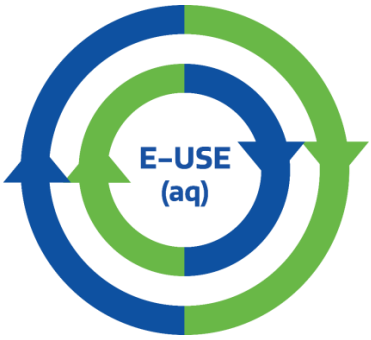
D1e E-USE(aq)
Technical performance & monitoring report Dutch pilot Utrecht

Europe-wide Use of
Sustainable Energy from Aquifers



Climate-KIC is supported by the
EIT, a body of the European Union

Contents

1 Introduction

1.1 General

Climate Knowledge and Innovation Communities (Climate-KIC) is an initiative supported by the European Institute for Innovation and Technology (EIT) with the aim to overcome the challenges of bringing climate-focused innovation to market. One of the research programmes of Climate-KIC concerns sustainable production systems.

Aquifer Thermal Energy Storage (ATES) is a cost-efficient sustainable production system that involves storing energy resulting from cooling and heating in water-bearing soil layers and acquiring heat and/or cold from extracted groundwater whenever needed.

In recent years, approximately 2500 ATES systems have been successfully applied in the Dutch subsurface (with an estimated yearly turnover of 270M€). Due to this success, it is expected that remunerative application will happen elsewhere in Europe, but to date the widespread application of ATES systems is hampered by socio-economic, legal and technical barriers.

Together with national and international partners, Deltares has conducted pilot studies in the Netherlands, Italy, Spain, Belgium and Denmark to prove the attractiveness and potential of large-scale ATES applications. One of these pilot studies concerns the ATES system of sports center Nieuw Welgelegen, at the Grebbeberglaan in Utrecht, which is used to test the combination i of ATES and groundwater remediation.

1.2 Barriers

Soil contaminations may be a barrier for the application of ATES systems, as the continuous extraction and injection of water could lead to migration of pollutants and increase of contaminated groundwater volumes. Therefore in the Netherlands, regulations do not allow ATES systems in areas with contaminated groundwater. These regulations aim to avoid the intake of contaminated groundwater for the preparation of drinking water. This drinking water preparation is often located in the vicinity of urban areas. As 70% of drinking water is prepared from groundwater in the Netherlands the protection of groundwater is regarded as very important.

However, recent laboratory studies of the sub-department of Environmental Technology at Wageningen University (ETE-WUR) showed that ATES systems can increase the biodegradation rate of chlorinated organic compounds (COCs) to more than 13 times in comparison to the natural attenuation rate (Zhuobiao Ni et al., 2015). It was shown that in the presence of abundant carbon source as electron donor temperature was the dominating factor when abundance of *Dehalococcoides* species was sufficient. In May 2018, a field study was published where groundwater was heated to 20-30 °C which accelerated reductive dechlorination, providing there was sufficient substrate for the microorganisms (Němeček et al., 2018). If this acceleration can be further demonstrated in other pilot studies under different conditions, it could facilitate increased implementation.

1.3 Partners and funding sources

A total of 6 partners were involved in this pilot study. The names and roles of each partner are summarised in Table 1.

Table 1: List of partners and roles performed during this project

Partner	Role
Deltares	Monitoring, physical, chemical and DNA analyses in groundwater samples, data interpretation
Bioclear	Development of DHC culture, placement and monitoring of soil in-situ mesocosms
T&K Service	Injection of DHC culture, placement of bioaugmentation injection well
Municipality of Utrecht (Gemeente Utrecht)	Owner of sports centre, responsible for groundwater quality
Geotron	Placement of monitoring well
ULC Technisch Beheer	Operation of ATES and monitoring

The pilot study was funded by Climate-KIC and the municipality of Utrecht.

1.4 Organisational history

In the city of Utrecht, according to the underground Biowashing Machine concept, ATES systems are supposed to promote the degradation of contaminants. However, no convincing evidence for this effect has been found thus far, neither in a detailed study on a large site with an extensive ATES system nor with an evaluation of data obtained from the vast Utrecht city groundwater monitoring system. Also a side-study was performed, targeting the specific – supposedly positive – effect of heating contaminated soil. This effect was studied separately from other possible effects of ATES, both in the lab as well as at a number of field sites in the Netherlands and Belgium. The outcome of this side-study is that when biogeochemical conditions are not optimal, the heating has no positive effect on biodegradation. These results also explain the findings in the underground Biowashing Machine of Utrecht. A positive influence of ATES system operation on contamination has hitherto not been proven, but this can be attributed to the lack of suitable biogeochemical conditions. So, optimization of these conditions appears to be necessary in order to profit from the enhancing effect on biodegradation provided by ATES heat.

This situation of limited biodegradation potential is not unique. Various municipalities are facing large scale (mainly chlorinated solvents related) contaminations, which based on European Waterframework legislation should at least be contained and focused on quality improvement. The necessary improvement is based on the Prevent and Limit targets in the framework, in which the “Limit”-target is providing the base for “limiting as much as possible influx of contamination to the water”. In this respect actions for quality improvement are necessary. Natural attenuation without necessity of any human activity would be preferable, but in various cases natural biodegradation is limited.

In 2012 the Dutch project “Meer met Bodemenergie” (freely translated: “how to get more out of ATES”) various options were evaluated to be able to combine usage of ATES systems and simultaneously provide groundwater quality improvement. Based on these theoretical evaluations Bioclear earth described an additional possibility: just adding dechlorinating biomass in high concentration, without the addition of carbon sources. This concept was called ATES+. The idea is that the addition of highly concentrated and active biomass can be injected without any clogging in (existing) ATES wells and due to the high amount of biomass, redox changes may be less needed to still get the desired reductive dechlorination. Due to lack of additional carbon sources wells will not be clogged in the ATES system, which is very important to sustain energy supply (heat and cold) if needed. The injection will create a change in biodiversity and residual activity of dechlorinating biomass may take care of the (normally low concentrations of) intermediate degradation products of PCE and TCE dechlorination.

This new technology concept was tested in pilots in Den Bosch and Apeldoorn (both the Netherlands). Both systems were not yet coupled to an ATES system. From December 2015-June 2016 the pilot in Den Bosch was carried out, showing that with only a small volume – 80 litres – of high concentrated DHC-containing biomass the same effect could be observed as was found in the labscale test: a shift of 5% dechlorination ratio in 6 months. Although this seems rather limited, these degradation rates should be transposed over the total running time of an ATES system (20-30 years). If 5% degradation takes place every season, approximately 10 years would be sufficient to remove the residual chlorinated solvents.

The second pilot was carried out in Apeldoorn between February 2017 and August 2017. Since the newly developed 10 m^3 bioreactor was in operation by the end of 2016, in this pilot 9 m^3 of highly concentrated biomass could be injected in a contaminated groundwater area. From the monitoring data it was concluded that quite a large amount of the injected biomass seems to attach to the soil particles surrounding the injection point. More importantly: all chlorinated solvents – consisting of c-DCE and VC with total concentration of approx. 200-600 µg/l – were completely degraded to ethylene in the zone which was fed with solely biomass (no additional carbon sources). This positive effect was determined for at least 6 months. Measurements will be executed in fall of 2018 to check actual conditions and if still degradation capacity can be measured.

Based on these results ATES+ may be also interesting for groundwater quality improvement in Utrecht. Additional value would be to test the ATES+ approach within a running ATES system or at least in the near vicinity of a running ATES, since this would also provide new knowledge on whether bacteria attach to soil and stay active in higher groundwater flow rates, comparable to ATES-rates.

The Municipality of Utrecht initially offered the ATES system of Muziekpaleis as a test site for enhancing biodegradation by optimization of the biogeochemical conditions as it was assumed that this system is attracting groundwater contaminated with chlorinated solvents. However, verification showed that the system is not operating in groundwater contaminated with chlorinated solvents at detectable concentrations and the site was not suitable as a test site. Subsequently, the ATES system of sports centre Nieuw Welgelegen at the Grebbeberglaan was proposed by the Municipality, based on chlorinated solvent contaminations found in a nearby monitoring well. Sampling of the three ATES mono-wells present at the site showed VC concentrations at adequate levels in ATES well 3 (results included in this report). Therefore, it was decided to perform the pilot at ATES well 3 on the premises of Nieuw Welgelegen at the Grebbeberglaan in Utrecht.

2 Pilot description

2.1 Justification and aims of the Nieuw Welgelegen pilot study

Chlorinated hydrocarbons are polluting the first aquifer below the city of Utrecht, and spreading of these COCs pose a risk for groundwater drinking wells and other ecological valuable areas (Municipality of Utrecht, 2014). Hence, it is desired to contain and, if possible, remediate the contamination through reductive dechlorination (Figure 1).

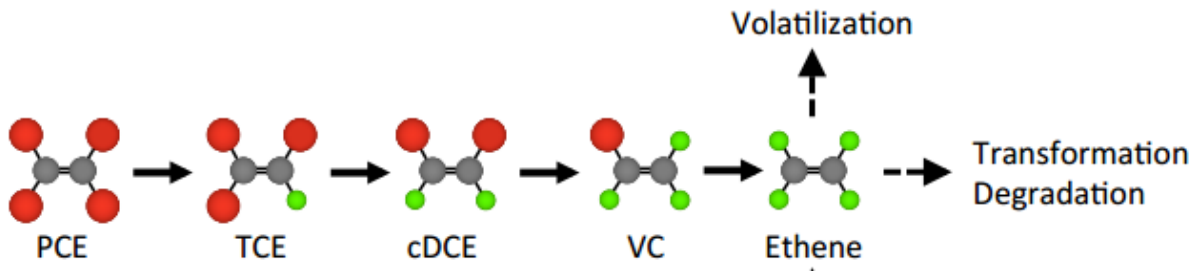


Figure 1: Schematic representation of reductive dechlorination. When organic matter is present as electron donor, under low redox conditions, chloride atoms are replaced by hydrogen through reductive dechlorination, performed by dehalorespiring organisms, especially Dehollococcïdes (DHC) species. The genes coding for the enzymes involved in

the last important degradation step, from Vinyl Chloride (VC) to ethene, are also known: vcrA and bvcA. Also oxidative degradation of VC is possible, for which the presence of the gene etnE provides evidence.

In a geochemical report on the subsurface of the Municipality of Utrecht (Grotenhuis, 2016), it was argued that reductive dechlorination of COCs was not likely to occur due to unfavorable redox conditions. It is possible to alter the redox conditions in order to stimulate reductive dechlorination in the subsurface. However, altering the redox conditions is hardly possible when dealing with thick aquifers, which is the case for the Municipality of Utrecht, where the aquifers range from 50 to 200 m thick (Municipality of Utrecht, 2014), which is also illustrated in Figure 2. Under such conditions large volumes of electron donors would have to be injected, which can result in well clogging and excessive costs.

An alternative technique to stimulate reductive dechlorination is bioaugmentation; the addition of living cells (bacteria). Bioaugmentation has been applied to remediate oil spills and chlorinated hydrocarbons in the subsurface, but can also be used for other purposes such as remediation of pesticide-polluted soil, wastewater treatment and biogas production (e.g. Cycoń et al., 2017; Nzila, 2017; Herrero and Stuckey, 2015). There is a lower risk of well clogging with bioaugmentation, and injection of a large culture also provides a food source for the microbial community, assuming not all of the injected bacteria will survive. Another benefit of the bioaugmentation approach is that the injected microorganisms can reside in localized areas where redox conditions are perhaps more optimal, and these localized areas probably overseen in the broad redox classification of Grotenhuis (2016).

The Nieuw Welgelegen ATES system was chosen for the ATES-bioaugmentation pilot test due to the demonstrated presence of COCs (Appendix 1). Vinylchloride (VC) was measured at fairly low concentrations in the ATES wells (0.3–6.6 µg/L). However, in a nearby monitoring well (B45), higher concentrations of VC were measured (0.5–62 µg/L), which exceed maximum allowable groundwater concentrations set by Dutch regulations[1].

[1] The Dutch National Institute for Public Health and the Environment (RIVM) has set target concentrations of VC in groundwater at 0.01 µg/L. If VC concentrations exceed 5 µg/L, the groundwater contamination is classified as severe and further evaluation is required to assess the need for remediation (https://rvszoeksysteem.rivm.nl/stof/detail/1324).

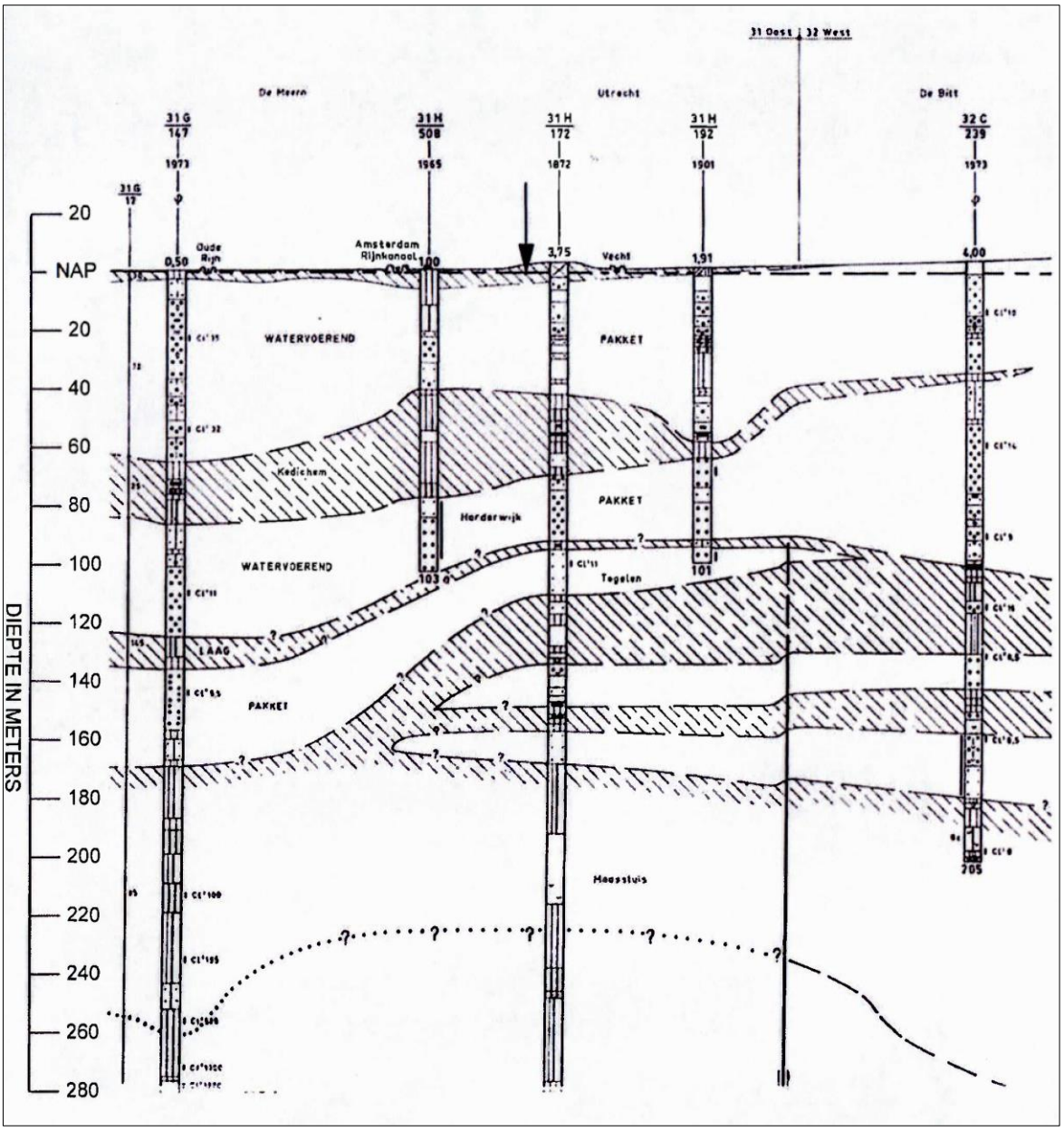


Figure 2: Soil stratification at pilot site (indicated with an arrow), light layers are aquifers, dark aquitards. Source: Kiefte, 2009.

The bioaugmentation approach is developed by Bioclear earth, a Dutch company that has a proven track record for bioremediation and bioaugmentation.

The bioaugmentation approach, as already described in paragraph 1.4, is developed by Bioclear earth, a Dutch company that has a proven track record for bioremediation and bioaugmentation.

Between 1996 and 1998 Bioclear earth investigated the possibility to develop a fully anaerobic bioreactor that would be able to transfer PCE and TCE into ethylene by reductive dechlorination. This was successful (>99% of PCE and TCE was transferred to ethylene within 20-30 days), but the anaerobic bioreactor would become too large and expensive to provide an alternative for the normally used air stripping for removing VOC from groundwater and activated carbon filtering of the contaminated air phase. However, due to coincidence and additional measurements Bioclear discovered a high biodegradation potential in the effluent stream: if PCE was added to the effluent biodegradation took place quite fast. The effluent contained a fair amount of DHC, and therefore the “groundwater treatment bioreactor” was transformed to an “on-site inoculation bioreactor”, providing bacteria on site to inoculate the soil/groundwater matrix. Thereby using the VOC contaminated groundwater from the site as feed to the on-site bioreactor to cultivate DHC bacteria. This concept has been perform full scale in 2000 at the Hoogeveen site, and has been successful

since then on more than 15 VOC sites, both in the Netherlands and Denmark. For the international market the technology is called BEAT® (Bioreactor Enhanced Augmentation Technology) (formerly known in the Netherlands as “TCE”).

The BEAT technology is used for large scale groundwater remediation applications, in which the bioreactor is used for augmenting the soil/groundwater, normally for 3-6 months. Besides inoculation carbon sources are added to the groundwater to provide growing potential to the bacteria (increasing the amount of DHC within several months) and provide sufficient electron donor for both redox changes in the groundwater and electrons/H2 for reductive dechlorination of the VOCs. Treated sites with BEAT often consist of up to 500,000 m3 of groundwater volume and an active phase – injection of biomass and carbon sources – of 3-9 months. In more than 90% of the cases very low residual concentrations (below 5 µg/l) of VOC is reached.

Based on this technology the aforementioned ATES+ was developed. For ATES+ even more concentrated biomass is needed and addition of carbon source is prevented. Therefore a new 10 m^3 anaerobic bioreactor was build, that is capable of providing 10^{10} DHC cells/liter.

Aims of the pilot study

The aim of the pilot in Utrecht is to determine whether a high concentrated biomass culture, that is injected nearby an existing and running ATES system, leads to groundwater quality improvement without negatively interferring with the ATES system.

2.2 Site depiction and pilot design

The pilot study discussed in this report is located at the Nieuw Welgelegen sports facility, Grebbeberglaan 3, Utrecht, the Netherlands (Figure 3). The 3 ATES mono-wells and B45 monitoring well were already present. The ATES installation was initially designed for energy supply only. To facilitate the pilot study and stimulate in-situ bioremediation at ATES sites, an injection well and a monitoring well were installed (Figure 4). A more detailed aerial photograph of the ATES-3 mono-well, bioaugmentation injection well and monitoring well is shown in Figure 5 and a schematic representation of the pilot is provided in Figure 6. For simplicity the ATES-3 warm (shallow 27-32 m) and cold (deep, 52-57 m) wells will hereafter be referred to as ATES-3 27 m and ATES-3 52 m.

Although Figure 2 shows the presence of a clay layer at approximately 40 m depth, the soil profiles of the ATES wells, injection and monitoring well (Appendix 1) do not show any evidence of this clay layer, and it is assumed that the clay layer resides deeper than 57 m in this area.

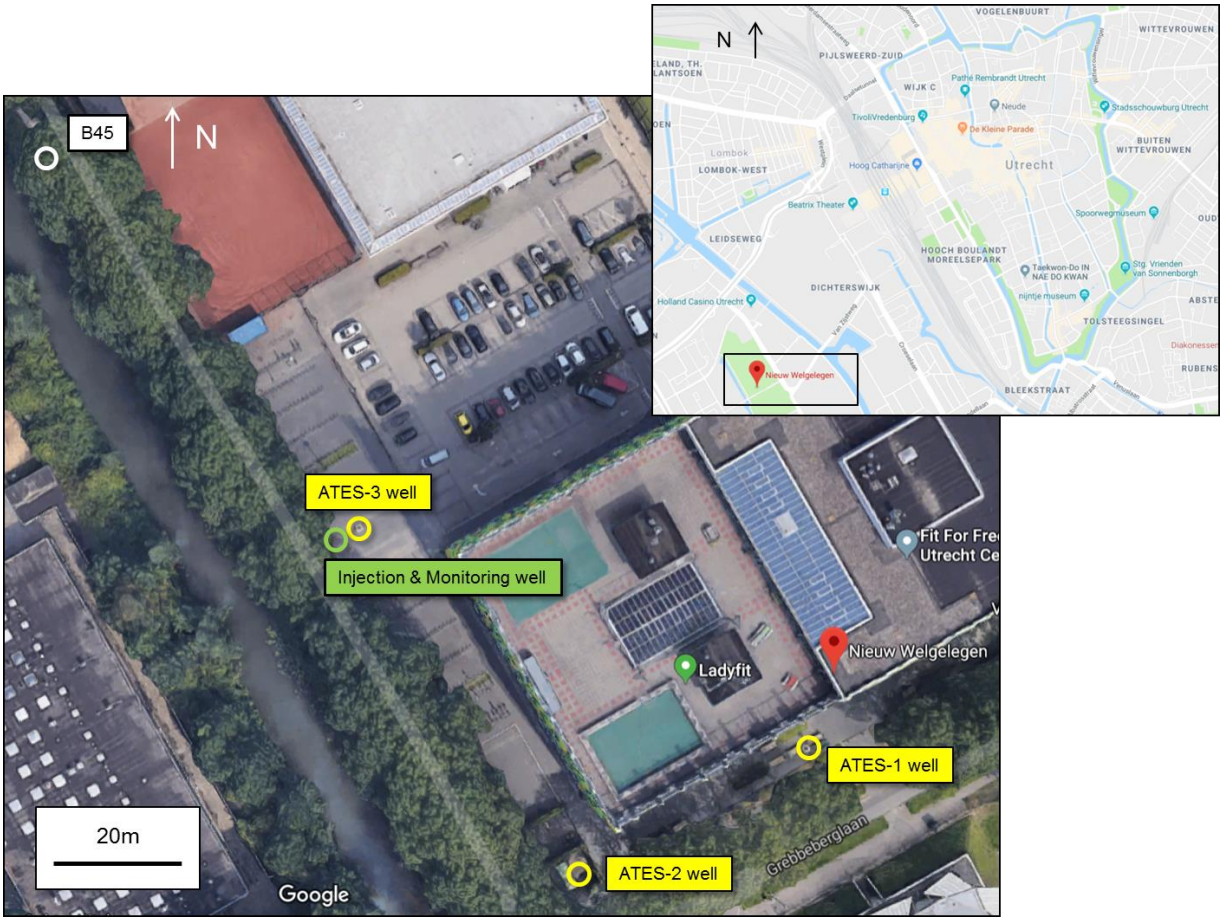


Figure 3: Location of the Nieuw Welgelegen sport facility in Utrecht, the Netherlands, and the 3 ATES mono-wells.

Figure 4: Installation of the monitoring well

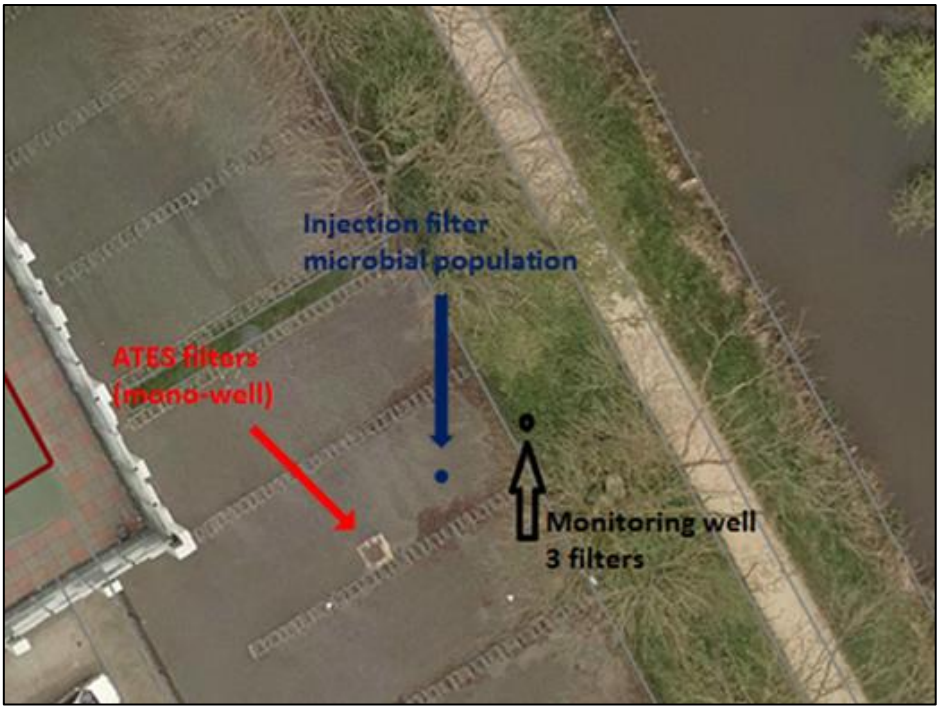


Figure 5: Location of the ATES-3 mono-well, bioaugmentation injection well and monitoring well. Note the different orientation of Figure 5 in comparison to Figure 3.

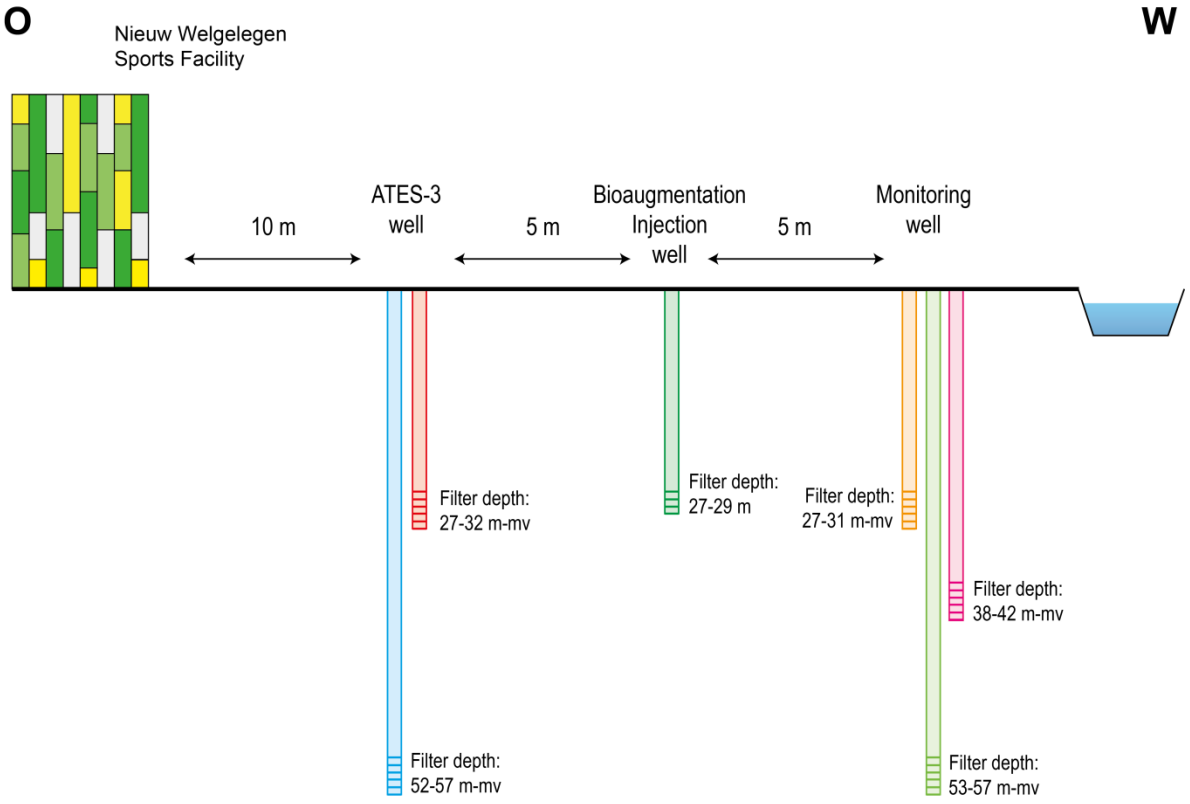


Figure 6: Schematic diagram of the Nieuw Welgelegen sports facility, ATES-3, the bioaugmentation injection well and monitoring well. Depths are given in m below ground level (m-mv). See Aappendix 1 for soil profiles. Monitoring filters were capped with a bentonite seal. Injection borehole well was refilled with clay from 27 m bgl to ground level.

