3.1 Description of the Austrian database of environmental isotopes and noble gases of deep groundwater, Austria

Title of Case Study	Database of environmental isotopes and noble gases in Austria's deep groundwaters
Location (region, Country)	Austria
Other information	

Description of Case Study (background information on the region)
In Austria, in the foreland basin and the intermountain basins of the Alps occur productive deep groundwaters (in the "Pilot info template" named "aquifer 1") and even thermal groundwaters ("aquifer 2") of great importance for water management. For instance, an important transboundary thermal groundwater body is situated between Regensburg in Bavaria and Linz in Upper Austria with a length of more than 120 km and a breadth of around 40 km. It is used for spas and district heating. In addition, the thermal springs and deep thermal aquifers of the Vienna and the Styrian basin – the two most important intermountain basins in Austria – also build the basis for several spas and thermal uses. The aquifers of these thermal water occurrences ("aquifer 2") are karstified Mesozoic or Palaeozoic carbonates as well as Cretaceous sandstones and Paleogene and Neogene sands. The foreland basins and the intermountain basins contain also potable deep groundwaters, which are in use for drinking water production ("aquifer 1"). The most important occurrences can be found in Upper Austria, Styria, and Burgenland, but even in Vienna there exist several deep wells that are in use. Layers or channels of sands and gravels within low permeable pelites mostly build the aquifers of these deep groundwaters. Not only in the basins, but also in the mountains thermal waters are present (in the "Pilot info template" named "aquifer 3"). Their recharge areas are situated in higher mountains and the hot springs discharge in valleys – for instance in Bad Kleinkircheim and Bad Gastein. In Bad Kleinkirchheim the aquifer is formed by karstified marbles, in Bad Gastein by fissured orthogneisses. Some of the deep groundwaters are not only used for water supply, spas or district heating, but also for other medical use – and as natural mineral water. Isotope and noble gas hydrology is important to understand the genesis and processes in groundwater – especially in such deep groundwater systems as they are given in Austria's foreland basin and deeper intermountain basins. On the one hand, there occurs an exchange between the very deep, but relatively sweet supra regional thermal water systems and the regional and sweet, but moderate deep groundwater circulations. In addition, there happens also mixing of these groundwater systems with more stagnant, highly mineralized formation waters. Isotope hydrology and noble gases plays an important role in the research of such complex groundwater systems, which are – in the case of the foreland basin and the Vienna basin – even in contact with hydrocarbon deposits. Until now there exist only few studies on the noble gases in such basins (*Byrne, D. J., Barry, P. H., Lawson, M. & Ballentine, C. J., 2017, Noble gases in conventional and unconventional petroleum systems, Special Publications, 468, 127-149, Geological Society, London https://doi.org/10.1144/SP468.5*). The aim of the Austrian database, which has been compiled in the frame of WP6, is to provide isotope and noble gas data on the Austrian deep groundwaters – basing one existing surveys

over the whole country – as basis for further investigations. The database will be exported into the hydrogeological core database of the Austrian Geological Survey in order to the provide data for further research (see below).

