catchment's sensitivity to low flows.

27. Improving hydrologic model realism by using stable water isotopes

The last century of hydrological research has led to significant improvements in representing different hydrological processes in rainfall-runoff models. Despite this progress, most rainfall-runoff models are calibrated only against streamflow, which informs the celerity i.e. the fast response behavior of a catchment. Using environmental tracers such as stable water isotopes can help constrain the velocity aspect of the catchment. However, stable water isotopes have either been used qualitatively to learn more about the dominant hydrological processes or to calibrate a much more complex solute transport model, where the added benefit of using stable water isotope data is not entirely clear.
In this study, we use stable water isotopes to design a semi-distributed conceptual rainfall-runoff model for an Alpine catchment (Vallon de Nant), and incorporate information about pre-event water fraction in the stream within the rainfallrunoff model. Pre-event water fraction is estimated using stable water isotope data and a Bayesian mixing model, and is used to calibrate the rainfall-runoff model. This kind of a calibration scheme increases the representation of pre-event water
fraction within the stream, thus making model simulations more realistic. We discuss the advantages and limitations of such a modeling approach and how it can be extended to other experimental catchments.

28. Climate change effects on groundwater recharge and temperatures - status and development for Swiss aquifers

Climate change will have both quantitative and qualitative effects on groundwater resources. These impacts differ for aquifers in solid and unconsolidated rock, urban or rural locations and the principal processes of groundwater recharge. Knowledge of the intrinsic key parameters (aquifer geometries, storage properties, groundwater renewal rates, residence times, etc.) and the principal groundwater recharge processes as well as temperature imprinting enables a comparison and forecast of the sensitivity of individual aquifers to climate change. The sensitivity of future groundwater temperature development for selected climate projections was investigated for representative Swiss unconsolidated rock groundwater resources on the Central Plateau, the Jura and the Alpine region. For non-urban and rural areas, climate change is expected to have a strong overall impact on groundwater temperatures.
In urban areas, however, direct anthropogenic influences are likely to dominate. Increased thermal subsurface use and waste heat from underground structures as well as adaptation strategies to mitigate global warming result in increased groundwater temperatures. Likewise, measurements for the city of Basel show that groundwater temperatures increased by an average of 3.0 ± 0.7 °C in the period from 1993 to 2016 and can exceed 18 °C, especially in densely urbanized areas. Similarly, regarding shallow aquifers with low groundwater saturated zone thicknesses, such as in Davos (Canton Grisons), groundwater temperatures will strongly be influenced by changes in groundwater recharge regimes. In contrast, groundwater temperature changes within deep aquifers with large groundwater saturated zone thicknesses, such as in Biel (Canton Bern), or in some cases with large distances from the surface to the groundwater table and extended unsaturated zones, e.g. in Winterthur (Canton Zurich), are strongly attenuated and can only be expected over long time periods.
We show that seasonal shifts in groundwater recharge processes could be an important factor for the future development of groundwater temperatures. Moreover, the interaction with surface waters and increased groundwater recharge during high runoff periods are likely to have a strong influence on groundwater temperatures. Accordingly, a shift in precipitation and river flood events from summer to

winter months is accompanied by an increase in groundwater recharge in comparatively cool seasons, which would be accompanied by a tendency for “cooling” groundwater.

29. From hydrological forecasts to adapted water management

Hydro-CH2018, a major FOEN research project to be completed in 2020, also included several targeted literature studies. One of them focused on the use and management of Swiss water resources, and how its objectives are challenged by a changing climate. To assess current and future water management in Switzerland, the sector was clustered into nine societal demands (see table 1). Some are of predominantly public interest (drinking water supply, waste water management, flood management, river and lake ecology), others are mainly commercial activities (thermal use, irrigation, tourism, industrial water use) or a combination of both (hydropower).

The literature study shows, that water resources in Switzerland are under pressure due to abstraction, pollution, encroachment of riparian areas, and hydro-morphological deficits. Recently introduced legislation on water protection aims to alleviate some of these pressures in the decades to come. The remaining pressures and climate change will exert a combined effect on water resources, to which water management will have to react. Generally, the impact of socioeconomic change on water management is at least as important as that of climate change. This finding is in tune with earlier research projects such as the Swiss national research program on sustainable water management (NRP 61, 2010-2014).
In some sectors, adaptation of water management to climate change is likely to increase conflicts and environmental problems. This will be particularly the case in summer and fall when demand for water in agriculture and for cooling is heightened. Also, groundwater use for climate-neutral heating systems has increased pressure on underground water resources.

Drinking water supply
Switzerland obtains ca. 80% of its drinking water from underground aquifers. Much of the groundwater is abstracted in heavily utilized river plains where its quality is under pressure from agricultural activities, transportation, industry, and expanding residential areas. In many regions, virtually all groundwater is influenced by societal activities preventing the appropriate protection of drinking water quality. Combined with climate-induced reductions in available quantity, the lack of adequately protected groundwater resources is becoming a major challenge for future drinking water supply. Lately, widespread exceedances of the legal drinking water limit for pesticide residues in large parts of the country have confirmed the vulnerability of the system.

Industrial water use
Industry and business are major users of water in Switzerland. Their consumption exceeds household use of water by a factor of 2.5. Some 73% are obtained from private wells, 27% from public water supply. Up-to-date information on industrial water use is lacking, the most recent figures concern the year 2006. Abstracted quantities are published only by one canton, most other cantons do not require abstractions to be measured and there is no fee on water consumption (other than concession fees independent of actual abstraction). Most industries and businesses discharge their wastewater via public treatment plants. To date, information about the chemicals contained in industrial wastewater are scarce. Their quantity is however significant: Chemicals from industry and business make up about a quarter of anthropogenic substances in the Rhine river at the border in Basel.

