

3.18 Description of the Holten case study, The Netherlands

Title of Case Study	Holten well field
Location (region, Country)	Twente region, province of Overijssel, Netherlands
Other information	The case study summarizes 2 studies that were published in peer-reviewed journals which focus on the applications of age dating of drinking water production wells. A method was developed to determine groundwater age distributions using a discrete shape-free age distribution model.

Description of Case Study

The production well field is located near Holten, in the eastern part of the Netherlands. The area is characterized by the Holterberg, an ice-pushed ridge north of Holten, consisting of thrust sediments reaching 70 meters above mean sea level (msl). The surface elevation in the rest of the area varies between 15 and 20 meters above msl. A phreatic groundwater system is present in the (partly ice-pushed) fluvial and periglacial deposits of 90 to 120 m thickness. The Holten well field produces 2.5 million cubic meters groundwater from a depth of 10 to 70 meters below the surface. The well field is vulnerable to contamination because of the agricultural land use and residential areas in the capture area, the sandy aquifer, expected short groundwater residence times and relatively deep groundwater levels (4-8 m below surface). Especially nitrate and agriculture related contaminants like heavy metals are the largest threat to the water quality in the production wells.

The well field currently has 19 pumped wells that were mostly constructed between 1960 and 1973 and were screened between 15 and 30 m below the surface. In 1985, three additional deep wells were drilled and screened from 45 to 70 m below the surface. These wells were intended to capture deep iron-rich anoxic groundwater to prevent well clogging that occurs when shallow oxic groundwater mixes with deep anoxic groundwater

Description of problem

The evolution of water quality in the well field was difficult to understand and especially fluctuations in concentrations of agriculturally derived contaminants including nitrate and sulfate made it uncertain which management options would be preferable for sustainable water production at the site.

Methods used in the Case Study

The case study included the application of a wide range of groundwater age and paleoclimate indicators including: $^3\text{H}/^3\text{He}$, ^{85}Kr , ^{39}Ar , ^4He and ^{18}O . The drinking water well field is surrounded by a network of multilevel monitoring wells with short screens (1-2 m); these monitoring wells were sampled for $^3\text{H}/^3\text{He}$ in order to determine discrete apparent ages and to deduce the age stratigraphy in the aquifer. Eleven production wells were selected for sampling based on their typical production, ensuring that both shallow and deep wells in close proximity were sampled. Samples for $^3\text{H}/^3\text{He}$ analysis were collected from all eleven wells, providing over 95% of the total production. Samples for krypton-85, argon-39, dissolved gas and stable isotope analysis were collected from seven of the eleven wells, capturing 69% of the total drinking water production. To quantify a groundwater age distribution from the available age tracer data, a shape-free discrete groundwater age distribution model was applied. The model describes the

groundwater age distribution by a number of age bins with a uniform age distribution within each bin.

Results from this Case Study

The sampling of the multi-level observation wells yielded a description of the age stratigraphy of the water in the aquifers with groundwater aging with depth, which could be represented by an exponential model with a mean travel time of 15-19 years that is truncated after 30-40 years.

The discrete groundwater age distribution model described the mixing from the pumped aquifers, with the shallower wells extracting a younger mix of groundwater than the deeper wells. This age distribution in the production wells appeared to be consistent with the vertical groundwater age profile in monitoring wells in the vicinity of the well field. We were able to estimate the contributions of water aged between 0-15, 15-30, 30-45, 45-60 and > 60 years using the discrete age distribution model. The shallow pumping wells produced young (0-30 y) groundwater mixed with possibly a small (15%) fraction of old groundwater. The apparent argon-39 ages in these wells suggest that the old fraction is several hundred years old at most, which is supported by low concentrations of radiogenic helium-4. Two of the three deep wells produce a mixture of 40% intermediate (15-30 y) groundwater and 60% old groundwater. The third deep well produces 90% old groundwater. The apparent age of the old groundwater component is 310 ± 90 years.

The study taught us that production wells compete for capture area and age of the pumped groundwater. When shallow and deep production wells are in close vicinity, the age of the groundwater is separated into an older mix in the deeper wells and a preferential younger mix in the shallower wells. Changing the pumping regime between shallower and deeper wells therefore influences the age of the pumped water, leading to fluctuations in water composition that were not properly understood beforehand. We learned that varying well pumping rates, abandoning wells or drilling additional wells will impact the groundwater captured by existing wells and therefore also the age distribution of individual wells.

