“Groundwater, the invisible treasure”

March 22, 2022 | Simone Kral
Topics: Drinking Water

For World Water Day 2022, the United Nations is focusing on our groundwater – an invisible treasure that it wants to bring into the social and political spotlight. For Eawag, groundwater as a resource has long been one of its most important research priorities. An overview.

Groundwater serves as drinking water for around half of the world’s population and provides water for over 40 percent of the world’s agriculture. So, there is no question that groundwater research plays an important role at Eawag. The aquatic research institute deals with groundwater quality, the regeneration of groundwater, geochemical processes in the subsurface and the treatment of groundwater to produce drinking water, both nationally and internationally. In this way, Eawag contributes to understanding the natural and anthropogenic impacts on groundwater, which is essential for the supply of drinking water, but also for the protection of the resource and associated ecosystems such as rivers, lakes and wetlands.

Specialists at work – whether SDGs, machine learning or modelling

For instance, Eawag researchers are developing and refining science-based criteria for the assessment and modelling of water resources. “Our criteria are based on a detailed understanding of physical, chemical, mineralogical and biogeochemical processes, and Eawag excels in researching how they are linked,” explains Michael Berg, Head of the Water Resources and Drinking Water Department. “The studies range from molecular to macroscopic scales, from test tubes to urban water supplies and from river basins to subcontinental regions,” Berg continues.

In recent years, Berg says, Eawag has also pioneered new statistical techniques and the use of machine learning to estimate the risk of natural (geogenic) contamination using geological, topographical and other environmental data, without having to examine all groundwater wells. For this

purpose, corresponding risk maps for safe and unsafe groundwater were drawn up at the regional to global level.

Risk maps and over 500,000 measured groundwater datasets are displayed free of charge on the online Groundwater Assessment Platform (GAP).

In Switzerland and Europe, the research focus is on industrial contaminants, plant treatment products and nitrates. Michael Berg adds: “In less developed regions of the world, naturally occurring pollutants such as arsenic and fluoride play a central role, with approximately 400 million people (5% of the global population) still exposed to chronic poisoning. Other international issues include groundwater salination and the vulnerability of aquifers.”

The Sustainable Development Goals (SDGs) are also guiding research. In connection with Goals 3, 4 and 11, Eawag researchers are investigating and developing methods for treating groundwater , whose quality is not adequate for direct use as drinking water for humans.

Challenges in groundwater research

Among the most urgent challenges in groundwater research are the predictions of climate change and the assessment of the associated consequences. For example, how to improve

water resource management to reduce global groundwater depletion or how to deal with the decline in regeneration of groundwater with a simultaneous increase in groundwater use.

Berg comments: “In addition, we address specific challenges such as groundwater pollution from agricultural activities or the interactions between groundwater and surface water with regard to river restoration and drinking water production close to rivers.” Competition for groundwater resources is also being researched, and the question is being explored of how geothermal energy and CO2 storage projects affect water quality and water supply – both technologies are rapidly gaining ground both internationally and in Switzerland.

World Water Day 2022 – “Our groundwater, the invisible treasure”

World Water Day, which the United Nations (UN) has held since 1992, is an annual reminder of the special nature of water as the most essential resource of all life. The theme of World Water Day 2022 is: “Our groundwater, the invisible treasure”. With this year’s theme, the UN wants to draw attention to the importance of groundwater worldwide and make people aware of it.

Many people are not really conscious of the elementary importance of groundwater as an indispensable resource and as part of the water cycle, as well as the pressures to which it has been exposed by human activities and increasingly by climate change. For this reason, and in view of imminent climate change, the United Nations is once again raising social and political awareness of the importance and value of our precious groundwater.

Cover picture: Climate change and other human influences are not only affecting groundwater in this country.
(Photo: Tom-Kichi, iStock)