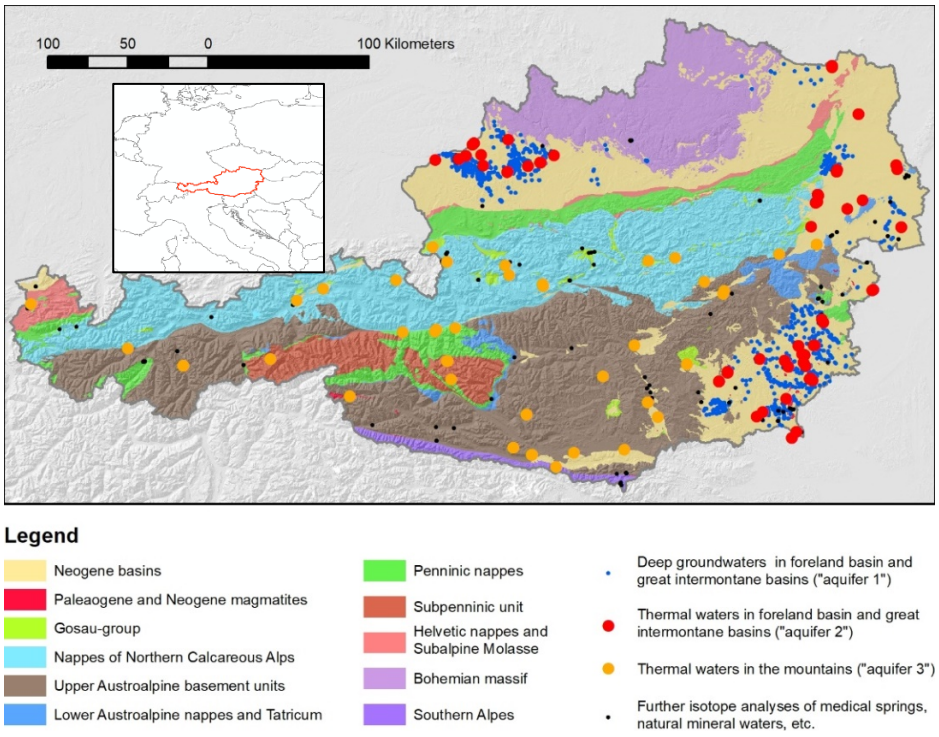
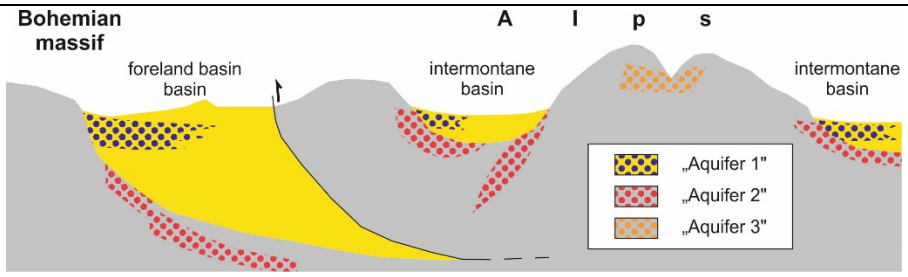
Description of problem (why is this location chosen for a Cases Study)
In Austria, deep groundwaters are common in the Alpine foreland basin and the bigger intermontane basins. Isotopes and nobel gases deliver important information on the deep groundwater systems in these regions. In Austria there already exists a public online service concerning isotopes in precipitation and groundwater (*https://secure.umweltbundesamt.at/webgis-portal/isotopen/map.xhtml*), but this database concerns mostly shallow groundwaters and data of deep groundwaters are rare. The actual database should close this gap.

Methods to be used in the Case Study (analytical and isotope techniques, modelling)
Within the last years in Austria there were made three surveys on deep and thermal groundwaters across the country. The results were published in monographies by the Geological Survey: *https://www.bmlrt.gv.at/wasser/wasserqualitaet/trinkbare_tiefen_gw.html (Schubert 2015)* *https://www.bmlrt.gv.at/wasser/wasserqualitaet/thermalwaesser.html (Elster et al. 2016)* *https://www.bmlrt.gv.at/wasser/wasserqualitaet/grundwasser/mineral_heilwaesser.html (Elster et al. 2018)* In the frame of WP6 the data of these publications have been compiled in a database which will be integrated into the hydrogeological core database of the Geological Survey in order to provide this data for further investigations. In the future also data of further projects will be maintained in this database.

Results from this Case Study
In the moment, the database contains analyses of the following parameters: deuterium, tritium, carbon-13, carbon-14, oxygen-18, sulphur-34, krypton-85, krypton-81, radon-222 and radium-226. The process of maintaining new data in the database is still going on.

Impact - how this Case Study contributes to the overall project aims
The database will give an overview on the isotope and noble gas data of Austria's deep groundwaters.

<table>
<tr><td>Name of pilot area / aquifers / type:
Austria / basement, Palaeozoic and Mesozoic carbonates and sandstones, Paleogene and Neogene sediments /porous and fissured</td><td colspan="2">Country: Austria

Region: foreland basin and intermountain basin, Alps</td></tr>
<tr><td>Study level</td><td colspan="2">Transboundary : ☐ Regional: x Local: ☐ Single well(s): ☐</td></tr>
<tr><td>Type of observations
(choose one of the options, create separate template if needed for each type if each type need specific information)</td><td colspan="2">☐ Short screened observation wells (not pumped)
☐ Long screened observation wells (not pumped)
x Pumped wells, long screens in one aquifer
☐ Pumped wells, long screens over multiple aquifers
x Springs
x Other (eg. research wells; indicate type and information on pumping): artesian wells</td></tr>
<tr><td>Approximate location of pilot:</td><td colspan="2"> 
</td></tr>
<tr><td>Geological cross section / conceptual model of the pilot area:</td><td colspan="2"> 
</td></tr>
</table>