Wastewater
Wastewater management is among the sectors requiring major adjustments due to climate change. Reduced run-off in summer and fall result in an increase of wastewater concentrations in rivers. To make up for this, Switzerland will upgrade at least 130 strategically selected wastewater treatment plants with ozonization and/or active carbon filtration technology. This will markedly increase the quality of drinking water abstracted downstream of WWTPs. However, large parts of the Swiss river system will still receive wastewater from treatment plants without advanced technology. A second challenge is that increasingly heavy storm water events are exceeding the capacity of sewage systems. To prevent untreated wastewater from overspilling into rivers, rain water is to be kept away from sewers by local infiltration and retention systems.

Agricultural irrigation
Agricultural irrigation is likely to become a key issue of water management in Switzerland. The area of crops requiring irrigation is rapidly increasing (+26% vegetable hectares 2010-2016). Extended additional

irrigation infrastructures are currently being planned or implemented, usually with substantial public support. However, the additional water demand of these new projects is unclear. There is no policy of recording water abstractions of agriculture in Switzerland. As a result, authorities are often unable to assess the impact of irrigation on water resources. Conflicts with other water users and aquatic ecology are likely to increase.

The emphasis of public policies for adapting irrigation to climate change is on water use efficiency and a shift to less waterconsuming crops or varieties. In practice, such demand management policies find little resonance. Almost all current irrigation development aims at increasing water availability. Hence, irrigation is a typical example for effects of societal change overriding those of climate change. In most areas, the extension of irrigated crop area has a larger impact on water consumption than rising temperatures.

One obvious solution to avoid increasing conflicts in times of water scarcity is a drought insurance. As soon as meteorological drought prevails, farmers are reimbursed for crop losses. Drought insurances also improve protection of rivers and groundwater from over-abstraction, as insured farmers will be obliged to stop abstracting water in times of low water tables.

Hydropower
Hydropower is expected to benefit from the general shift of runoff from summer to winter, as more water will be available in times of highest electricity demand. However, the effect of prolonged droughts could affect hydropower production also during winter. International political decisions and economic developments haven proven to substantially affect the demand for hydropower. Building hydropower infrastructure is expensive and time-consuming, and the general economic circumstances are unfavorable for further extensions. On the other hand, hydro-electricity is an important renewable energy source. Clearly, societal influences are much more important for the future of Swiss hydropower than hydrological changes brought about by climate change.

Outlook
Most societal activities concerning water are affected by both climate change and pre-existing pressures (abstraction, pollution, encroachment, infrastructure). Adaptation to climate change can only be successful if these pressures are also addressed. Quick and thorough implementation of existing legislation will make rivers, lakes and groundwater more resilient to the hydrological fall-out of climate change. At the same time, current water protection legislation ought to be assessed to make sure it is sufficient to safeguard future river and lake ecology.

30. Fully-integrated surface-subsurface hydrological modelling in steep, snow-dominated, geologically complex Alpine terrain

Most hydrological climate change impact assessments in Alpine areas continue to be underpinned by simple conceptual hydrological models. However, such models have numerous limitations that may ultimately affect the reliability of predictions generated using them. For instance, spatial variability in surface and subsurface material properties is often lumped together, empirical snow modelling approaches prevail, and the potential hydrological impacts of contemporaneous changes in other environmental system components such as vegetation and permafrost tend to be overlooked. Considerably more sophisticated physically-based, spatially explicit codes which are capable of simulating 2D surface flows, 3D variably-saturated subsurface flows, and evapotranspiration in a fully-integrated fashion appear to have great potential with respect to the simulation of mountainous hydrological processes. However, integrated models have not yet been applied in real steep, snow-dominated, geologically complex Alpine catchments. This presentation therefore describes the development, automated calibration, and application of a fully-integrated model of two adjacent headwaters in the western Swiss Alps under both historical and plausible future climatic, vegetation, and permafrost conditions. The model incorporates both a detailed representation of the 3D geological structures encountered in the study region and a sophisticated, energy balance-based snow modelling routine that additionally accounts for the gravitational redistribution of snow from steep slopes and was conditioned on two types of complementary snow observations. The results indicate that, for a moderate warming scenario towards the end of the century, “direct” climatic changes are found to dominate the impacts upon key hydrological variables such as streamflows and groundwater levels, whilst “indirect” forest expansion is likely to have a more modest modulating effect via enhanced evapotranspiration. Overall, the work attests to the potential of integrated models to provide a physically sound and internally coherent representation of hydrological dynamics in even the most complex of Alpine settings. That said, the

amount and diversity of the data required, as well as long execution times, mean that such an approach is presently only recommendable in exceptionally important or ecologically sensitive catchments.

31. Elevated concentrations of toxic elements in high-alpine streams of the Eastern Alps: a manifestation of climate change?

In the Eastern Alps, there are several high-alpine streams with distinctivley white-colored streambeds (Fig. 1). The white color originates from the precipitation of nanocrystalline basaluminite [Al4OH10(SO4)·(H2O)3] sticking to the bedload of the streams (Wanner et al., 2018). The phenomenon is triggered at the origin of the streams where the oxidation of pyrite leads to the production of sulfuric acid and the subsequent dissolution of aluminum from the host rock. Owing to its strong pHdependent solubility, precipitation of basaluminite eventually occurs when the acidic and aluminum-rich streams are neutralized along their flow paths. For this contribution, we present chemical water analyses for seven high-alpine streams with clearly visible basaluminite precipitates. The streams are all located in the canton of Grisons. Geologically, the catchments are located within the crystalline basement of the Australpine nappes and the exposed host-rock is dominated by pyrite-bearing mica-schists. All streams show low pH conditions (2700 m a.s.l.), and their generally north-facing orientation. The apparent importance of permafrost in generating low streamwater pH values and elevated toxic element concentrations implies that the impact of climate change on the water quality of such high-alpine streams should be assessed. A likely scenario is that the ongoing permafrost retreat will expose more pyrite-bearing bedrock to aerobic waters and that the production of sulfuric acid and mobilization of toxic elements will increase in the future. This scenario is supported by a long-term monitoring study performed in a smilar setting in the Rocky Mountains, demonstrating that the concentrations of sulfate and Zn strongly increased over the past 40 years (Todd et al., 2012). Moreover, the importance of climate change in adversely affecting the water quality of high-alpine streams is also demonstrated at one of the investigated catchments in the Eastern Alps. There, from aerial photographs it can be inferred that the onset of basaluminite formation only dates back to the year 2000, implying that the phenomonon is relatively new. In conclusion, we propose to initiate a long-term water quality monitoring of the affected high-alpine streams in the Eastern Alps to assess the future impact of climate change on these particular water ressources.