Publications on the topic

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sand filter; transformation products; abatement; la
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reactive moieties were spiked to lak
e water in the influent of a drinking water pilot plant consisting of an ozo
nation followed by a biological sand filtration. During ozonation, 227 trans
formation products (OTPs) from 39 of the spiked 51 MPs were detected after
solid phase extraction by liquid chromatography high-resolution mass spectro
metry (LC-HRMS/MS). Based on the MS/MS data, tentative molecular structures
are proposed. Reaction mechanisms for the formation of a large number of OTP
s are suggested by combination of the kinetics of formation and abatement an
d state-of-the-art knowledge on ozone and hydroxyl radical chemistry. OTPs f
orming as primary or higher generation products from the oxidation of MPs co
uld be differentiated. However, some expected products from the reactions of
ozone with activated aromatic compounds and olefins were not detected with
the applied analytical procedure. 187 OTPs were present in the sand filtrati
on in sufficiently high concentrations to elucidate their fate in this treat
ment step. 35 of these OTPs (19%) were abated in the sand filtration step, m
ost likely due to biodegradation. Only 24 (13%) of the OTPs were abated more
efficiently than the parent compounds, with a dependency on the functional
group of the parent MPs and OTPs. Overall, this study provides evidence, tha
t the common assumption that OTPs are easily abated in biological post-treat
ment is not generally valid. Nevertheless, it is unknown how the OTPs, which
escaped detection, would have behaved in the biological post-treatment.' (1592 chars)
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review of threats to groundwater quality in the anthropocene' (62 chars) journal =>
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chars) otherpage => protected'154' (3 chars) categories => protected'water resources;
groundwater quality; anthropogenic activity; contamination;
sustainable; transdisciplinary' (107 chars) description => protected'Awareness
concerning sustainable groundwater consumption under the context o
f land use and climate change is gaining traction, raising the bar for adequ
ate understanding of the complexities of natural and anthropogenic processes
and how they affect groundwater quality. The heterogeneous characteristics
of aquifers have hampered comprehensive source, transport and contaminant id
entification. As questions remain about the behavior and prediction of well-
known groundwater contaminants, new concerns around emerging contaminants ar
e on the increase. This review highlights some of the key contaminants that
originate from anthropogenic activities, organized based on land use categor
ies namely agricultural, urban and industrial. It further highlights the ext
ensive overlap, in terms of both provenance as well as contaminant type, bet
ween the different land use sectors. A selection of case studies from litera
ture that describe the continued concern of established contaminants, as wel
l as new and emerging compounds, are presented to illustrate the many qualit

ative threats to global groundwater resources. In some cases, the risk of gr
oundwater contamination lacks adequate gravity, while in others the underlyi
ng physical and societal processes are not fully understood and activities m
ay commence without adequately considering potential impacts. In the agricul
tural context, the historic and current application of fertilizers and plant
protectants, use of veterinary pharmaceuticals and hormones, strives to saf
eguard the growing food demands. In the context of a sprawling urban environ
ment, waste, human pharmaceuticals, and urban pesticide outputs are increasi
ng, with adequate runoff and sanitation infrastructure often lagging. Finall
y, industrial activities are associated with accidental leaks and spills, wh
ile the large-scale storage of industrial byproducts has led to legacy conta
minants such as those stemming from raw mineral extraction. With this review
paper, we aim to unders...' (2202 chars) serialnumber => protected'0048-9697' (9
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protected'Naturally occurring arsenic in groundwater affects millions of people worldw
ide. We created a global prediction map of groundwater arsenic exceeding 10
micrograms per liter using a random forest machine-learning model based on 1
1 geospatial environmental parameters and more than 50,000 aggregated data p
oints of measured groundwater arsenic concentration. Our global prediction m
ap includes known arsenic-affected areas and previously undocumented areas o
f concern. By combining the global arsenic prediction model with household g
roundwater-usage statistics, we estimate that 94 million to 220 million peop
le are potentially exposed to high arsenic concentrations in groundwater, th
e vast majority (94%) being in Asia. Because groundwater is increasingly use
d to support growing populations and buffer against water scarcity due to ch
anging climate, this work is important to raise awareness, identify areas fo
r safe wells, and help prioritize testing.' (954 chars) serialnumber =>
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protected'Chlorothalonil transformation products in drinking water resources: widespre
ad and challenging to abate' (103 chars) journal => protected'Water Research' (14
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activated ca