2.2.1 Rationale behind the location of the injection and monitoring well

Before the installation of the injection and monitoring well, hydrogeological design calculations were performed to ensure the wells were placed at suitable locations.

The ATES-3 mono-well and bioaugmentation injection was modelled using a 12.5 by 12.5 m grid which included a quarter of the ATES' area of influence (Kiefte, 2009), and half of the injection influenced area assuming symmetry. In the model, the injection was placed 5 m north of the ATES well and the observation well was placed 10 m north of the ATES well, based on site lay-out.

The reported ATES data consists of monthly averaged pumped volumes from 2013 onwards. For the period July until September average well rates were obtained and used in the model. The warm well screen was set at 26–31 m in the model and the cold well screen is at 49–58 m. The well rates were divided by a factor 4 as only a quarter of the ATES influence area was modeled.

The number of model layers is 48 starting at 1 m below surface level. Until 19 m below surface level the layers are 2 m thick. Below 19 m, the layers are 1 m thick until 57 m – surface level. At 47 m below surface level a 0.5 m clay layer was encountered (see Appendix 1). There, two layers of 0.5 m were used with the upper layer representing clay.

The hydraulic conductivities used were 20 m/day for the sand layers and 0.01 m/day for the clay layer. Longitudinal dispersivity was set relatively high at 0.25 m, but any overestimation of mixing due to dispersion is assumed not to be a problem as it is mainly used to derive the minimum concentration needed during injection.

To simulate the bioaugmentation process, a 5 m^3 injection was modeled assuming injection can occur within 1 hour. It was also assumed that the ATES is running during the injection. The injection depth was set at 25–27 m below surface level. The observation well 5 m downstream has the same screen depth. Injection concentration was set at unity.

Modeling results

Figure 7 shows contour lenses at 26 m below surface, directly after the injection (left) and after 10 days (right).

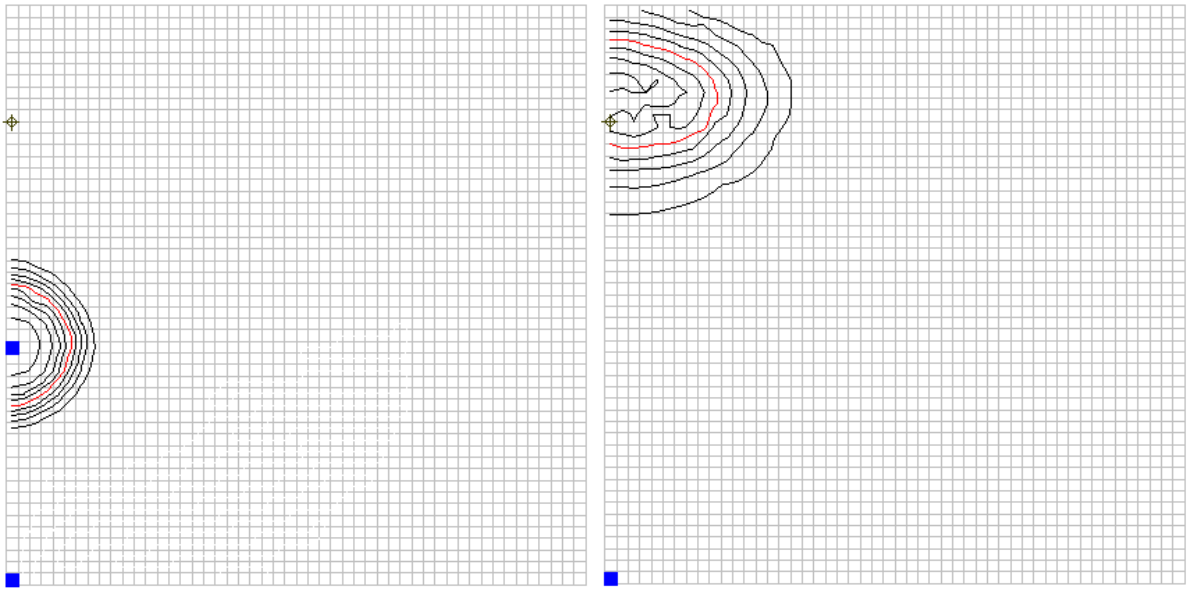


Figure 7: Concentration at 26 m below surface level: left after 1 hour (end of injection) and right after 10 days contour lines have steps of 0.1 (left) and 0.02 (right) of and the red contour line is 0.5 (left) and 0.1 (right). Blue squares represent the location for the ATES well and the injection well when active. The observation well is shown as the black 'target' sign.

A cross section profile after 8 days is shown in Figure 8. Figure 8 shows that the plume is also present several meters above and 1 m below the screen depth of the observation well. The

observation well is located at the same depth as the upper cell of the ATES well (given in blue) and 1 m (= 1 model layer) above as well. It indicates that some difference in the flow direction due to heterogeneity will not directly result in a wrongly positioned observation well.

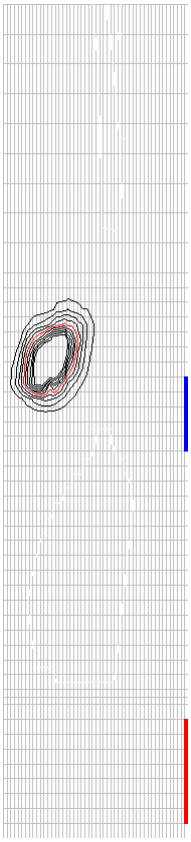


Figure 8: Cross-section after 8 days; contour lines have steps 0.02 right of and the red contour line is 0.1.

The predicted time series in the observation well is shown in Figure 9.

The modeling results suggest that it will take approximately 8-10 days for a 5 m^3 injection to reach the monitoring well, if these wells are placed at 5 and 10 m from the ATES-3 mono-well. As 8-10 days is a suitable time period to monitor the progress of the injection, these distances were maintained during the installation of the wells.

However in reality, the breakthrough time will strongly depend on the actual ATES extraction and injection rates. In this case the average over 4 years during the period July-September was used, but extraction and injection rates will strongly depend on the daily temperatures, solar radiation and show fluctuation during the day as well.

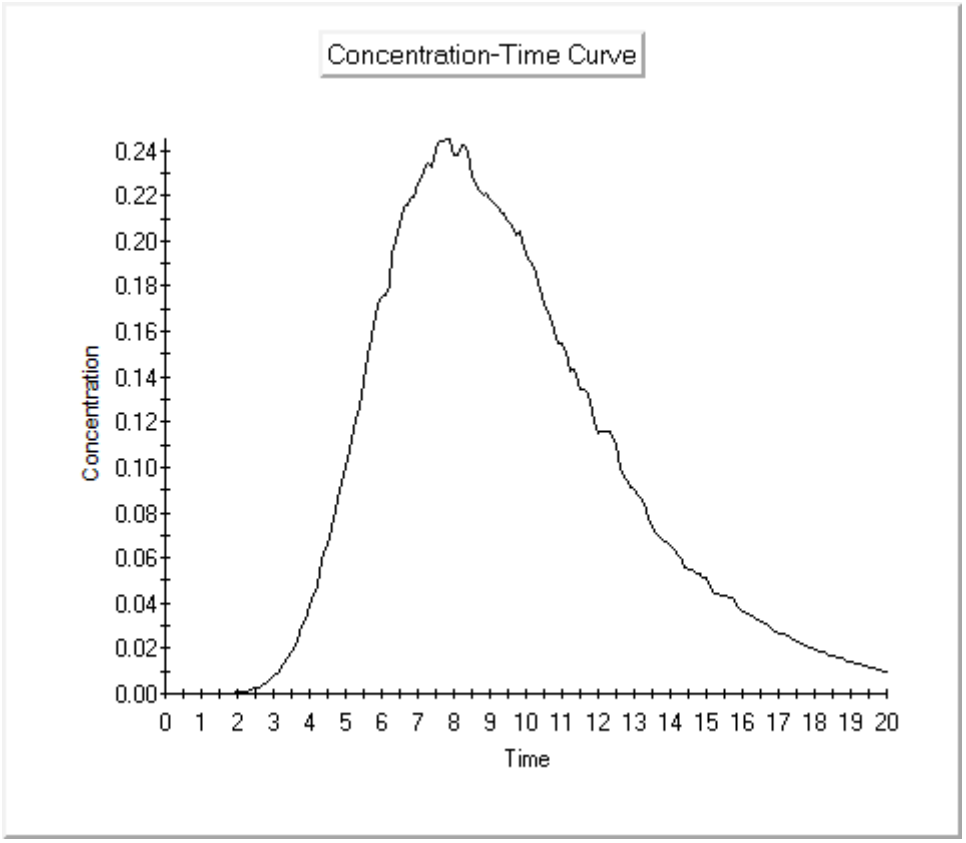


Figure 9: Predicted concentrations at the monitoring well with time in days and concentration relative to the injection concentration.

2.3 ATES system installation and operation

The Nieuw Welgelegen ATES installation is supplying heat and cold to the sports facility by 3 separate mono-wells. In these mono-wells the warm water storage is always positioned above the cold water at sufficient distance to prevent potential mixing (Figure 10). The filters have been placed between 15 and 60 meter below ground surface (Appendix 1). Injection and abstraction occurs in the first aquifer of the city of Utrecht (Kiefte, 2009). The ATES system at Nieuw Welgelegen was installed in 2009 and has been in operation since. The average yearly groundwater displacement is approximately 211,340 m^3 (Kiefte, 2009). The injected groundwater during winter has a temperature of 9.0 °C and during summer the injected water temperature is 14.0 °C (Kiefte, 2009). Model calculations indicate that the phreatic groundwater table and deeper aquifers are not influenced by the ATES system, and the change in hydraulic head is less than 5 cm at a distance of 30 m away from the mono-wells (Kiefte, 2009).

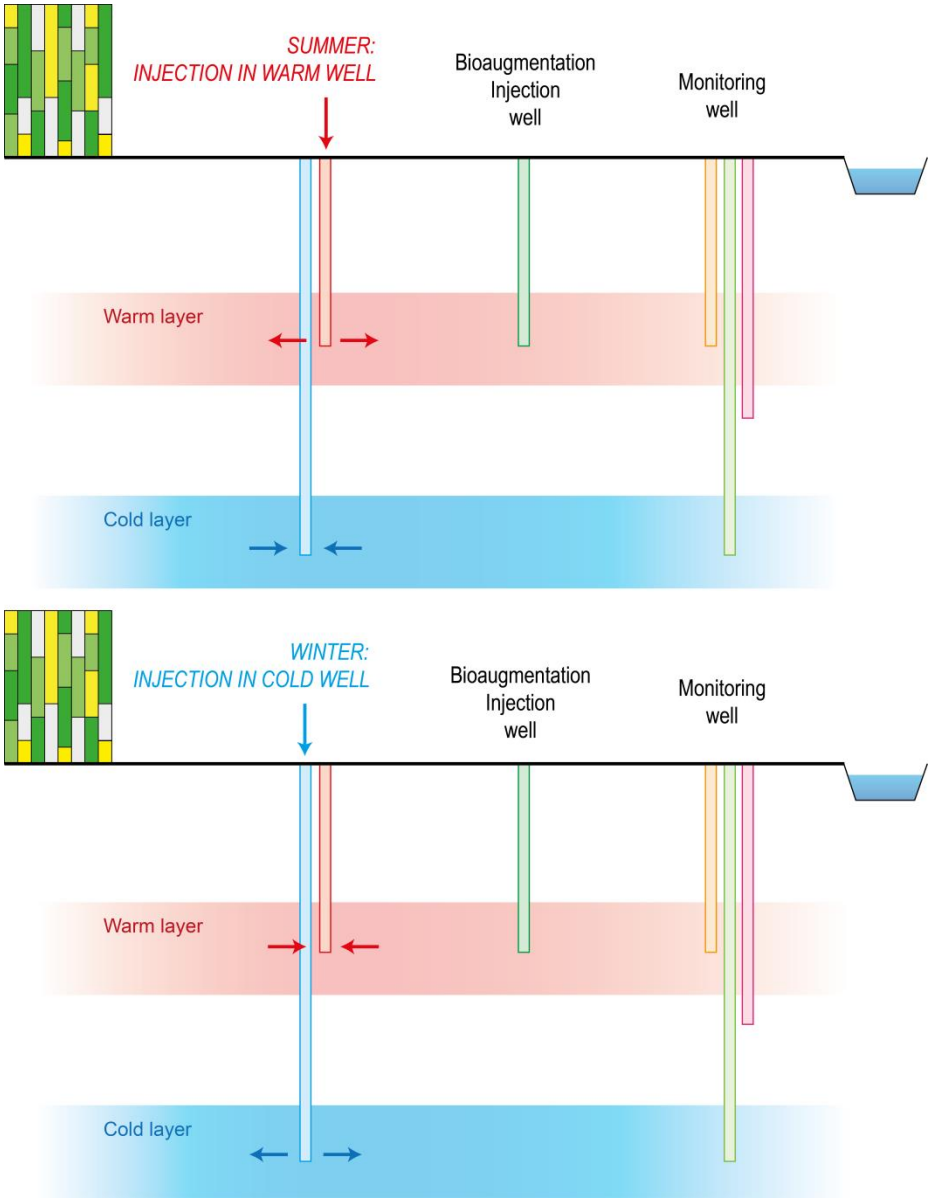


Figure 10: Schematic representation of the ATES system during summer and winter

Daily and monthly extraction volumes were available from May 2017, and provided by UCL groep (https://www.ulcgroep.nl/). The data is summarised in Figure 11 and Table 2. Cooling represents extraction from the cold well and injection into the warm well which occurs in summer. Loading represents extraction from the warm well and injection into the cold well which occurs in winter. A clear transition can be observed between the extraction from the hot and cold well around October 2017 and April 2018 (Figure 11).

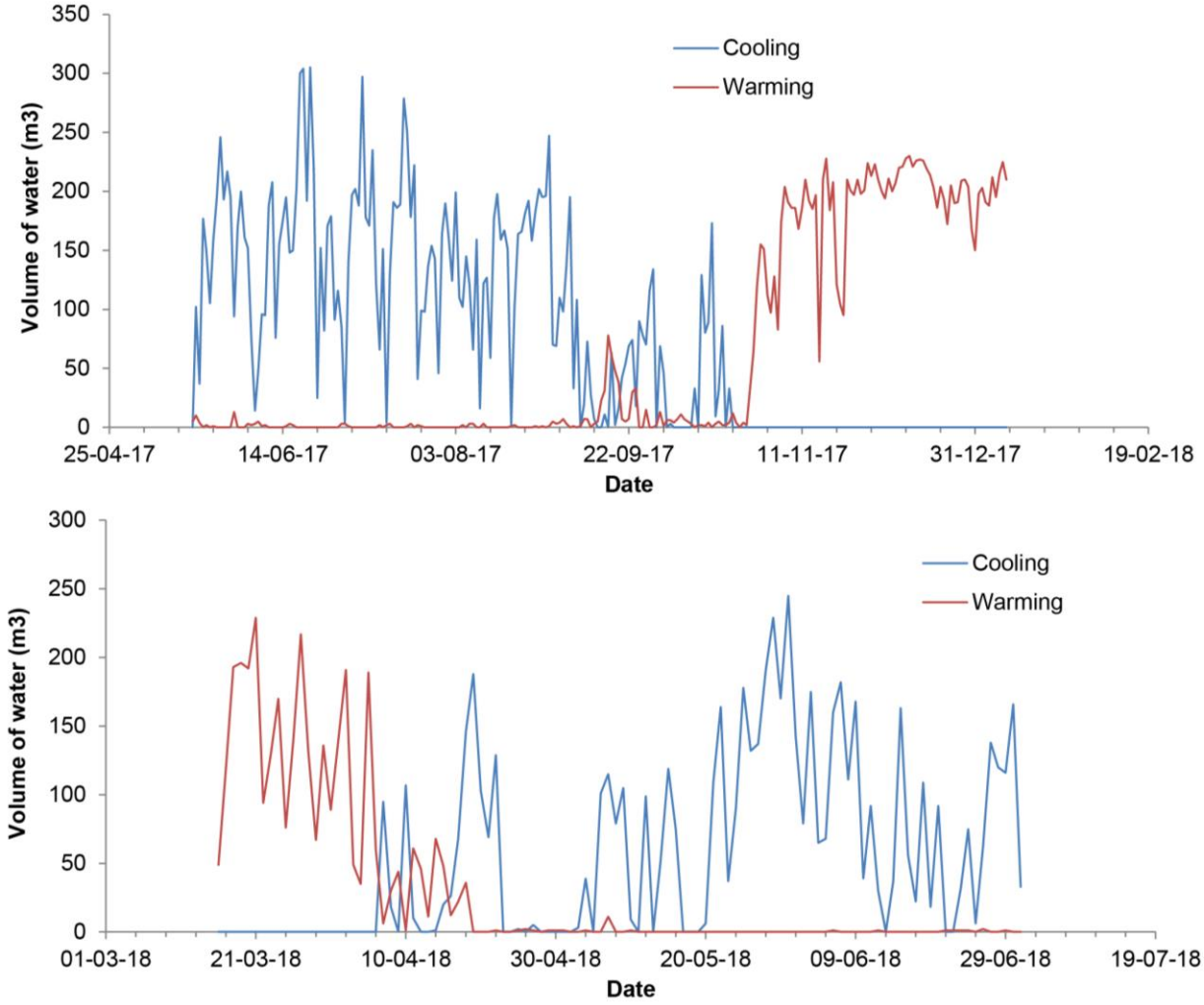


Figure 11: Extraction values in m^3/day from the ATES-3 warm well (red, 27-32 m-mv) and cold well (blue; 52-57 m-mv).

Table 2: Extraction values in m^3/month from the ATES-3 cold well (cooling) and warm well (warming)

Month	Cooling (m^3)	Warming (m^3)
May 2017	2803	852
June 2017	4643	22
July 2017	4734	21
August 2017	4419	22
September 2017	1713	419
October 2017	782	634
November 2017	0	5146
December 2017	0	6374
January 2018	0	5632
February 2018	0	5804
March 2018	0	4185
April 2018	987	1054

2.4 Field activities and monitoring: bioaugmentation, tracer tests and Distributed Temperature Sensing (DST)

Table 3 and Table 4 summarise all activities and laboratory analyses that were performed in 2017 and 2018. The sampled wells are shown in Figure 3. B45 is a monitoring well approximately 40 meters north of the ATES system, located along the canal (Figure 3).

Groundwater samples were taken in February and April 2017 to determine (i) the presence and initial concentrations of chlorinated solvents, and (ii) the background concentrations of bacteria (in particular DHC).

From the 12th of July 2017, the bioaugmentation injection well was used for the injection of tracers including fluorescein, rhodamine, Na, Br, Li and Cl (Table 3, Table 4). The first tracer test using fluorescein, Na, Br, Li and Cl was performed on the 18th of July 2017. Injection of the DHC culture was executed on the 26th and 27th of July, 2017. A total of 4 m^3 was injected over two days (6 hours per day). The injected biomass medium included the components: KH_2PO_4, NH_4Cl, Yeast Extract 50%, NaLactate, NaAcetate TRI and vitamin B12, B1 and H/B8. The mix also included inert elements that could be used for tracers including: cobalt chloride (4 mg/l) and sodium molybdate (0.2 mg/l) to monitor the pathway of the bacteria (second tracer test). The bacteria were monitored by DNA analysis of groundwater samples.

In addition, soil in-situ mesocosms were placed in the injection well, which were sampled to determine the fraction of bacteria attached to the soil matrix. Mesocosms are small containers that hold a sample of site related soil. These small containers are placed at the various filter depths in the monitoring filters and injection filter. Groundwater will flow through/around these containers and bacteria may be attached to the soil particles in the mesocosm. By removing and measuring the mesocosm content on total and specific biomass, the (increasing) attachment of organisms can be followed. Mesocosms for Utrecht were prepared using a soil sample taken at a depth of 28 m-gl during placement of the injection well. Extraction of attached DNA was followed by using molecular analysis on e.g. specific DHC organisms and vcrA genes.

A third tracer test was performed with the pigment rhodamine, K and Cl, on the 28th of July 2017. After the bioaugmentation and tracer tests in July-August 2017, monthly monitoring and sampling rounds were performed.

Because of questions that arose concerning the groundwater flow paths, a fourth tracer test was performed in June 2018 with NaBr, LiCl and fluorescein (Table 4). Monthly monitoring and sampling continued until September 2018.

Monitoring of the subsurface temperature was performed from 17/08/2017 to 4/10/2018 by Distributed Temperature Sensing (DTS) using glass fibre optical cables. This technique enables continuous monitoring with high temporal and spatial resolution, and has been previously applied in different ATES system located in Utrecht, de Uithof (Sommer et al., 2015a). This study showed that from the temperature profile the flow pattern of the warm and cold water could be determined in much larger groundwater volume than possible before by only temperature measurements in the injection and extraction wells. Further details on the DTS fibre optics methodology can be found in Sommer (2015b).

Table 3: Overview of activities and analyses during 2017

Date	Activity	pH, EC, T, Redox, O_2	Analysis						Visual tracers (pigments)		Location (wells)
			COCs	Anions, Cations	TOC	Bacteria/DNA GW	Bacteria/DNA soil	H_2	Fluor	Rhod	
08-02-17	Monitoring & Sampling										*ATES 1-3, B45*
19-04-17	Monitoring & Sampling										*ATES 1-3*
	Placement of monitoring and injection well										
12-07-17	Monitoring & Sampling										*ATES-3, Injection, Monitoring*
18-07-17	**Injection of Fluorescein, NaBr and LiCl**										***Injection (tracer test 1)***
21-07-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
24-07-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
26-07-17	**Injection of DHC culture, monitoring round**										***Injection (tracer test 2)***
27-07-17	**Injection of DHC culture**										***Injection (tracer test 2)***
28-07-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
28-07-2017	**Injection of Rhodamine and KCl**										***Injection (tracer test 3)***
31-07-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
02-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring, B45*
04-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
07-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
10-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
17-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
28-08-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
22-09-17	Monitoring & sampling										*ATES-3, Injection, Monitoring*
13-12-17	Monitoring & sampling										*ATES 1-3, Injection, Monitoring B45*

COCs: Chlorinated Organic Compounds, Bacteria/DNA soil: samples taken from soil samples that were placed in the bioaugmentation injection well as mesocosms, see section 2.4

Fluor: fluorescein, Rhod: rhodamine

Table 4: Overview of activities and analyses during 2018

			Analysis						Visual tracers (pigments)		
Date	Activity	pH, EC, T, Redox, O2	COC	Anions, Cations	NPOC	Bacteria/DNA GW	Bacteria/DNA soil	H2	Fluor	Rhod	Location (wells)
14-03-18	Monitoring & sampling										*ATES-1-3, Injection, Monitoring, B45*
04-06-18	**Injection of Fluorescein, NaBr and LiCl** *(groundwater samples taken prior to injection)*										*ATES-3, Injection, Monitoring*
05-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
06-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
07-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
08-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
09-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
10-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
11-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
12-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
13-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
14-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
15-06-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
04-07-18	Monitoring & sampling										*ATES-1-3, Injection, Monitoring, B45*
08-08-18	Monitoring & sampling										*ATES-3, Injection, Monitoring*
11-09-18	Monitoring & sampling										*ATES-3, Injection, Monitoring, B45*

COCs: Chlorinated Organic Compounds, Bacteria/DNA soil: samples taken from soil samples that were placed in the bioaugmentation injection well as mesocosms, see section 2.4

Fluor: fluorescein, Rhod: rhodamine

3 Results and discussion

3.1 Background concentrations of COCs and DNA

As mentioned in section 2.1, VC was present at fairly low concentrations in the ATES wells (0.3–6.6 µg/L). In B45, higher VC concentrations were found (0.5–62 µg/L). Apart from VC, no other COCs were detected (Appendix 3).

Bacteria, including *Dehalococcoides*, were present in all three ATES wells during the sampling round of April 2017. Total bacteria count varied from $2.6x10^4$ to $7.5x10^4$gene copies/mL groundwater. Apart from the shallow filter of ATES-3, DHC was detected in all samples, albeit at low concentrations (8.7–69 gene copies/mL groundwater). The genes vcrA and VC anaerobic were also present (ranging from 2.24–144 gene copies/mL groundwater), but bvcA was not detected. On the 12th of July, just before the bioaugmentation, total bacteria count was an order of magnitude higher, but the DHC, vcrA and bvcA genes were not detected in the groundwater samples (Appendix 4).

The background concentrations of DHC and vcrA were also determined in the soil used for the mesocosms. Soil samples for these analyses were taken at 28 m depth during placement of the bioaugmentation injection filter. Results show that the concentrations of DHC and vcrA in this soil sample were below the detection limit of 1300 gene copies/g soil, indicating that the actual soil matrix hardly contains VOC degrading microorganisms for the reductive dechlorination route This also represents time zero (starting) point, before augmentation.

3.2 Tracer tests

3.2.1 Fluorescein and rhodamine

The pigment fluorescein was added as a visual tracer and the absorbance was measured at each time period during the tracer test of 2017 and 2018 (Table 3, Table 4). In 2017, fluorescein was detected in the shallow, middle and deep filters of the monitoring well on the 24th of July, 6 days after the injection. The pigment rhodamine was not detected in the monitoring well during the third tracer test (Table 3), presumably since this tracer – used in surface water tests – adsorbs to the soil too much.

In 2018, during the fourth tracer test, fluorescein was detected in the shallow filter of the monitoring well on the 10th of June, 5 days after the injection (Figure 12). Two days later the pigment was detectable in the deep filter of the monitoring well (Figure 12). Fluorescein was not detected in the middle filter of the monitoring well. Measurements were performed over a period of 12 days, which is likely insufficient to observe the breakthrough of fluorescein in the middle filter, as it took 23 days for fluorescein to be detected in the middle filter during the 2017 tracer test.

Fluorescein was not detected in the ATES-3 wells, nor was rhodamine.

Figure 12: Fluorescein pigment in the groundwater samples taken during the 2018 tracer test, from the 4th of June until the 13th of June. In every photograph the groundwater sample bottles are placed in the same order, which is shown and labeled in the top left photograph.

3.2.2 NaBr and LiCl

The injection of conservative ions such as Cl, Br and Li can be used to monitor the groundwater flow and the spreading behavior of the injected biomass. As discussed in section 2.5, four tracer tests were performed in 2017 and in 2018. On the 18th of July 2017, NaBr and LiCl were injected,

prior to the injection of the DHC culture, which was performed on the 26th and 27th of July (Table 3). The DHC culture consisted of biomass and growth medium, which introduced a second source of Na and Cl (see section 2.4). The results of the 2017 tracer tests are shown in Figure 13. Different from expectations, also the deeper filters were impacted.

From the Li concentrations it can be observed that it took 3–6 days of travelling time to reach the upper filter (27-31 m) of the monitoring well (Figure 13B). This is shorter than the initially estimated 8–10 days (section 2.2.1), which indicates that the hydraulic conductivity may have been underestimated in the modeled calculations, or that preferential flow paths are present. Average ATES injection rates used in the model calculations could also be an underestimation of the actual injection at the time of the bioaugmentation and tracer tests.