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

The case study is one of the first examples for demonstrating the use of groundwater age distributions for understanding the evolution of water quality at drinking water production well fields. It also represents one of the first successful application of ^{39}Ar age dating in such a setting. The HOVER project will extend this work under task 6.4 in order to test and develop new techniques for estimating age distributions of groundwater bodies with residence times mainly in the age range of 100 to 1000 years, for which a number of demonstration pilots at drinking water well fields have been sampled in 2019 and 2020. Under task 6.4, we intend to develop a common methodology for characterization of the age distribution of pumped wells by using a suite of tracers and models. The Holten study is one of the case studies to provide input for this work.

Name of pilot area / aquifers / type: Holten well field		Country: Netherlands Region: Holten well field, Overijssel, The Netherlands	
Study level	Transboundary : ☐ Regional: X Local: X Single well(s): ☐		
Type of observations	X 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 ☐ Springs ☐ Other (eg. research wells; indicate type and information on pumping):		
Approximate location of pilot (WGS84): minX: 6.327500 maxX: 6.500000 minY: 52.250000 maxY: 52.310000			
Geological cross section / conceptual model of the pilot area:			
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)
	750	200-300	10	< 5 m
Pumped wells only		Typical pump discharge of sampled individual well (m ³ /day): 800	Typical pump discharge of complete well field (m ³ /day): 10,000	
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	Aquifer/aquitard type and/or name	Lithology	Depth range (m)	GW age range (yr)
Aqf-1:	Quaternary sands	Fluvial fine to coarse fluvioglacial sands	10	< 30
Porosity type	Porous: X	Fissured: ☐	Karst: ☐	Fissured and porous / dual porosity: ☐
Aqf-2:	Quaternary sands	Fluvial coarse sands	10-30	< 60
Porosity type	Porous: X	Fissured: ☐	Karst: ☐	Fissured and porous / dual porosity: ☐
Aqf-3:	Quaternary sands	Shallow marine fine sands	30-70	60-500
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) Applied recharge temperature indicators (¹⁸ O)		Aquifer-1 ³ H/ ³ He		
		Aquifer-2 ³ H, ³ H/ ³ He, ³⁹ Ar, ⁸⁵ Kr, ⁴ He, ¹⁸ O		
		Aquifer-3 ³ H, ³ H/ ³ He, ³⁹ Ar, ⁸⁵ Kr, ⁴ He, ¹⁸ O		
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: ☐		
		Aquifer-3 1-5: ☐ 5-10: X 10-25: ☐ >25: ☐		
GW age range (GAR) GAR-1: Modern (< 60 yr) GAR-2: Old (> 60 yr and 10 kyr)		Aquifer-1 GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: X GAR-2: 1-10%: X 10-25%: ☐ 25-50%: ☐ >50%: ☐		



GAR-3: Paleowaters (> 10 kyr)		GAR-3: 1-10%: 0 10-25%: ☐ 25-50%: ☐ >50%: ☐			
		Aquifer-2			
		GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: X			
		GAR-2: 1-10%: X 10-25%: X 25-50%: ☐ >50%: ☐			
		GAR-3: 1-10%: 0 10-25%: ☐ 25-50%: ☐ >50%: ☐			
		Aquifer-3			
		GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: X			
		GAR-2: 1-10%: ☐ 10-25%: ☐ 25-50%: X >50%: X			
Groundwater age ranges (GAR) estimated by:		Tracer based estimates			
Objective of age dating studies:					
Basic research or General groundwater management	Assessment of pollutant history		Assessment of the efficiency of remediation and mitigation measures		Indication of vulnerability of aquifers and water supply wells
					X
Water Usage	Water supply		Irrigation	Industry	Other
	X				
Geoenergy related activities	Shallow Geo-T	Deep Geo-T	Hydrocarbons		Nuclear waste disp.
Mining activities	Construction materials		Minerals / metals	Coal	Other
REFERENCES					
OPEN Access reports and papers (PDF versions made available in EGD repository making them downloadable via maps and keyword / free text searches):			Reports and papers with restricted access:		
			Visser, A., Broers, H. P., Purtschert, R., Sültenfuß, J., & de Jonge, M. (2013). Groundwater age distributions at a public drinking water supply well field derived from multiple age tracers (85Kr, 3H/3He, and 39Ar). Water Resources Research, 49(11), 7778-7796.		
			Massoudieh, A., Visser, A., Sharifi, S., & Broers, H. P. (2014). A Bayesian modeling approach for estimation of a shape-free groundwater age distribution using multiple tracers. Applied geochemistry, 50, 252-264.		
Remarks / other relevant information:					