32. Assessing pockmark activity in lakes under influence of drainage area processes

The water balance in enclosed aquatic systems are dependent on the amount of water entering into and leaving a body of water. Measuring inflows and outflows require good knowledge of local conditions as well as high quality instruments in sufficient quantity to measure each source and sink. The nature of this problem usually result in ample quality of outflow measurements compared to incomplete assessment of inflows at temperate latitudes. The result is usually a negative water balance, where sources and sinks do not add up to water level observations in lakes or reservoirs. Measurements in the drainage area of Lake Neuchâtel from 2015 to 2016 of known sources and sinks compared to water level observations obtained inside this lake showed a volume deficit between the two methods of ~20 m3 s-1. High-resolution bathymetric surveys (multi-beam and Lidar) have in recent years resolved both oceans and inland waters such as lakes and reservoirs to an unprecedented detail. This has been used to pinpoint key geological features such as underwater canyons, sediment slides and pockmarks. Pockmarks, i.e. crater-like depressions, are common morphological features on the floor created by the focused upwards migration of fluids (gas and water) through the unconsolidated sediment column. A variety of fluids may form pockmarks: escaping interstitial gases (Solheim and Elverhøi, 1993), pore water seepage due to compression and overpressure (Harrington, 1985), and meteoric groundwater discharge (Morellón et al., 2014). While marine pockmarks have been recognized as a usual component of the oceans, the importance of pockmarks in lakes as element of the hydrological, chemical and sedimentological system has been less well researched. Recent bathymetric surveys in Lake Neuchâtel reviled multiple pockmarks, the largest Chez-le-Bart spanning 160 m across containing suspended sediment (Loher et al., 2016; Reusch et al., 2015). Through a bi-annual measurement campaign, we were able to investigate the long-term development of pockmarks in lake Neuchâtel. We find multiple functional types of pockmarks, either actively emitting water or being in a semi dormant stage with liquefied sediments. We investigate the long-term variability of the lithosphere in Chez-le-Bart pockmark and link this to hydraulic activity in the surrounding catchment.

33. Regional groundwater flow systems in the context of karst development - an example from north-western Switzerland

Based on geological and hydraulic 3D models, the groundwater circulation for regional-scale aquifers within the Rhine Valley within the Tabular Jura east of Basel (Switzerland) was investigated. The main aquifers comprise the Quaternary aquifer of the unconsolidated gravel deposits along the river Rhine and its tributaries as well as the regional-scale karst aquifer within the upper part of the Muschelkalk. Land subsidence indicates further subordinate groundwater bearing segments and complex groundwater interactions between deeper and higher groundwater along fault zones. The current state of regional-scale groundwater regimes within the investigated aquifer systems could be simulated and visualized in relation to the geology, including lithostratigraphic units and fault structures and their parameterization with hydraulic properties as well as the definition of the most important hydraulic boundaries. Scenario calculations were used to investigate the sensitivity of the aquifer systems to hydraulic parameter changes, the change of regional groundwater flow systems during Quaternary aggradation and degradation in the main valley, as well as the base-level changes of the rivers Rhine and Birs, including anthropogenic changes such as the influence of dam and power plants and the reasons for large-scale land subsidence. For this purpose, probable historical base levels before river regulation were considered. Focus was also placed on scenarios considering increased groundwater recharge rates, e.g. due to low frequency, long-lasting precipitation or heavy rainfall events in the catchment area. The results indicate that increased groundwater recharge rates in the catchment areas during low frequency precipitation events (or periods) are associated with orders of magnitude increases of the regional inflow into the karst aquifer of the Upper Muschelkalk. Furthermore, the range of groundwater fluctuations and groundwater saturated regions within the karst aquifer shift in the model calculations to locations where high densities of sinkholes are documented. Adaptation of the surface water baselevels to probable historical levels leads to increased hydraulic gradients (local lowering of the groundwater level by up to 7 m), which are associated with increased groundwater flow within some aquifer regions that are particularly vulnerable to karst development.

34. Changing Groundwater Dynamics in Urbanizing Catchments: A Swiss Case Study

Land development and urbanization have significant impacts on groundwater – surface water interactions and groundwater availability, both in terms of water quantity and water quality. As the populations towns and cities in Switzerland and across the globe are ever-increasing, it is important to understand exactly how these changes occur. Much of the infrastructure inherent to cities – impervious surfaces, storm drains, sewer mains, among others – has particular significance in the surface runoff – groundwater recharge relationship during storm events. Observed increases in surface runoff from storm events have been observed in many urbanized areas, which can constitute a major loss factor in the groundwater balance, and also acts as a conduit of pollutants from the surface into aquifers. We have investigated the relationship between urbanization, groundwater – surface water interactions, in a small, urbanizing catchment within the Canton of Zürich. This area is undergoing active growth, which is expected to continue due to its proximity to the city of Zürich. With this study site, we have begun an observation network that may be used to monitor changes in groundwater dynamics as the urban areas continue to expand. We explore these impacts using two approaches: first with a conceptual water balance, and second by making use of chemical tracers. For our conceptual water balance, we have estimated storm runoff, using two empirical approaches: comparing hydrograph separation against an improved version of the widely used Curve Number approach. These runoff estimates are in turn used to estimate groundwater recharge. This groundwater recharge estimate is then compared to results from the conceptual HBV-Light model and to literature estimates in order to assess its performance. Following this, we applied chemical tracers to groundwater and surface water samples. We used these data to identify localized areas of groundwater – surface water interactions, and to identify areas vulnerable to pollution from storm runoff. We first carried out a multivariate statistical cluster analysis using data from stable water isotopes combined with dissolved ions, which allowed us to identify the respective signature of both water types, and areas of interaction. We then made use of organic micropollutants including pesticides, industrial compounds, and the lifestyle product caffeine – which are unequivocal evidence of human impacts – in

order to identify the magnitude of these imacts, and to validate zones of interaction obtained from our cluster analysis. These analyses have offered insight on the current conditions of the study area, and have allowed us to identify zones of vulnerability, which helps to direct future monitoring efforts.

