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Monitoring groundwater circulation during tunnel works by environmental tracers

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INTRODUCTION

Construction of new railroads for more rapid trains is often having an impact on the groundwater recharge and circulation patterns. In particular when dealing with long tunnels and deep excavations there is a risk for permanent disturbances of the hydrogeological system and environmental consequences. This study aims to developing a methodology for monitoring groundwater circulation times in and contacts between different aquifer units as an effect of groundwater drainage at large tunnel projects.

The Hallandsås horst, southern Sweden, is selected as study area as hundreds of observation wells have been installed there during the on-going railway tunnel works (Fig. 1).

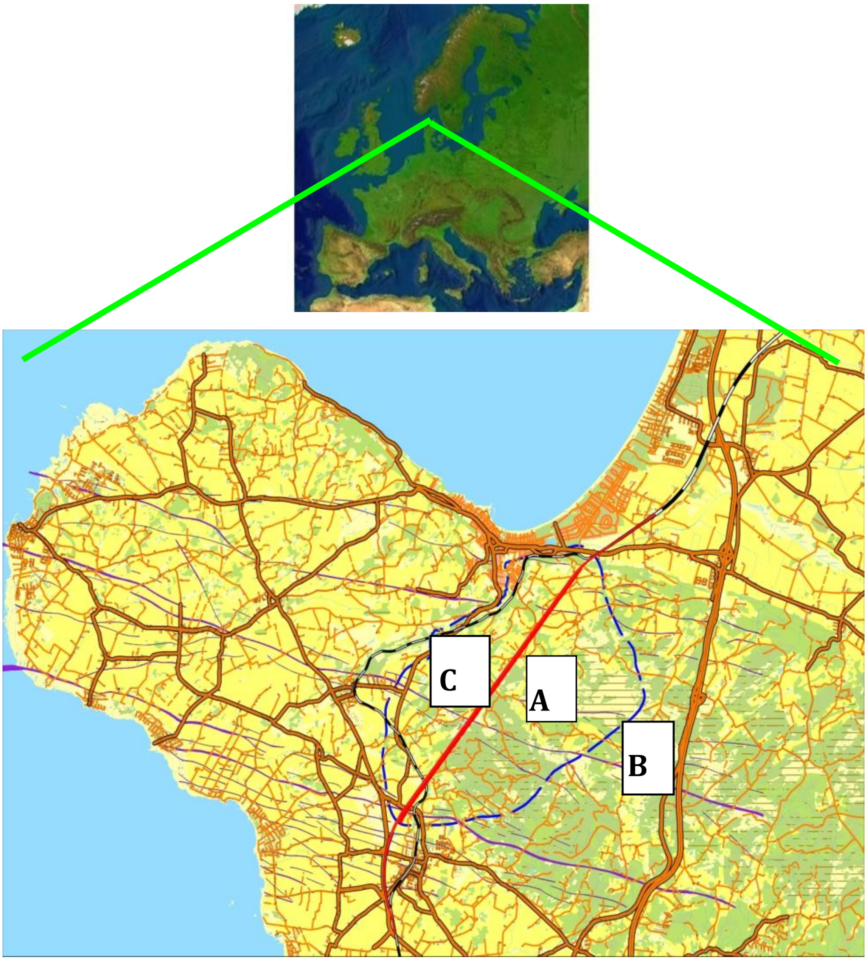

Figure 1. Overview of Europe (top map). The Hallandsås horst, southern Sweden, is situated where the two green lines are meeting. The western part of the horst and the Bjäre peninsula is shown on the bottom map. The two parallel 8.6 km long railway tunnels are marked with a thick red line, which also gives an approximate scale of the map. North is upwards on the maps and the blue dashed line around the tunnels shows the outer limit of the estimated area, where the groundwater levels could be influenced by the tunnel works. The letters A-C mark sampling positions explained below.

Many of the wells are still accessible and they are in contact with the aquifers of fractured and often weathered Precambrian rocks at different levels. There are also shallow observation wells in the relatively thin soil cover (typically 5–15 meters thick), mainly consisting of dense till.

Environmental tracers occur by natural processes or as a result of large-scale human activities. If the tracers mainly follow the movements of the groundwater they may provide a relatively direct and independent assessment of groundwater velocity and age. The residence time or age of groundwater is the mean travel time of water from the point of recharge to the point of collection and can be used to characterize flow, transport processes and to reconstruct past releases of contaminants to aquifers (Bockgård et al., 2004). In this study the main selected metods of monitoring have been measurements of the contents of different CFC's and the contents of the radioactive isotope tritium. These values have been interpreted together with results from analyses of the major ions dissolved in the groundwater, general hydrochemical properties and the contents of oxygen-18.