Name of Shape- / Geopackage file defining the area:		**Projection to be used:** WGS84 (Epsg4326)		
Hydrological parameters:	**Mean annual precipitation (mm or range in mm)**	**Mean annual groundwater recharge (mm or range in mm)**	**Mean annual groundwater recharge temperature (°C)**	**Thickness of unsaturated zone (range in m)**
	400–3800, in average 1100 (*BMLRT 2007*)		0–11, in average 6 (*BMLRT 2007*)	0–1000 (in the karst of the Northern Calcareous Alps groundwater table can be very deep)
Pumped wells only		**Typical pump discharge of sampled individual well (m^3/day):** 864–6912 (artesian overflow 2–691)		**Typical pump discharge of complete well field (m^3/day):** *If relevant*
List of aquifers and aquitards in pilot area		**No. of confined or semiconfined aquifers in pilot area:** 2		**No. of unconfined aquifers in pilot area:** 1
Aquifer no. (aqf): 3 **Aquitard no. (aqt):** 2 **Aquiclude no. (aqc):** 1	**Aquifer/aquitard type and/or name**	**Lithology *(Resource WP6 terminology)***	**Depth range (m)**	**GW age range (yr)**
Aqf-1:	Paleogene and Neogene sands confined by pelite aquitards	fine sand to gravel	10–500	60–> 10,000
Porosity type	Porous: X	Fissured: ☐	Karst: ☐	Fissured and porous / dual porosity: ☐
Aqt-1:	Paleogene and Neogene marine and limnic-fluvial pelites	clay-silt, marl		
Porosity type	Porous: ☐	Fissured: ☐	Fissured and porous / dual porosity: ☐	No hydraulically active porosity: X
Aqf-2:	Jurassic carbonates, Cretaceous sandstones, Paleogene sands	dolomite, limestone, sandstone	0–> 6000	> 10,000–565,000
Porosity type	Porous: X	Fissured: X	Karst: X	Fissured and porous / dual porosity: X

Aqt-2:	Palaeozoic and Mesozoic shales, Paleogene and Neogene pelites	shales, clay-silt, marl		
Porosity type	Porous: ☐	Fissured: ☐	Fissured and porous / dual porosity: ☐	No hydraulically active porosity: X
Aqf-3:	Crystalline basement in mountain regions	marl, orthogneiss	0–2000	0–> 60
Porosity type	Porous: ☐	Fissured: X	Karst: X	Fissured and porous / dual porosity: ☐
Aqc-3:	Crystalline basement in mountain regions	phyllites, mica schists, phyllonites		
Porosity type	Porous: ☐	Fissured: X	Fissured and porous / dual porosity: ☐	No hydraulically active porosity: X

Applied tracer age indicators (^{3}H, ^{3}H/^{3}He, ^{85}Kr, ^{39}Ar, ^{14}C, ^{36}Cl, ^{81}Kr, ^{4}He, CFCs, SF_6, etc.) **Applied recharge temperature indicators** (^{18}O, D, noble gases)	**Aquifer-1** ^{3}H, ^{14}C, ^{4}He, ^{18}O, D, noble gases
	Aquifer-2 ^{3}H, ^{85}Kr, ^{14}C, ^{81}Kr, ^{4}He, ^{18}O, D, noble gases
	Aquifer-3 ^{3}H, ^{14}C, ^{18}O, D
Number of sites (wells/springs) with age indicators	**Aquifer-1** **1-5:** ☐ **5-10:** ☐ **10-25:** ☐ **>25:** X
	Aquifer-2 **1-5:** ☐ **5-10:** ☐ **10-25:** ☐ **>25:** X
	Aquifer-3 **1-5:** ☐ **5-10:** ☐ **10-25:** ☐ **>25:** X
GW age range (GAR) **GAR-1: Modern (< 60 yr)** **GAR-2: Old (> 60 yr and 10 kyr)** **GAR-3: Paleowaters (> 10 kyr)**	**Aquifer-1** **GAR-1: 1-10%:** ☐ **10-25%:** X **25-50%:** ☐ **>50%:** ☐ **GAR-2: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** X **>50%:** ☐ **GAR-3: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** X **>50%:** ☐
	Aquifer-2 **GAR-1: 1-10%:** X **10-25%:** ☐ **25-50%:** ☐ **>50%:** ☐ **GAR-2: 1-10%:** X **10-25%:** ☐ **25-50%:** ☐ **>50%:** ☐ **GAR-3: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** ☐ **>50%:** X
	Aquifer-3 **GAR-1: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** X **>50%:** ☐ **GAR-2: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** X **>50%:** ☐ **GAR-3: 1-10%:** ☐ **10-25%:** ☐ **25-50%:** ☐ **>50%:** ☐
Groundwater age ranges (GAR) estimated by:	**Tracer based estimates** X **Flow and age model simulations** ☐ **Combination of model and tracer estimates** ☐