HYDRO-CH2018

35. AgriAdapt – Modellgestützte Untersuchung der Einflüsse von Klima- und Landnutzungsänderungen auf Grundwasserressourcen im Berner Seeland

Klimawandel beeinflusst sowohl die Wasserressourcen, als auch die landwirtschaftliche Produktion. Mit steigenden Temperaturen und abnehmenden Sommerniederschlägen ist zu erwarten, dass die landwirtschaftliche Produktion in Zukunft vermehrt durch Trockenheit limitiert sein wird. Wo Wasserressourcen für Bewässerung zur Verfügung stehen, ist mit einer Zunahme der Wasserentnahmen für Bewässerung zu rechnen. Somit werden Wasserressourcen unter Klimawandel in zweifacher Hinsicht beeinträchtigt. Erstens direkt durch Änderungen in der saisonalen Niederschlagsverteilung, die die Grundwasserneubildung beeinflussen und zweitens durch Änderungen in der Wassernutzung. Es stellt sich somit die Frage ob Konflikte um die Ressource Wasser in Zukunft zunehmen. Vor diesem Hintergrund war es Ziel dieses Projektes, zu untersuchen, (1) wie Agrarproduktion, Wasserbedarf für Bewässerung, Abflüsse und Grundwasserdynamik durch zukünftige Klimaänderungen beeinflusst werden und (2) wie Klimawandelauswirkungen sich in Kombination mit Änderungen in der landwirtschaftlichen Wassernutzung auf die Grundwasserdynamik auswirken. Das Projekt leistet damit im Rahmen des BAFU-Programms Hydro-CH2018 einen wichtigen Beitrag zum besseren Verständnis der kombinierten Klima- und Landnutzungseinflüsse auf die Wasserressourcen. Zur Beantwortung der Forschungsfragen wurde ein gekoppelter Modellansatz entwickelt, der Modelle aus drei Fachrichtungen miteinander verbindet: ein landwirtschaftliches Pflanzenwachstumsmodell, ein hydrologischhydraulisches Modell und ein hydrogeologisches Modell. Die Koppellung wurde für das Gebiet des Grundwasserleiters «Berner Seeland» implementiert und getestet. Das Gebiet wird überwiegend landwirtschaftlich genutzt, wobei die Möglichkeit zur Grundwassernutzung für Bewässerung eine wichtige Rolle für die Ertragssicherung spielt. Gleichzeitig versorgt der Grundwasserleiter die Gemeinden der Umgebung mit Trinkwasser. Eine potentielle Verschärfung eines Nutzungskonfliktes zwischen Trinkwassernutzung und landwirtschaftlicher Wassernutzung ist hier deshalb von zentraler Bedeutung. Bewertet wurden im Rahmen dieser Studie die Auswirkungen von erwarteten Klimaänderungen bis zum Ende des Jahrhunderts ausgehend von drei verschiedenen Emissionsszenarien (RCP2.6 = mit Klimaschutz, RCP4.5, RCP8.5 = ohne Klimaschutz). Landnutzungsänderungsszenarien verbunden mit Zu- oder Abnahme von Bewässerung wurden erstellt und bewertet, um die kombinierten Auswirkungen von Klima- und möglichen Nutzungsänderungen auf die Grundwasserdynamik des Untersuchungsgebietes abschätzen zu können. Die Modellergebnisse zeigen, dass Ertragsänderungen nicht nur durch Trockenheitslimitierungen, sondern auch durch steigende Temperaturen getrieben sind. Am Beispiel von Mais konnte gezeigt werden, dass die Wahl von spätreiferen Sorten zur Anpassung an steigende Temperaturen sinnvoll sein kann, um das Ertragsniveau zu halten bzw. noch zu steigern. Allerdings kann ein potentieller Ertragszuwachs nur mit Bewässerung realsiert werden. Simulationsergebnisse zeigen, dass der Wasserbedarf für Bewässerung ohne Klimaschutz (RCP8.5) bis zum Ende des Jahrhunderts bei unveränderter Wachstumsperiode um 40% und mit Sortenanpassung um bis zu 80% zunehmen könnte. Mit Klimaschutz (RCP2.6) bliebe die Zunahme an Wasserbedarf für Bewässerung auf 7% beschränkt. Die Zunahme an Bewässerung und saisonale Abnahme der Neubildungsraten mit abnehmenden Sommerniederschlägen bewirkt im Gebiet eine Absenkung der Grundwasserstände in den Spätsommer- und Herbstmonaten. Diese würde durch eine Intensivierung der Bewässerungspraxis akzentuiert und durch eine Extensivierung reduziert. Implikationen der errechneten Änderungen der Grundwasserdynamik auf den Abbau organischer Böden, den Schadstofftransport, die Biodiversität und Bewässerungskosten sind in weiterführenden Studien abzuschätzen.

Le changement climatique affecte non seulement les ressources en eau mais aussi la production agricole. Avec la hausse des températures et la diminution des précipitations estivales, on s'attend à ce qu'à la production agricole soit à l'avenir de plus en plus limitée par la sécheresse. Là où des ressources en eau sont disponibles pour l'irrigation, il faut escompter une augmentation des prélèvements d'eau pour l'irrigation. Le changement climatique porte donc atteinte aux ressources en eau de deux manières.

