3.8 Description of the Northern Jutland – Loekken – case study, Denmark

Title of Case Study	Loekken water supply well
Location (region, Country)	Loekken, Northern Jutland, Denmark
Other information	Water supply well located close to and between a golf course and corn fields applying pesticides regulated in 1995, which are still found in the well

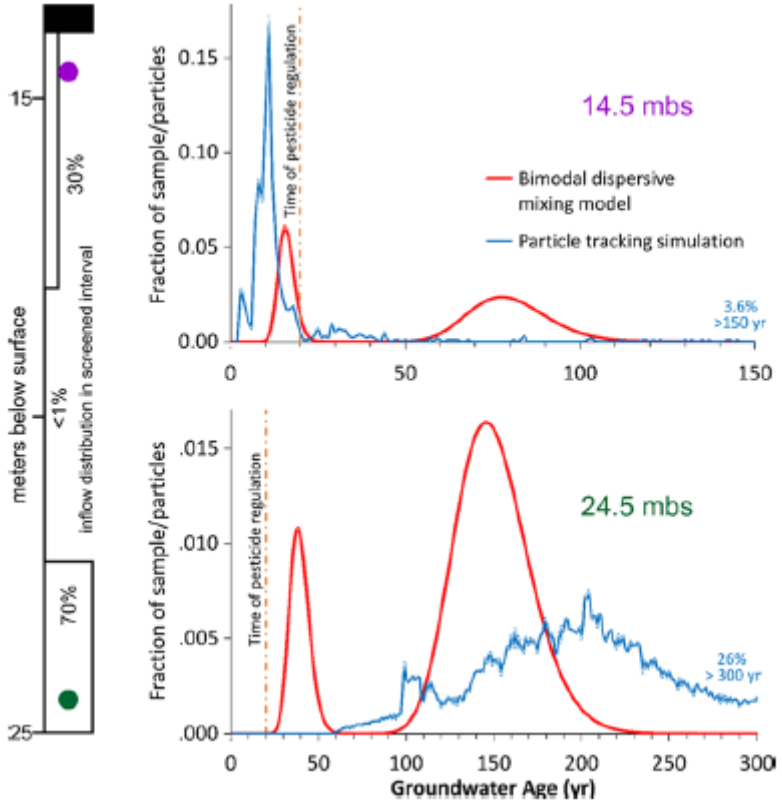
Description of Case Study (background information on the region)
Pilot study in a 25 m deep water supply well with a 12 m screen, 13-25 m below surface, in a Holocene marine and aeolian sand aquifer used for water supply. The well is in a holiday area with significant seasonal variation in abstractions. The project was conducted by GEUS for the Danish Environmental Protection Agency (Jakobsen et al., 2020) to investigate the history and fate of pesticides observed in the well. The water supply well was sampled at different specific levels (top, center and bottom of the screen) by separation pumping (Nilsson et al., 1995) to identify, which parts of the aquifer were contaminated by the pesticides. The samples were collected in collaboration with the environmental radionuclides research group at the Physics Institute of University of Bern, and the "Helis – Helium isotope studies Bremen" lab. At university of Bremen. The dating tracers $^{3}H/^{3}He$ were analysed by the Helis laboratory at University of Bremen, the ^{39}Ar and ^{85}Kr tracers were analysed by University of Bern. The tracer and age distribution at different levels in the water supply well were then simulated by a lumped parameter model (TracerLPM) developed by the USGS (Jurgens et al., 2012) and particle tracking.

Description of problem (why is this location chosen for a Case Study)
The two pesticides, bentazon and dichlorprop, have been found at the top and bottom of the 25 m deep water supply well, respectively. The pesticides are still found in the well although they were regulated in 1995, and the Danish EPA wanted to understand, why they are still found in the well.

