

3.17 Description of the Noord-Brabant & Limburg case study, The Netherlands

Title of Case Study	Noord-Brabant and Limburg
Location	Provinces of Noord-Brabant and Limburg, Netherlands
Other information	The case study summarizes 3 studies that were published in peer-reviewed journals which focus on the applications of age dating of shallow groundwater for trend detection and process understanding in one of the most intensive farming areas of Europe. The case study is focusing on the consequences of excessive use of manure and fertilizer on agricultural lands and leaching of veterinary antibiotics from manure towards groundwater.

Description of Case Study
The provinces of Noord-Brabant and the Northern part of the province of Limburg present one of the areas in Europe which is most affected by agricultural pollution, because intensive livestock farming in the area produces a large surplus of manure. Agricultural land covers > 60% in the sandy regions of Noord-Brabant and Limburg. The agricultural area of these provinces is vulnerable to diffuse groundwater pollution with nitrate because groundwater and contaminants can easily reach deeper parts of the aquifer due to the permeable sandy subsoil. The subsurface consists of fluvial unconsolidated sand and gravel deposits from the Meuse River, locally overlain by an approximately 30 m thick cover of Middle- and Upper-Pleistocene fluvio-periglacial and aeolian deposits consisting of fine sands and loam. In large parts of the pilot region, pyrite occurs in the subsurface. Zhang et al. (2009) describe nitrate reduction by pyrite oxidation as a process determining the fate of nitrate. The pilot region is a relatively flat area with altitudes ranging from 0 m above mean sea level (MSL) in the north and west to about 40 m above MSL in the southeast. Groundwater tables are generally shallow, usually within 5 m below the surface.

Description of problem
Since around 1985 a set of measures was introduced to reduce the impacts of farming on the environment including groundwater resources. The legislation started with the Dutch Manure Law from (1985) and was followed by the EU Nitrate Directive (2000), the Directive on veterinary medicinal products (2001/82/EC) and the Dutch regulation on veterinary medication (nr. WJZ/12375453, 2012). Groundwater age dating has been applied in order to evaluate the effectiveness of these measures with respect to the contamination of groundwater. Because our pilot area is one of the most affected and known for exceedance of nitrate concentrations in shallow groundwater, the monitoring networks of the two provinces were used as a starting point for surveillance monitoring. Initial work has focuses on the fate and transport of nitrate (Visser et al. 2007, 2009a,b,c) and reaction products of nitrate reduction (Zhang et al. 2009, 2013). Recent work focuses on the fate and transport of veterinary antibiotics (Kivits et al. 2018).

Methods to be used in the Case Study (analytical and isotope techniques, modelling)
The studies make use of an existing set of multi-level observation wells which are part of the



provincial monitoring networks of the provinces of Noord-Brabant and Limburg and dedicated multi-level wells at an abandoned drinking water well field in Oostrum (Limburg). The wells consist of purpose-built nested piezometers with a diameter of 2 inch and a screen length of 2 m between depth of 2 and 40 m below surface. The wells were sampled for $^3\text{H}/^3\text{He}$ which was used to quantify the apparent groundwater age, correcting for degassing where necessary. A correction for degassing appeared to be necessary, as the reduction of excessive nitrate sometimes led to the of a N_2 gas phase. The use of CFC's and SF_6 as age tracers has been explored, but appeared to be ineffective due to the degradation of the CFC's and degassing of SF_6 in our hydrogeological situation (Visser et al. 2009c). PHT3D modelling of ages and geochemical processes was applied in the Zhang et al. 2013 study. Measured $^3\text{H}/^3\text{He}$ profiles were used to support the calibration of flow and conservative transport processes, while the comparison of simulated and measured sulfur isotope signatures acted as additional calibration constraint for the reactive processes affecting sulfur cycling.

Results from this Case Study

Using the results of the $^3\text{H}/^3\text{He}$ age dating, we could clearly demonstrate the trend reversal of groundwater nitrate, showing that concentrations increased in groundwater recharged before the enactment of the Manure Law in 1985 and decreased subsequently after 1990. Age dating also helped to unravel the hydrogeochemical processes, such as nitrate reduction coupled to pyrite oxidation. The calibrated age model of Zhang et al. 2013 was used to understand the lag times of nitrate and sulfate in receiving surface waters. The model illustrated that denitrification largely prevented an elevated discharge of nitrate to surface waters, while sulfate discharges were significantly increased, peaking around 15 years after the maximum nitrogen inputs. The Kivits (2018) study clearly links the presence of veterinary antibiotics to the application history of the medicinal products in farming. Antibiotics were found in water of 25 years age and in deeper mixed waters with an apparent age of ~ 40 years.