Premièrement, directement par des changements dans la distribution saisonnière des précipitations, qui influencent la recharge de la nappe phréatique et, deuxièmement, par des changements dans l'utilisation de l'eau. La question se pose donc de savoir si les conflits liés aux ressources en eau vont s'intensifier à l'avenir. Dans ce contexte, l'objectif de ce projet était d'étudier (1) comment la production agricole, les besoins en eau pour l'irrigation, le ruissellement et la dynamique des eaux souterraines sont affectés par le changement climatique futur et (2) comment les impacts du changement climatique combinés aux changements dans l'utilisation de l'eau d'irrigation pour l'agriculture vont influencer la dynamique des eaux souterraines. Ce projet apporte ainsi une contribution importante à une meilleure compréhension des effets combinés du climat et de l'utilisation des sols sur les ressources en eau dans le cadre du programme Hydro-CH2018 de l'OFEV. Pour répondre aux questions de recherche, une approche de modèles couplés a été développée qui combine des modèles de trois disciplines: un modèle agricole de croissance des plantes, un modèle hydrologique et hydraulique et un modèle hydrogéologique. Cette couplage a été mise en place et testée pour la zone de la nappe aquifère du Seeland bernois. Cette zone est principalement utilisée à des fins agricoles, la possibilité d'utiliser les eaux souterraines pour l'irrigation jouant un rôle important dans la garantie des rendements. En même temps, la nappe aquifère alimente en eau potable les communes environnantes. L'aggravation potentielle d'un conflit entre l'utilisation de l'eau comme eau potable et à des fins agricoles est donc d'une importance capitale ici. Dans le cadre de cette étude, les impacts des changements climatiques attendus d'ici à la fin du siècle ont été évalués sur la base de trois scénarios d'émissions différents (RCP2.6 = avec protection du climat, RCP4.5, RCP8.5 = sans protection du climat). Des scénarios de changement d'utilisation des terres associés à une augmentation ou à une diminution de l'irrigation ont été élaborés et évalués pour estimer les effets combinés du changement climatique et des éventuels changements d'utilisation des terres sur la dynamique des eaux souterraines de la zone étudiée. Les résultats du modèle montrent que des modifications au niveau du rendement ne sont pas seulement dues aux limitations provoquées par la sécheresse, mais aussi à la hausse des températures. A l'exemple du maïs, on a pu montrer qu'utiliser des variétés à maturation plus tardive pour s'adapter à la hausse des températures peut être un choix judicieux pour maintenir, voire augmenter le niveau de rendement. Cependant, une augmentation potentielle du rendement ne peut être réalisée qu'avec l'irrigation. Les résultats de la simulation montrent que les besoins en eau pour l'irrigation sans protection du climat (RCP8.5) pourraient augmenter de 40 % d'ici à la fin du siècle avec une saison de croissance inchangée et jusqu'à 80 % avec l'adaptation des variétés. Avec une protection du climat (RCP2.6), l'augmentation des besoins en eau pour l'irrigation serait limitée à 7 %. L'augmentation de l'irrigation et la diminution saisonnière des taux de recharge de la nappe phréatique due à la diminution des précipitations estivales entraînent une baisse du niveau des eaux souterraines dans la région à la fin de l'été et en automne. Cette situation serait accentuée par une intensification de la pratique de l'irrigation et réduite par une extensification. Les implications des changements calculés dans la dynamique des eaux souterraines sur la dégradation des sols organiques, le transport des polluants, la biodiversité et les coûts d'irrigation doivent être estimées dans des études ultérieures.

36. Dynamiques du stockage en eau souterraine et du régime hydrologique des bassins versants Alpins face aux changements climatiques

Der Klimawandel wird den Wasserhaushalt von alpinen Gebieten besonders stark beeinflussen. Der Temperaturanstieg führt zu einem Rückzug der Gletscher, der Anteil an Niederschlag der als Schnee fällt nimmt ab, und die Schneeschmelze findet früher im Jahr statt. Diese Veränderungen können zu geringeren Abflüssen im Sommer und Herbst führen und möglicherweise zu einem regionalen Wassermangel. Wie sich das Abflussflussverhalten von alpinen Einzugsgebieten ändert hängt wesentlich davon ab, wieviel Schmelzwasser und Niederschlag als Grundwasser zwischengespeichert wird. Bis zu einem gewissen Grad könnte die Speicherung von Wasser im Untergrund die Abnahme von der Speicherung in der Form von Schnee und Eis kompensieren. Allerdings ist bislang vergleichsweise wenig über die hydrogeologische Funktionsweise von alpinen Gebieten bekannt. Das Projekt verfolgte zwei Ziele. Einerseits haben wir den Zusammenhang zwischen geologischen Gebietseigenschaften, Grundwasserspeicherung und dem Abflussverhalten unter aktuellen Bedingungen untersucht. Anderseits haben wir abgeklärt, wie sich der Klimawandel auf die Dynamik im Grundwasser und in Fliessgewässern auswirken könnte mit einem Schwerpunkt auf sommerliche Trockenperioden. Es ging dabei insbesondere um die Frage ob Einzugsgebiete mit grösseren Grundwasserspeichern ein stabileres Abflussverhalten haben. Die Untersuchungen konzentrierten auf kleinere, hochalpine Einzugsgebiete deren Wasserhaushalt durch Schnee dominiert ist und für welche meist mehrjährige Abflussdaten vorhanden sind. Die Untersuchungen zum Einfluss der Geologie zeigten, dass der Niedrigwasserabfluss mit zunehmendem Flächenanteil an Lockergesteinsablagerungen steigt und in geringerem Masse auch durch Festgestein mit einer höheren Durchlässigkeit beeinflusst wird. Ausgedehnte Lockergesteinsablagerungen