The concentrations of Na and Cl were likely too low to observe a breakthrough that exceeds the background concentrations. However, a travel time of 5–6 days is also evident from the Cl and Na concentrations which were introduced during the DHC culture injection, serving as tracer test 2, which show a breakthrough on the 1st of August, 6 days after the injection date (Figure 13B). In the deepest filter of the monitoring well (53-57 m), an increase in Li, Cl and Na is observed on the same day as in the upper filter, but concentrations are lower (Figure 13D). For example in the upper filter, Cl concentrations reach 476 mg/L, whereas in the deepest filter the maximum Cl concentration is 142 mg/L. The second, middle filter of the monitoring well (38-42 m) does not show the same trend as the shallow and deep filters (Figure 13C). No breakthrough curve is observed for Na and Cl, and concentrations remain within the range of background values (baseline). The Li concentrations increase from 0.03 mg/L to 0.07 mg/L between 24/7/2017 and 26/7/2017 (Figure 13C), but as there is no clear breakthrough curve these results need to be treated with caution.

In 2018, the tracer test was performed with higher concentrations of NaBr and LiCl (Figure 14). Groundwater samples were taken daily for a period of 10 days, to provide a higher frequency of monitoring points in comparison to the tracer tests of 2017, in order to find possible preferential flow pathways, suggested by DHC-monitoring results (as shown further on)

Figure 14B shows that it took 5-6 days for Cl, Br, Li and Na to reach the upper filter of the monitoring well. The anions Cl and Br show a very similar pattern (Figure 14B) whereas the Li concentrations show a two-step increase. In contrast to the upper filter, results of the lower filter show different arrival times for the anions and cations. Br concentrations increase after 5-6 days, whereas it takes 7-8 days before Cl and Li concentrations exceed background values (Figure 14D).

Li, Br and Na do not show a significant increase above baseline concentrations in the middle filter of the monitoring well (38-42 m) (Figure 14C). A gradual increase in Cl concentrations is observed, which is different to the trends detected in the upper and lower filters (Figure 14B, 14D).

Concentrations in the ATES-3 well

During the 2017 and 2018 tracer tests, anions and cations were also monitored in the shallow and deep filters of the ATES-3 well (Figure 15). Results of the 2017 tracer test show a tiny increase Cl above the background concentrations (up to 102 mg/L, background values are up to 99 mg/L) directly after the DHC culture injection (Figure 15A, 15B). However this increase is not observed in the other conservative ions (Figure 15A, 15B). In 2018, Cl, Li, Br and Na did not show any increase above the background concentrations in the shallow and deep filters of the ATES-3 well (Figure 15C, 15D).

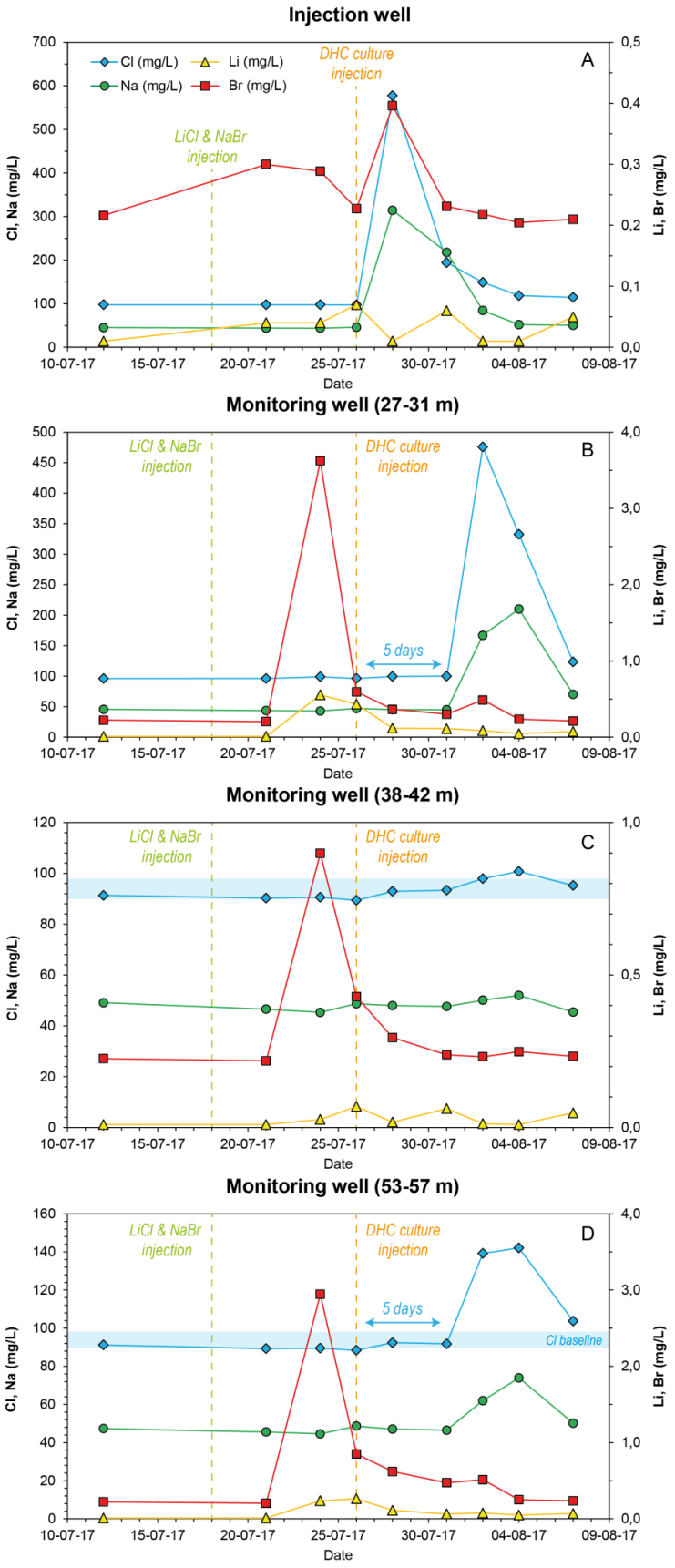


Figure 13: Concentrations of Cl, Na, Li, Br in the bioaugmentation injection well and monitoring well prior to and after the tracer test of 2017.

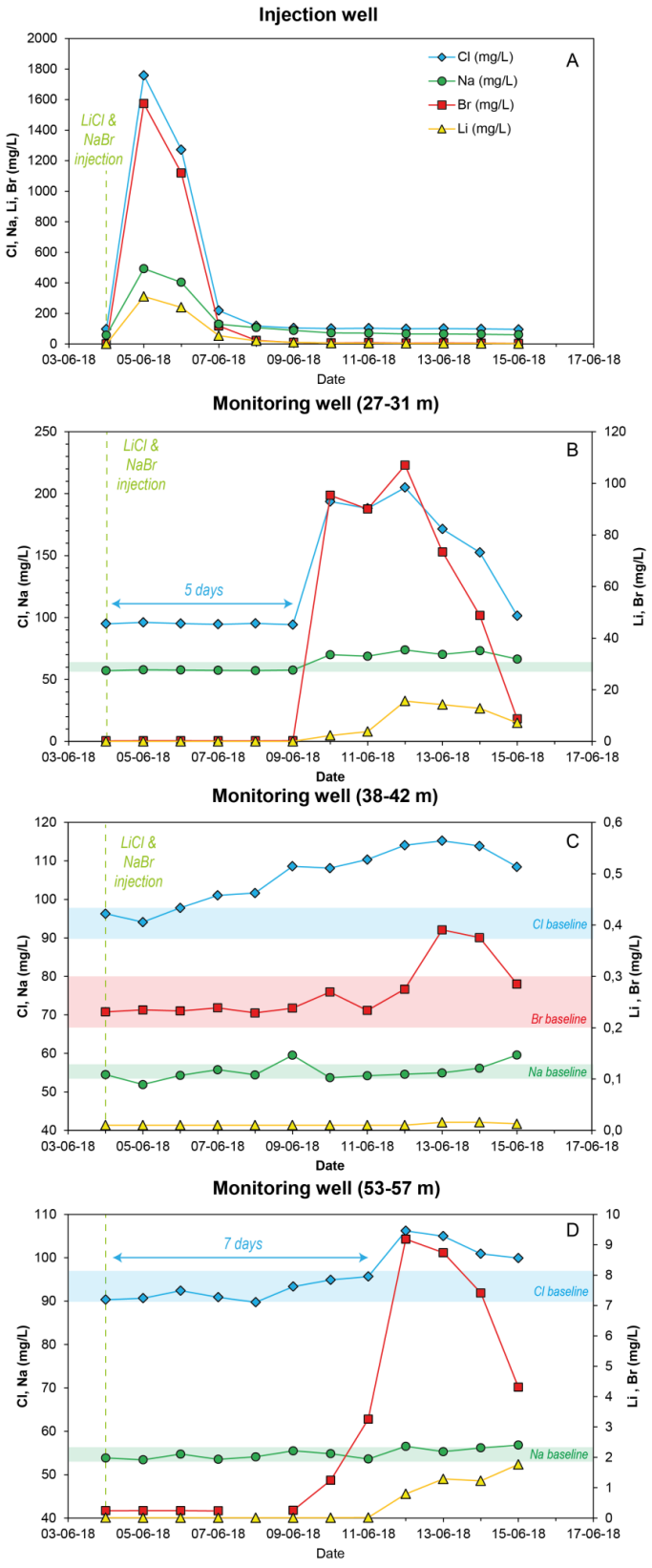


Figure 14: Concentrations of Cl, Na, Li, Br in the bioaugmentation injection well and monitoring well during the tracer test of 2018. Cl baseline and Na baseline represent the concentration range (min-max) prior to injection. The baseline of Li is taken as 0.01 (detection limit) and Br has a baseline of 0.2–0.3 mg/L.

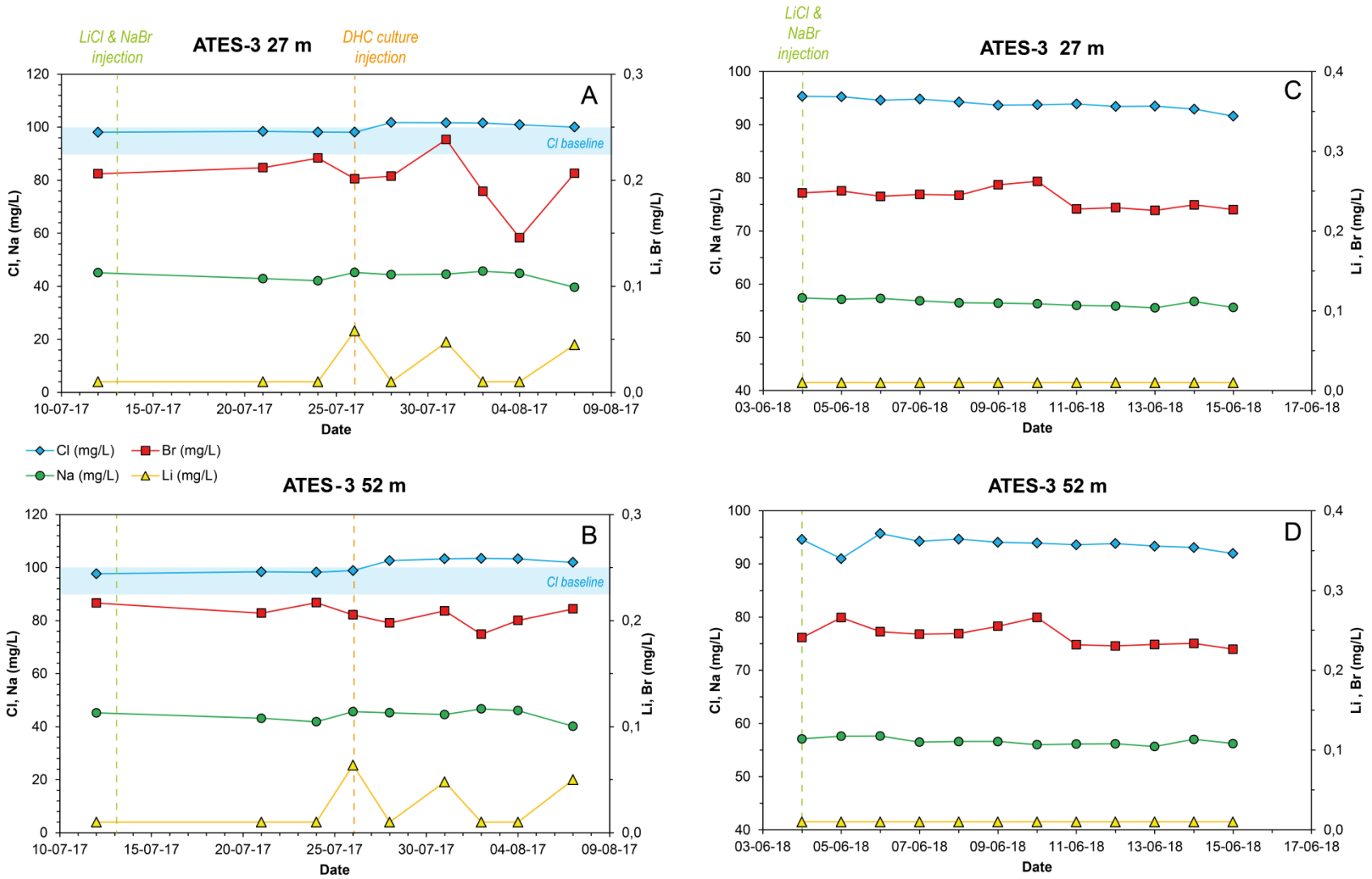


Figure 15: Concentrations of Cl, Na, Li, Br in the ATES well during the 2017 and 2018 tracer tests

3.2.3 Reactive ions

Figures 16 and 17 show the concentrations of K, PO_4, NH_4 measured after the DHC culture injection (serving as tracer test 2) in the injection well and the shallow filter of the monitoring well. An increase in K, PO_4 and NH_4 is observed on the 28th of July in the injection well (Figure 16).

In the shallow filter of the monitoring well, a peak in PO_4 concentrations is observed on the 7th of August (10-11 days after injection) and maximum NH_4 concentrations occur on the 10th of August (13-14 days after injection) (Figure 18).

On the 4th of August 2017 (7-8 days after injection), an increase in PO_4 (from 0 to 15 mg/L) is observed in the deepest filter of the monitoring well. This trend is not observed for K and NH_4, where an increase in concentrations is observed much later; on the 28th of August in the deep filter.

The oxygen content of the groundwater did not show any major variations. Concentrations range between 0.01 and 0.4, with an average O_2 concentration of 0.05 mg/L. A few outliers are present in the dataset, with values ranging from 0.26 to 1.19 mg/L (Appendix 2).

No changes in K, NH_4 and PO_4 concentrations were observed in the ATES-3 wells and the middle filter of the monitoring well.

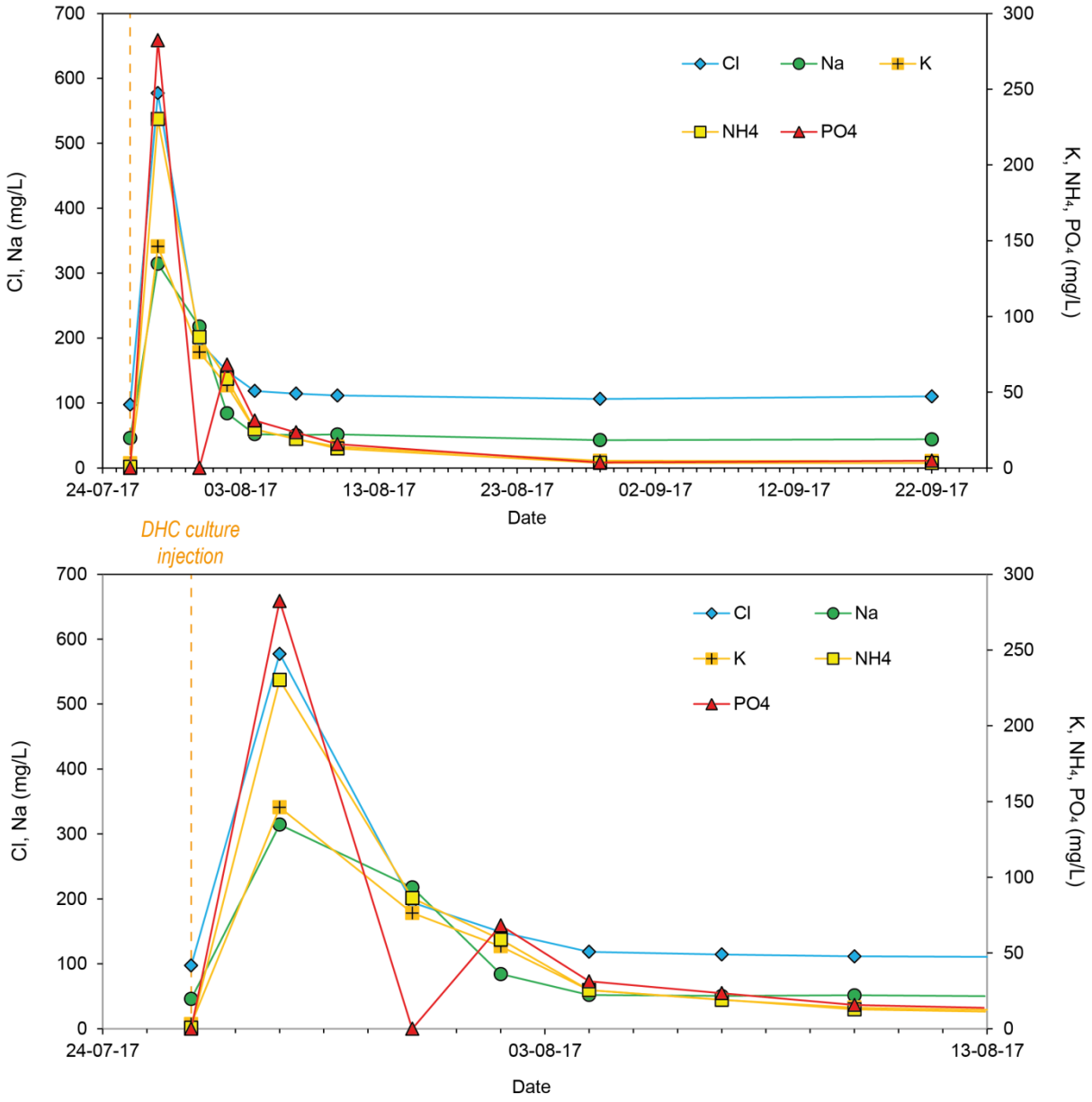


Figure 16: Concentrations of Cl, Na, K, NH4 and PO4 in the injection well, showing different time periods. The top graph shows measurements until the 22nd of September and the bottom graph until the 10th of August 2017, for details.

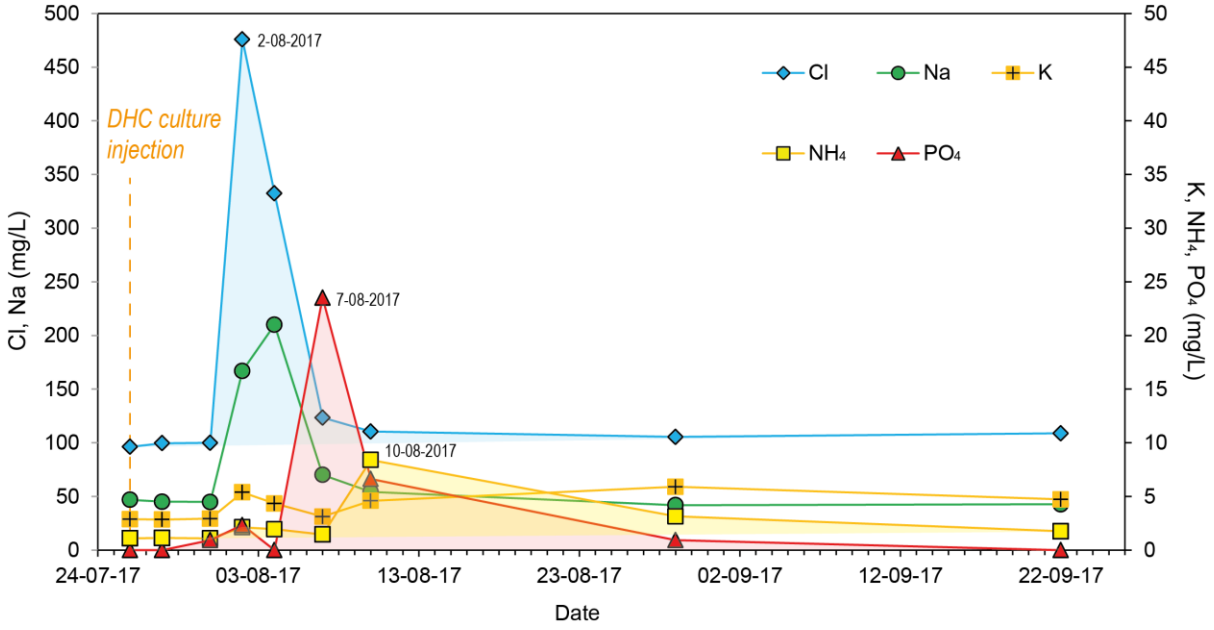


Figure 17: Concentrations of Cl, Na, K, NH4 and PO4 in the monitoring well (27-31 m). Shaded areas are shown to highlight the change in shape of the breakthrough curves of the reactive ions PO_4 (red) and NH_4 (yellow) with respect to the conservative ion Cl (blue).

3.2.4 Insights into groundwater flow patterns from tracer tests

The 2017 and 2018 tracer tests were performed in summer, during which warm water is injected in the shallow ATES-3 well at 27-32 m depth (Figure 10). This will have a strong influence on the groundwater flow patterns and travel times, and the filters of the injection well and monitoring well were placed at the same depth to monitor this effect. The ATES injection volume during each tracer test is listed in Table 5 and the volumes of each tracer test are listed in Table 6. As shown in Table 6, the injection volume during tracer test 2 is greater than during tracer test 4.

Table 5: ATES extracted/injected volumes during the tracer tests

Tracer test	Start	Breakthrough of Cl	Breakthrough of Li	Injection volume at ATES-3 27-32m during this period (m^3)
1	18-07-2018	-	24-07-2017	1159
2	26-07-2017	02-08-2017	-	992
4	04-06-2018	10-06-2018	10-06-2018	793

The Cl concentrations from 2017 and 2018 are consistent and indicate a travel time of 5-6 days. Li concentrations from 2017 indicate a travel time of 3-6 days, whereas during the tracer test of 2018 Li follows the same trend as Cl and shows a breakthrough after 5-6 days. Reason for the discrepancy is unclear, but due to the lower concentrations of the 2017 tracer tests (Table 6), it is likely that the travel times of the 2018 tracer test are more reliable, especially considering that Cl, Br, Na and Li all show a breakthrough after 5-6 days (Figure 14B).

Table 6: Concentrations and volumes that were injected during the tracer tests

Tracer test	Mass Cl injected (g)	Injection volume (L)	Concentration in injection well (mg/L)
1	42.5	50	Below baseline (<100)
2	528.8	4000	600
3	-	-	
4	833	100	1800

The shape of the breakthrough curve of Li indicates that it is retarded in comparison to Cl and Br (Figure 14B). Cl and Br are both anions, and it is possible that the positively charged Li ions are retarded due to interactions with negatively charged clay particles.

The results from the three filters in the monitoring well suggest the presence of an impermeable layer that resides at the depth of the middle filter (38–42m), as a breakthrough curve is not observed at this depth in neither the 2017 or 2018 tracer tests. However, a breakthrough curve is seen in the deepest filter which suggests that the impermeable layer is discontinuous and water can flow around it. From previous field works it was suggested that seepage occurred from the upper filter to the deepest filter, so an alternative explanation would be an (unexpected) downward movement of the water due to seepage along the well (short circuit flow within the monitoring well).

Table 7: Travel times observed in the middle and deep filters of the monitoring well, for the conservative and reactive tracers

Well	Conservative tracers (Cl, Na, Li, Br)	Reactive tracers (K, PO_4, NH_4)
	Travel time (days)	*Travel time (days)*
M 27-31	5-6	10-25
M 53-57	5-7	31

Throughout all tracer tests, the ATES-3 wells were monitored to evaluate groundwater flow and a potential connection between the injection well and ATES-3 wells. During the second tracer test a slight increase in Cl was observed in the ATES-3 wells, a day after the injection. During the fourth tracer test, where the injected concentrations were higher (Table 6), no increase in Cl was observed in the ATES-3 wells (Figure 15). This suggests that the greater volume that was injected during tracer test 2 (4000L in comparison to 100L) impacted the flow patterns. The most likely explanation is that an injection of 4000L invoked interference with the zone of influence of the deep ATES-3 well, which is used for extraction during summer. In contrast, the 100L injection of tracer test 4 was still insufficient to enter the zone of influence of the deep ATES-3 well, and hence no effect was observed in the Cl, Na, Li and Br concentrations.

Potassium, Phosphate, Ammonium, Oxygen and Hydrogen are all present in the medium of the DHC culture and are involved in different biological processes related to energy

production and/or growth of biomass. In contrast to the conservative tracers of which the amount is constant after injection in the system, the concentrations of these compounds may decrease or increase depending on the processes they are involved in. For example phosphate and ammonia will be depleted during biomass growth.

From Figure 17 it is evident that PO_4 and NH_4 are retarded in comparison to Cl, as the breakthrough curves occur a few days after the breakthrough curve of Cl. In the deep filter of the monitoring well, an increase in K and NH_4 is observed approximately a month later (28th of August 2017), but this increase is not observed for PO_4. It remains difficult to interpret these trends due to the possibility of leakage along the monitoring well from the upper filter to the deepest filter. What can be concluded is that the retardation seems to be greater for NH_4 than PO_4.

The percentage of NH_4 and PO_4 that is measured in the monitoring well is approximately 2-4% of the initial concentration that was measured at the injection well on the 28th of August 2017. In contrast, the percentage of Cl found in the monitoring well is more than 80% of the initial concentration. These results provide a good indication that the majority of the nutrients are retained within a 5 m radius of the injection well.

3.3 Redox potential and redox sensitive compounds

Redox parameters such as O_2 and the redox potential were measured during the monitoring rounds to provide insights into the potential redox processes that can occur. Low oxygen concentrations and a redox potential lower than -100 mV indicate anoxic conditions. Thermodynamically favorable reactions under these conditions are iron reduction (-50 mV) and sulfate reduction (-220 mV) (Schwarzenbach et al. 2003). Other redox sensitive compounds such as Fe and SO_4 were also measured (Table 8). The groundwater samples from the monitoring well and ATES-3 well showed no major variations in redox potential and redox sensitive compounds. In the injection well, some variations were observed on the 28th of July, directly after the bioaugmentation process (Table 8).

Table 8: Range of redox parameters measured in the ATES-3, bioaugmentation injection and monitoring wells

Redox parameter	Background value	Observations in injection well on 28th of July 2017
Redox potential	-106 to -182 mV	**Decrease to -220 mV**
O_2	0.03−0.12 mg/L	No major changes
Fe	7−11 mg/kg	*Not measured on 28/7*
Mn	0.6−0.8 mg/kg	*Not measured on 28/7*
SO_4	41−45 mg/L	**Decrease to 8.9 mg/L**
NO_3	< 0.5 mg/L	No major changes
Other compounds		
Mg	10−12 mg/L	**Decrease to 6.3 mg/L**
Ca	122−127 mg/L	**Decrease to 19.7 mg/L**

These variations likely represent the bioaugmentation process which involved the injection of a volume of water which does not contain Ca, Mg and SO_4. However, a proportionate concentration decrease in Ca, Mg and SO_4 would be expected if the changes were solely

induced by the injection process. Other (physio)chemical processes could be occurring, but this is difficult to specify with the current data.

A decrease in redox potential indicates a shift towards (slightly) more reducing conditions. The standard reduction potential in water (E_h^0 (w)) required for the reduction of SO_4 to H_2S is -220 mV (Schwarzenbach et al. 2003), suggesting that the decrease in SO_4 could alternatively be caused by sulfate reducing bacteria. The redox potential required for the reduction of VC is theoretically lower than for the reduction of SO_4, but in reality a redox potential of -50 to -250 would be sufficient for reductive dechlorination to occur.