rbon' (80 chars) description => protected'Chlorothalonil, a fungicide applied for decades worldwide, has recently been
banned in the European Union (EU) and Switzerland due to its carcinogenicit
y and the presence of potentially toxic transformation products (TPs) in gro
undwater. The spread and concentration range of chlorothalonil TPs in differ
ent drinking water resources was examined (73 groundwater and four surface w
ater samples mainly from Switzerland). The chlorothalonil sulfonic acid TPs
(R471811, R419492, R417888) occurred more frequently and at higher concentra
tions (detected in 65-100% of the samples, ?2200 ngL⁻¹) than th
e phenolic TPs (SYN507900, SYN548580, R611968; detected in 10-30% of the sam
ples, ?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 st
andard in Switzerland and other European countries. Therefore, the abatement
of chlorothalonil TPs was investigated in laboratory and pilot-scale experi
ments and along the treatment train of various water works, comprising aquif
er recharge, UV disinfection, ozonation, advanced oxidation processes (AOPs)
, activated carbon treatment, and reverse osmosis. The phenolic TPs can be a
bated during ozonation (second order rate constant k_{O3} ?10<sup>
4</sup> M⁻¹s⁻¹) and by reaction with hydroxyl radical
s (OH) in AOPs (k_{OH} ?10⁹ M⁻¹s<sup>-1</su
p>). In contrast, the sulfonic acid TPs, which occurred in higher concentrat
ions in drinking water resources, react only very slowly with ozone (k<sub>O
3</sub> <0.04 M⁻¹s⁻¹) and OH (k_{OH} <
5.0 × 10⁷ M⁻¹s⁻¹) and therefore persist
in ozonation and OH-based AOPs. Activated carbon retained the very polar TP
R471811 only up to a specific throughput of 25 m³kg⁻¹
(20% breakthrough), similarly to the X-ray contrast agent diatrizoic acid.
Reverse osmosis was capa...' (2050 chars) serialnumber => protected'0043-1354' (9 chars) doi => protected'10.1016/j.watres.2020.116066' (28 chars) uid => protected21025 (integer) _localizedUid => protected21025 (integer)modified _languageUid => protectedNULL _versionedUid => protected21025 (integer)modified pid => protected124 (integer) 4 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=19902, pid=124) originalId => protected19902 (integer) authors => protected'Popp, A. L.; Manning, C. C.; Brennwald, M. S.;
Kipfer, R.' (92 chars) title => protected'A new in situ method for tracing denitrification in riparian groundwater' (72 chars) journal => protected'Environmental Science and Technology' (36 chars) year => protected2020 (integer) volume => protected554 (integer) issue => protected'' (0 chars) startpage => protected'1562' (4 chars) otherpage => protected'1572' (4 chars) categories => protected'' (0 chars) description => protected'The spatio-temporal dynamics of denitrification in groundwater are still not
well understood due to a lack of efficient methods to quantify this biogeoc
hemical reaction pathway. Previous research used the ratio of N₂
to argon (Ar) to quantify net production of N₂ via denitrificatio
n by separating the biologically-generated N₂ component from the
atmospheric-generated components. However, this method does not allow to qua
ntify the atmospheric components accurately since the differences in gas par
titioning between N₂ and Ar are being neglected. Moreover, conven
tional (noble) gas analysis in water is both expensive and labor-intensive.