METHODOLOGY

Three shallow (less than 7 metres deep) and sixteen deep (40–174 metres deep) observation wells have been sampled. The shallow wells represent an unconfined aquifer in the top soil layer (chiefly consisting of till), while the deep wells represent confined or leaky confined aquifers in the fractured crystalline basement rocks. The sampling sites are situated at different distances from the on-going tunnel works at Hallandsås. The deep wells have been sampled by a simplified depth specific method using two submersible pumps with different capacities simultaneously. The sample is supposed to represent the upper part of the well when it is extracted by the upper, low capacity, pump. The latter pump is lowered below the high capacity pump when a sample from the lower part of the well is desired. The samples have been analyzed by GEUS, Denmark, as regards major hydrochemistry and contents of CFC-11, -12 and -113 (detection limit 1 pg L^{-1}). The analysis was following the methodology described by Busenberg and Plummer 1992. The recharge temperature was assumed to be equal to the estimated average air temperature (8 ºC) for all sites. Ten selected samples have also been analyzed by Geological & Nuclear Sciences, New Zeeland, concerning contents of tritium and using electrolytic enrichment and calibration by deuterium concentration (detection limit 0.04 TU).

RESULTS AND DISCUSSION

Results regarding nitrate, tritium and CFC-based ages from different parts of the study area are shown in table 1. Tritium values below 1 T.U. indicates an average circulation time longer than 55 years in southern Sweden, while 8-10 T.U. in todays groundwater could correspond to very recent recharge as well as mixes of groundwater, mainly recharged 10-40 years ago.

The content of oxygen-18 is about -9.0 — -9.2 ‰ vs. SMOW in all sampled wells which supports the assumption of an equal recharge temperature, which facilitates a reliable estimation of CFC-based ages. The results in table 1 can be split in two major groups, one where the different analytical results are pointing towards the same direction and a second one where the different results are partly contradictory.

Table 1. Contents of nitrate and tritium and also age based on contents of CFC in different parts of the studied aquifer system in January 2006.

Well No. Type	Sampling depth (m b s)	Site characteristics	Nitrate (mg/L)	Tritium (T.U.)	CFC-based age (years)
GVR610 Shallow **A** in Fig. 1	6	Not very close to tunnel area. Recharge area	6.00	8.46	< 5
GVR720 Shallow **A** in Fig. 1	5	Not very close to tunnel area. Discharge area	0.46	8.48	18
BP31 Deep **C** in Fig. 1	39 (above 45)	Not very close to tunnel area.	< 0.02	10.18	30
	46 (45–150)	Not very close to tunnel area.	< 0.02	1.81	49
MI23 Deep **B** in Fig. 1	35 (above 42)	Outside area of influence	7.01	8.66	17
	46 (42–52)	Outside area of influence	20.19	8.23	17
MI26 Deep **B** in Fig. 1	28 (above 31)	Outside area of influence	< 0.02	0.021	56
	35 (31–40)	Outside area of influence	< 0.02	0.052	60

The wells GVR 610 (position A in figure 1) and MI26 (position B in figure 1) are corresponding to the first group even if they have very different characteristics. GVR610 is a shallow well in the top soil layer of a recharge area with high contents of nitrate and tritium and a low CFC-based age. Furthermore the content of oxygen is very high in this shallow well. This situation corresponds to the shallow well, marked by a red vertical bar, to the left at the local hill in the schematic sections of figure 2 (no tunnel) and 3 (drainage into a partly unsealed tunnel).

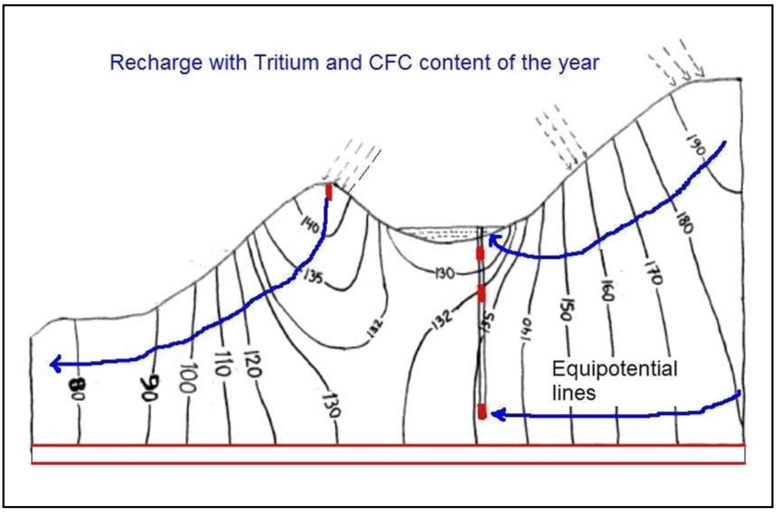

Figure 2. Schematic groundwater flow-net in a vertical section along the planned railway tunnel (see Fig. 1). Blue lines indicate the qroundwater flow direction and the black lines are equipotential lines (m.a.s.-l.). No drainage of water into the future tunnel in this situation.