3.4 Monitoring of the DHC microbial culture

As discussed in section 2.4, 4 m^3 of the DHC microbial culture mix was injected on the 26th and 27th of July, 2017.

The injection period had to be spread out over two days. Despite the large injected volumes of pre-grown culture, there were no major problems with the injection. No clogging problems were observed in the bioaugmentation injection well nor at the upper monitoring well.

The presence, behavior of the DHC culture was monitored by:

1. Determining the presence of DHC, vcrA, bvcA and etnE genes within the groundwater samples (in gene copies/mL groundwater), as well as total bacteria; and
2. Determining the presence of DHC and vcrA, genes within the soil through mesocosm analysis.

For both groundwater and mesocosm samples, DNA is collected and analysed by qPCR analysis, targeting Dehalococcoides spp. and functional genes involved in the dechlorination process.

The mesocosms of 2018 were also analysed for iron and sulfur reducing bacteria to determine the abundance of DHC relative to other bacteria present in the subsurface. To provide an indication of the activity of the detected DHC cells, groundwater samples of September 2018 were additionally analysed for vPCR (DNA), to determine the number of living cells, and qPCR (RNA), to determine the number of active cells.

A summary of all data can be found in Appendix 4.

Mesocosm analysis (soil samples)

Concentrations of DHC genes in the mesocosm samples are summarised in Table 9. In 2017 mesocosms were placed in (i) the bioaugmentation injection well and (ii) the shallow filter of the monitoring well and were analysed several times throughout 2017 (Table 9). In 2018, new ('fresh') mesocosms were placed in the bioaugmentation injection well, as well as the shallow, middle and deep filters of the monitoring well. These mesocosms were analysed in July 2018 and September 2018 (Table 9).

Results show that an order of 10^7 DHC (gene copies/g soil) were present in the bioaugmentation injection well, directly after introducing the DHC culture on the 26th and 27th of July 2017. DHC gene concentrations remain at this order of magnitude until December 2017 (Table 9). Taking into account the bandwidth of the analyses (spreading between 0.5*N and 2*N) all data in the total measuring period of July until December 2017 show equal and stable amounts of DHC genes in the injection well. This seems to indicate a

stable culture that is attached to the soil 1-2 days after injection of the biomass. For vcrA similar results were found. The mesocosms of 2018 also contained DHC and vcrA genes, but concentrations were lower (Table 9).

DHC gene concentrations in mesocosms placed in the shallow filter of the monitoring well were 1-2 orders of magnitude smaller in comparison to the results from the bioaugmentation injection well. DHC concentrations were below detection limits in the shallow filter of the monitoring well during the first monitoring round. DHC genes were detected in the middle and deep filter of the monitoring well in July and September 2018.

The initially injected DHC culture contained $2*10^8$ cells/mL of *Dehalococcoides*. Assuming 1 gene copy is equal to one bacteria cell, these results suggest that approximately 20% of the introduced DHC bacteria attached to the soil matrix, 1-2 days after injection. Twelve months later, the DHC bacteria are still present in the mesocosms at the injection well at higher concentrations, suggesting the DHC population has sustained and multiplied itself (although it is not impossible that mesocosms filtrate inactive bacteria from the groundwater). In 2018, the new mesocosms were also colonised, albeit at slightly lower concentrations (10^5 DHC gene copies/g soil).

In 2018, mesocosms from the middle and deep monitoring well also contained DHC bacteria. From the available data it is unclear whether it took a year for the bacteria to colonize the mesocosms in the middle and deep monitoring filter, as there are no analyses from 2017. Based on the conservative tracers it seems viable that colonisation of the deeper mesocosms occurred at a later stage in comparison to the mesocosm in the shallow monitoring filter, but given the quick colonisation observed in 2017, it is likely that DHC bacteria were present in the soil at the middle and deep filters of the monitoring well.

Groundwater samples

DHC, vcrA and BvcA genes have been detected in groundwater samples from the bioaugmentation injection well, monitoring well and ATES-3 well. The DHC gene concentrations in the groundwater samples of the ATES-3 well show a maximum concentration on the 31st of July, prior to the peak observed in the injection and monitoring well (4th of August 2017) (Figure 19). The concentrations of genes (gene copies/mL groundwater) are highest in the upper filter and lowest in the middle filter. In addition the maximum gene concentration in the middle filter occurs after the concentration peak in the upper and lower filter. These trends are also observed for the vcrA and BvcA genes in the groundwater samples.

The initially injected DHC culture contained $2*10^8$ cells/mL of *Dehalococcoides*. Assuming 1 gene copy represents one cell, approximately 10% of the culture was detected in the monitoring well, as well as the ATES-3 wells (10^7 gene copies/mL groundwater) (Figure 19).

Although the maximum groundwater concentrations in the shallow monitoring well were measured on 4/8/2017, the first detection of DHC bacteria in groundwater was on the 31st of July, 4 days after injection. As the mesocosm analyses indicate that DHC bacteria were present in the soil from 4/8/2017 onwards, it seems likely that the observed increase in DHC concentration in the groundwater is partly due to “release” of the bacteria from the soil at the bioaugmentation injection well and the monitoring well.

Results in Table 9 suggest that the DHC bacteria prefer to be attached to the soil than present in the groundwater. Comparison of the DHC concentrations in soil and groundwater show that the DHC concentrations in groundwater are highly variable, whereas the DHC

concentrations in soil are much more constant. It is expected that the injected DHC culture will distribute itself between the soil and groundwater, but a constant ratio between the two phases cannot be deduced from the current dataset, due to the groundwater displacement of the ATES system. During some monitoring rounds, the ratio is 1:1, whereas during others the DHC distribution between soil:groundwater is approximately 10:1 or 100000:1.

Background concentrations of total bacteria in groundwater are around 2 to 4 orders of magnitude lower than the injected culture (Appendix 4). Background concentrations of *Dehalococcoides* are even lower, ranging from <4 to 9 gene copies/mL groundwater. Although the bioaugmentation process injects a significantly larger amount of bacteria, results from 2018 show that the bacteria concentrations in the monitoring and ATES-3 wells in the groundwater decreased to the background concentrations. The exception is the injection well, where elevated total bacteria and DHC concentrations are found in the groundwater samples.

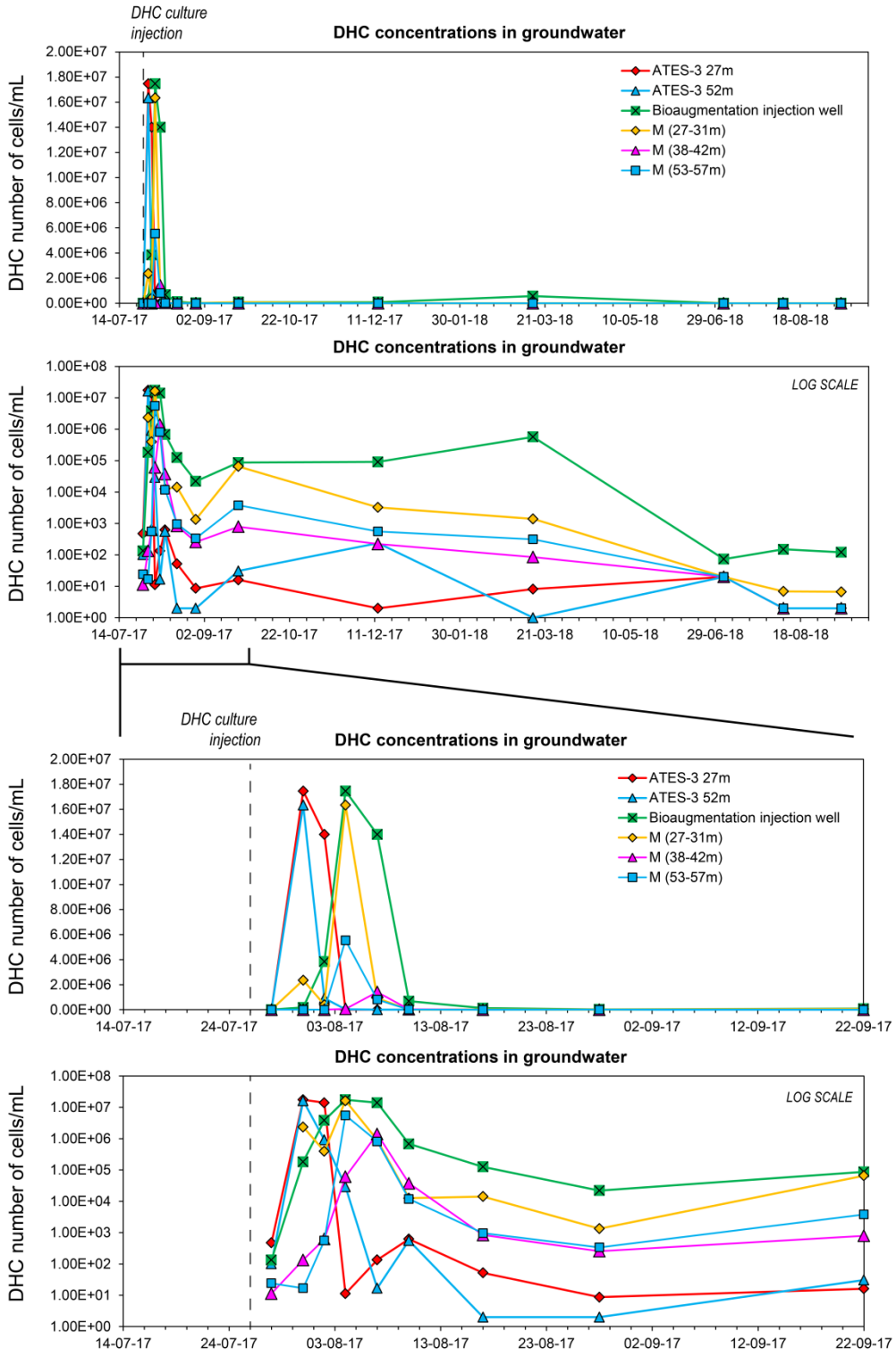


Figure 18: DHC concentrations in groundwater from the ATES-3, bioaugmentation injection well and monitoring wells. Data with measurements <4 are shown as 2 and <40 are shown as 20 gene copies/mL. Values are also listed in Table 9 for reference.

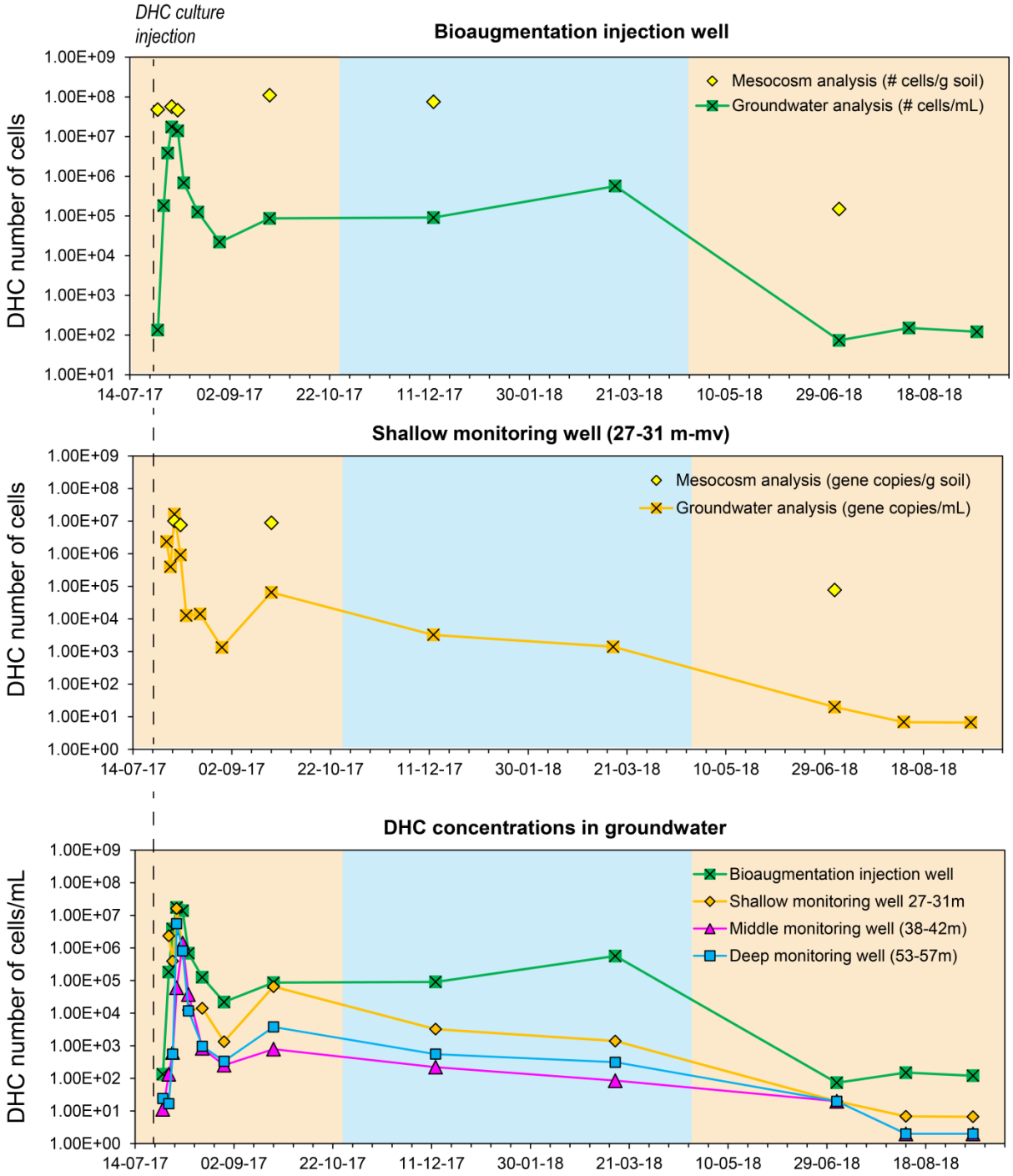


Figure 19: DHC results in the bioaugmentation injection well and monitoring wells. Measurements below the detection limits (see Table 9) are not shown in the graphs. Data with measurements <4 are shown as 2 and <40 are shown as 20 gene copies/mL. Values are also listed in Table 9 for reference.

Table 9: Summary of DHC concentrations in soil and groundwater. Injection of the DHC culture occurred on the 26th and 27th of July 2017.

		Mesocosm round 1												*Mesocosm round 2*		
Location	**Sample type**	**12-07-17**	**28-07-17**	**31-07-17**	**02-08-17**	**04-08-17**	**07-08-17**	**10-08-17**	**17-08-17**	**28-08-17**	**22-09-17**	**13-12-17**	**14-03-18**	**04-07-18**	**08-08-18**	**11-09-18**
Bioaug. well	**Mesoc.**	*na*	4.80E+07	*na*	*na*	5.70E+07	4.60E+07	*na*	*na*	*na*	1.10E+08	7.50E+07	*na*	1.50E+05	*na*	*na***
Bioaug. well	**GW**	<4	1.34E+02	1.82E+05	3.84E+06	1.75E+07	1.40E+07	6.83E+05	1.26E+05	2.20E+04	8.69E+04	9.11E+04	5.68E+05	7.37E+01	1.51E+02	1.21E+02
M 27-31 m	**Mesoc.**	*na*	bdl	*na*	*na*	1.00E+07	7.60E+06	*na*	*na*	*na*	8.80E+06		*na*	7.70E+04	*na*	*na***
M 27-31 m	**GW**	<4	<4	2.36E+06	3.98E+05	1.63E+07	9.18E+05	1.26E+04	1.42E+04	1.34E+03	6.54E+04	3.25E+03	1.40E+03	<40	6.90E+00	6.68E+00
M 38-42m	**Mesoc.**	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	5.90E+03	*na*	3.10E+04
M 38-42m	**GW**	<4	1.13E+01	1.34E+02	6.24E+02	6.07E+04	1.41E+06	3.76E+04	8.36E+02	2.56E+02	7.92E+02	2.22E+02	8.55E+01	<40	<4	<4
M 53-57m	**Mesoc.**	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	nd	*na*	4.90E+04
M 53-57m	**GW**	<4	2.42E+01	1.68E+01	5.58E+02	5.54E+06	8.14E+05	1.18E+04	9.63E+02	3.36E+02	3.80E+03	5.58E+02	3.14E+02	<40	<4	<4

The deviation of the analysis results lies between 0.5*N and 2*N, whereas N = the number of detected cells or DNA-copies.

na: not analysed
**: mesocosm samples were lost and could not be analysed.
nd: not detected
bdl: below detection limits

Presence and abundance of other bacteria and archaea

The mesocosm samples from 4/07/2018 were analysed by q-PCR for iron reducing and sulfur reducing bacteria, as well as total bacteria and total archaea (Table 10).

Assuming one gene copy equals one cell, results show that after one year the DHC bacteria make up less than 1% of the total bacteria present in the soil. Furthermore, the DHC cell count is also less than the iron and sulfur reducing bacteria, but in the same order of magnitude. In comparison to archaea, DHC bacteria are more abundant in some cases, for example in the injection well and middle filter of the monitoring well. Based on these results it seems viable to assume that the DHC bacteria are abundant enough to compete with other bacteria that would be active under the governing redox conditions (e.g. sulfur reducing bacteria).

Table 10: DNA analyses from soil samples taken on 4-07-2018

Bacteria in mesocosms	Unit	Bioaugm. Injection well	Monitoring well (27-31m)	Monitoring well (38-42m)	Monitoring well (53-57m)
Detection limit		*1.3E+03*	*4.2E+03*	*7.0E+03*	*1.6E+03*
Total bacteria	DNA-copies/g	2.3E+09	2.6E+09	1.8E+08	6.3E+08
Total Archaea	DNA-copies/g	2.5E+04	3.7E+05	n.d.	*n.d.*
DHC	DNA-copies/g	1.5E+05	7.7E+04	5.9E+03	*n.d.*
vcrA	DNA-copies/g	8.3E+03	1.3E+04	n.d.	*n.d.*
Iron reducing bacteria (*Geobacter spp*)	DNA-copies/g	6.7E+05	2.1E+05	4.1E+06	7.2E+05
Sulfur reducing bacteria	DNA-copies/g	3.7E+05	*n.d.*	2.4E+05	*n.d.*

vPCR (DNA) and RNA analyses

The groundwater samples taken on the 11th of September 2018 were analysed for vPCR (DNA) and qPCR (RNA) to provide an estimate of the number of living and active cells present. The results indicated that none of the detected cells in the groundwater samples were living or active, and it can be assumed that, for this monitoring round, the detected DNA represents dead bacteria. This raises the question whether the DHC bacteria that are transported together with the groundwater can attach to the soil matrix if these are not living cells. Nonetheless, mesocosm data from the middle monitoring filter (38-42m) suggest that during this time period (04/07/18-11/09/18) the DHC concentrations increased in the soil. It seems viable that the introduced DHC bacteria are still active in September 2018, but the underlying processes and mechanisms of transport and colonization remain unclear. It could be possible that the groundwater DNA analyses are not representative of what is occurring at the pore scale (and where the bacteria are active), because of the continuous pumping and abstraction of large volumes of water by the ATES system.

3.5 Total organic carbon

Total organic carbon (TOC) content was monitored during the pilot study, but not for each monitoring round, as shown in Table 3 and Table 4. Results are provided in Appendix 7. Background TOC concentrations in the groundwater samples amount to 4-5 mg/L. After the DHC culture injection, the following trends were observed:

- 1 day after DHC injection (28/07/2017) TOC @ injection well: 45 mg/L
- 5-6 days after DHC injection (02/08/2017) TOC @ monitoring well (27-31 m): 36 mg/L
- 7-8 days after DHC injection (04/08/2017) TOC @ monitoring well (27-31 m): 117 mg/L
- 7-8 days after DHC injection (04/08/2017) TOC @ monitoring well (53-57 m): 30.5 mg/L
- ATES-3 shallow and upper filters; TOC concentrations remain around 4-5 mg/L (not influenced)

Results indicate that TOC concentrations follow the same trends as observed for the tracers discussed in section 4.2.1 and 4.2.2.

3.6 Chlorinated organic compounds and biodegradation products

Concentrations of dichloromethane, tetrachloromethane (TETRA), trichloromethane (chloroform), 1,1-dichloroethane, trans-1,2-dichloroethane, cis/trans-1,2-dichloroethane, trichloroethylene and 1,1,1-trichloroethane were below detection limits in all the groundwater samples analysed in this study (Appendix 3).

Ethylene was detected in the injection well on the 28th and 31st of July 2017 (2.2–2.4 µg/L) and in the upper filter of the monitoring well on the 2nd of August 2017 (2.9 µg/L).

Ethane was present in all the groundwater samples prior to the DHC culture injection (12th of July 2017), and ranged from 2.3–3.6 µg/L. The measurements are highly variable with the exception of two monitoring rounds in September 2017 and December 2017, where ethane concentrations were below detection limits (Appendix 3).

Prior to the DHC culture injection, methane concentrations were fairly constant in all the groundwater samples and range from 0.22–0.37 mg/L. After the DHC culture injection, methane concentrations increased in the injection well to 11 mg/L (31-07-2017), and subsequently decreased to 360 µg/L (22-09-2017). Other COCs, including 1,1,2-trichloroethane and 1,2-dichloroethane show a similar trend with increasing concentrations directly after the bioaugmentation. These increased COC and methane concentrations directly after the culture injection likely represent the growth medium and trace COCs that were introduced in the subsurface with the *Dehalococcoides*.

Vinylchloride (VC) was present in all the groundwater samples prior to the DHC culture injection (12th of July 2017), and ranged from 2.6–4.3 µg/L (Figure 24). Two days after the injection of the DHC culture the VC concentration decreased to below detection limits. A decreasing trend is also observed in the upper filter of the monitoring well (Figure 23).

The VC concentrations also show some fluctuations and sudden increases in concentrations, which seem to be related to seasonal variations, i.e. the switch between

injection/abstraction of the ATES wells. Based on the results of B45, VC concentrations are high at depths where the warm layer resides (up to 60 µg/L) and significantly lower in the cold layer (up to 3.5 µg/L). In summer, water from the cold layer (low VC concentrations) is abstracted and injected in the warm layer, which causes the observed seasonal decrease in VC concentrations. In winter, the opposite occurs, which subsequently increases the measured VC concentrations in the ATES-3 well. This increase is particularly evident in the ATES-3 well on the 14th of March 2018, where VC concentrations increased from <0.2–1.9 to 6.1–10 µg/L.

The decrease in VC concentrations in the bioaugmentation injection well is a good indicator that biodegradation is occurring. The decrease in VC is also concomitant with an observed increase in ethylene (the degradation product of VC), in the injection well, but this was only observed in two time measurements, 2 and 5 days after the bioaugmentation. The remaining COCs depicted in Figure 24 show an increase in the injection well directly after the bioaugmentation, and subsequently 6 days later an increase is observed in the upper filter of the monitoring well, suggesting these compounds were introduced during the bioaugmentation process and do not reflect biodegradation. Although an increase in ethylene is measured, it remains unclear whether this can be directly related to biodegradation of VC. Ethylene could also have been introduced with the *Dehalococcoides*, especially considering that it was initially detected in the bioaugmentation injection well, and 5 days later in the shallow monitoring well. However, if the measured ethylene concentrations were only influenced by transport processes, it would be expected that the concentrations would decrease downstream from the source. This is not the case, as slightly higher ethylene concentrations were found in the shallow filter of the monitoring well (2.9 µg/L) in comparison to the bioaugmentation injection well (2.4 µg/L).

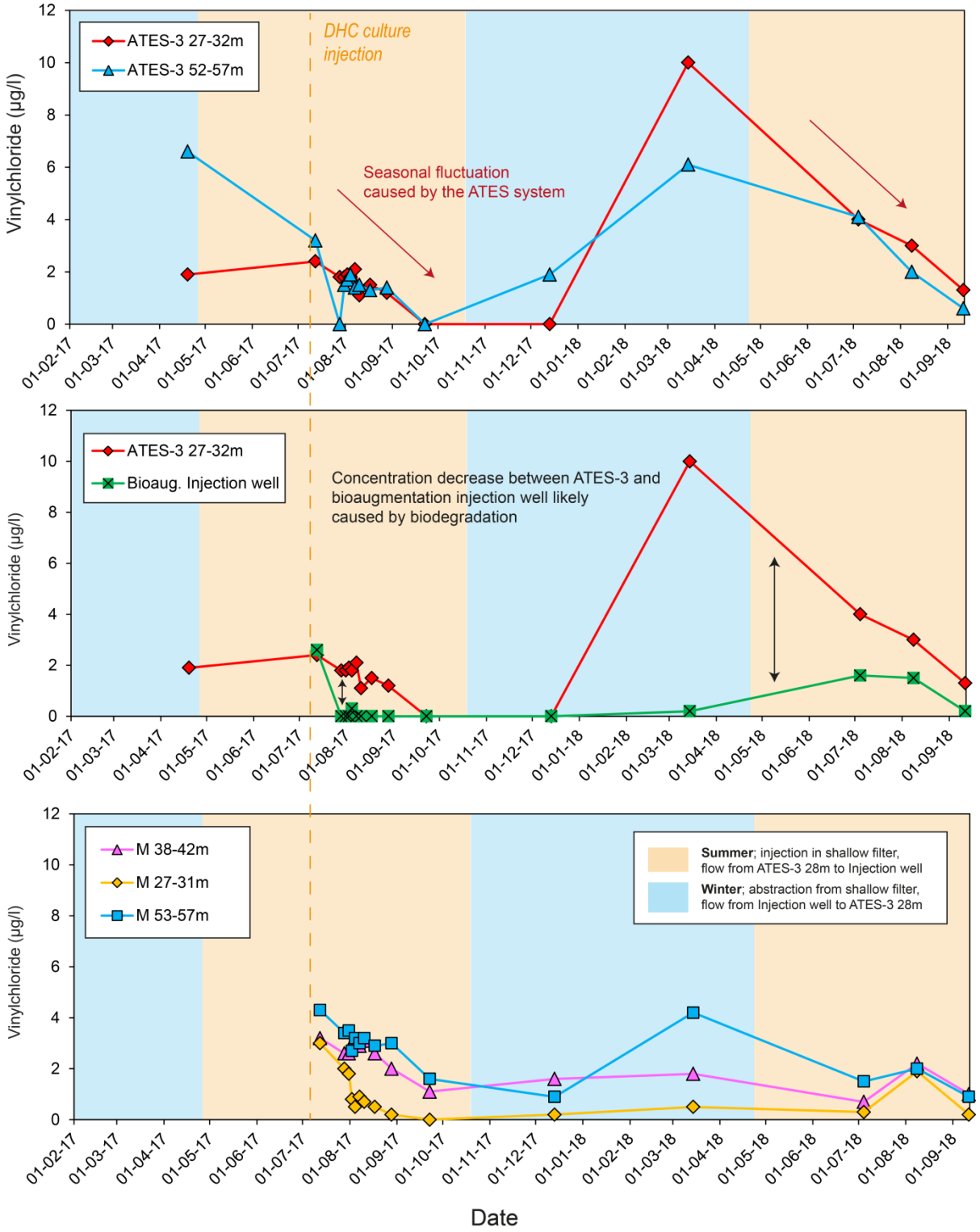


Figure 20: Concentrations of vinylchloride in the ATES-3, monitoring and injection wells.

