

3.9 Description of the Eastern Jutland and Funen area, water supply wells case study, Denmark

Title of Case Study	Travel time distributions in 30 long-screened water supply wells
Location (region, Country)	Eastern Jutland and Funen, Denmark
Other information	Mainly long-screened water supply wells of the three major Danish water supply companies TREFOR, VCS Denmark and Aarhus Vand were investigated in order to assess the age and travel time distributions in the wells and their vulnerability towards pollution from the surface. Many of the investigated wells are contaminated with pesticides or their degradation products.

Description of Case Study (background information on the region)
Pilot study in collaboration with three major Danish water companies responsible for water supply to the second and third largest cities in Denmark, Aarhus and Odense, respectively, and an important urbanized region of Eastern Jutland. About 30 wells were sampled and analysed for a wide range of dating tracers in order to investigate the age and vulnerability of the wells towards pollution. The screens of the wells are between 3 and 40 meters long, but most are between 10 and 15 meters and installed at depths between 20 and 150 m below surface. The pilot study is made possible through funding from Innovation Fund Denmark (IFD) supporting the Danish part of all the GeoERA groundwater projects, Minerals4EU and the information platform project (GIP) of the GeoERA programme. IFD funds about half of the tracer analyses, while the other half is funded by the involved water companies. The well selection and sampling were done in collaboration with the water companies, the environmental radionuclides research group at the Physics Institute of University of Bern, and the "Helis – Helium isotope studies Bremen" laboratory at university of Bremen and TNO. The dating tracers $^3\text{H}/^3\text{He}$ were analysed by the Helis laboratory at University of Bremen, the ^{39}Ar and ^{85}Kr tracers were analysed by University of Bern. A few wells were selected for the analysis of veterinary antibiotics found in some Dutch aquifers in collaboration with TNO.

Description of problem (why is this location chosen for a Case Study)
The wells were selected in well fields experiencing impacts of pesticide pollution to improve the understanding of travel times from potential pollutant source areas at the surface and the vulnerability of the wells and well fields towards pollution from the surface. Observed pollutants in the investigated wells include pesticides and their degradation products e.g. Disphenyl Chloridazon (DPC), Dimethylsulfide (DMS), 4-Chlorophenoxy-propionic acid (4-CPP), a degradation product of dichlorprop (DPCC), mechlorprop, dichlorobenzamide. Most of the observed pesticides have either been completely banned or regulated.

Methods used or to be used in the Case Study (analytical and isotope techniques, modelling)
The case study include the application of the groundwater age indicators ^{85}Kr, ^{39}Ar, $^3\text{H}/^3\text{He}$, ^4He, ^{14}C, $\delta^{13}\text{C}$, CFCs and SF_6 the lumped parameter modelling tool "TracerLPM" (https://www.usgs.gov/software/tracerlpm, Jurgens et al. 2012) and particle tracking by



groundwater models. ^{85}Kr and ^{39}Ar sampling and analyses were conducted by the research group on environmental radionuclides at Climate and Environmental Physics, University of Bern (https://www.climate.unibe.ch/research/research_groups/environmental_radionuclides/index_eng.html), - $3\text{H}/3\text{He}$ and ^4He were analysed by the Helis laboratory at University of Bremen <https://www.noblegas.uni-bremen.de/eng/>.

Results from this Case Study

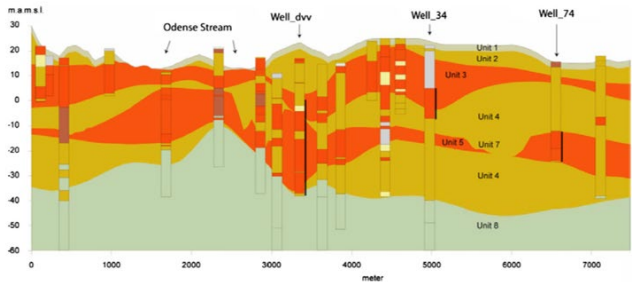
The Study is on-going, and some analyses have been delayed due to the Covid-19 pandemic, which temporarily closed the laboratories. This delays the deliverables of HOVER WP6 and many other activities in the GeoERA program. Preliminary results were presented at the virtual General Assembly of the European Geosciences Union (EGU2020) in April (Hinsby et al., 2020). The EGU abstract and a pdf of the presentation will be uploaded to the document repository of the GeoERA information platform (EGDI, the European Geological Data Infrastructure).