<table>
<tr><td colspan="3"></td><td colspan="3">Expert judgement: X</td></tr>
<tr><td colspan="6">Objective of age dating studies:</td></tr>
<tr><td>Basic research or General groundwater management</td><td colspan="2">Assessment of pollutant history</td><td colspan="2">Assessment of the efficiency of remediation and mitigation measures</td><td>Indication of vulnerability of aquifers and water supply wells</td></tr>
<tr><td>X</td><td colspan="2"></td><td colspan="2"></td><td>X</td></tr>
<tr><td rowspan="2">Water Usage
(not relevant for observation wells)</td><td colspan="2">Water supply</td><td>Irrigation</td><td>Industry</td><td>Other</td></tr>
<tr><td colspan="2">X</td><td></td><td>X</td><td>spas, medical use, natural mineral water, district heating</td></tr>
<tr><td rowspan="2">Geoenergy related activities
(not relevant for observation wells)</td><td>Shallow Geo-T</td><td>Deep Geo-T</td><td colspan="2">Hydrocarbons</td><td>Nuclear waste disp.</td><td>CO_2 storage</td></tr>
<tr><td>X</td><td>X</td><td colspan="2">X</td><td></td><td></td></tr>
<tr><td rowspan="2">Mining activities
(not relevant for observation wells)</td><td colspan="2">Construction materials</td><td>Minerals / metals</td><td>Coal</td><td colspan="2">Other</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="6">REFERENCES
Elster, D., Goldbrunner, J., Wessely, G., Niederbacher, P., Schubert, G., Berka, R., Philippitsch, R. & Hörhan, T., 2016, Erläuterungen zur geologischen Themenkarte Thermalwässer in Österreich 1:500.000, 296 p., Geological Survey of Austria, Vienna, ISBN: 978-3-85316-086-2
Elster, D., Fischer, L., Hann, S., Goldbrunner, J., Schubert, G., Berka, R., Hobiger, G., Legerer, P. & Philippitsch, R., 2018, Österreichs Mineral- und Heilwässer, 448 p., Geological Survey of Austria, Vienna, ISBN: 978-3-85316-097-8
Schubert, G. (Ed.), Trinkbare Tiefengrundwässer in Österreich, Abhandlungen der Geologischen Bundesanstalt, 64, 179 p., Geological Survey of Austria, Vienna, ISSN 0378-0864, ISBN 978-3-85316-085-5
Heidinger, M., Eichinger, F., Purtschert, R., Mueller, P., Wirsing, G., Geyer, T., Fritzer, T., Groß, D., 2019, Altersbestimmung an thermalen Tiefenwässern im Oberjura des Molassebeckens mittels Krypton-Isotopen, 81Kr/85Kr-Dating of thermal groundwaters in the Upper Jurassic (Molasse Basin), Grundwasser, 24, 287-294 p., Springer, doi.org/10.1007/s00767-019-00431-0
BMLRT (Ed.), 2007, Hydrologischer Atlas Österreichs, Österreichischer Kunst- und Kulturverlag, ISBN 3-85437-250-7
</td></tr>
<tr><td colspan="3">OPEN Access reports and papers (PDF versions made available in EGDI repository making them downloadable via maps and keyword / free text searches):
https://www.bmnt.gv.at/wasser/wasserqualitaet/thermalwaesser.html
https://www.bmnt.gv.at/wasser/wasserqualitaet/grundwasser/mineral_heilwaesser.html
https://www.bmnt.gv.at/wasser/wasserqualitaet/trinkbare_tiefen_gw.html</td><td colspan="3">Reports and papers with restricted access:</td></tr>
<tr><td colspan="6">Remarks / other relevant information:</td></tr>
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