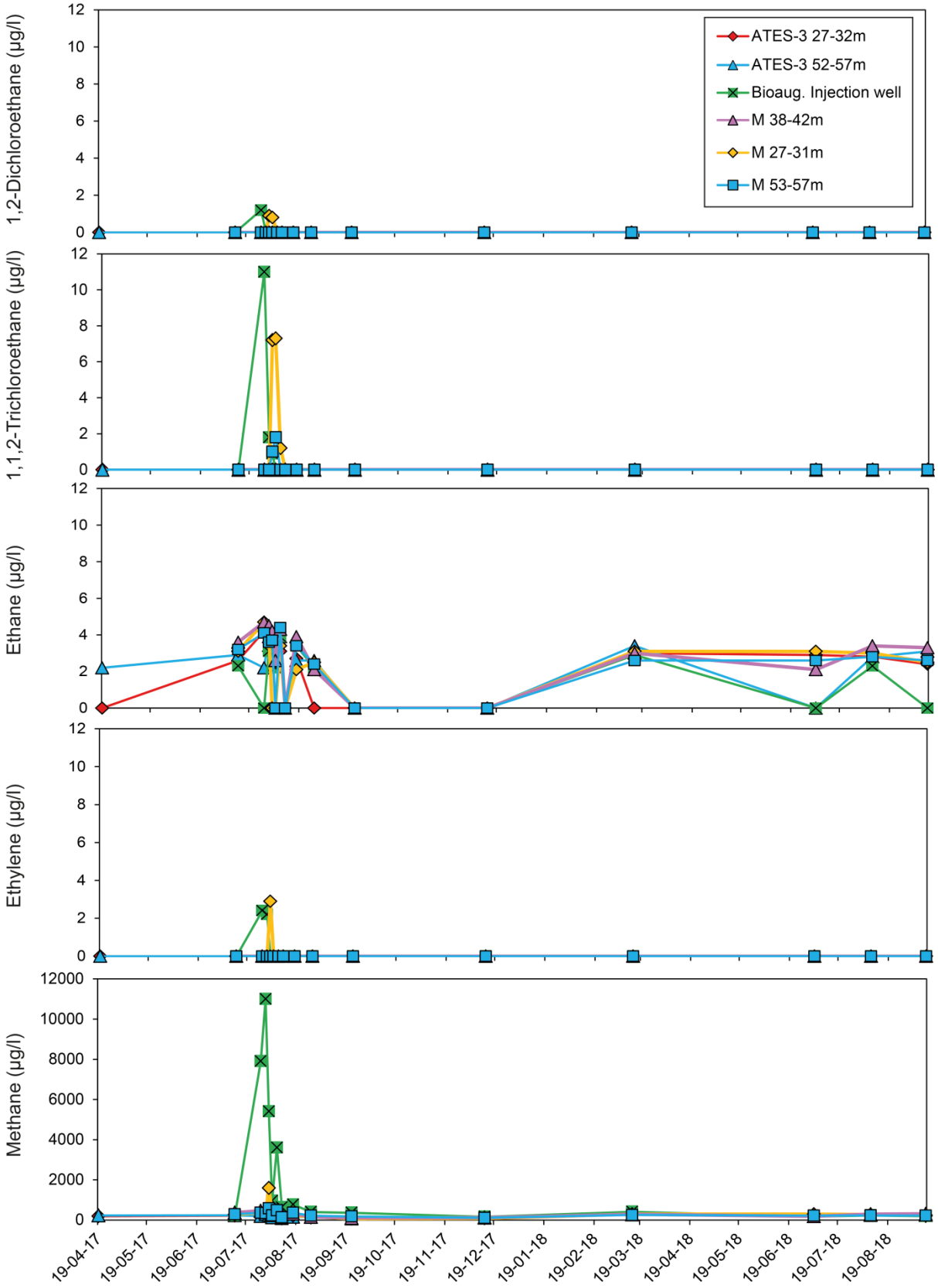


Figure 21 Concentrations of selected COCs

3.7 H_2 measurements

Hydrogen was measured in groundwater samples taken on the 4th and 10th of August 2017 (Table 10).

Table 10: H_2 concentrations in the groundwater samples

Location	H_2 (nM)	H_2 (nM)
	04-08-2017	*10-08-2017*
ATES-3 (28 m)	0.14	0.16
ATES-3 (51 m)	0.21	0.16
Injection well	1.71	0.85
Monitoring well 27-31 m	1.31	0.76
Monitoring well 38-42 m	0.86	0.5
Monitoring well 53-57 m	1.21	0.45

Hydrogen serves as the electron donor for the reductive dechlorination, which can be supplied by adding organic compounds which subsequently ferment and produce hydrogen (e.g. Kueper et al. 2014). The observed decrease in H_2 (Table 10) occurs during the time period where a decrease in VC was measured, suggesting that the decrease may be related to H_2 being used by dechlorinating bacteria.

3.8 Monitoring of the subsurface temperature: DTS monitoring

From June until August 2017 the DTS glass fiber technology was installed and has been in operation since August 2017. Four glass fibers were installed; one in the piezometer monitoring the cold well of ATES-3 (~52 m bsl), one in the piezometer monitoring the warm well of ATES-3 (~29 m bsl), one at the injection well (28 m bsl) and one at the monitoring well (~58 m bsl). Temperature monitoring started on the 17th of August, 2017 and records were kept until the 4th of October 2018. Cold water that is injected has an average temperature of 10°C and the warm water has an average temperature of 15°C.

Unfortunately installation of the glass fibers was not completed before the bioaugmentation experiment; hence there is no temperature data of the culture injection. Temperature monitoring at ATES-3 from August 2017–October 2018 is shown in Figure 22. The temperature data show the injection and extraction of warm water at approximately 26 to 31 m below surface level (bsl). A cold zone can also be distinguished at a depth of approximately 49 to 56 meters (Figure 22).

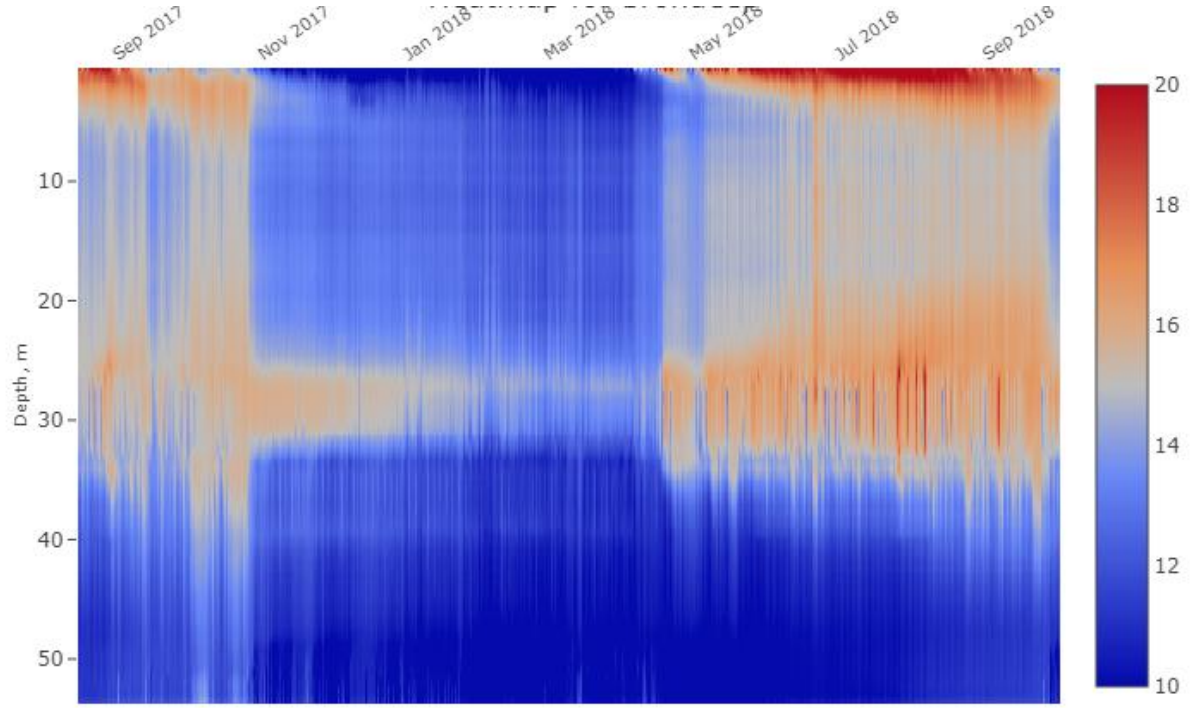


Figure 22: Temperature distribution at the ATES-3 system from September 2017 to October 2018. Scale bar (right) shows temperature range in °C. The positons of the warm (26 – 31 m bsl) well and cold well (49 – 56 m bsl) can be seen.

The transition between extracting warm water from the warm well and injecting warm water in the warm well is visible in the temperature data (Figure 23). During injection, the measured temperatures are more variable than during extraction, due to the varying surface water temperatures (Figure 23). The same trend is observed for the cold water at the cold well (Figure 27, Figure 28).

Around the 20th of April 2018 warm water is injected into the warm well. When tracing the warm water towards the bioaugmentation injection well one can detect the arrival at this location on the 22nd of April 2018 (Figure 24). In the shallow filter of the monitoring well it is hard to detect a breakthrough within the temperature data. There is a possible breakthrough observed on 28th of May 2018 (Figure 25).

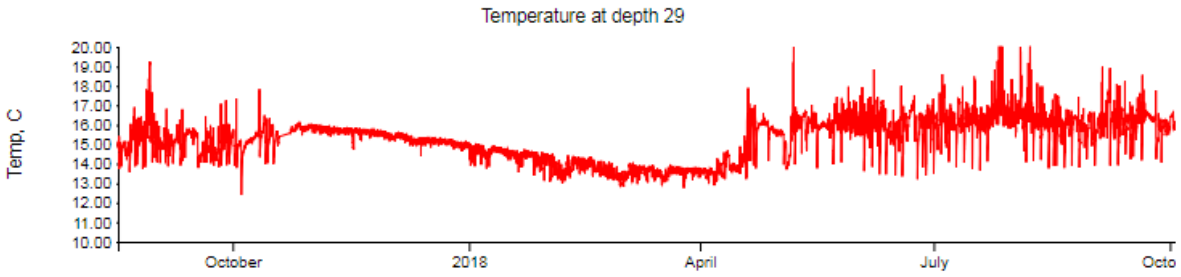


Figure 23: Temperature profile at a depth of 29 m bsl at the ATES-3 warm well. '2018' on the horizontal time axis marks January 2018.

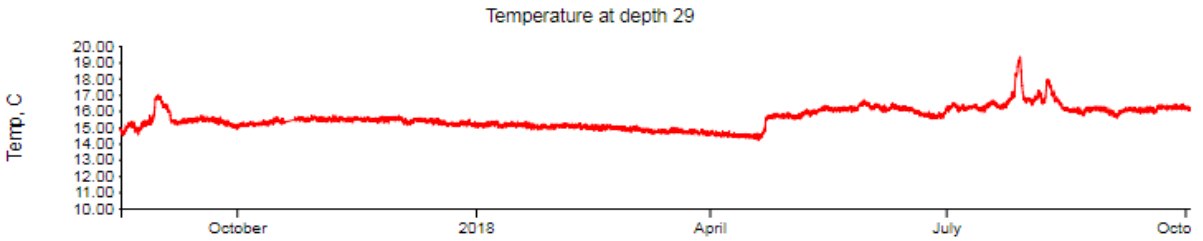


Figure 24: Temperature profile at the bioaugmentation injection well. '2018' on the horizontal time axis marks January 2018.

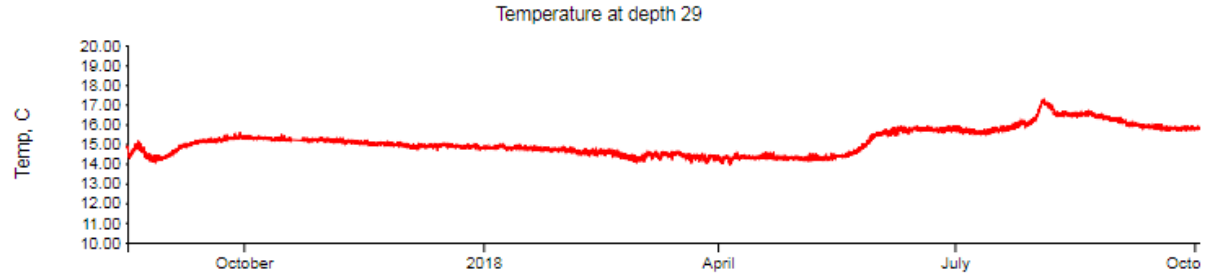


Figure 25: Temperature profile at the shallow filter of the monitoring well (29 m). '2018' on the horizontal time axis marks January 2018.

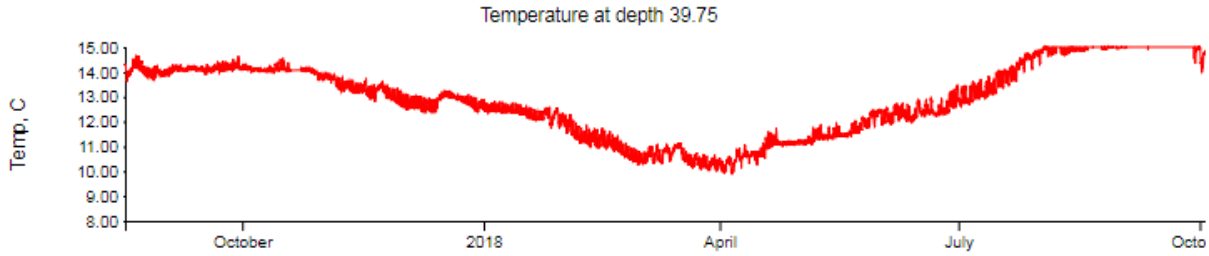


Figure 26: Temperature profile at the middle filter of the monitoring well (40 m). '2018' on the horizontal time axis marks January 2018.

Figure 22 shows that at certain time intervals in summer a warm zone extends vertically into the cold zone. This suggests that the injection of warm water during summer has a 'downward influence', which is in contrast with the initial conceptual model (Figure 10). Figure 26 shows the temperature profile recorded in the middle filter of the monitoring well, and from this it can be observed that the warm water also extends to this depth at the monitoring well, as temperatures are around 14-15°C during the summer period, and decrease to 10°C in the winter period (Figure 26).

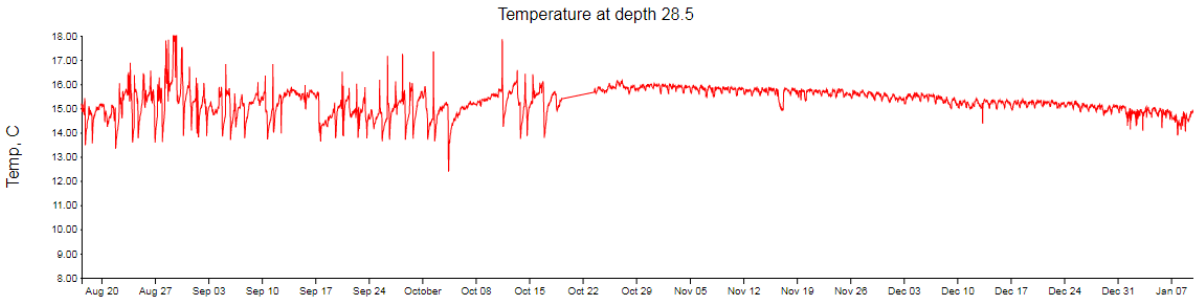


Figure 27: Temperature profile at the ATES-3 warm well (29 m). Note the different scale bar on the x-axis, starting from the 20th of August 2017 (Aug 20) until the 7th of January 2018 (Jan 07).

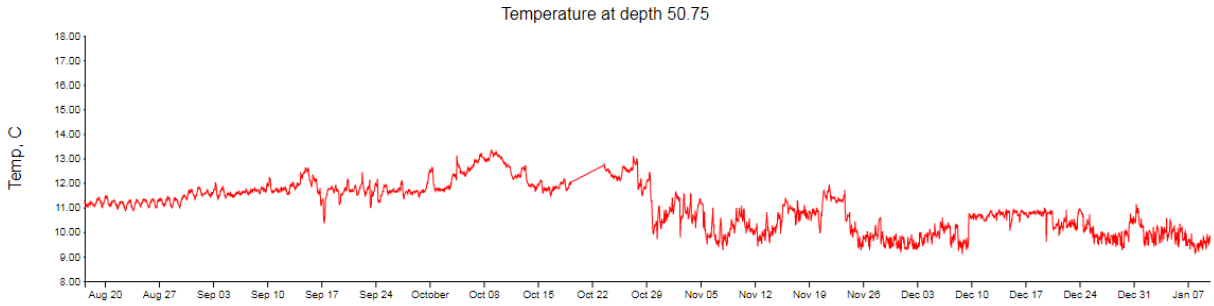


Figure 28: Temperature profile at the ATES-3 cold well (51 m). Note the different scale bar on the x-axis, starting from the 20th of August 2017 (Aug 20) until the 7th of January 2018 (Jan 07).

3.9 B45, ATES-1, ATES-2

B45 is a nearby monitoring well (Figure 3) which has been sampled throughout the study to assess whether the activities of this pilot have any effect on the nearby surroundings. Field measurements, selected anions and cations, vinylchloride and DNA analyses are summarized in Tables 11, 12, 13, 14 and 15.

Table 11: Range of redox parameters in B45

Redox parameter	Range
Redox potential	-64 to -142 mV
O_2	0.03−0.14 mg/L
Fe	7−11 mg/kg
Mn	0.6−0.8 mg/kg
SO_4	36−96 mg/L
NO_3	< 0.5 mg/L
Other compounds	
Mg	11−22 mg/L
Ca	81−127 mg/L

Table 12: VC concentrations in B45

Vinyl chloride (µg/l)	02-08-17	13-12-17	14-03-18	04-07-18	11-09-18
B 45 10-14m	**0.5**	**0.4**	**0.4**	<0.2	**0.4**
B 45 22-26 m	**21**	**16**	**9.6**	**11**	**11**
B 45 34-38 m	**62**	**56**	**40**	**49**	**33**
B 45 57-59 m	**3.5**	**3.6**	**0.7**	**1.1**	**1.1**

Table 13: Ethylene concentrations in B45

Ethylene (µg/l)	02-08-17	13-12-17	14-03-18	04-07-18	11-09-18
B 45 10-14m	<2.0	<2.0	<2.0	<2.0	<2.0
B 45 22-26 m	<2.0	<2.0	<2.0	<2.0	<2.0
B 45 34-38 m	**2.5**	<2.0	**2.2**	<2.0	<2.0
B 45 57-59 m	<2.0	<2.0	<2.0	<2.0	<2.0

Table 14: DNA analyses in groundwater

Well	Depth	Date	*Total Bacteria*	*DHC*	*vcrA*
B 45	10-14m	02-08-17	1.28E+04	4.73E+02	2.13E+02
B 45	22-26 m	02-08-17	3.75E+03	1.02E+02	1.67E+02
B 45	34-38 m	02-08-17	2.46E+03	3.47E+01	6.40E+01
B 45	57-59 m	02-08-17	1.73E+03	<4	3.34E+00
B45	10-14m	13-12-17	1.97E+04	<4	<3
B45	22-26m	13-12-17	5.22E+03	4.41E+00	4.69E+00
B45	34-38m	13-12-17	5.48E+03	8.63E+01	1.89E+01
B45	57-79m	13-12-17	6.37E+03	<4	4.60E+01
B 45	10-14m	14-03-18	1.46E+04	2.85E+00	<3
B 45	22-26m	14-03-18	5.06E+04	4.95E+02	<3
B 45	34-38m	14-03-18	1.26E+04	5.52E+00	4.85E+01
B 45	53-57m	14-03-18	4.52E+03	3.90E+00	<3
B45	10-14m	04-07-18	1.12E+04	<40	4.13E+01
B45	22-26m	04-07-18	1.08E+04	<40	3.47E+01
B45	34-38m	04-07-18	4.99E+03	<40	6.04E+01
B45	53-57m	04-07-18	1.91E+03	<40	4.01E+01

In comparison to redox conditions observed in the wells at Nieuw Welgelegen, the redox conditions measured in B45 are slightly higher, which may be unfavorable for reductive dechlorination.

VC concentrations were initially higher in B45 than in the ATES wells and ranged from (0.5–62 µg/L). Throughout the pilot study, VC concentrations decreased in the bottom three filters of B45 (Table 12). In the shallow filter no major changes were observed. Ethylene was also present slightly above detection limits in the filter at 34-38m depth (Table 13). As the DHC gene concentrations are not extremely high in the groundwater samples from B45 (Table 14) the observed decrease in VC cannot be directly related to reductive dechlorination at this

location. However, it is possible that the observed decrease in VC, from 60 to 30 µg/L within 1 year, is a result of dilution caused by the groundwater displacement of the Nieuw Welgelegen ATES system. In this line of reasoning, it would be expected that the decrease observed at 30 m depth should lead to an increase at 50 m depth, as the VC would be transported through the ATES system. This is not the case and suggests that the VC concentrations are heterogeneous in these surroundings, causing a dilution effect. However, these results could also point towards removal of VC from the system through reductive dechlorination.

Table 15: DNA analyses (gene copies/mL) of groundwater samples ATES-1 and ATES-2

Well	Depth	Date	*Total Bacteria*	*DHC*	*vcrA*	*bvcA*	*etnE*
Bron 1	27m	19-04-17	6.60E+04	1.33E+01	1.31E+02	<3	1.20E+01
Bron 1	50m	19-04-17	2.81E+04	9.90E+00	<2,5	<3	3.35E+00
Bron 1	27m	13-12-17	3.02E+04	6.27E+01	1.07E+02	3.99E+00	<20
Bron 1	50m	13-12-17	8.29E+03	<4	<3	<3	<20
Bron 1	27m	14-03-18	9.73E+03	1.18E+02	1.07E+02	<3	<6
Bron 1	50m	14-03-18	3.68E+03	6.22E+01	2.22E+01	<3	<6
Bron 1	27m	04-07-18	3.84E+03	<40	1.63E+02	<3	8.95E+00
Bron 1	50m	04-07-18	4.65E+03	<40	2.75E+02	<3	8.86E+00
Bron 1	27m	11-09-18	1.46E+03	6.68E+00	<12	<3	<5
Bron 1	50m	11-09-18	3.07E+03	<4	<12	<3	<5
Bron 2	28m	19-04-17	3.31E+04	6.86E+01	4.10E+01	<3	1.44E+02
Bron 2	51m	19-04-17	2.62E+04	2.69E+01	3.93E+01	<3	2.24E+00
Bron 2	28m	13-12-17	5.73E+04	2.46E+02	<3	<3	2.44E+01
Bron 2	51m	13-12-17	7.34E+03	<4	<3	<3	<20
Bron 2	28m	14-03-18	2.67E+04	4.45E+00	<3	<3	<6
Bron 2	51m	14-03-18	6.09E+03	7.76E+00	9.12E+00	<3	<6
Bron 2	28m	04-07-18	5.59E+03	<40	3.89E+02	<3	2.17E+00
Bron 2	51m	04-07-18	5.54E+03	<40	5.17E+02	<3	7.35E+00
Bron 2	28m	11-09-18	1.56E+03	<4	<12	<3	<5
Bron 2	51m	11-09-18	1.74E+03	5.26E+00	<12	<3	<5

4 Evaluation

4.1 Functioning of the ATES system

The groundwater temperatures monitored during the pilot study are similar to values discussed by Kiefte (2009). The groundwater displacement in ATES-3 monitored from May 2017 to June 2018 is approximately 40,000−60,000 m3 (data from 10-01-2018 to 15-03-2018 was not provided by the servicing company). These values are significantly less than the average yearly groundwater displacement (211,340 m3) reported by Kiefte (2009) which likely reflects the total volume displaced by the three mono-wells combined. If the displacement is fairly evenly distributed amongst the three mono-wells a total displacement would be approximately 180,000 m3 which comes reasonably close to the value initially reported by Kiefte (2009).

The DST measurements show that there is interaction between the warm and cold layer, which is contradictory to the conceptual model (Figure 10). During times of high extraction/injection rates the warm water extends downward into the cold layer (Figure 29). The system would be more efficient if the warm and cold layer are completely separated. For future ATES systems within this area it seems more efficient to implement doublet systems instead of mono systems.

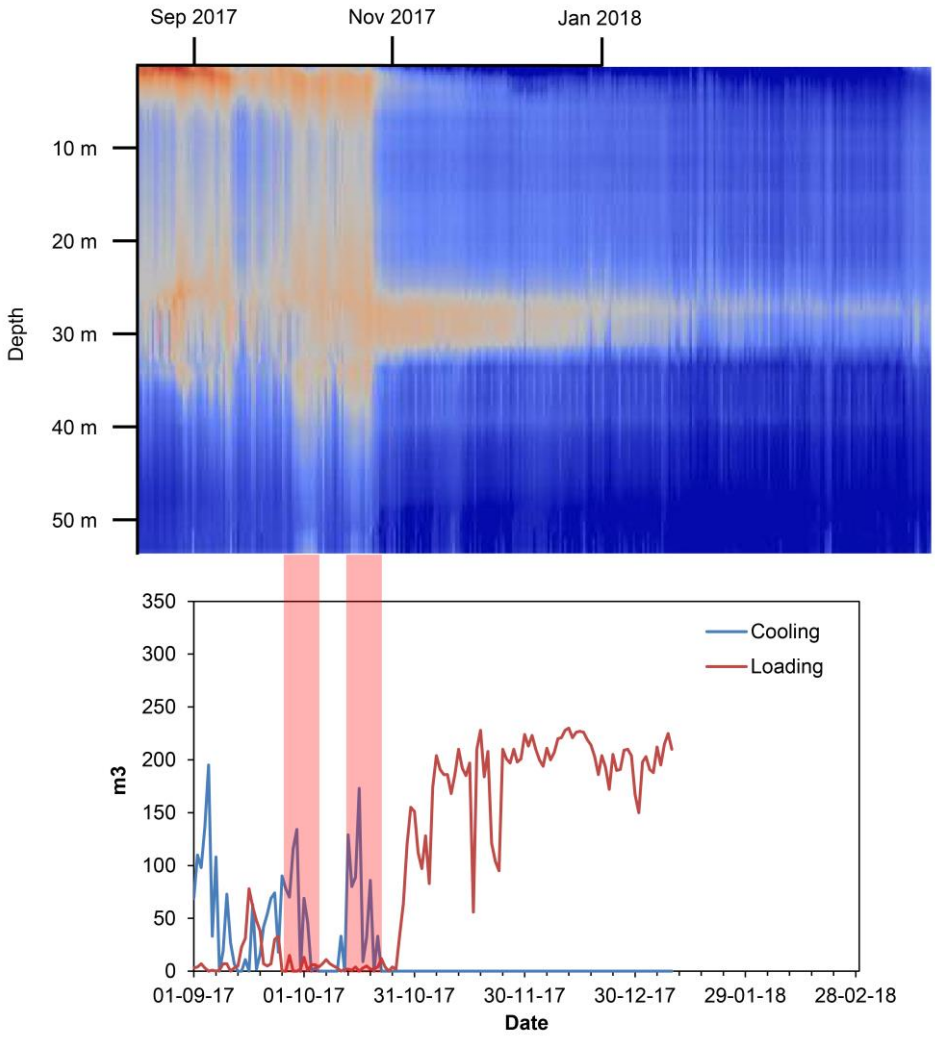


Figure 29: Comparison of extraction rates of the ATES-3 and the measured temperature distribution.

4.2 Flow paths

With respect to the flow paths between the injection well and monitoring well, the visual tracer (fluorescein), conservative tracers, reactive tracers, DNA analyses, TOC and organic compounds all show the same trend. Groundwater flows from the injection well towards the monitoring well and initially arrives at the shallow filter, then the deepest filter and subsequently the middle filter. The arrival times of the different compounds vary slightly due to (i) the reactivity of the tracers and (ii) ATES-3 injection rates, but this trend was always observed.

The flow paths between the injection well and ATES-3 well are more complex and contrasting results are obtained. The visual, conservative and reactive tracers, TOC and individual organic compounds (e.g. methane) do not increase significantly in the deep or

shallow filter of the ATES-3 well. However DHC genes were detected at high concentrations in the groundwater sampled from the ATES-3 well, 2-5 days after the bioaugmentation process. These results suggest that the behavior and transport of DHC cannot be directly related to the transport of conservative ions or volatile organic compounds such as chloride and methane. This is not surprising, as a large DHC culture ($2*10^8$ cells/mL) likely has a much larger mass and the cells may coagulate and not be transportable in the groundwater. Thus, it can be argued that the flow of DHC bacteria to the ATES-3 well were (strongly) influenced by physical processes (vertical transport due to high density).