fördern wahrscheinlich die Infiltration. Sie können signifikante Mengen an Wasser speichern, und die saisonalen Defizite zum Teil kompensieren. Die saisonale Speicherung von Grundwasser in solchen Ablagerungen wurde durch gravimetrische und Isotopenmessungen im einem Forschungseinzugsgebiet bestätigt. Der Effekt des Klimawandels auf die Grundwasser- und Abflussdynamik haben wir mittels einer Kopplung von klimatischen mit hydro(geo)logischen Modellen untersucht. Für ein Forschungseinzugsgebiet kam ein Modell zur Anwendung, welches Grundwasser- und Oberflächenwasserprozesse gekoppelt simuliert. Für die weiteren Einzugsgebiete wurde ein konzeptuelles hydrologisches Modell verwendet. Die Simulationen zeigten, dass aufgrund der früheren Schneeschmelze Ende Sommer/Anfangs Herbst die Menge an gespeichertem Grundwasser und der Abfluss tendenziell geringer sein wird. Die relative Abnahme in der Grundwassermenge ist aber wesentlich geringer als für den Oberflächenabfluss. In der fernen Zukunft verschiebt sich der minimale Abfluss vom Winter- ins Sommerhalbjahr. Der minimale zukünftige Abfluss im Sommer/Herbst bleibt aber höhere als der aktuelle minimale Abfluss im Winter. Zudem weisen Einzugsgebiete mit ausgedehnten geologischen Formationen mit einem guten Wasserspeichervermögen einen höheren Niedrigwasserabfluss auf. Dies verdeutlicht die ausgleichenden Wirkungen von Grundwasserprozessen. Das Projekt verdeutlicht, dass hydrogeologische Prozesse eine äusserst wichtige Rolle für die Regulierung des Wasserhaushalts in alpinen Einzugsgebieten spielen, insbesondere im Kontext des Klimawandels. Anhand der geologischen Bedingungen lässt ich abschätzen, wie Einzugsgebieten auf eine frühere Schneeschmelze und sommerliche Trockenperioden reagieren könnten. Aktuelle Niedrigwasserabflüsse im Winter liefern zudem wichtige Hinweise ob in einem Einzugsgebiete Grundwasserspeicher vorhanden sind die über eine Zeitskala von mehreren Monaten grössere Mengen an Grundwasser speichern und wieder freisetzten können. Bislang gibt es aber nur wenig Messstellen im alpinen Bereich, um die Dynamik von Grundwasserspeichern direkt beobachten zu können, was zu Unsicherheiten im aktuellen Projekt führte. Weiterhin weisen auch Niederschlagsdaten im alpinen Bereich grosse Unsicherheiten auf. Angesichts der grossen zu erwarteten Veränderungen sollten die Datengrundlage für alpine Gebiete verbessert werden.

Le changement climatique aura un impact particulièrement fort sur le bilan hydrique des régions alpines. L'augmentation de la température entraîne un recul des glaciers, la proportion des précipitations qui tombent en forme de neige diminue, et la fonte des neiges se produit plus tôt dans l'année. Ces changements peuvent entraîner une diminution des débits des cours d'eau en été et en automne et éventuellement des pénuries d'eau régionales. La façon dont le régime hydrologique des bassins versants alpins changent dépend de la quantité d'eau de fonte et de précipitation qui est temporairement stockée sous forme d'eau souterraine. Dans une certaine mesure, le stockage souterrain de l'eau pourrait compenser la diminution du stockage sous forme de neige et de glace. Cependant, on en sait relativement peu à ce jour sur le fonctionnement hydrogéologique des zones alpines. Le projet poursuivait deux objectifs. D'une part, nous avons étudié la relation entre les caractéristiques géologiques des bassins, le stockage des eaux souterraines et l'écoulement de surface dans les conditions actuelles. D'autre part, nous avons étudié comment le changement climatique pourrait affecter la dynamique des eaux souterraines et des cours d'eau, en mettant l'accent sur les périodes d'étiages estivales. En particulier, nous avons cherché à savoir si les bassins versants comportant des réservoirs d'eaux souterraines plus importants vont subir moins de changement de leur régime hydrologique. Les recherches se sont concentrées sur les petits bassins versants des hautes Alpes dont le bilan hydrique est dominé par la neige et pour lesquels on dispose principalement de données pluriannuelles pour les cours d'eau. Les recherches sur l'influence de la géologie ont montré que les débits d'étiages augmentent avec l'augmentation de la surface des sédiments non consolidés et sont également influencés dans une moindre mesure par les roches solides à plus forte perméabilité. De vastes dépôts de roche meuble favorisent probablement l'infiltration. Ils peuvent stocker des quantités importantes d'eau et compenser partiellement les déficits saisonniers. Le stockage saisonnier des eaux souterraines dans de tels formations géologiques a été confirmé par des mesures gravimétriques et isotopiques dans un bassin versant de recherche. Nous avons étudié l'effet du changement climatique sur la dynamique des eaux souterraines et les débits des cours d'eau en couplant les modèles climatiques et les modèles hydro(géo)logiques. Pour un bassin de recherche, un modèle a été utilisé qui simule de manière couplée les processus des eaux souterraines et des eaux de surface. Pour les autres bassins versants, un modèle hydrologique conceptuel a été utilisé. Les simulations ont montré qu'en raison de la fonte des neiges plus précoce, la quantité d'eau souterraine stockée et le les débits des cours d'eaux auront tendance à être plus faibles à la fin de l'été/début de l'automne. Toutefois, la diminution relative du volume des eaux souterraines est bien moindre que pour les débits des cours d'eaux. Dans un avenir lointain, le débit des cours d'eaux minimal se déplacera de l'hiver vers les mois d'été. Toutefois, le débit minimal futur en été/automne reste supérieur au minimum actuel en hiver. En outre, les bassins versants présentant des

formations géologiques étendues avec une bonne capacité de stockage de l'eau présentent un débit minimal plus élevé. Cela illustre les effets d'équilibrage des processus liés aux eaux souterraines. Le projet montre que les processus hydrogéologiques jouent un rôle important dans la régulation du bilan hydrique des bassins versants alpins, en particulier dans le contexte du changement climatique. En fonction des conditions géologiques, il est possible d'estimer comment les bassins versants pourraient réagir à une fonte des neiges plus précoce et à des périodes de sécheresse estivales. Les débits d'étiages actuels en hiver fournissent également des informations importantes sur l'importance réservoirs d'eaux souterraines dans un bassin versant et leur capabilité de stocker et libérer de l'eau sur une échelle de temps de plusieurs mois. À ce jour, cependant, il n'existe que quelques sites de surveillance dans la région alpine où la dynamique des réservoirs d'eaux souterraines peut être observée directement, ce qui a entraîné des incertitudes dans le projet actuel. En outre, les données sur les précipitations dans la région alpine présentent également de grandes incertitudes. Compte tenu des grands changements attendus, la base de données pour les zones alpines devrait être améliorée.