Impact - how this Case Study contributes to the overall project aims

The case study investigate the vulnerability, groundwater age and travel time distributions of a long-screened water supply wells of the major Danish water companies by new tracer techniques and hence it contributes to the objectives of WP6 task 6.4 on groundwater age and travel time distributions of long-screened wells, as well as related studies in HOVER WP5 and 7 on travel times for nitrate and pesticides and the vulnerability of aquifers towards pollution from the surface, respectively.

We hope that the studies will inspire to other similar studies and make the application of the dating tracers for vulnerability assessments of water supply wells and the history and fate of contaminants in these (Jakobsen et al., 2020) much more common. Information on groundwater ages and travel times to water supply wells in well fields will enable much better management and protection of the well fields e.g. by optimizing groundwater abstraction from the different wells and better regulation on the use of pesticides etc.

The cited references and access information are listed at the end of the following information template.

Name of pilot area / aquifers / type: Eastern Jutland and Funen – complex Pleistocene confined, semi-confined and unconfined aquifer systems		Country: Denmark Region: Eastern Jutland and Funen	
Study level	Transboundary : ☐ Regional: ☐ Local: ☐ Single well(s): X		
Type of observations <i>(choose one of the options, create separate template if needed for each type if each type need specific information)</i>	X Short screened observation wells (not pumped) ☐ Long screened observation wells (not pumped) X Pumped wells, long screens in one aquifer X Pumped wells, long screens over multiple aquifers ☐ Springs ☐ Other (eg. research wells; indicate type and information on pumping):		
Approximate location of pilot:			
Geological cross section / conceptual model of the pilot area:	The example below shows a cross section of the complex aquifer systems, which are typical for the case study area. The shown example is from the Odense region in the lower right corner of the blue rectangle on the map above. Simplified model KML1 KML2 KS1 Clay tills Aquifers 		
Name of Shape- / Geopackage file defining the area:  HoverDKPilotsSub.shp		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)
	750 - 1000	150 - 500	9	1 - 50
Pumped wells only		Typical pump discharge of sampled individual well (m ³ /day): 50 – 100 m ³	Typical pump discharge of complete well field (m ³ /day): <i>If relevant</i>	
List of aquifers and aquitards in pilot area		No. of confined or semiconfined aquifers in pilot areas: 2-3	No. of unconfined aquifers in pilot areas: 0-1	
Aquifer no. (aqf): 2 Aquitard no. (aqt): 3 Aquiclude no. (aqc):	Aquifer/aquitard type and/or name	Lithology (<i>Resource WP6 terminology</i>)	Depth range (m)	GW age range (yr)
Aqf-1:	Pleistocene sands locally confined by clay/silt	Fine to medium sand and gravel	Varying (0 – ~60)	Not yet estimated
Porosity type	Porous: X	Fissured: ☐	Karst: ☐	Fissured and porous / dual porosity: ☐
Aqt-1:	Clay tills			
Porosity type	Porous: X	Fissured: ☐	Fissured and porous / dual porosity: ☐	No hydraulically active porosity: ☐
Aqf-2:	Pleistocene sands	Fine to medium sand and gravel	Varying (40 - ~150)	Not yet estimated
Porosity type	Porous: X	Fissured: ☐	Karst: ☐	Fissured and porous / dual porosity: ☐
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/ ³ He, ⁴ He, ³⁹ Ar, ⁸⁵ Kr, ¹⁴ C, (CFCs and SF ₆ – only on Funen)		
		Aquifer-2 ³ H/ ³ He, ⁴ He, ³⁹ Ar, ⁸⁵ Kr, ¹⁴ C, (CFCs and SF ₆ – only on Funen)		
Number of sites (wells/springs) with age indicators		Aquifer-1 1-5: ☐ 5-10: ☐ 10-25: X >25: ☐		
		Aquifer-2 1-5: ☐ 5-10: ☐ 10-25: X >25: ☐		
GW age range (GAR)		Aquifer-1 – (preliminary assessment) GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: X		