Due to the proposed vertical transport, the DHC bacteria are assumed to have entered the zone of influence of the deep ATES-3 well, which extracts groundwater during summer. This would have "flushed" the bacteria through the ATES-3 mono-well, being pumped up by the cold well and subsequently re-injected in the subsurface through the warm well, after which the DHC bacteria were detected again in the bioaugmentation well on the 4th of August, 8 days after the DHC culture injection (Figure 30).

The cause of the 'arrival trend' observed in the monitoring well (tracers and bacteria are first detected at the shallow filter, then at the deep filter and subsequently at the middle filter), is unclear. This could be related to an impermeable layer present at this depth, leakage along the well (Figure 30), or potentially due to the placement of the middle filter behind the deep filter (Appendix 1).

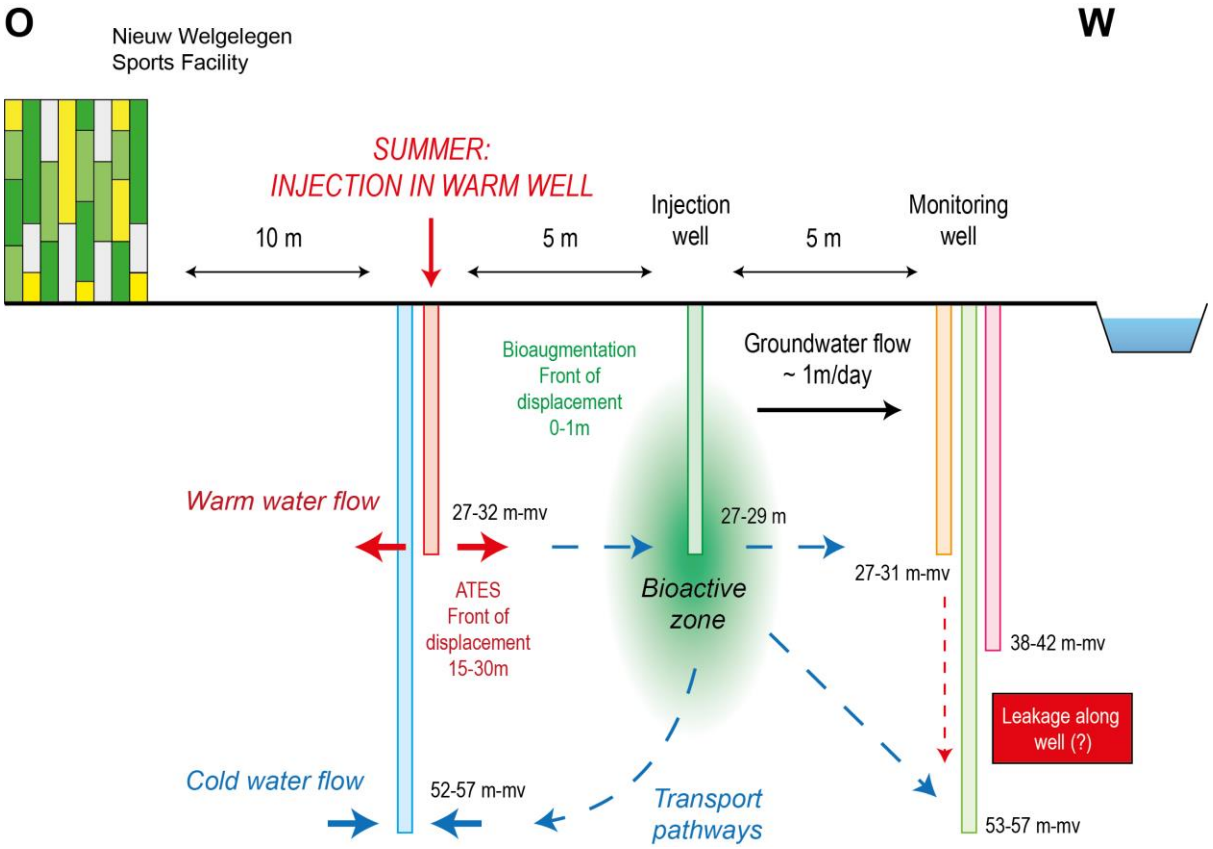


Figure 30: Conceptual diagram of the ATES system showing groundwater flow and presumed transport pathways. The front of displacement was estimated based on calculations, which are provided in Appendix 8

4.3 Biodegradation

Although the concentrations of COCs are generally low, several observations indicate that biodegradation is occurring. These include (i) decreasing VC concentrations in the bioaugmentation injection well (Figure 20), and (ii) the detection of ethylene during certain time measurements.

According to the molar ratios for the conversion of VC, a reduction of 5 mg/L VC will produce 2.28 mg/L ethylene. This supports the field observations reported here, as VC concentrations were initially 2−6.6 mg/L, and ethylene was subsequently detected at 2.2−2.4 mg/L. Furthermore, redox conditions indicate that the reduction of VC is thermodynamically feasible.

The VC dechlorination rate, as determined by various studies (Saiyari et al. 2018 and references therein), ranges between 54 µM/d and 407 µM/d. With 10E7 number of cells present in the groundwater it seems reasonable for the VC concentrations to be reduced in 1-2 days.

The ATES system strongly influences groundwater flow and the continuous injection of fairly large volumes of water in the shallow filter may hamper our ability to evaluate the effectiveness of the bioaugmentation experiment; i.e. whether a bioactive zone has established around the injection well. The groundwater samples taken for analysis likely represent “fresh” or “autochtonous” water coming from the ATES system, rather than groundwater that is present in the pores around the injection well. These groundwater samples may underrepresent the amount of bacteria present in the region, and also underestimate the potential sulfate reduction that is taking place.

A further question is how well the injected DHC culture can be sustained in the subsurface as there are no chlorinated ethenes present (anymore). DHC bacteria can only grow by using halogenated compounds as electron acceptors, but they can be sustained without the presence of halogenated compounds. The concentration of cells will however decrease due to transport through groundwater.

If the lower VC concentrations measured in the bioaugmentation injection well in comparison to the ATES-3 well are a direct result of biodegradation, then it is seems that the DHC community was active in 2017 and 2018, although activity decreased in 2018 in comparison to 2017.

5 Conclusions and recommendations

The Nieuw Welgelegen pilot study was aimed at demonstrating the potential benefits that ATES systems can have on in-situ bioremediation techniques. If effective, the field scale demonstrations presented here would make it more attractive to implement ATES systems in areas where groundwater is contaminated.

A concentrated cultivation of Dehalococcoide (DHC) bacteria was injected in the warm layer of the Nieuw Welgelegen ATES system to stimulate the reductive dechlorination of chlorinated ethenes that are currently contaminating the first aquifer in this area. The pilot study is complex and involved numerous analyses, tracer tests and implementation of novel techniques (bioaugmentation/soil mesocosm analysis). The results are promising and suggest reductive dechlorination of vinylchloride is occurring.

Due to the various aspects of the pilot study, major findings and conclusions are listed below as bullet points:

- The bioaugmentation process did not cause well clogging, nor did it hamper the operation of the ATES system,
- The DHC bacteria attached to the soil matrix around the bioaugmentation injection well and monitoring well.
- Results suggest that the bacteria prefer to be attached to the soil matrix than present in the groundwater, but this might be a biased signal as the groundwater concentrations will strongly be influenced by the abstraction/injection rates of the ATES system
- The DHC bacteria attached to the soil matrix decreased in concentration (from 10^7 to 10^5) and due to the limited monitoring period it is unclear whether the DHC bacterial community will be able to sustain itself over longer time periods
- The groundwater DNA data indicate that the DHC bacteria spread throughout the first aquifer and also the ATES-3 mono-well
- Multiple lines of evidence suggest reductive dechlorination is occurring:
    - Favorable redox conditions, including hydrogen levels (reductive dechlorination is thermodynamically feasible)
    - Decreasing VC concentrations at the bioaugmentation injection well and B45
    - Increasing ethylene concentrations

Recommendations

If it is desirable to further test the activity of the DHC bacteria, groundwater from the nearby monitoring well B45 could be injected, to provide “fresh” chlorinated ethenes as electron acceptor. Evaluation whether an additional electron donor would be necessary.

Considering the decrease in DHC bacteria during the 2018 monitoring rounds, it could be useful to characterise the microbial community in a broader context (e.g. also investigating the presence and abundance of sulfate reducing bacteria or methanogens), rather than solely focusing on the *Dehalococcoides* community. Microbes in the environment often form

competitive relationships with other bacteria in the system, and DHC are not capable of synthesizing a compound essential for their growth and reply on other organisms to provide nutrients (Saiyari et al. 2018). Thus, optimization of the bioaugmentation stategy may benefit from identifying the required microbial community for the *Dehalococcoides* to be sustained (on the long term).

If it is desired to further continue groundwater sampling for DNA analyses, it is recommended to include the pore water in the mesocosms, to determine whether the groundwater samples are representative for the microbial community.

Measurements in the expected flow path both in winter and summer status can help to identify whether the injected biomass is still active. This would need further analyses on the volatile organic compounds that are pumped around in the ATES-3 system. If bacteria are still active, this will result in measuring low concentrations in the injected area and downstream of that zone, although ATES-3 is injection fresh VC coming from surrounding area.

Further investigation can be focused on using RNA-based and/or v-PCR analysis to get more insights in the actual activity of the present cells.

Modelling of the DHC culture injection as a dense non aqueous phase liquid, might provide further insight into the flow paths and transport processes of the bacteria.

6 References

Cycoń, M., Mrozik, A., Piotrowska-Seget, Z., (2017). Bioaugmentation as a strategy for the remediation of pesticide-polluted soil: A review. Chemosphere 172, 52-71.

Grotenhuis, T. (2016). Setup of analysis monitoring data Municipality Utrecht (Rep.). Wageningen.

Herrero, M., Stuckey, D.C., (2015). Bioaugmentation and its application in wastewater treatment: A review. Chemosphere 140, 119-128.

Kiefte, J. (2009). Revisiegegevens/machineboek energieopslagsysteem Nieuw Welgelegen te Utrecht en Vergunningaanvraag Grondwaterwet energieopslagsysteem. Geocomfort, Rapportnr Prg070951.drv01 3 augustus 2007

Municipality of Utrecht (2014). Gebiedsplan gebiedsgericht grondwaterbeheer en visie op duurzaam gebruik van de ondergrond, hoofdrapport. https://www.utrecht.nl/fileadmin/uploads/documenten/wonen-en-leven/milieu/bodem/2015-04-29-Hoofdrapport-Gebiedsplan-gebiedsgericht-grondwaterbeheer.pdf

Němeček, J., Steinová, J., Špánek, R., Pluhař, T., Pokorný, P., Najmanová, P., Knytl, V., Černík, M., 2018. Thermally enhanced in situ bioremediation of groundwater contaminated with chlorinated solvents – A field test. Science of the Total Environment 622-623, 743-755 https://doi.org/10.1016/j.scitotenv.2017.12.047

Nzila, A., (2017). Mini review: Update on bioaugmentation in anaerobic processes for biogas production. Anaerobe 46, 3-12.

Saiyari, D.M., Chuang, H., Senoro, D.B., Lin, T., Whang, L., Chiu, Y., Chen, Y., 2018 A review in the current developments of genus Dehalococcoides, itsconsortia and kinetics for bioremediation options of contaminated groundwater. Sustainable Environmental Research 28, 149-157.

Sommer W, Valstar J, Leusbrock I, Grotenhuis T, Rijnaarts H (2015a). Optimization and spatial pattern of large-scale aquifer thermal energy storage. Applied Energy 137, 322-337

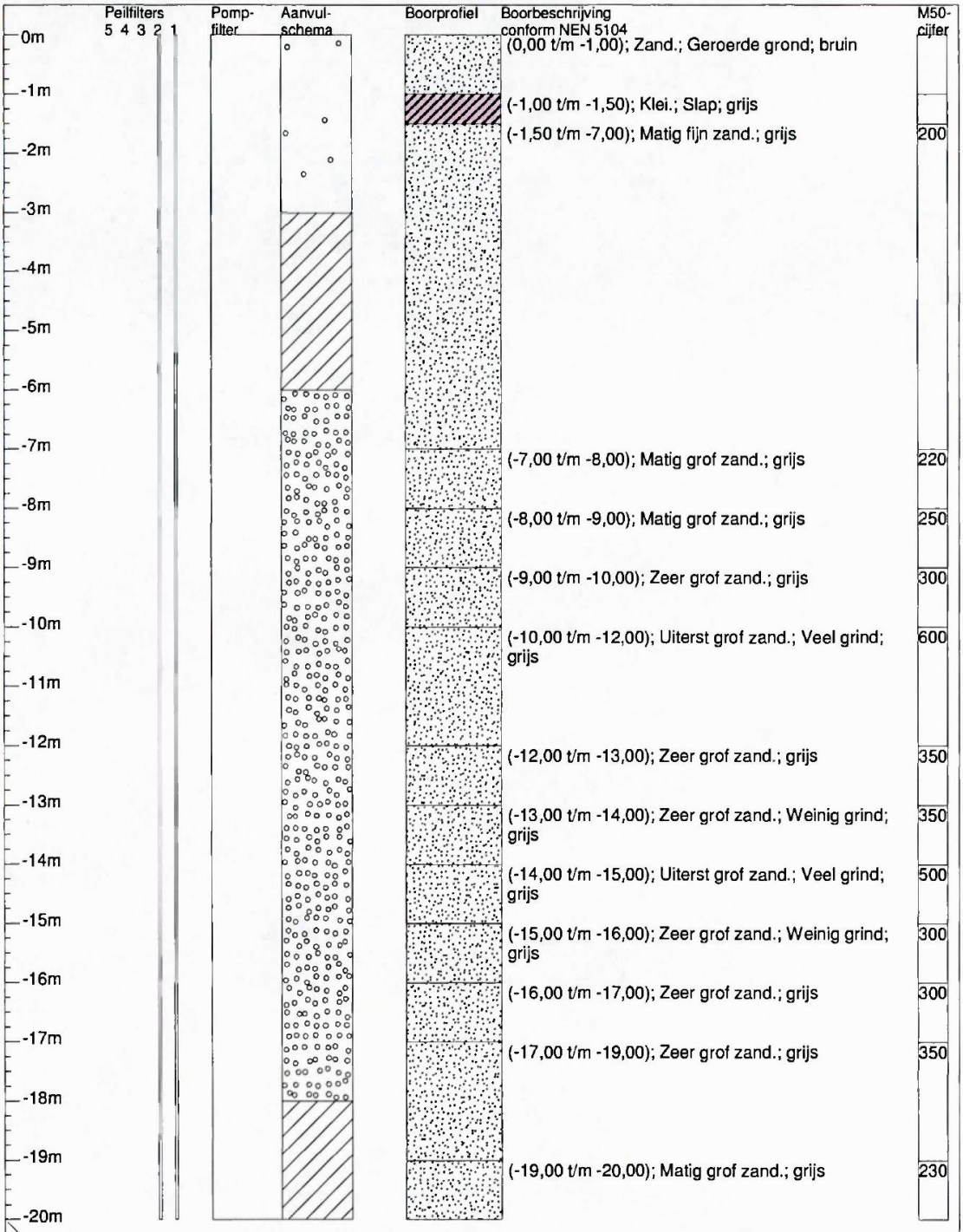
Sommer, W. (2015b). Modelling and monitoring of Aquifer Thermal Energy Storage, Impacts of heterogeneity, thermal interference and bioremediation, PhD thesis, Wageningen University, Wageningen, NL. http://edepot.wur.nl/342495

Zhuobiao Ni, Pauline van Gaans, Martijn Smit, Huub Rijnaarts, Grotenhuis T (2015): Biodegradation of cis-1,2-Dichloroethene in Simulated Underground Thermal Energy Storage Systems. Environmental Science and Technology 49, 13519−13527

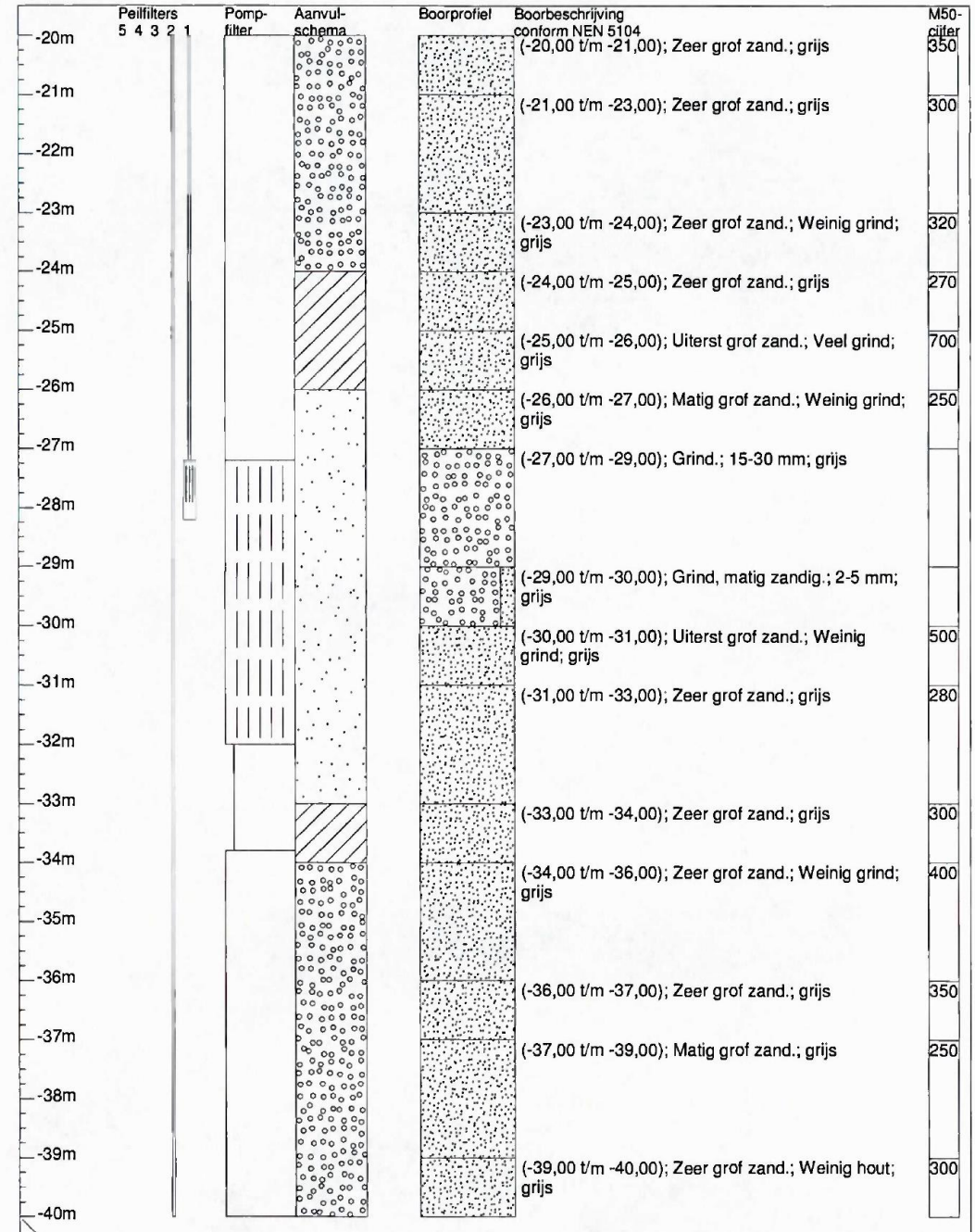
Zhuobiao Ni, Rijnaarts H. H. M., Grotenhuis J. T. C., and Van Gaans P. F. M.. Bioremediation of chlorinated ethenes in aquifer thermal energy storage. Wageningen: Wageningen University, 2015.

Kueper, B.H., Stroo, H.F., Vogel, C.M., Ward, C.H., (Eds), (2014). Chlorinated Solvent Source Zone Remediation, Springer ISBN:978-1-461-6921-6

Appendix 1: Well logs and soil profiles

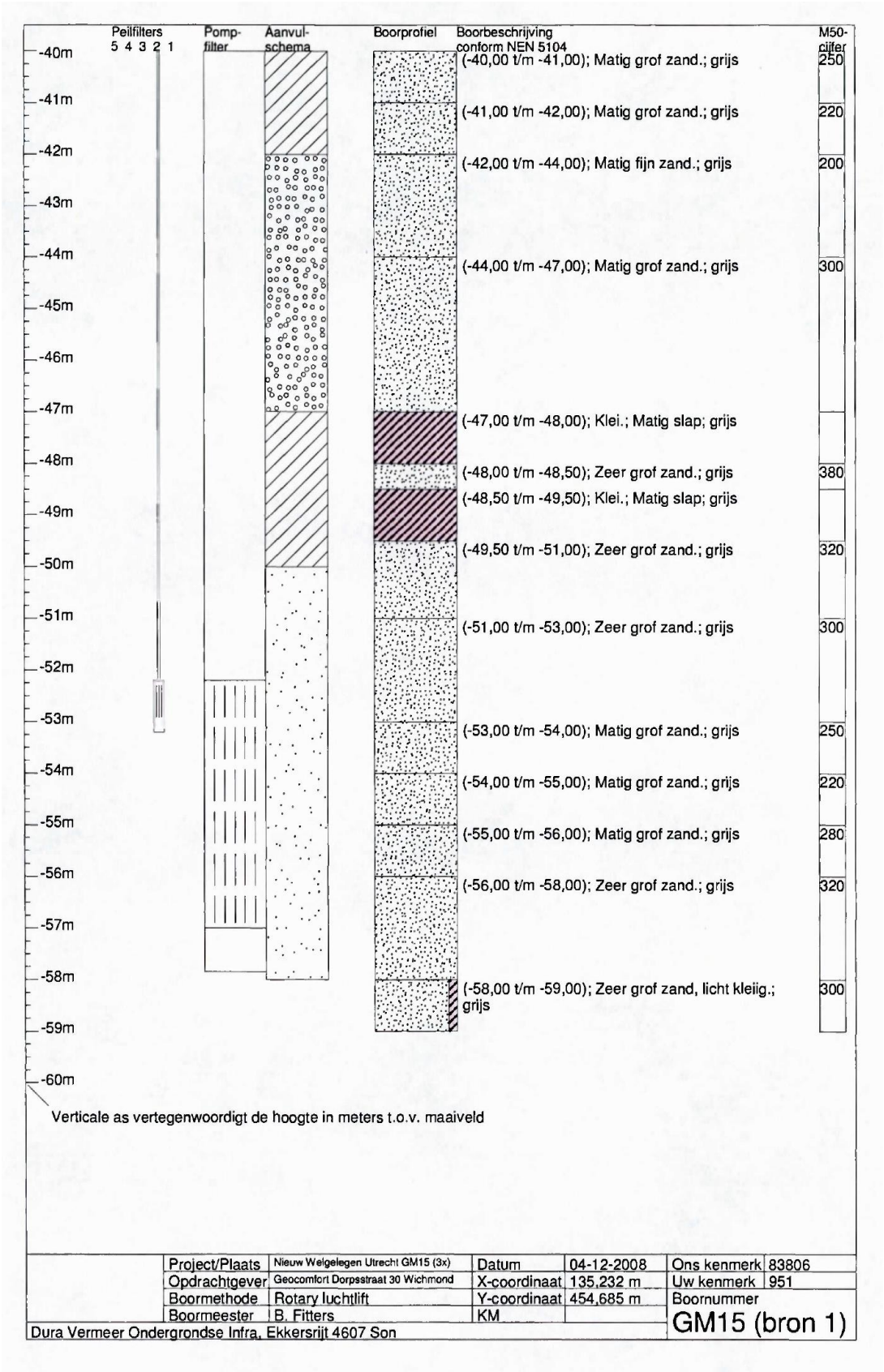


	Project/Plaats	Nieuw Welgelegen Utrecht GM15 (3x)	Datum	04-12-2008	Ons kenmerk	83806
	Opdrachtgever	Geocomfort Dorpsstraat 30 Wichmond	X-coordinaat	135.232 m	Uw kenmerk	951
	Boormethode	Rotary luchtlift	Y-coordinaat	454.685 m	Boornummer	
	Boormeester	B. Fitters	KM		GM15 (bron 1)	
Dura Vermeer Ondergrondse Infra, Ekkersrijt 4607 Son						



Project/Plaats	Nieuw Welgelegen Utrecht GM15 (3x)	Datum	04-12-2008	Ons kenmerk	83806
Opdrachtgever	Geocomfort Dorpsstraat 30 Wichmond	X-coordinaat	135,232 m	Uw kenmerk	951
Boormethode	Rotary luchtlift	Y-coordinaat	454,685 m	Boornummer	
Boormeester	B. Fitters	KM		GM15 (bron 1)	

Dura Vermeer Ondergrondse Infra, Ekkersrijt 4607 Son

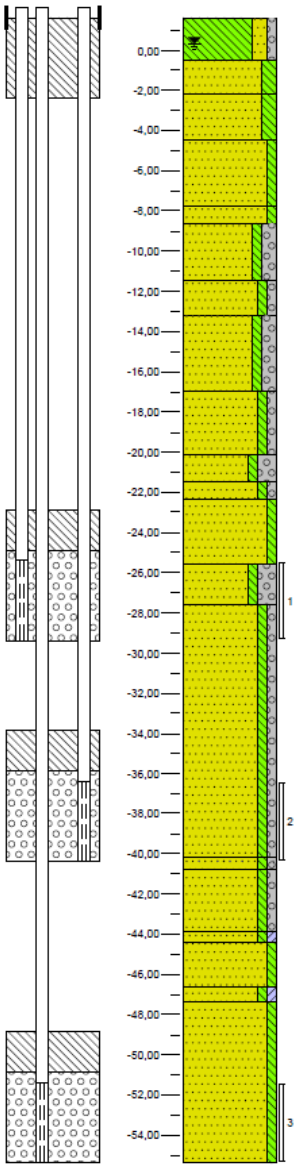


Soil profile ATES well 3 (originally named bron 1, but later renamed)

Boring: 314

Datum: 16-06-2017
X: 135221.00
Y: 454678.00
Maaiveld (mNAP): 1.62
Boormeester: Willem Smits

GWS (cm-mv): 130



0,00 berm
Leem, matig zandig, zwak grindig, zwak wortelhoudend, bruin, Edelmanboor

2,10 Zand, matig fijn, matig siltig, zwak houthoudend, grijs, Puisinstallatie machinaal

3,80 Zand, matig grof, matig siltig, zwak houthoudend, grijs, Puisinstallatie machinaal

6,10 Zand, matig grof, zwak siltig, zwak houthoudend, lichtgrijs, Puisinstallatie machinaal

9,40

10,20 Zand, zeer grof, zwak siltig, zwak houthoudend, grijs, Puisinstallatie machinaal

Zand, zeer grof, zwak siltig, matig grindig, grijs, Puisinstallatie machinaal

13,10 Zand, zeer grof, zwak siltig, zwak grindig, lichtgrijs, Puisinstallatie machinaal

14,80 Zand, zeer grof, zwak siltig, matig grindig, grijs, Puisinstallatie machinaal

18,60 Zand, zeer grof, zwak siltig, zwak grindig, lichtgrijs, Puisinstallatie machinaal

21,80 Zand, zeer grof, zwak siltig, sterk grindig, grijs, Puisinstallatie machinaal

23,10

24,00 Zand, matig grof, zwak siltig, zwak grindig, donkergrijs, Puisinstallatie machinaal

Zand, matig grof, zwak siltig, zwak houthoudend, grijs, Puisinstallatie machinaal

27,20 Zand, zeer grof, zwak siltig, sterk grindig, zwak houthoudend, donkergrijs, Puisinstallatie machinaal

29,20 Zand, zeer grof, zwak siltig, zwak grindig, grijs, Puisinstallatie machinaal

41,80

42,40 Zand, zeer grof, zwak siltig, zwak grindig, resten kalk, grijs, Puisinstallatie machinaal, kalkpitten