The groundwater composition and the groundwater circulation is not plausible to change due to tunnel works in such a position. MI26 is a deep well situated far away from the railway tunnel works, outside the estimated area of influence. Groundwater from this well has very low contents of nitrate and tritium and a high CFC-based age at all sampled depths. The contents of oxygen is close to zero. This situation corresponds to the two lowest sampling points of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a very long circulation time in this situation. However, if this well somehow should become affected by the drainage towards the tunnel works, the groundwater age will decrease substantially and the situation will correspond to the lower part of the deep well of figure 3.

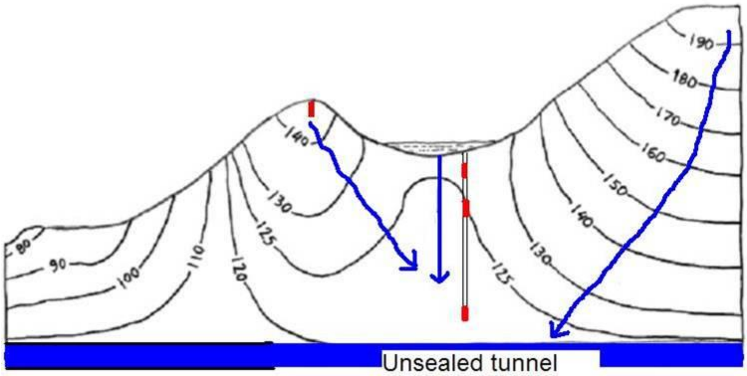

Figure 3. Schematic groundwater flow-net in a vertical section along the planned railway tunnel (see Fig. 1). Blue lines indicate the qroundwater flow direction and the black lines are equipotential lines (m.a.s.-l.). The section is identical to figure 2, but in figure 3 there is a considerable drainage of groundwater into the unsealed tunnel.

However, there are also intermediate cases like GVR720, a shallow well in the top soil layer of a discharge with a low but not negligible content of nitrate, a high content of tritium and a moderately low CFC-based age. This situation corresponds to the upper sampling point of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a longer circulation time in this situation compared to the one of GVR610 but not as long as in the case of MI26. The composition of the groundwater in GVR720 will most probably change to something similar to GVR610 if water is drained into the tunnel (see figure 3).

In BP31 (position C in figure 1) there is a significant difference in the tritium content in the water flowing into the upper part of the well (high value) compared to the lower part (low value). Also the CFC-based age is higher in the lower part of the well while the contents of nitrate are negligible in all parts of the well. This situation is not very easy to interpret in an unambiguous way. The position corresponds to the two lowest sampling points of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a long circulation time in this situation, which is supported by the low nitrate concentration and the relatively high CFC-ages. The upper part of well BP31 could be in contact with a fracture in the crystalline bedrock, which supplies the well with groundwater mainly recharged during the 60-ies and early 70-ies with a high content of tritium.

Well MI23 (position B in figure 1) is situated in the fractured crystalline bedrock outside the estimated area of influence around the tunnel works. The groundwater in the well has a high content of nitrate and tritium but with a moderately low CFC-based age. Most probably there is an inflow to the well of young water with a high content of nitrate due to fractures and/or leakage along the well construction.

As some of the last cases indicate, the water samples could of course consist of mixtures of groundwater from different levels and then the CFC-age has no real meaning (Laier 2004) and it is necessary to use several conservative tracers with different input functions to be able to calculate the relative contribution of the different components of the groundwater mixture (Bockgård et al. 2004).

CONCLUSIONS

A combination of hydrochemical, tritium and CFC analyses seems to make it possible to monitor variations in groundwater circulation times at large-scale infrastructural projects. However, more detailed interpretations of the observations are necessary and mixing of flow within a fractured aquifer makes some interpretations difficult. Furthermore, other tracers, detailed groundwater potentials and fracture maps are often necessary for a detailed interpretation.

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