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

The case study is beneficial for the aim of establishing a good practice protocol on the application of age indicators and for demonstrating the use of groundwater age information for the evaluation of the effectiveness of monitoring programs. The study gives practical guidance for the assessment of pollution trends and trend reversal in relation with the application history of contaminants introduced under farmlands and yields better understanding of the fate and transport of contaminants in a reactive subsoil which has major implications for the assessment and understanding of groundwater chemical status.

Name of pilot area / aquifers / type: Noord-Brabant		Country: Netherlands Region: Noord-Brabant province, Netherlands	
Study level	Transboundary : ☐ Regional: X Local: ☐ Single well(s): ☐		
Type of observations	☒ Short screened observation wells (not pumped) ☐ Long screened observation wells (not pumped) ☐ Pumped wells, long screens and open wells 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: 4.193000 maxX: 6.247500 minY: 51.130000 maxY: 51.845000			
Geological cross section / conceptual model of the pilot area:	Depth (m below surface level) Groundwater age (years) ■ Antibiotics detected ● No antibiotics detected		

Name of Shape- / Geopackage file defining the area: Netherlands pilot HOVER shape		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
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): 2 Aquitard no. (aqt): Aquiclude no. (aqc):	Aquifer/aquitard type and/or name	Lithology (Resource WP6 terminology)	Depth range (m)	GW age range (yr)
Aqf-1:	Eolian and fluvio-periglacial fine sands and loam (Quaternary)	Mostly fine sands	0 – 15	< 60 year in recharge areas
Porosity type	Porous: X			
Aqf-2:	Fluvial sands and gravel (Quaternary)	Fine sand to gravel	0-50	< 60 year in recharge areas
Porosity type	Porous: X			
Applied tracer age indicators (³H, ³H/³He)		Aquifer-1 ³ H, ³ H/ ³ He		
Applied recharge temperature indicators none		Aquifer-2 ³ H, ³ H/ ³ He		
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) 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%: ☐ 25-50%: ☐ >50%: X GAR-2: 1-10%: ☐ 10-25%: X 25-50%: ☐ >50%: ☐ GAR-3: 1-10%: 0 10-25%: ☐ 25-50%: ☐ >50%: ☐		

		Aquifer-2 GAR-1: 1-10%: ☐ 10-25%: ☐ 25-50%: ☐ >50%: ☒ GAR-2: 1-10%: ☐ 10-25%: ☒ 25-50%: ☐ >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 X Combination of model and tracer estimates X			
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		X		X
Water Usage	Water supply		Irrigation	Industry	Other
Geoenergy related activities	Shallow Geo-T	Deep Geo-T	Hydrocarbons		Nuclear waste disp.
Mining activities	Construction materials		Minerals / metals	Coal	Other
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OPEN Access reports and papers Kivits, T., Broers, H., Beeltje, H., Vliet, M., Griffioen, J., 2018. Presence and fate of veterinary antibiotics in age-dated groundwater in areas with intensive livestock farming. Environ Pollut 241, 988–998.			Reports and papers with restricted access: Visser, Broers, H.P., van der Grift, Bierkens, M.F.P., 2007. Demonstrating trend reversal of groundwater quality in relation to time of recharge determined by 3H/3He. Environmental Pollution 148, 797–807. Visser, A. H.P. Broers, R. Heerink and M.F.P. Bierkens (2009a) Trends in pollutant concentrations in relation to time of recharge and reactive transport at the groundwater body scale. Journal of Hydrology, 369:427-439. Visser, A., Dubus, I., Broers, H., Brouyère, S., Korcz, M., Orban, P., Goderniaux, P., Batlle-Aguilar, J., Surdyk, N., Amraoui, N., Job, H., Pinault, J., Bierkens, M. (2009b). Comparison of methods for the detection and extrapolation of trends in groundwater quality. J Environ Monitor 11, 2030–2043. Visser, A. J.D. Schaap, H.P. Broers and M.F.P. Bierkens (2009c). Degassing of 3H/3He, CFCs and SF6 by denitrification: measurements and two-phase transport simulations. Journal of		



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Remarks / other relevant information:	