We overcome these limitations by using a portable mass spectrometer system, which enables a fast and efficient in situ analysis of dissolved (noble) gas es in groundwater. By analyzing a larger set of (noble) gases (N₂ , He, Ar and Kr) combined with a physically meaningful excess air model, we quantified N₂ originating from denitrification. Consequently, we were able to study the spatio-temporal dynamics of N₂ production due to denitrification in riparian groundwater over a six-month period. Our results show that denitrification is highly variable in space and time, emph asizing the need for spatially and temporally resolved data to accurately ac count for denitrification dynamics in groundwater.' (1418 chars) serialnumber => protected'0013-936X' (9 chars) doi => protected'10.1021/acs.est.9b05393' (23 chars) uid => protected19902 (integer) _localizedUid => protected19902 (integer)modified _languageUid => protectedNULL _versionedUid => protected19902 (integer)modified pid => protected124 (integer) 5 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=20372, pid=124) originalId => protected20372 (integer) authors => protected'Moeck, C.; Grech-Cumbo, N.; Podgorski, J.; Bretzler, A.; Gurdak, J. J.; Berg, M.; Schirmer, M.' (134 chars) title => protected'A global-scale dataset of direct natural groundwater recharge rates: a revie w of variables, processes and relationships' (119 chars) journal => protected'Science of the Total Environment' (32 chars) year => protected2020 (integer) volume => protected717 (integer) issue => protected'' (0 chars) startpage => protected'137042 (19 pp.)' (15 chars) otherpage => protected'' (0 chars) categories => protected'groundwater recharge; groundwater quantity; global-scale dataset; arid regio ns; model validation' (96 chars) description => protected'Groundwater recharge indicates the existence of renewable groundwater resour ces and is therefore an important component in sustainability studies. Howev er, recharge is also one of the least understood, largely because it varies in space and time and is difficult to measure directly. For most studies, on ly a relatively small number of measurements is available, which hampers a c omprehensive understanding of processes driving recharge and the validation of hydrogeological model formulations for small- and large-scale application s.
 We present a new global recharge dataset encompassing >5000 loca tions. In order to gain insights into recharge processes, we provide a syste matic analysis between the dataset and other global-scale datasets, such as climatic or soil-related parameters. Precipitation rates and seasonality in temperature and precipitation were identified as the most important variable s in predicting recharge. The high dependency of recharge on climate indicat es its sensitivity to climate change. We also show that vegetation and soil structure have an explanatory power for recharge. Since these conditions can be highly variable, recharge estimates based only on climatic parameters ma y be misleading.
 The freely available dataset offers diverse possibili ties to study recharge processes from a variety of perspectives. By noting t he existing gaps in understanding, we hope to encourage the community to ini tiate new research into recharge processes and subsequently make recharge da ta available to improve recharge predictions.' (1565 chars) serialnumber => protected'0048-9697' (9 chars) doi => protected'10.1016/j.scitotenv.2020.137042' (31 chars) uid => protected20372 (integer) _localizedUid => protected20372 (integer)modified _languageUid => protectedNULL _versionedUid => protected20372 (integer)modified pid =>

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h a new logistic regression map of these vulnerability index values on the o
nline GAP platform (right). The red colour shows areas with the highest vuln
erability. The green areas are less vulnerable or adequately protected from
surface contamination.' (326 chars) serialnumber => protected'' (0 chars) doi => protected'' (0 chars) uid => protected18761 (integer) _localizedUid => protected18761 (integer)modified _languageUid => protectedNULL _versionedUid => protected18761 (integer)modified pid => protected124 (integer) 7 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=14228, pid=124) originalId => protected14228 (integer) authors => protected'Hering, J. G.; Katsoyiannis, I. A.; Ahumada Theoduloz,&n
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raints in practice' (94 chars) journal => protected'Journal of Environmental Engineering' (36 chars) year => protected2017 (integer) volume => protected143 (integer) issue => protected'5' (1 chars) startpage => protected'03117002 (9 pp.)' (16 chars) otherpage => protected'' (0 chars) categories => protected'' (0 chars) description => protected'Treatment of drinking water for arsenic (As) removal has been implemented in
centralized facilities worldwide, reflecting the increasingly stringent nat
ional and international drinking water standards for As, for which a standar
d of 10 ?g=L has been widely adopted. It might therefore be expect
ed that information on the performance of installed treatment processes coul
d serve as basis for process optimization and more-informed decisions on pro
cess selection. A review of available information on installed treatment doe
s provide some insight into the scale of implementation, factors driving pro
cess selection and difficulties that have arisen in practice (as a complemen
t to more accessible information on bench-scale and pilot-scale studies). Th
e availability of information on treatment performance at full-scale treatme
nt is, however, severely limited. The rapid advances in information technolo
gy and consequent elimination of technical barriers to sharing information a
nd knowledge should allow the development of an international, accessible da
tabase or even a metadata portal for installed technologies for As removal t
hat would offer the potential to benefit from past and ongoing experience in
practice.' (1226 chars) serialnumber => protected'0733-9372' (9 chars) doi => protected'10.1061/(ASCE)EE.1943-7870.0001225' (34 chars) uid => protected14228 (integer) _localizedUid => protected14228 (integer)modified _languageUid => protectedNULL _versionedUid => protected14228 (integer)modified pid => protected124 (integer) 8 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=21198, pid=124) originalId => protected21198 (integer) authors => protected'Hug, S. J.; Winkel, L. H. E.; Voegelin, A.; Be