Zand, zeer grof, zwak siltig, zwak grindig, grijs, Puisinstallatie machinaal

45,50

46,00 Zand, zeer grof, zwak siltig, zwak kleilg, zwak houthoudend, resten kiel, grijs, Puisinstallatie machinaal

Zand, zeer grof, zwak siltig, zwak houthoudend, lichtgrijs, Puisinstallatie machinaal

48,20

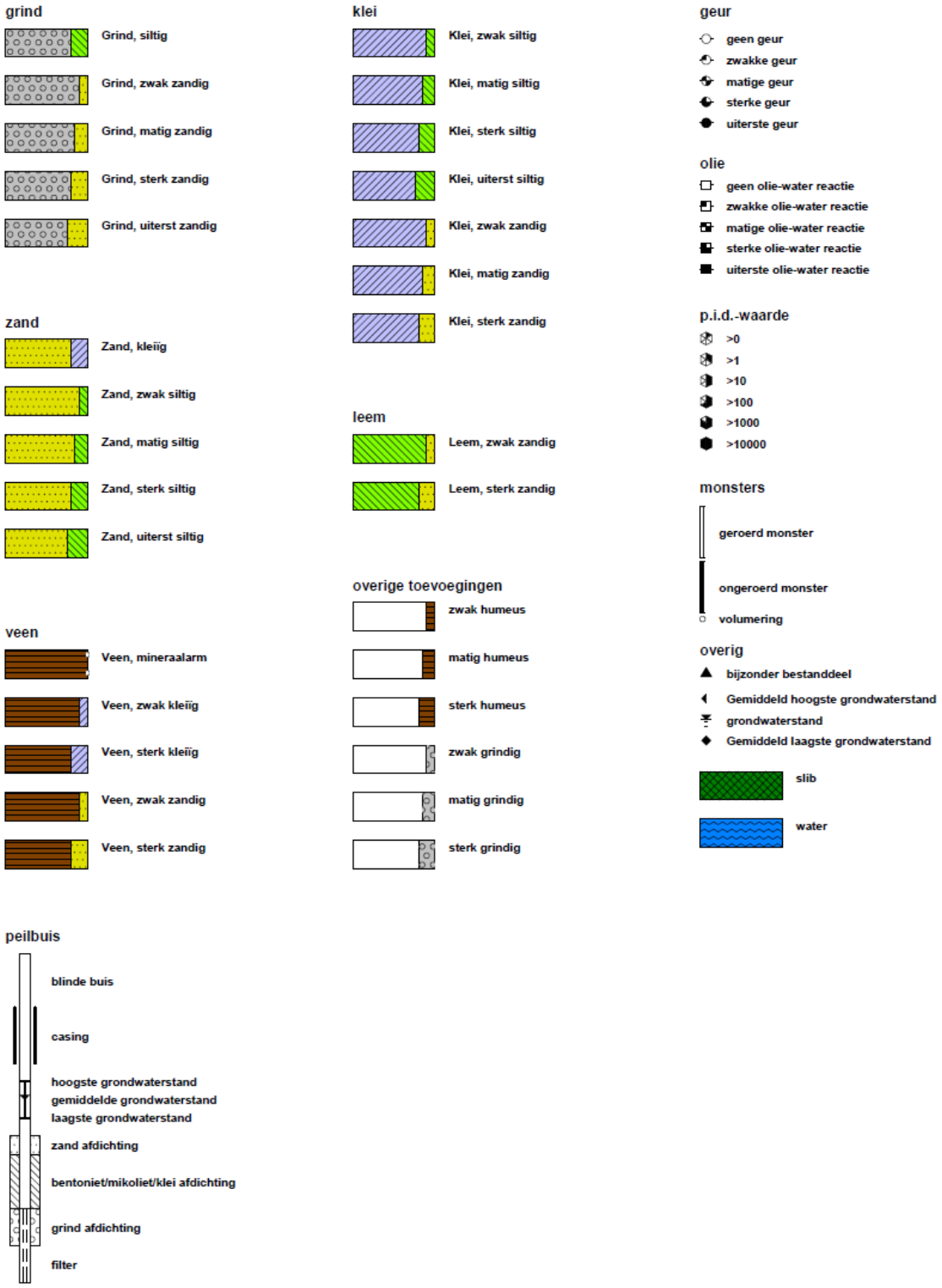
49,00 Zand, matig grof, zwak siltig, zwak kleilg, laagjes kiel, zwak houthoudend, grijs, Puisinstallatie machinaal

Zand, matig grof, zwak siltig, zwak houthoudend, lichtgrijs, Puisinstallatie machinaal

57,00

Projectnaam:	Boringen Gebiedsplan Utrecht	Boormeester:	Diversen
Opdrachtgever:	Gemeente Utrecht	Projectleider	J. Kalkwijk
Projectcode:	P16154	Bijlage:	Pagina: 1 / 1

Legenda (conform NEN 5104)



Soil profile monitoring well

Appendix 2: Field measurements

Sample	Date	GW	pH	EC	T	Redox	O2
Bron-3 (Nulmeting)	12-07-17	1.28 m			15.1	-151	0.08
Bron-3 (Nulmeting)	12-07-17	1.35 m			14.3	-131	0.04
injectie (Nulmeting)	12-07-17				14.9	-167	0.03
monitor (Nulmeting)	12-07-17	1.95 m			14.9	-193	0.04
monitor (Nulmeting)	12-07-17	1.93 m			14.7	-153	0.1
monitor (Nulmeting)	12-07-17	1.88 m			14.7	-161	0.12
Bron-3 (T=1) (Tracertest)	21-07-17	1.23 m			15.5	-142	0.1
Bron-3 (T=1) (Tracertest)	21-07-17	1.21 m			15	-142	0.16
injectie (T=1) (Tracertest)	21-07-17				15	-114	0.09
monitor (T=1) (Tracertest)	21-07-17	1.81 m			14.7	-149	0.04
monitor (T=1) (Tracertest)	21-07-17	1.79 m			14.6	-157	0.04
monitor (T=1) (Tracertest)	21-07-17	1.76 m			14.4	-195	0.03
Bron-3 (Tracertest)	24-07-17				15.1	-126	0.04
Bron-3 (Tracertest)	24-07-17				14.4	-133	0.04
injectie (Tracertest)	24-07-17				15	-106	0.04
monitor (Tracertest)	24-07-17	1.78 m			14.7	-130	0.04
monitor (Tracertest)	24-07-17	1.76 m			14.6	-138	0.03
monitor (Tracertest)	24-07-17	1.72 m			14.4	-182	0.03
Bron-3 (Tracertest)	26-07-17				15.4	-145	0.03
Bron-3 (Tracertest)	26-07-17				14.3	-150	0.03
injectie (Tracertest)	26-07-17				15.1	-132	0.03
monitor (Tracertest)	26-07-17	1.77 m			14.9	-173	0.04
monitor (Tracertest)	26-07-17	1.74 m			14.7	-166	0.03
monitor (Tracertest)	26-07-17	1.72 m			14.3	-180	0.03
Bron-3 (T=1)	28-07-17				15.2	-122	0.05
Bron-3 (T=1)	28-07-17				14.5	-132	0.03
injectie (T=1)	28-07-17				15.7	-220	0.02
monitor (T=1)	28-07-17	1.84 m			14.9	-168	0.04
monitor (T=1)	28-07-17	1.82 m			14.9	-170	0.03
monitor (T=1)	28-07-17	1.78 m			14.7	-186	0.02
Bron-3 (T=2)	31-07-17				15.2	-142	0.02
Bron-3 (T=2)	31-07-17				14.6	-146	0.02
injectie (T=2)	31-07-17				15.2	-225	0.02
monitor (T=2)	31-07-17	1.87 m			15	-188	0.03
monitor (T=2)	31-07-17	1.85 m			14.7	-182	0.02
monitor (T=2)	31-07-17	1.82 m			14.4	-194	0.02
Bron-3 (T=3)	02-08-17				15.2	-142	0.02
Bron-3 (T=3)	02-08-17				14.3	-139	0.02
injectie (T=3)	02-08-17				15.1	-207	0.02
monitor (T=3)	02-08-17	1.87 m			15.1	-200	0.03
monitor (T=3)	02-08-17	1.87 m			14.8	-165	0.02
monitor (T=3)	02-08-17	2.02 m			14.4	-180	0.02
B-45 (T=3)	02-08-17	1.81 m			12.6	-64	0.08
B-45 (T=3)	02-08-17	1.80 m			12.6	-90	0.07
B-45 (T=3)	02-08-17	1.74 m			12.7	-117	0.1
B-45 (T=3)	02-08-17	1.70 m			12.8	-91	0.14
Bron-3 (T=4)	04-08-17				14.8	-143	0.03
Bron-3 (T=4)	04-08-17				14.7	-127	0.03
injectie (T=4)	04-08-17				15.2	-204	0.01
monitor (T=4)	04-08-17	1.93 m			15.5	-203	0.01
monitor (T=4)	04-08-17	1.91 m			15.4	-165	0.02
monitor (T=4)	04-08-17	1.88 m			15.4	-190	0.01
Bron-3 (T=5)	07-08-17				15.1	-130	0.02
Bron-3 (T=5)	07-08-17				14.2	-131	0.02
injectie (T=5)	07-08-17				15	-169	0.02
monitor (T=5)	07-08-17	1.96 m			15	-205	0.02
monitor (T=5)	07-08-17	1.94 m			14.7	-183	0.02

monitor (T=5)	07-08-17	1.90 m			14.2	-192	0.02

Sample	Date	GW level	pH	EC	T	Redox	O2
Bron-3 (T=6)	10-08-17				14.7	-68	0.03
Bron-3 (T=6)	10-08-17				14.1	-72	0.02
injectie (T=6)	10-08-17				15	-154	0.02
monitor (T=6)	10-08-17	1.91 m			15	-156	0.02
monitor (T=6)	10-08-17	1.89 m			15.2	-145	0.02
monitor (T=6)	10-08-17	1.86 m			15	-150	0.02
Bron-3 (T=7)	17-08-17				15.5	-97	0.02
Bron-3 (T=7)	17-08-17				14.1	-100	0.02
injectie (T=7)	17-08-17				14.9	-146	0.02
monitor (T=7)	17-08-17	1.79 m			15	-146	0.02
monitor (T=7)	17-08-17	1.77 m			14.9	-138	0.02
monitor (T=7)	17-08-17	1.73 m			14.4	-155	0.02
Bron 3 (T=8)	28-08-17				15.5	-16	0.02
Bron-3 (T=8)	28-08-17				14.6	-14	0.03
injectie (T=8)	28-08-17				15.3	-55	0.01
monitor (T=8)	28-08-17	1.85 m			14.9	-40	0.26
monitor (T=8)	28-08-17	1.82 m			14.9	-31	0.03
monitor (T=8)	28-08-17	1.80 m			14.5	-28	0.02
Bron 3 (T=9)	22-09-17				14.4	-136	0.03
Bron-3 (T=9)	22-09-17				14.3	-132	0.04
injectie (T=9)	22-09-17				14.9	-163	0.04
monitor (T=9)	22-09-17	1.75 m			14.8	-147	0.04
monitor (T=9)	22-09-17	1.73 m			14.8	-140	0.04
monitor (T=9)	22-09-17	1.70 m			14.1	-146	0.03
Bron 3 (T=10)	13-12-17				12.3	-139	0.01
Bron-3 (T=10)	13-12-17				11.2	-139	0.01
injectie (T=10)	13-12-17				13.6	-172	0.03
monitor (T=10)	13-12-17	1.51 m			13.4	-136	0.03
monitor (T=10)	13-12-17	1.47 m			12.6	-138	0.03
monitor (T=10)	13-12-17	1.31 m			12.5	-120	0.03
Bron-1 (T=10)	13-12-17	1.54 m			12.2	-141	0.05
Bron-1 (T=10)	13-12-17	0.88 m			11.2	-131	0.11
Bron-2 (T=10)	13-12-17	1.31 m			12.2	-126	0.07
Bron-2 (T=10)	13-12-17	0.50 m			11.7	-130	0.07
B-45 (T=10)	13-12-17	1.39 m			11.2	-99	0.03
B-45 (T=10)	13-12-17	1.38 m			11.4	-97	0.07
B-45 (T=10)	13-12-17	1.33 m			11.6	-142	0.1
B-45 (T=10)	13-12-17	1.29 m			11.3	-105	0.1

Sample	Date	GW level	pH	EC	T	Redox	O2
B45 10-14 m	11-09-18	1.80 m	7.02	758	12.7	-80	0.07
B45 22-26 m	11-09-18	1.80 m	7	904	12.8	-77	0.07
B45 34-38 m	11-09-18	1.74 m	7.25	851	13	-118	0.09
B45 57-59 m	11-09-18	1.71 m	7	916	13.1	-90	0.09
M 27-31 m	11-09-18	1.91 m	7.07	844	15.5	-124	0.04
M 38-42 m	11-09-18	1.88 m	7.09	850	15.2	-122	0.04
M 53-57 m	11-09-18	1.85 m	7.08	855	14.6	-118	0.04
Injectie 28.50 m	11-09-18	1.45 m	7.07	850	15.7	-110	0.04
Bron 1 27 m	11-09-18	1.45 m	7.15	862	16.4	-106	0.08
Bron 1 51 m	11-09-18	2.68 m	7.16	856	15.4	-113	0.11
Bron 2 28 m	11-09-18	0.99 m	7.1	851	16.1	-106	0.09
Bron 2 51 m	11-09-18	2.52 m	7.07	857	15.4	-100	0.11
Bron 3 28 m	11-09-18	x	7.06	846	16.3	-101	0.04
Bron 3 51 m	11-09-18	x	7.06	855	15	-103	0.04
M 27-31 m	08-08-18	1.92 m	7.08	873	15.9	-129	0.04
M 38-42 m	08-08-18	1.92 m	7.09	880	15.5	-130	0.04
M 53-57 m	08-08-18	2.10 m	7.08	893	15.1	-116	0.05
Injectie	08-08-18	1.45 m	7.09	882	15.8	-115	0.04
Bron 3 28 m	08-08-18	x	708	879	16.2	-104	0.04
Bron 3 51 m	08-08-18	x	7.09	881	15.2	-106	0.04
Injectie extra	08-08-18	1.40 m	7.07	880	16.3	-110	0.09
B45 10-14 m	04-07-18	1.69 m	6.95	869	12.4	-78	0.06
B45 22-26 m	04-07-18	1.67 m	6.96	955	12.4	-84	0.08
B45 34-38 m	04-07-18	1.61 m	7.2	896	12.5	-125	0.09
B45 57-59 m	04-07-18	1.58 m	6.96	923	12.6	-99	0.12
M 27-31 m	04-07-18	1.75 m	7.06	899	14.8	-111	0.03
M 38-42 m	04-07-18	1.73 m	7.08	901	14.2	-120	0.03
M 53-57 m	04-07-18	1.70 m	7.06	910	13.8	-115	0.03
Injectie 28 m	04-07-18	1.35 m	7.08	900	15.3	-135	0.03
Bron 1 27 m	04-07-18	1.26 m	7.13	900	17.3	-123	0.06
Bron 1 51 m	04-07-18	1.47 m	7.15	903	15.7	-121	0.09
Bron 2 28 m	04-07-18	1.23 m	7.05	893	16.7	-108	0.06
Bron 2 51 m	04-07-18	1.22 m	7.08	898	14.8	-112	0.06
Bron 3 28 m	04-07-18	x	7.03	895	17.3	-124	0.03
Bron 3 51 m	04-07-18	x	7.06	895	14.9	-117	0.03
B 45 (10-14 m)	14-03-18	1.69 m	7	813	12	-65	0.09
B 45 (22-26 m)	14-03-18	1.66 m	6.99	943	12	-73	0.05
B 45 (34-38 m)	14-03-18	1.61 m	7.19	896	12	-113	0.05
B 45 (53-57 m)	14-03-18	1.58 m	7	894	11.8	-90	0.07
M (27-31 m)	14-03-18	1.78 m	7.08	875	13.8	-92	0.06
M (38-42 m)	14-03-18	1.75 m	7.07	885	12.9	-104	0.07
M (53-57 m)	14-03-18	1.69 m	7.11	881	12.6	-99	0.09
Injectie (28.72 m)	14-03-18	1.44 m	6.99	880	13	-111	0.07
Bron 3 (28.00 m)	14-03-18	x	6.91	873	11.7	-79	0.04
Bron 3 (51.00 m)	14-03-18	x	7	877	10.4	-95	0.04
Bron 2 (28.00 m)	14-03-18	1.29 m	7.08	865	12.1	-100	0.07
Bron 2 (51.00 m)	14-03-18	1.29 m	7.1	876	11.1	-103	0.11
Bron 1 (27.50 m)	14-03-18	1.57 m	7.1	879	12.3	-95	0.04
Bron 1 (51.30 m)	14-03-18	1.54 m	7.19	878	11.1	-102	0.06

Appendix 3: Organic compounds

Dichloromethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	0.6	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,50											<0,5	<0,5	<0,5		<0,5

Tetrachloromethane (Tetra) (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,1							<0,1	<0,1	<0,1		<0,1
B-45 22-26 m					<0,1							<0,1	<0,1	<0,1		<0,1
B-45 34-38 m					<0,1							<0,1	<0,1	<0,1		<0,1
B-45 57-59 m					<0,1							<0,1	<0,1	<0,1		<0,1
ATES-3 28 m	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
ATES-3 51 m	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
injection		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 27/31 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 38/42 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 53/57 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
ATES-1 27,5 m	<0,1											<0,1	<0,1	<0,1		<0,1
ATES-1 50,30 m	<0,1											<0,1	<0,1	<0,1		<0,1
ATES-2 28 m	<0,1											<0,1	<0,1	<0,1		<0,1
ATES-2 51 m	<0,1											<0,1	<0,1	<0,1		<0,1

Trichloromethane (Chloroform) (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,50											<0,5	<0,5	<0,5		<0,5

1,1-Dichloroethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					0.5							0.50	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,50											<0,5	<0,5	<0,5		<0,5

1,2-Dichloroethane (µg/l)																

	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	**1.2**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	**0.9**	**0.8**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,50											<0,5	<0,5	<0,5		<0,5

1,1,1-Trichloroethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,50	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,50											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,50											<0,5	<0,5	<0,5		<0,5

Cis-1,2-Dichloroethylene (µg/l)																
	19-04-	12-07-	28-07-	31-07-	02-08-	04-08-	07-08-	10-08-	17-08-	28-08-	22-09-	13-12-	14-03-	04-07-	08-08-	11-09-

	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	18
B-45 10-14m					<0,50							<0,50	<0,50	<0,50		<0,50
B-45 22-26 m					**1.5**							**1.5**	**1.2**	**1.1**		**1**
B-45 34-38 m					**0.83**							**0.6**	**0.82**	**0.74**		**0.7**
B-45 57-59 m					<0,50							<0,50	<0,50	<0,50		<0,50
ATES-3 28 m	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
ATES-3 51 m	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
injection		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 27/31 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 38/42 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 53/57 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
ATES-1 27,5 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-1 50,30 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-2 28 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-2 51 m	<0,50											<0,50	<0,50	<0,50		<0,50

Vinyl chloride (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					0.5							0.4	0.4	<0.2		0.4
B-45 22-26 m					21							16.00	9.60	11.00		11
B-45 34-38 m					62							56.00	40.00	49.00		33
B-45 57-59 m					3.5							3.6	0.7	1.1		1.1
ATES-3 28 m	1.9	2.4	1.8	1.8	1.9	1.8	2.1	1.1	1.5	1.2	<0,2	<0,2	10.00	4.00	3	1.3
ATES-3 51 m	6.6	3.2	<0,2	1.5	1.7	1.9	1.4	1.5	1.3	1.4	<0,2	1.9	6.1	4.1	2	0.6
injection		2.6	<0,2	<0,2	<0,2	0.3	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	0.20	1.60	1.5	0.2
monitor 27/31 m		3	2	1.8	0.8	0.5	0.9	0.7	0.5	0.2	<0,2	0.2	0.50	0.3	1.9	0.2
monitor 38/42 m		3.2	2.6	2.6	3	2.9	2.9	3.1	2.6	2	1.1	1.6	1.80	0.7	2.2	1
monitor 53/57 m		4.3	3.4	3.5	2.7	3.2	3	3.2	2.9	3	1.6	0.9	4.20	1.5	2	0.9
ATES-1 27,5 m	1											0.6	0.40	1.1		0.7
ATES-1 50,30 m	0.6											0.9	0.4	1.1		0.8
ATES-2 28 m	0.3											0.4	1.9	0.4		0.3
ATES-2 51 m	0.4											0.5	1.2	0.4		0.4

Trans-1,2-Dichloroethylene (µg/l)																
	19-04-	12-07-	28-07-	31-07-	02-08-	04-08-	07-08-	10-08-	17-08-	28-08-	22-09-	13-12-	14-03-	04-07-	08-08-	11-09-

	17	17	17	17	17	17	17	17	17	17	17	17	18	18	18	18
B-45 10-14m					<0,50							<0,50	<0,50	<0,50		<0,50
B-45 22-26 m					<0,50							<0,50	<0,50	<0,50		<0,50
B-45 34-38 m					<0,50							<0,50	<0,50	<0,50		<0,50
B-45 57-59 m					<0,50							<0,50	<0,50	<0,50		<0,50
ATES-3 28 m	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
ATES-3 51 m	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
injection		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 27/31 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 38/42 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
monitor 53/57 m		<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50	<0,50
ATES-1 27,5 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-1 50,30 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-2 28 m	<0,50											<0,50	<0,50	<0,50		<0,50
ATES-2 51 m	<0,50											<0,50	<0,50	<0,50		<0,50

Trichlorethylene (Tri) (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,5											<0,5	<0,5	<0,5		<0,5

Tetrachlorethylene (Per) (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,1							<0,1	<0,1	<0,1		<0,1
B-45 22-26 m					<0,1							<0,1	<0,1	<0,1		<0,1

B-45 34-38 m					<0,1							<0,1	<0,1	<0,1		<0,1
B-45 57-59 m					<0,1							<0,1	<0,1	<0,1		<0,1
ATES-3 28 m	<0,1	**0.6**	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
ATES-3 51 m	<0,1	<0,1	<0,1	<0,1	<0,1	**0.3**	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
injection		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 27/31 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 38/42 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
monitor 53/57 m		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
ATES-1 27,5 m	<0,1											<0,1	<0,1	<0,1		<0,1
ATES-1 50,30 m	<0,1											<0,1	<0,1	<0,1		<0,1
ATES-2 28 m	**0.1**											<0,1	<0,1	<0,1		<0,1
ATES-2 51 m	<0,1											<0,1	<0,1	<0,1		<0,1

Ethylene (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<2,0							<2,0	<2,0	<2,0		<2,0
B-45 22-26 m					<2,0							<2,0	<2,0	<2,0		<2,0
B-45 34-38 m					2.5							<2,0	**2.20**	<2,0		<2,0
B-45 57-59 m					<2,0							<2,0	<2,0	<2,0		<2,0
ATES-3 28 m	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
ATES-3 51 m	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
injection		<2,0	**2.4**	**2.2**	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
monitor 27/31 m		<2,0	<2,0	<2,0	**2.9**	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
monitor 38/42 m		<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
monitor 53/57 m		<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0	<2,0
ATES-1 27,5 m	<2,0											<2,0	<2,0	<2,0		<2,0
ATES-1 50,30 m	<2,0											<2,0	<2,0	<2,0		<2,0
ATES-2 28 m	<2,0											<2,0	<2,0	**3.10**		<2,0
ATES-2 51 m	<2,0											<2,0	<2,0	<2,0		<2,0

Ethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<2,0							<2,0	<2,0	<2,0		<2,0
B-45 22-26 m					14							5	6.1	4.8		6.8
B-45 34-38 m					11							4.2	9.1	8.8		9

B-45 57-59 m					3.3							<2,0	<2.0	<2.0		<2,0
ATES-3 28 m	<2.0	2.6	4.2	3.1	3.7	<2,0	3.1	<2,0	2.7	<2,0	<2,0	<2,0	3.00	2.90	2.8	2.4
ATES-3 51 m	2.2	2.9	2.2	3.9	4	<2,0	3.9	<2,0	2.6	2.6	<2,0	<2,0	3.40	<2.0	2.8	3.1
injection		2.3	<2,0	3.1	3.7	2.2	3.9	<2,0	3.4	2.2	<2,0	<2,0	2.90	<2.0	2.3	<2,0
monitor 27/31 m		3.1	4.7	4.1	<2,0	<2,0	3.4	<2,0	2.1	2.5	<2,0	<2,0	3.10	3.10	3	2.5
monitor 38/42 m		3.6	4.7	4.5	4.2	2.6	4.3	<2,0	3.9	2.1	<2,0	<2,0	3.00	2.10	3.4	3.3
monitor 53/57 m		3.2	4.1	3.6	3.7	<2,0	4.4	<2,0	3.4	2.4	<2,0	<2,0	2.60	2.60	2.8	2.6
ATES-1 27,5 m	<2,0											<2,0	<2,0	<2,0		<2,0
ATES-1 50,30 m	<2,0											<2,0	<2,0	<2,0		<2,0
ATES-2 28 m	2.70											<2,0	<2,0	<2,0		<2,0
ATES-2 51 m	<2,0											<2,0	<2,0	<2,0		<2,0

Methane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					52							17	31	32		38
B-45 22-26 m					330							110	92	90		110
B-45 34-38 m					570							340	710	580		540
B-45 57-59 m					150							68	83	86		67
ATES-3 28 m	190	220	290	270	280	130	280	80	210	130	82	94	340	270	270	200
ATES-3 51 m	230	240	200	300	270	140	260	96	160	150	78	140	280	190	250	250
injection		230	7900	11000	5400	960	3600	630	770	400	360	160	410	170	230	190
monitor 27/31 m		270	370	310	1600	390	470	130	220	180	68	87	290	290	270	240
monitor 38/42 m		370	460	390	410	240	430	150	320	160	110	120	280	190	290	310
monitor 53/57 m		290	360	350	580	230	490	140	360	220	180	110	250	220	230	220
ATES-1 27,5 m	240											120	220	170		120
ATES-1 50,30 m	230											120	200	140		130
ATES-2 28 m	110											46	66	95		95
ATES-2 51 m	88											40	49	69		100

1,1,2-Trichloroethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5

ATES-3 28 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	**11**	**1.8**	**0.9**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	**7.2**	**7.3**	**1.2**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	**1**	**1.8**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,5											<0,5	<0,5	<0,5		<0,5

1,2-Dichloroethane (µg/l)																
	19-04-17	12-07-17	28-07-17	31-07-17	02-08-17	04-08-17	07-08-17	10-08-17	17-08-17	28-08-17	22-09-17	13-12-17	14-03-18	04-07-18	08-08-18	11-09-18
B-45 10-14m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 22-26 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 34-38 m					<0,5							<0,5	<0,5	<0,5		<0,5
B-45 57-59 m					<0,5							<0,5	<0,5	<0,5		<0,5
ATES-3 28 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-3 51 m	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
injection		<0,5	**1.2**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 27/31 m		<0,5	<0,5	<0,5	**0.9**	**0.8**	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 38/42 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
monitor 53/57 m		<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
ATES-1 27,5 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-1 50,30 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 28 m	<0,5											<0,5	<0,5	<0,5		<0,5
ATES-2 51 m	<0,5											<0,5	<0,5	<0,5		<0,5