37. Ist-Zustand und Temperatur-Entwicklung Schweizer Lockergesteins-Grundwasservorkommen

Der Klimawandel wird sowohl quantitative als auch qualitative Auswirkungen auf Grundwasservorkommen haben. Diese Auswirkungen unterscheiden sich für Grundwasservorkommen im Fels- und Lockergestein, urban oder ländlich geprägten Standorten sowie den vorherrschenden Prozessen der Grundwasserneubildung. Für ein Verständnis der Entwicklung zukünftiger Grundwassernutzungen und -temperaturen bedarf es einer differenzierten Betrachtung der geologischen Standortbedingungen und relevanten hydrogeologischen Prozesse, einschliesslich der Prozesse der Grundwasserneubildung, „positiver und negativer Rückkoppelungen“ sowie direkter anthropogener Einflüsse. Diese Grundlagen sind wesentlich, um die Reaktion von Grundwasservorkommen auf anthropogene Veränderungen und Einflüsse des Klimawandels zu verstehen. Projektziel des HydroCH2018 Zusatzmoduls „Ist-Zustand und Temperatur-Entwicklung Schweizer LockergesteinsGrundwasservorkommen“ war eine differenzierte Betrachtung der Einflüsse, welche die Grundwassertemperaturen bestimmen. Hierzu sind einerseits Kenntnisse charakteristischer Eigenschaften von Grundwasservorkommen notwendig, einschliesslich räumlicher Dimensionen und Grundwassererneuerungsraten. Anderseits ermöglicht die Ableitung repräsentativer Schlüsselparameter (Aquifergeometrien, Speichereigenschaften, Grundwassererneuerungsraten und -verweilzeiten, etc.) sowie eine Kenntnis der Grundwasserneubildungsprozesse und der Temperaturprägung einen Vergleich aber auch Prognosen über die Sensitivität einzelner Grundwasservorkommen auf den Klimawandel. Ein Vergleich der charakteristischen hydraulischen und thermischen Randbedingungen verschiedener repräsentativer Schweizer Lockergesteins-Grundwasservorkommen im Mittelland, dem Jura und dem Alpenraum ist Grundlage für die Ableitung der Übertragbarkeit auf Schweizer Grundwasservorkommen im Allgemeinen. Eine Auswahl, der im Rahmen von Hydro-CH2018 erarbeiteten Klimaprojektionen (CH2018, 2018), ermöglichte es die Sensitivität von Grundwassertemperaturen in Zusammenhang mit den wesentlichen Grundwasserneubildungsprozessen zu beschreiben. Für nicht-urbane und ländliche Gebiete wird erwartet, dass der Klimawandel insgesamt einen starken Einfluss auf die Grundwassertemperaturen hat. Hingegen dürften in urbanen Gebieten direkte anthropogene Einflüsse weiterhin dominieren (Epting und Huggenberger 2013). So resultiert die vermehrte thermische Nutzung des Untergrundes und die Abwärme von Untergrundstrukturen als auch Anpassungsstrategien in Zusammenhang mit der Klimaerwärmung („positive Rückkopplung“) in erhöhten Grundwassertemperaturen. Messdaten für Basel zeigen, dass Grundwassertemperaturen, allein für den Zeitraum von 1993 bis 2016, im Mittel um 3.0 ± 0.7 K stiegen und in stark urbanisierten Gebieten sogar über 18 °C erreichen können. Bei flachgründigen Grundwasservorkommen mit geringer Mächtigkeit, wie z.B. in Davos, ist damit zu rechnen, dass die Temperaturen des Grundwassers stark beeinflusst werden. Dagegen sind Temperaturveränderungen bei tiefgründigen Grundwasserressourcen, wie z.B. in Biel, oder teilweise grossen Flurabständen, wie z.B. Winterthur, nur stark gedämpft und über lange Beobachtungszeiträume zu erwarten. Auswirkungen auf die Grundwassertemperaturen hängen vor allem mit saisonalen Verschiebungen der Grundwasserneubildung zusammen. So geht eine Verlagerung von Niederschlags- und Hochwasserereignissen vom Sommer in die Wintermonate einher mit einer Zunahme der Grundwasserneubildung in vergleichsweise „kühlen Jahreszeiten“ („negative Rückkopplung“). Wie schon in vorausgehenden Arbeiten (z.B. CH2014-Impacts (2014)) konnte aufgezeigt werden, dass die Interaktion mit Oberflächengewässern und eine verstärkte Grundwasserneubildung während hoher Wasserführung der Fliessgewässer die Temperaturprägung des Grundwassers stark beeinflussen werden. Mit den Resultaten der Forschungsarbeit konnten Grundlagen geschaffen und Wissenslücken im Zusammenhang mit der Variabilität hydraulischer und thermischer Grundwasserregime Schweizer Lockergesteins-Grundwasservorkommen geschlossen werden. Adäquate Monitoring-Konzepte und quantitativer

Analysemethoden (Modellierung, GIS), erlauben es dabei den Spielraum für lokale Anpassungsstrategien, wie z.B. vermehrte Nutzung der „Abfallwärme“ aus urbanen Grundwasserleitern mit gleichzeitig Reduktion erhöhter Grundwassertemperaturen, zielgerichteter und effizienter zu nutzen.