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n surface water. However, natural (geogenic) hazardous elements can contamin
ate groundwater and lead to severe health problems in consumers. Arsenic con
centrations exceeding the WHO drinking water guideline of 10 ?g/L globally
affect over 220 million people and can cause arsenicosis (skin lesions and c
ancers). Fluoride, while preventing caries at low concentrations, has detrim
ental effects when above the WHO drinking water guideline of 1.5 mg/L and pu
ts several hundred million people at risk of dental and skeletal fluorosis.
In this article, we report on the geochemistry and occurrence of arsenic and
fluoride in groundwater and on the development of global and regional risk
maps that help alert governments and water providers to take appropriate mit
igation measures for the provision of safe drinking water. We then summarize
research on the removal of arsenic and fluoride from drinking water, focusi
ng on adapted technologies for water treatment. Finally, we discuss the appl
icability of various measures in a larger context and future challenges in r
eaching the goal of access to safe drinking water for all.' (1198 chars) serialnumber => protected'0009-4293' (9 chars) doi => protected'10.2533/chimia.2020.524' (23 chars) uid => protected21198 (integer) _localizedUid => protected21198 (integer)modified _languageUid => protectedNULL _versionedUid => protected21198 (integer)modified pid => protected124 (integer) 9 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=22645, pid=124) originalId => protected22645 (integer) authors => protected'Seltzer, A. M.; Ng, J.; Aeschbach, W.; Kipfer, R.;
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um' (78 chars) journal => protected'Nature' (6 chars) year => protected2021 (integer) volume => protected593 (integer) issue => protected'7858' (4 chars) startpage => protected'228' (3 chars) otherpage => protected'232' (3 chars) categories => protected'' (0 chars) description => protected'The magnitude of global cooling during the Last Glacial Maximum (LGM, the co
ldest multimillennial interval of the last glacial period) is an important c
onstraint for evaluating estimates of Earth’s climate sensitivity<sup>1,2<
/sup>. Reliable LGM temperatures come from high-latitude ice cores<sup>3,4</
sup>, but substantial disagreement exists between proxy records in the low l
atitudes^{1,5–8}, where quantitative low-elevation records on land
are scarce. Filling this data gap, noble gases in ancient groundwater recor
d past land surface temperatures through a direct physical relationship that
is rooted in their temperature-dependent solubility in water^{9,10}
. Dissolved noble gases are suitable tracers of LGM temperature because of t
heir complete insensitivity to biological and chemical processes and the ubi
quity of LGM-aged groundwater around the globe^{11,12}. However, alt
hough several individual noble gas studies have found substantial tropical L

GM cooling^{13–16}, they have used different methodologies and pro
vide limited spatial coverage. Here we use noble gases in groundwater to sho
w that the low-altitude, low-to-mid-latitude land surface (45 degrees south
to 35 degrees north) cooled by 5.8 ± 0.6 degrees Celsius (mean ± 95
% confidence interval) during the LGM. Our analysis includes four decades of
groundwater noble gas data from six continents, along with new records from
the tropics, all of which were interpreted using the same physical framewor
k. Our land-based result broadly supports a recent reconstruction based on m
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sitivity than previous estimates^{5–7}.' (1721 chars) serialnumber =>
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protected'Pool, S.; Francés, F.; Garcia-Prats, A.; Puertes, C.; P
ulido-Velazquez, M.; Sanchis-Ibor, C.; Schirmer, M.; Yang,&nb
sp;H.; Jiménez-Martínez, J.' (186 chars) title => protected'Impact of a
transformation from flood to drip irrigation on groundwater rech
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protected'The sustainability of agriculture in the Mediterranean climate is challenged
by high irrigation water demands and nitrogen fertilizer losses to the envi
ronment, causing significant pressure on groundwater resources and groundwat
er-dependent ecosystems. Advanced irrigation technologies and improved ferti
lizer management have been promoted as key solutions to reduce the agricultu
ral impact on aquatic systems. However, it remains unclear how different irr
igation-fertilizer practices perform on the long-term under a highly variabl
e climate, such as the Mediterranean one. Here, we conduct hydrological simu
lations over a fifty-year period to quantify the magnitude and dynamics of g
roundwater recharge and nitrogen leaching under five real-case irrigation-fe
rtilizer practices observed in Valencia (eastern Spain). The Valencian Regio
n is the largest citrus-producing region of Europe and current irrigation-fe
rtilizer practices reflect the ongoing transformation of irrigation systems
from flood to drip irrigation. Our simulations highlight three major implica
tions of the irrigation transformation for groundwater resources. First, the
transformation from flood to drip irrigation reduces the recharge fraction
(19% vs. 16%) and especially the nitrogen leaching fraction (33% vs. 18%) on
the long term. Second, the long-term performance of the two irrigation prac
tices is subject to substantial inter-annual differences controlled by preci
pitation variability. The sensitivity of recharge and nitrogen leaching to a
nnual meteorological conditions is stronger in drip irrigation, which eventu
ally leads to a similar performance of flood and drip irrigation in wet year
s if fertilizer inputs are similar. Third, we identify a pronounced year-to-