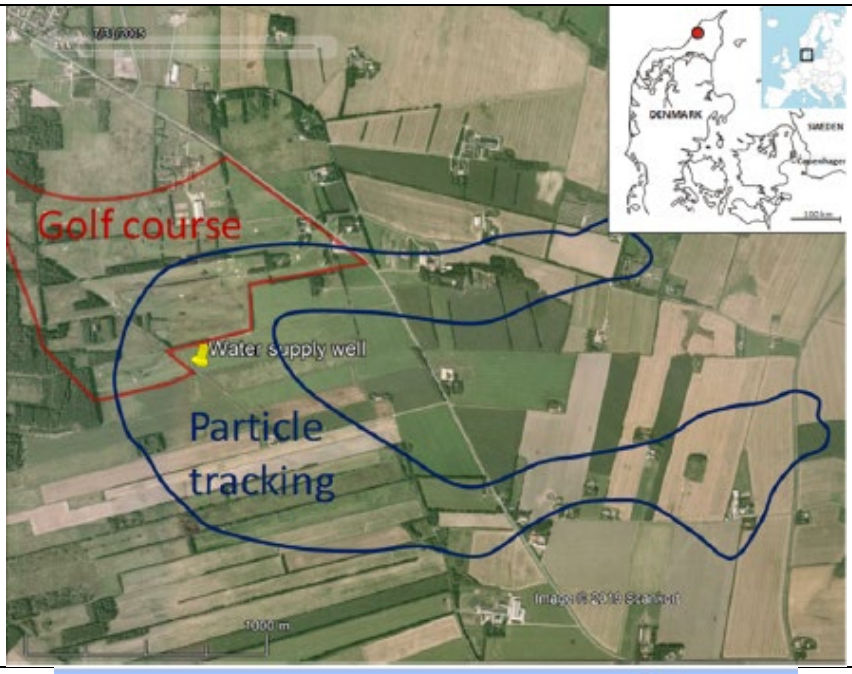
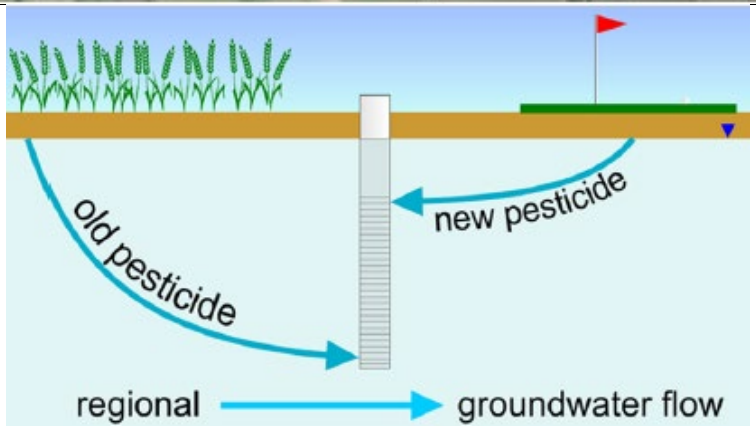
Methods used in the Case Study (analytical and isotope techniques, modelling)
The case study include the application of the groundwater age indicators ^{85}Kr, ^{39}Ar, $^{3}H/^{3}He$, the lumped parameter modelling tool "TracerLPM" (https://www.usgs.gov/software/tracerlpm) and particle tracking by MODFLOW and MODPATH modules in GMS. ^{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), - $^{3}H/^{3}He$ were analysed by the Helis lab. At University of Bremen https://www.noblegas.uni-bremen.de/eng/.

Results from this Case Study
The assessment show that the upper part of the screen, which is contaminated by bentazon has a bimodal age distribution of which a significant part is less than 10 years and another significant part is older than 60 years (65%), see figure below. The lower part, which is contaminated by dichlorprop also has a bimodal distribution with a significant part (about 15%) with an age of less than 60 years and another part (85%) with an age of more than 100 years.

Hence, the investigations show that the bentazon pollution in the top of the well occurred after the regulation in 1995, and the dichlorprop found at the bottom of the well occurred long before the regulation (in the 1970's). The bentazon contamination in the top of the well indicates that the regulation in 1995 is either not followed or not strict enough.



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 well in Northern Jutland, Denmark, 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. The cited references and access information are listed at the end of the following information template.

Name of pilot area / aquifers / type: North Jutland / Holocene marine and aeolian sand semi-confined aquifer / porous	**Country:** Denmark **Region:** Northern Jutland
Study level	Transboundary : ☐ Regional: ☐ Local: ☐ Single well(s): X
Type of observations *(choose one of the options, create separate template if needed for each type if each type need specific information)*	☐ Short screened observation wells (not pumped) ☐ Long screened observation wells (not pumped) ☐ 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:	 Conceptual model of groundwater flow with dissolved pesticides to water supply well