Le changement climatique aura des effets à la fois quantitatifs et qualitatifs sur les ressources en eaux souterraines. Ces effets diffèrent selon le type d’aquifère d’une roche meuble ou dure, dans une zone urbaine ou rurale et selon les processus dominants de recharge des nappes. Afin de comprendre l’évolution des changements futurs de l'utilisation et la et température des eaux souterraines, il nécessite au préalable une étude différenciée des conditions géologiques des sites, des processus hydrogéologiques et des recharges des nappes, des "rétroactions positives et négatives", ainsi que l’influence anthropique directe. Ces bases sont essentielles afin de comprendre la répercussion des ressources des eaux souterraines aux changements anthropiques et aux effets du changement climatique. L’objectif du projet du module complémentaire Hydro-CH2018 "État actuel et évolution de la température des ressources en eau souterraine des roches meubles" était une prise en compte différenciée des influences déterminant la température des eaux souterraines de la roche meuble. Pour ce faire, il nécessite une connaissance des propriétés caractéristiques des ressources en eau souterraine, ainsi que les dimensions spatiales et les taux de renouvellement. D’une autre part, la dérivation des paramètres clés représentatifs (géométrie de l’aquifère, propriétés de stockage, taux de renouvellement des eaux souterraines et temps de rétention, etc.), ainsi que les processus essentiels de la recharge des eaux souterraines et de la formation de la température permettent de comparer, mais aussi de pronostiquer sur la sensibilité des différentes ressources des eaux souterraines du changement climatique. Une comparaison des contraintes hydrauliques et thermiques caractéristiques des diverses aquifères en roche meuble représentatifs du Plateau Suisse, Jura et de la région alpine sert de base afin d’estimer la transférabilité des ressources en eaux souterraines suisses. Pour les zones rurales, le changement climatique dans son ensemble devrait avoir un impact considérable sur la température des eaux souterraines. Concernant les zones urbaines, les influences directes d’origine anthropique continueront de primer (Epting et Huggenberger 2013). L’augmentation de l’utilisation thermique du sous-sol, de la chaleur résiduelle des structures souterraines, ainsi que des stratégies d’adaptation liée au réchauffement climatique (« rétroaction positive ») entraînent une augmentation des températures de la nappe. Durant la période de 1993-2016, des mesures ont été effectuées dans la ville Bâle. Ces derniers montrent que la température des eaux souterraines a augmenté en moyenne de 3,0 ± 0,7 K. En particulier dans les zones de haute densité, la température peut atteindre les 18°C. Dans le cas des eaux souterraines peu profondes et à faible épaisseur, par exemple à Davos, il faut s’attendre à ce que la température soit davantage influencée. Au contraire pour les eaux souterraines profondes, par exemple à Bienne, ou dans certains cas avec des grandes distances par rapport à la surface, par exemple à Winterthur, les changements de température sont atténués et peuvent être observés sur une longue période. Les effets sur les températures des eaux souterraines sont principalement liés aux changements saisonniers de sa recharge. Ainsi, un déplacement des précipitations et des inondations d’été vers les mois d’hiver est accompagné d’une augmentation de la recharge des eaux souterraines en comparaison des "saisons fraîches" ("rétroaction négative"). Comme dans les études précédentes (par ex. CH2014-Impacts (2014)), il a pu être démontré à nouveau, que l’interaction avec les eaux de surface et l’augmentation de la recharge des eaux souterraines lors des périodes de grandes crues influenceront fortement les caractéristiques des nappes. Les résultats des travaux de recherche ont permis d’apporter de nouvelles connaissances sur la variabilité des régimes hydrauliques et thermiques des nappes phréatiques de roche en meuble de la Suisse. Des concepts de surveillance adéquats et des méthodes d'analyse quantitative (modélisation, SIG) permettent une utilisation plus ciblée et plus efficace des possibilités de stratégies d'adaptation locales, par exemple une utilisation accrue de la "chaleur résiduelle" des aquifères urbains résultant une réduction des températures élevées des eaux souterraines.

Übersichtspublikationen / Publications synoptiques

38. Hydrologisches Jahrbuch der Schweiz 2019 / Annuaire hydrologique de la Suisse 2019

Abfluss, Wasserstand und Wasserqualität der Schweizer Gewässer

Das Hydrologische Jahrbuch der Schweiz wird vom Bundesamt für Umwelt (BAFU) herausgegeben und liefert einen Überblick über das hydrologische Geschehen auf nationaler Ebene. Es zeigt die Entwicklung der Wasserstände und Abflussmengen von Seen, Fliessgewässern und Grundwasser auf und enthält

Angaben zu Wassertemperaturen sowie zu physikalischen und chemischen Eigenschaften der wichtigsten Fliessgewässer der Schweiz. Die meisten Daten stammen aus Erhebungen des BAFU.

Débit, niveau et qualité des eaux suisses

Publié par l'Office fédéral de l'environnement (OFEV), l'Annuaire hydrologique de la Suisse donne une vue d'ensemble des événements hydrologiques de l'année au niveau national. Il présente l'évolution des niveaux et des débits des lacs, des cours d'eau et des eaux souterraines. Des informations sur les températures de l'eau ainsi que sur les propriétés physiques et chimiques des principaux cours d'eau du pays y figurent également. La plupart des données proviennent des relevés de l'OFEV.

39. Magazin «die umwelt» 4/2020 - Wird in der Schweiz das Wasser knapp?

Dossier: Warum es im Wasserschloss ungemütlich wird | Wie wir das Wasser ins Trockene bringen | Wie wir das Wasser fair verteilen | Wie sich Wasserengpässe vermeiden lassen | Wie sich Wasser clever nutzen lässt | Warum naturnahe Gewässer fitter sind | Warum es bei den Gletschern nur noch um Schadensbegrenzung geht

360°: Wasser: Wie man Antibiotikaresistenzen das Wasser abgräbt | Wald: Wie es dem Schweizer Wald geht | Gewässerschutz: Weshalb die Gewässer mehr Platz brauchen | Umweltbildung: Wie Schulen den Klimaschutz leben | Lichtemissionen: Wie eine Vollzugshilfe Dunkel ins Licht bringt.

Dossier: Pourquoi le « château d'eau » vacille | Comment gérer les conflitsautour de l'eau | Comment distribuer l'eau équitablement | Comment éviter les pénuries | Comment favoriser une utilisationréfléchie de l'eau | Pourquoi les cours d'eau naturelssont plus résilients | Comment limiter le recul inéluctabledes glaciers

360°: Eaux Éliminer les germes antibiorésistants | Forêts Le point sur l'état des forêts suisses | Protection des eauxL'importance de l'espace réservé aux eaux | Éducation à l'environnementL'engagement des écoles pour le climat | Émissions lumineusesComment retrouver la nuit noire.