year nitrogen memory in the soil, whereby an enhanced (decreased) nitrogen l eaching is observed after anomalously dry (wet) years, affecting the perform ance of irrigation-fertilizer practices. Overall, the study demonstrates the highly variable nature ...' (2208 chars) serialnumber => protected'0048-9697' (9 chars) doi => protected'10.1016/j.scitotenv.2022.153805' (31 chars) uid => protected24474 (integer) _localizedUid => protected24474 (integer)modified _languageUid => protectedNULL _versionedUid => protected24474 (integer)modified pid => protected124 (integer) 11 => Snowflake\Publications\Domain\Model\Publicationprototypepersistent entity (uid=17664, pid=124) originalId => protected17664 (integer) authors => protected'Moeck, C.; Radny, D.; Huggenberger, P.; Affolter, A.; Au ckenthaler, A.; Hollender, J.; Berg, M.; Schirmer, M.' (149 chars) title => protected'Verteilung anthropogen eingetragener Stoffe im Grundwasser: ein Fallbeispiel aus der Nordschweiz' (96 chars) journal => protected'Grundwasser' (11 chars) year => protected2018 (integer) volume => protected23 (integer) issue => protected'4' (1 chars) startpage => protected'297' (3 chars) otherpage => protected'309' (3 chars) categories => protected'stable water isotopes; organic micropollutants; chlorinated solvents; artifi cial groundwater recharge; urban hydrogeology; Switzerland' (134 chars) description => protected'Im Wassergewinnungsgebiet Hardwald werden rund 15 Mio. m<small>^{3</s up></small>/a Trinkwasser produziert. Es finden sich jedoch Spuren von chlor ierten organischen Verbindungen im Grundwasser. Als Fallstudie werden hier d ie Ergebnisse von Feld- und Laborarbeiten zur Bestimmung der räumlichen Ver teilung der chlorierten organischen Verbindungen, der stabilen Wasserisotope (?<small>¹⁸</small>O und ?<small>²</small>D), der H auptkationen- und -anionen und ausgewählter Spurenstoffe, welche über ein Rheininfiltrat eingetragen werden, vorgestellt. Als Ergebnis der Untersuchun gen zeigte sich, dass die künstliche Rheinwasserinfiltration ganz entscheid end zur Trinkwassersicherheit beiträgt und das entnommene Grundwasser vorwi egend der chemischen Signatur des infiltrierten Rheinwassers entspricht. Jed och zeigt sich auch, dass durch die über die Fläche ungleichmäßig vertei lte Infiltration vor allem eine Beimischung von Muschelkalkwasser in süd-we stlichen Bereichen des Untersuchungsgebiets wahrscheinlich ist. Diese Interp retation wird durch die Verteilung der chlorierten organischen Verbindungen, Hauptkationen- und -anionen, stabilen Wasserisotopen und Spurenstoffen gest ützt. Trotz der hier vorhandenen komplexen Randbedingungen wird durch das Z usammenspiel von künstlicher Infiltration und Entnahme eine sichere Trinkwa sserversorgung ermöglicht.

 At the Hardwald study site, Switzerlan d, 15 million cubic metres per year of drinking water is being pumped. Chlor inated compounds, however, have been detected in the groundwater. We present results from field sampling and lab analyses to determine the spatial distr ibution of chlorinated organic compounds, stable water isotopes (?<small><s up>18}</small>O und ?<small>²</small>D), major ions as well as selected micropollutants, which enter the groundwater by artificial rech arge. We demonstrate that artificial groundwater recharge is essential for w ater security and that t...' (2549 chars) serialnumber => protected'1430-483X' (9 chars) doi => protected'10.1007/s00767-018-0403-6' (25 chars) uid => protected17664 (integer) _localizedUid => protected17664 (integer)modified _languageUid => protectedNULL _versionedUid => protected17664 (integer)modified pid => protected124 (integer) Gulde, R.;

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