<table>
<tr><td colspan="2">Name of Shape- / Geopackage file defining the area:
HoverDKPilotsSub.shp</td><td colspan="4">Projection to be used:
WGS84 (Epsg4326)</td></tr>
<tr><td rowspan="2">Hydrological parameters:</td><td>Mean annual precipitation (mm or range in mm)</td><td>Mean annual groundwater recharge (mm or range in mm)</td><td colspan="2">Mean annual groundwater recharge temperature (°C)</td><td>Thickness of unsaturated zone (range in m)</td></tr>
<tr><td>1000</td><td>400</td><td colspan="2">8</td><td>2</td></tr>
<tr><td colspan="2">Pumped wells only</td><td colspan="2">Typical pump discharge of sampled individual well (m³/day): 50 – 100 m³</td><td colspan="2">Typical pump discharge of complete well field (m³/day):
If relevant</td></tr>
<tr><td colspan="2">List of aquifers and aquitards in pilot area</td><td colspan="3">No. of confined or semiconfined aquifers in pilot area: 2</td><td>No. of unconfined aquifers in pilot area: 0</td></tr>
<tr><td>Aquifer no. (aqf): 2
Aquitard no. (aqt): 1
Aquiclude no. (aqc):</td><td>Aquifer/aquitard type and/or name</td><td>Lithology (Resource WP6 terminology)</td><td>Depth range (m)</td><td colspan="2">GW age range (yr)</td></tr>
<tr><td>Aqf-1:</td><td>Holocene sands locally confined by clay/silt</td><td>Fine to medium sand to gravel</td><td>13 - 18</td><td colspan="2">< 5 - 100</td></tr>
<tr><td>Porosity type</td><td>Porous: X</td><td>Fissured: ☐</td><td>Karst: ☐</td><td colspan="2">Fissured and porous / dual porosity: ☐</td></tr>
<tr><td>Aqt-1:</td><td>Holocene marine silty clay</td><td>Silty clays</td><td>18-22</td><td colspan="2"></td></tr>
<tr><td>Porosity type</td><td>Porous: X</td><td>Fissured: ☐</td><td>Fissured and porous / dual porosity: ☐</td><td colspan="2">No hydraulically active porosity: ☐</td></tr>
<tr><td>Aqf-2:</td><td>Holocene sands</td><td>Medium sand</td><td>22 -25</td><td colspan="2">25 - 250</td></tr>
<tr><td>Porosity type</td><td>Porous: X</td><td>Fissured: ☐</td><td>Karst: ☐</td><td colspan="2">Fissured and porous / dual porosity: ☐</td></tr>
<tr><td colspan="2" rowspan="2">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)</td><td colspan="4">Aquifer-1
^{3}H/^{3}He, ^{39}Ar , ^{85}Kr,</td></tr>
<tr><td colspan="4">Aquifer-2
^{3}H/^{3}He, ^{39}Ar , ^{85}Kr,</td></tr>
<tr><td colspan="2" rowspan="2">Number of sites (wells/springs) with age indicators</td><td colspan="4">Aquifer-1
1-5: X 5-10: ☐ 10-25: ☐ >25: ☐</td></tr>
<tr><td colspan="4">Aquifer-2
1-5: X 5-10: ☐ 10-25: ☐ >25: ☐</td></tr>
</table>

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<tr><td rowspan="2">GW age range (GAR)
GAR-1: Modern (< 60 yr)
GAR-2: Old (> 60 yr and <10 kyr)
GAR-3: Paleowaters (> 10 kyr)</td><td colspan="5">Aquifer-1
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%: □</td></tr>
<tr><td colspan="5">Aquifer-2
GAR-1: 1-10%: □ 10-25%: X 25-50%: □ >50%: □
GAR-2: 1-10%: □ 10-25%: □ 25-50%: □ >50%: X
GAR-3: 1-10%: □ 10-25%: □ 25-50%: □ >50%: □</td></tr>
<tr><td>Groundwater age ranges (GAR) estimated by:</td><td colspan="5">Tracer based estimates □
Flow and age model simulations □
Combination of model and tracer estimates X
Expert judgement: □</td></tr>
<tr><td colspan="6">Objective of age dating studies:</td></tr>
<tr><td>Basic research or General groundwater management</td><td>Assessment of pollutant history</td><td colspan="2">Assessment of the efficiency of remediation and mitigation measures</td><td colspan="2">Indication of vulnerability of aquifers and water supply wells</td></tr>
<tr><td>x</td><td>x</td><td colspan="2">x</td><td colspan="2">x</td></tr>
<tr><td rowspan="2">Water Usage
(not relevant for observation wells)</td><td>Water supply</td><td>Irrigation</td><td>Industry</td><td colspan="2">Other</td></tr>
<tr><td>x</td><td></td><td></td><td colspan="2"></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></td><td></td><td colspan="2"></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</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):

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.</td><td colspan="3">Reports and papers with restricted access:

Jakobsen, Rasmus, Klaus Hinsby, Jens Aamand, Peter van der Keur, Jacob Kidmose, Roland Purtschert, Bryant Jurgens, Jürgen Sültenfuss, and Christian N. Albers. 2019. “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 .</td></tr>
<tr><td colspan="6">Remarks / other relevant information:</td></tr>
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