GAR-1: Modern (< 60 yr) GAR-2: Old (> 60 yr and <10 kyr) GAR-3: Paleowaters (> 10 kyr)	GAR-2: 1-10%: ☐ 10-25%: ☐ 25-50%: X >50%: ☐ GAR-3: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: ☐			
	Aquifer-2 – (preliminary assessment) GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: X >50%: ☐ GAR-2: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: X 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 (X) Expert judgement: ☐			
Objective of age dating studies:				
Basic research or General groundwater management	Assessment of pollutant history		Assessment of the efficiency of remediation and mitigation measures	
X	X		X	
Water Usage <i>(not relevant for observation wells)</i>	Water supply		Irrigation	Industry
	X			
Geoenergy related activities <i>(not relevant for observation wells)</i>	Shallow Geo-T	Deep Geo-T	Hydrocarbons	
Mining activities <i>(not relevant for observation wells)</i>	Construction materials		Minerals / metals	Coal
Other				
Other				
REFERENCES				
OPEN Access reports and papers (PDF versions made available in EGD repository making them downloadable via maps and keyword / free text searches): Presentation of preliminary results at EGU2020 by: Hinsby, K., Purtschert, R., Musy, S., Sültenfuss, J., Wachs, D., Aeschbach-Hertig, W., Kidmose, J., Trolborg, L. and Guldbrandsen. 2020. Use of multiple tracers and groundwater flow modelling for the estimation of groundwater travel times to water supply wells, vulnerability assessments and improved management of well fields. https://doi.org/10.5194/egusphere-egu2020-20340		Reports and papers with restricted access: The investigations conducted in this study are expected to provide results similar to what was presented in the study below, which is also described in the Loekken – NJutland information tables of the previous study Jakobsen, Rasmus, Klaus Hinsby, Jens Aamand, Peter van der Keur, Jacob Kidmose, Roland Purtschert, Bryant Jurgens, Jürgen Sültenfuss, and Christian N. Albers. 2020. "History and Sources of Co-Occurring Pesticides in an Abstraction Well Unraveled by Age Distributions of Depth-Specific Groundwater Samples." Environmental Science & Technology. https://doi.org/10.1021/acs.est.9b03996 .		



Jurgens, B. C.; Bohlke, J. K.; Eberts, S. M. TracerLPM (Version 1): An Excel Workbook for Interpreting Groundwater Age Distributions from Environmental Tracer Data. U.S. Geological Survey Techniques and Methods Report, 4-F3, 60; 2012.
<https://pubs.er.usgs.gov/publication/tm4F3>
<https://doi.org/10.3133/tm4F3>

The TracerLPM Workbook described in the report above will be used for simulation of tracer and groundwater age distributions in the investigated water supply wells

Remarks / other relevant information:

The investigations conducted in this study are expected to provide results similar to what was presented in the study by Jakobsen et al. above, which is also described in the Loekken – NJutland information tables of the previous pilot study. However, the studies conducted in the pilot area presented here collected only one mixed sample per well except for one well, which had three samples taken (top, bottom and mixed). The study is on-going and part of WP6 task 6.4 on new techniques for the investigation of groundwater age distributions in long-screened wells with groundwater ages in the range of 10 – 1000 years. The majority of the 30 wells investigated in this study is a mixture of young contaminated or potentially contaminated groundwater and old and pristine groundwater. A research paper is expected to be submitted at the end of GeoERA illustrating the mixing ratios etc. The information template will be updated as soon as all tracer results and simulations are ready and the paper has been published.