Appendix 4: DNA analyses

Groundwater samples

Well	Depth	Date	*Total Bacteria*	*DHC*	*vcrA*	*bvcA*	*etnE*
Bron 1	27,5m	19-04-17	6.60E+04	1.33E+01	1.31E+02	<3	1.20E+01
Bron 1	51,3m	19-04-17	2.81E+04	9.90E+00	<2,5	<3	3.35E+00
Bron 2	28m	19-04-17	3.31E+04	6.86E+01	4.10E+01	<3	1.44E+02
Bron 2	51m	19-04-17	2.62E+04	2.69E+01	3.93E+01	<3	2.24E+00
Bron-3	28 m	19-04-17	4.20E+04	<4	<2,5	<3	3.36E+00
Bron-3	51 m	19-04-17	7.57E+04	8.70E+00	<2,5	<3	1.28E+01
Bron-3	28 m	12-07-17	1.86E+05	<4	<3	<3	<20
Bron-3	51 m	12-07-17	2.13E+05	<4	<3	<3	<20
Injectie	29 m	12-07-17	2.47E+06	<4	<3	<3	<20
Monitor	27-31m	12-07-17	4.41E+06	<4	<3	<3	3.40E+02
Monitor	38-42m	12-07-17	6.37E+05	<4	<3	<3	<20
Monitor	53-57m	12-07-17	6.85E+06	<4	<3	<3	4.35E+01
Bron-3	28 m	28-07-17	2.34E+03	4.73E+02	4.30E+02	<3	<20
Bron-3	51 m	28-07-17	2.42E+03	1.02E+02	3.44E+02	3.67E+00	<20
Injectie	29 m	28-07-17	4.71E+07	1.34E+02	4.94E+02	<3	<20
Monitor	27-31m	28-07-17	1.07E+04	<4	5.78E+00	<3	3.08E+02
Monitor	38-42m	28-07-17	2.95E+03	1.13E+01	1.27E+02	<3	<20
Monitor	53-57m	28-07-17	1.26E+04	2.42E+01	<3	<3	6.71E+01
Bron-3	28 m	31-07-17	1.97E+03	1.75E+07	2.21E+07	2.14E+06	<20
Bron-3	51 m	31-07-17	1.15E+03	1.63E+07	1.89E+07	1.02E+06	<20
Injectie	29 m	31-07-17	1.65E+07	1.82E+05	2.09E+05	1.18E+04	7.11E+02
Monitor	27-31m	31-07-17	4.53E+03	2.36E+06	2.71E+06	1.33E+05	<20
Monitor	38-42m	31-07-17	1.05E+04	1.34E+02	2.11E+02	<3	<20
Monitor	53-57m	31-07-17	7.93E+03	1.68E+01	7.38E+01	<3	<20
Bron-3	28 m	02-08-17	3.78E+03	1.40E+07	1.73E+07	1.66E+06	<20
Bron-3	51 m	02-08-17	3.91E+03	9.18E+05	1.11E+06	8.28E+04	<20
Injectie	29 m	02-08-17	1.12E+07	3.84E+06	4.48E+06	1.79E+05	2.94E+02
Monitor	27-31m	02-08-17	3.72E+06	3.98E+05	4.87E+05	1.89E+04	<20
Monitor	38-42m	02-08-17	1.88E+04	6.24E+02	7.68E+02	6.56E+00	<20
Monitor	53-57m	02-08-17	2.69E+05	5.58E+02	5.12E+02	1.73E+01	<20
B-45	10-14m	02-08-17	1.28E+04	4.73E+02	2.13E+02	<3	<20
B-45	22-26 m	02-08-17	3.75E+03	1.02E+02	1.67E+02	2.03E+00	<20
B-45	34-38 m	02-08-17	2.46E+03	3.47E+01	6.40E+01	<3	1.15E+02
B-45	57-59 m	02-08-17	1.73E+03	<4	3.34E+00	<3	5.08E+01
Bron-3	28 m	04-08-17	3.45E+03	1.13E+01	6.47E+01	<3	<20
Bron-3	51 m	04-08-17	1.38E+04	2.91E+04	<3	<3	<20
Injectie	29 m	04-08-17	4.51E+06	1.75E+07	5.72E+06	6.31E+05	2.91E+01
Monitor	27-31m	04-08-17	4.37E+06	1.63E+07	4.92E+06	3.14E+05	2.37E+01
Monitor	38-42m	04-08-17	1.19E+04	6.07E+04	2.57E+04	1.62E+03	<20
Monitor	53-57m	04-08-17	1.39E+06	5.54E+06	7.88E+05	4.47E+04	<20
Bron-3	28 m	07-08-17	2.11E+03	1.34E+02	1.04E+02	<3	<20
Bron-3	51 m	07-08-17	1.67E+03	1.68E+01	3.76E+01	<3	<20
Injectie	29 m	07-08-17	3.19E+06	1.40E+07	4.49E+06	4.89E+05	2.09E+01
Monitor	27-31m	07-08-17	2.21E+05	9.18E+05	3.24E+05	2.77E+04	<20
Monitor	38-42m	07-08-17	3.85E+05	1.41E+06	4.64E+05	2.21E+04	<20
Monitor	53-57m	07-08-17	3.24E+05	8.14E+05	1.58E+05	7.07E+03	<20

Well	Depth	Date	*Total Bacteria*	*DHC*	*vcrA*	*bvcA*	*etnE*
Bron-3	28 m	10-08-17	2.86E+03	6.24E+02	3.60E+02	3.54E+00	<20
Bron-3	51 m	10-08-17	3.14E+03	5.58E+02	2.42E+02	9.02E+00	<20
injectie	29 m	10-08-17	6.98E+05	6.83E+05	1.11E+06	7.58E+04	2.34E+01
Monitor	27-31m	10-08-17	3.13E+04	1.26E+04	2.01E+04	8.37E+02	<20
Monitor	38-42m	10-08-17	6.56E+04	3.76E+04	6.30E+04	2.68E+03	<20
Monitor	53-57m	10-08-17	6.31E+04	1.18E+04	2.26E+04	8.09E+02	<20
Bron-3	28 m	17-08-17	2.47E+03	5.19E+01	7.48E+01	3.57E+00	<20
Bron-3	51 m	17-08-17	2.62E+03	<4	9.50E+00	<3	<20
Injectie	29 m	17-08-17	4.10E+05	1.26E+05	2.22E+05	1.52E+04	2.68E+01
Monitor	27-31m	17-08-17	4.44E+04	1.42E+04	2.93E+04	1.60E+03	<20
Monitor	38-42m	17-08-17	1.42E+04	8.36E+02	1.12E+03	4.05E+01	<20
Monitor	53-57m	17-08-17	1.22E+04	9.63E+02	1.87E+03	1.01E+02	<20
Bron-3	28 m	28-08-17	1.44E+03	8.67E+00	7.40E+00	<3	<20
Bron-3	51 m	28-08-17	1.01E+03	<4	<3	<3	<20
Injectie	29 m	28-08-17	1.24E+05	2.20E+04	4.72E+04	3.41E+03	<20
Monitor	27-31m	28-08-17	5.34E+03	1.34E+03	2.23E+03	1.75E+02	<20
Monitor	38-42m	28-08-17	1.59E+03	2.56E+02	5.57E+02	3.74E+01	<20
Monitor	53-57m	28-08-17	5.50E+03	3.36E+02	7.10E+02	6.03E+01	<20
Bron3	28m	22-09-17	4.26E+03	1.61E+01	1.00E+01	<3	<20
Bron 3	51m	22-09-17	4.85E+03	3.07E+01	3.18E+01	<3	<20
injectie	29 m	22-09-17	1.38E+05	8.69E+04	9.51E+04	1.03E+04	<20
Monitor	27-31m	22-09-17	1.81E+05	6.54E+04	9.06E+04	1.22E+04	8.00E+01
Monitor	38-42m	22-09-17	6.23E+03	7.92E+02	1.10E+03	6.95E+01	<20
Monitor	53-57m	22-09-17	3.76E+04	3.80E+03	7.29E+03	5.13E+02	<20
Bron 3	28m	13-12-17	3.85E+03	<4	<3	<3	<20
Bron 3	51m	13-12-17	4.48E+03	2.37E+02	2.06E+02	1.05E+01	<20
Injectie	29 m	13-12-17	4.42E+05	9.11E+04	1.41E+05	1.48E+04	3.32E+01
Monitor	27-31m	13-12-17	7.47E+04	3.25E+03	4.78E+03	2.19E+02	<20
Monitor	38-42m	13-12-17	8.75E+04	2.22E+02	3.67E+02	9.61E+00	1.86E+02
Monitor	53-57m	13-12-17	1.51E+04	5.58E+02	8.98E+02	6.73E+01	<20
Bron 1	27,5m	13-12-17	3.02E+04	6.27E+01	1.07E+02	3.99E+00	<20
Bron 1	51,3m	13-12-17	8.29E+03	<4	<3	<3	<20
Bron 2	28m	13-12-17	5.73E+04	2.46E+02	<3	<3	2.44E+01
Bron 2	51m	13-12-17	7.34E+03	<4	<3	<3	<20
B45	10-14m	13-12-17	1.97E+04	<4	<3	<3	<20
B45	22-26m	13-12-17	5.22E+03	4.41E+00	4.69E+00	<3	<20
B45	34-38m	13-12-17	5.48E+03	8.63E+01	1.89E+01	<3	<20
B45	57-79m	13-12-17	6.37E+03	<4	4.60E+01	<3	<20

Well	Depth	Date	*Total Bacteria*	*DHC*	*vcrA*	*bvcA*	*etnE*
B 45	10-14m	14-03-18	1.46E+04	2.85E+00	<3	<3	<6
B 45	22-26m	14-03-18	5.06E+04	4.95E+02	<3	<3	<6
B 45	34-38m	14-03-18	1.26E+04	5.52E+00	4.85E+01	<3	<6
B 45	53-57m	14-03-18	4.52E+03	3.90E+00	<3	<3	<6
Monitor	27-31m	14-03-18	4.08E+04	1.40E+03	1.29E+03	1.67E+02	<6
Monitor	38-42m	14-03-18	7.03E+03	8.55E+01	1.73E+02	2.39E+01	<6
Monitor	53-57m	14-03-18	8.94E+03	3.14E+02	5.92E+02	4.22E+01	<6
Injectie	29 m	14-03-18	1.93E+07	5.68E+05	1.25E+06	8.06E+04	5.71E+02
Bron 3	28m	14-03-18	4.28E+03	8.19E+00	1.61E+01	<3	<6
Bron 3	51m	14-03-18	3.30E+03	<2	6.64E+01	<3	<6
Bron 2	28m	14-03-18	2.67E+04	4.45E+00	<3	<3	<6
Bron 2	51m	14-03-18	6.09E+03	7.76E+00	9.12E+00	<3	<6
Bron 1	27,5m	14-03-18	9.73E+03	1.18E+02	1.07E+02	<3	<6
Bron 1	51,3m	14-03-18	3.68E+03	6.22E+01	2.22E+01	<3	<6
B 45	10-14m	04-07-18	1.12E+04	<40	4.13E+01	<3	8.37E+00
B 45	22-26m	04-07-18	1.08E+04	<40	3.47E+01	<3	6.36E+00
B 45	34-38m	04-07-18	4.99E+03	<40	6.04E+01	<3	1.04E+01
B 45	53-57m	04-07-18	1.91E+03	<40	4.01E+01	<3	2.15E+00
Monitor	27-31m	04-07-18	4.83E+03	<40	5.54E+01	<3	1.48E+00
Monitor	38-42m	04-07-18	5.14E+03	<40	2.85E+01	<3	1.03E+01
Monitor	53-57m	04-07-18	9.54E+03	<40	6.93E+01	<3	7.07E+00
Injectie	29m	04-07-18	2.35E+04	7.37E+01	1.13E+02	6.81E+00	1.28E+01
Bron 1	28m	04-07-18	3.84E+03	<40	1.63E+02	<3	8.95E+00
Bron 1	51m	04-07-18	4.65E+03	<40	2.75E+02	<3	8.86E+00
Bron 2	28m	04-07-18	5.59E+03	<40	3.89E+02	<3	2.17E+00
Bron 2	51m	04-07-18	5.54E+03	<40	5.17E+02	<3	7.35E+00
Bron 3	27m	04-07-18	1.76E+04	<40	2.03E+02	<3	8.60E+00
Bron 3	52m	04-07-18	7.83E+03	<40	1.48E+01	<3	7.25E+00
Monitor	27-31m	08-08-18	4.53E+03	6.90E+00	<2	<3	<2
Monitor	38-42m	08-08-18	4.80E+03	<4	<2	<3	<2
Monitor	53-57m	08-08-18	5.36E+03	<4	<2	<3	<2
Injectie	29 m	08-08-18	1.59E+05	1.51E+02	1.89E+01	7.97E+00	<2
Bron 3	28m	08-08-18	3.43E+03	<4	<2	<3	<2
Bron 3	51m	08-08-18	4.24E+03	<4	<2	<3	<2
Monitor	27-31m	11-09-18	3.44E+02	<4	3.86E+01	<3	<5
Monitor	38-42m	11-09-18	1.14E+03	2.92E+01	3.71E+02	<3	<5
Monitor	53-57m	11-09-18	1.14E+03	<4	<12	<3	<5
Injectie	29m	11-09-18	1.42E+04	1.21E+02	1.57E+02	<3	<5
Bron 1	28m	11-09-18	1.46E+03	6.68E+00	<12	<3	<5
Bron 1	51m	11-09-18	3.07E+03	<4	<12	<3	<5
Bron 2	28m	11-09-18	1.56E+03	<4	<12	<3	<5
Bron 2	51m	11-09-18	1.74E+03	5.26E+00	<12	<3	<5

Appendix 5: Certificate of microbial culture

bioclear
microbial analysis

Bioclear earth b.v.
T.a.v. de heer M. Henssen
Postbus 2262
9704 CG GRONINGEN

ons kenmerk	uw kenmerk	datum
20177517/1553	20165183	10 november 2017

betreft

Analyserapport

Geachte heer Henssen,

Hierbij ontvangt u de resultaten van de microbiële analyse ten behoeve van uw project 20165183. Dit rapport mag uitsluitend in zijn originele vorm worden gereproduceerd.

Geconserveerde monsters worden tot drie maanden na het versturen van het analyserapport bewaard. Indien u monsters langer bewaard wilt hebben dient u dit binnen deze periode kenbaar te maken.

We hopen u hiermee voldoende te hebben geïnformeerd. Mocht u nog vragen hebben, neemt u dan gerust contact met ons op.

Met vriendelijke groet,

Aaltje Joldersma
Microbial Analysis

bioclear
microbial analysis

Microbiële analyseresultaten

Het volgende monster is ontvangen op 19 juli 2017:

Monstercode	Uw monsternaam	Datum bemonstering	Monstertype
001	1 19 juli 2017	19 juli 2017	vloeistof

Per monster wordt de detectielimiet van de analyses bepaald aan de hand van interne controles, deze kunnen daarom per monster variëren. De eenheid van de detectielimieten en van de analyses is aantal cellen per milliliter (N/ml), waarbij wordt aangenomen dat 1 DNA-kopie gelijk staat aan 1 cel.

Monstercode	Eenheid (N)	001 (N/ml)
Monsterspecifieke detectielimiet		$2{,}2x10^{2}$
Dehalococcoides spp.	Cellen	$2{,}0x10^{8}$

De spreiding van de analyseresultaten ligt tussen 0,5*N en 2*N (N=aantal gedetecteerde cellen)

Appendix 6: Anions and cations

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
12-07-17	**ATES-3 28 m**	n.a.	41.75	0.06	98.09	n.a.	0.21	n.a.	< MDL (0)	45.11	1.13	3.05	10.41	124.74
12-07-17	**ATES-3 51 m**	< MDL (0.01)	41.36	0.06	97.66	n.a.	0.22	< MDL (0.02)	< MDL (0)	45.19	1.11	3.07	10.45	125.12
12-07-17	**Injection (28.72 m)**	< MDL (0.02)	42.38	0.06	97.81	n.a.	0.22	n.a.	< MDL (0)	45.17	1.12	3.00	10.50	124.97
12-07-17	**M (27-31 m)**	n.a.	42.43	0.07	96.10	n.a.	0.22	n.a.	< MDL (0)	45.64	1.15	2.80	10.90	125.27
12-07-17	**M (38-42 m)**	< MDL (0.03)	43.96	0.10	91.34	n.a.	0.23	n.a.	< MDL (0)	49.10	1.09	1.96	11.43	122.83
12-07-17	**M (53-57 m)**	n.a.	44.60	0.11	91.22	n.a.	0.22	n.a.	< MDL (0)	47.34	1.05	2.33	11.91	127.21
21-07-17	**ATES-3 28 m**	< MDL (0.05)	39.15	0.06	98.42	n.a.	0.21	< MDL (0.2)	< MDL (0)	42.91	1.16	3.16	9.28	111.14
21-07-17	**ATES-3 51 m**	n.a.	39.11	0.06	98.40	n.a.	0.21	< MDL (0.12)	< MDL (0)	43.16	1.16	3.21	9.29	110.59
21-07-17	**Injection (28.72 m)**	< MDL (0.02)	39.52	0.06	97.75	n.a.	0.30	n.a.	0.04	44.09	1.16	3.13	9.34	110.87
21-07-17	**M (27-31 m)**	n.a.	39.29	0.06	96.21	n.a.	0.20	n.a.	< MDL (0)	43.54	1.18	2.83	9.64	110.95
21-07-17	**M (38-42 m)**	n.a.	41.74	0.10	90.28	n.a.	0.22	n.a.	< MDL (0)	46.58	1.13	1.93	10.19	109.00
21-07-17	**M (53-57 m)**	n.a.	41.96	0.10	89.28	n.a.	0.20	n.a.	< MDL (0)	45.59	1.09	2.27	10.45	111.70
21-07-17	**ATES-3 28 m**	< MDL (0,85)	39.45	< MDL (0,1)	95.65	n.a.	n.a.	n.a.	.	.	.	.	.	.
21-07-17	**ATES-3 51 m**	< MDL (0,37)	37.97	< MDL (0,09)	95.48	n.a.	< MDL (0,21)	n.a.	.	.	.	.	.	.
21-07-17	**Injection (28.72 m)**	< MDL (0,36)	38.46	< MDL (0,09)	95.17	n.a.	< MDL (0,29)	n.a.	.	.	.	.	.	.
21-07-17	**M (27-31 m)**	< MDL (0,28)	37.80	< MDL (0,09)	93.08	n.a.	n.a.	n.a.	.	.	.	.	.	.
21-07-17	**M (38-42 m)**	< MDL (0,3)	40.51	< MDL (0,13)	87.91	n.a.	< MDL (0,2)	n.a.	.	.	.	.	.	.
21-07-17	**M (53-57 m)**	< MDL (0,29)	40.52	0.15	86.57	n.a.	< MDL (0,29)	n.a.	.	.	.	.	.	.
24-07-17	**ATES-3 28 m**	< MDL (0.03)	39.54	0.05	98.17	n.a.	0.22	n.a.	< MDL (0)	42.07	1.08	3.10	9.10	110.16
24-07-17	**ATES-3 51 m**	< MDL (0.02)	39.61	0.05	98.25	n.a.	0.22	n.a.	< MDL (0.01)	41.85	1.08	3.11	9.10	109.94
24-07-17	**Injection (28.72 m)**	n.a.	40.05	0.06	97.75	n.a.	0.29	n.a.	0.04	43.73	1.06	3.07	9.20	110.04
24-07-17	**M (27-31 m)**	< MDL (0.02)	39.15	0.06	98.98	n.a.	3.62	n.a.	0.55	42.97	1.12	2.82	9.48	110.30
24-07-17	**M (38-42 m)**	< MDL (0.03)	41.50	0.10	90.62	n.a.	0.90	n.a.	0.03	45.31	1.09	1.98	10.05	109.20
24-07-17	**M (53-57 m)**	< MDL (0.1)	41.82	0.10	89.50	n.a.	2.94	n.a.	0.24	44.58	1.02	2.14	10.45	110.55

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
26-07-17	**ATES-3 28 m**	< MDL (0.03)	38.822	0.05	98.13	n.a.	0.20	< MDL (0.11)	0.06	45.20	1.07	3.21	10.17	111.14
26-07-17	**ATES-3 51 m**	< MDL (0.04)	38.6935	0.06	98.85	n.a.	0.21	n.a.	0.06	45.65	1.05	3.25	10.24	109.93
26-07-17	**Injection (28.72 m)**	< MDL (0.03)	38.79	0.06	97.38	n.a.	0.23	n.a.	0.07	45.99	0.74	3.13	10.34	112.50
26-07-17	**M (27-31 m)**	< MDL (0.04)	38.6123	0.07	96.30	n.a.	0.59	n.a.	0.43	46.98	1.10	2.89	10.53	110.03
26-07-17	**M (38-42 m)**	< MDL (0.04)	40.7765	0.10	89.41	n.a.	0.43	n.a.	0.07	48.70	1.05	1.96	11.26	106.96
26-07-17	**M (53-57 m)**	< MDL (0.04)	41.0748	0.11	88.40	n.a.	0.85	n.a.	0.26	48.64	1.00	2.23	11.59	109.87
28-07-17	**ATES-3 28 m**	< MDL (0.07)	40.58	0.05	101.76	n.a.	0.20	< MDL (0.24)	< MDL (0.01)	44.40	1.10	3.16	10.21	114.30
28-07-17	**ATES-3 51 m**	< MDL (0.04)	40.32	0.06	102.62	n.a.	0.20	< MDL (0.19)	< MDL (0)	45.22	1.08	3.22	10.30	113.89
28-07-17	**Injection (28.72 m)**	< MDL (0.21)	8.86	n.a.	577.39	n.a.	0.40	282.37	< MDL (0.03)	314.44	230.32	146.16	6.29	19.73
28-07-17	**M (27-31 m)**	< MDL (0.02)	40.17	0.06	99.57	n.a.	0.36	n.a.	0.12	45.10	1.14	2.85	10.61	114.43
28-07-17	**M (38-42 m)**	< MDL (0.03)	42.59	0.10	92.94	n.a.	0.30	n.a.	0.02	47.99	1.08	1.91	11.30	112.50
28-07-17	**M (53-57 m)**	< MDL (0.03)	42.62	0.10	92.40	n.a.	0.62	n.a.	0.11	47.06	1.03	2.26	11.45	114.72
31-07-17	**ATES-3 28 m**	< MDL (0.06)	39.54	0.05	101.66	n.a.	0.24	< MDL (0.22)	0.05	44.55	1.05	3.28	9.98	111.30
31-07-17	**ATES-3 51 m**	< MDL (0.05)	39.91	0.06	103.28	n.a.	0.21	< MDL (0.13)	0.05	44.57	1.04	3.28	9.97	111.36
31-07-17	**Injection (28.72 m)**	< MDL (0.02)	30.43	n.a.	194.38	n.a.	0.23	n.a.	0.06	217.79	86.29	76.45	6.29	34.17
31-07-17	**M (27-31 m)**	< MDL (0.03)	39.39	0.06	100.03	n.a.	0.30	0.93	0.11	44.96	1.10	2.94	10.26	112.04
31-07-17	**M (38-42 m)**	< MDL (0.02)	41.73	0.10	93.38	n.a.	0.24	n.a.	0.06	47.65	1.05	2.00	10.99	110.84
31-07-17	**M (53-57 m)**	0.52	41.86	0.09	91.80	n.a.	0.47	n.a.	0.07	46.50	0.99	2.34	10.99	112.24
02-08-17	**ATES-3 28 m**	< MDL (0.41)	40.46	0.05	101.58	n.a.	0.19	< MDL (0.23)	< MDL (0)	45.70	1.07	3.18	9.85	106.39
02-08-17	**ATES-3 51 m**	< MDL (0.43)	41.47	0.06	103.45	n.a.	0.19	< MDL (0.14)	< MDL (0)	46.69	1.05	3.21	9.91	104.87
02-08-17	**Injection (28.72 m)**	0.48	33.84	< MDL (0.01)	149.05	n.a.	0.22	68.30	0.01	84.28	58.89	54.48	9.62	56.96
02-08-17	**M (27-31 m)**	0.49	14.99	0.04	475.90	n.a.	0.49	2.33	0.09	166.98	2.13	5.39	24.89	268.19
02-08-17	**M (38-42 m)**	< MDL (0.46)	41.76	0.08	97.93	n.a.	0.23	n.a.	0.01	50.13	1.06	2.06	11.11	106.86
02-08-17	**M (53-57 m)**	0.50	38.79	0.08	139.20	n.a.	0.51	n.a.	0.08	61.99	1.06	2.44	13.27	129.95

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
04-08-17	**ATES-3 28 m**	< MDL (0.05)	38.66	0.04	100.92	n.a.	0.15	n.a.	< MDL (0)	44.88	1.05	3.16	9.67	116.29
04-08-17	**ATES-3 51 m**	0.60	40.28	0.05	103.29	n.a.	0.20	n.a.	< MDL (0)	46.07	1.03	3.19	9.71	114.94
04-08-17	**Injection (28.72 m)**	0.55	36.80	< MDL (0.01)	118.50	n.a.	0.20	31.29	< MDL (0.01)	52.08	25.55	25.44	10.94	91.61
04-08-17	**M (27-31 m)**	< MDL (0.26)	23.08	0.03	332.47	n.a.	0.24	n.a.	0.05	210.02	1.95	4.35	14.28	153.80
04-08-17	**M (38-42 m)**	< MDL (0.11)	39.70	0.04	100.76	n.a.	0.25	n.a.	< MDL (0.01)	52.00	1.07	2.17	10.96	118.22
04-08-17	**M (53-57 m)**	< MDL (0.12)	36.37	0.07	142.15	n.a.	0.25	14.83	0.05	73.98	1.12	2.53	11.99	127.28
07-08-17	**ATES-3 28 m**	n.a.	39.79	0.04	100.04	n.a.	0.21	< MDL (0.08)	0.04	39.62	1.03	3.23	9.52	106.72
07-08-17	**ATES-3 51 m**	n.a.	40.54	0.05	101.95	n.a.	0.21	n.a.	0.05	40.17	0.99	3.26	9.57	105.59
07-08-17	**Injection (28.72 m)**	n.a.	34.94	< MDL (0.01)	114.48	n.a.	0.21	23.48	0.05	50.60	19.21	19.02	10.40	90.75
07-08-17	**M (27-31 m)**	n.a.	35.45	0.06	123.45	n.a.	0.21	23.53	0.07	70.20	1.46	3.13	9.91	106.01
07-08-17	**M (38-42 m)**	n.a.	40.85	0.08	95.23	n.a.	0.23	n.a.	0.05	45.44	1.03	2.03	10.56	106.09
07-08-17	**M (53-57 m)**	n.a.	39.48	0.08	103.72	n.a.	0.24	0.93	0.07	50.17	1.02	2.51	10.68	108.77
10-08-17	**ATES-3 28 m**	< MDL (0.05)	39.80	0.05	102.02	n.a.	0.24	n.a.	0.05	44.76	1.02	3.25	9.92	93.59
10-08-17	**ATES-3 51 m**	n.a.	39.98	0.05	102.62	n.a.	0.23	n.a.	0.05	45.25	1.00	3.28	9.97	94.97
10-08-17	**Injection (28.72 m)**	n.a.	36.38	< MDL (0.01)	111.52	n.a.	0.24	15.79	0.06	51.68	12.85	13.99	10.76	93.62
10-08-17	**M (27-31 m)**	n.a.	36.53	0.07	110.47	n.a.	0.26	6.63	0.08	54.25	8.40	4.60	9.93	103.12
10-08-17	**M (38-42 m)**	n.a.	40.68	0.09	94.89	n.a.	0.27	n.a.	0.05	48.43	1.09	2.10	11.04	90.01
10-08-17	**M (53-57 m)**	n.a.	39.02	0.09	98.72	n.a.	0.26	0.93	0.07	50.81	2.20	2.68	11.16	96.65
28-08-17	**ATES-3 28 m**	< MDL (0.08)	39.36	0.04	105.77	0.03	0.18	n.a.	< MDL (0)	41.62	1.05	3.32	10.01	115.33
28-08-17	**ATES-3 51 m**	< MDL (0.07)	44.50	0.04	109.84	n.a.	0.20	< MDL (0.51)	< MDL (0)	45.56	0.98	3.32	10.01	111.90
28-08-17	**Injection (28.72 m)**	< MDL (0.07)	37.84	0.02	106.35	n.a.	0.19	3.56	< MDL (0)	42.89	3.35	4.77	10.03	116.75
28-08-17	**M (27-31 m)**	< MDL (0.08)	38.59	0.02	105.47	0.01	0.23	0.93	< MDL (0)	41.96	3.15	5.90	10.12	112.18
28-08-17	**M (38-42 m)**	< MDL (0.09)	40.10	0.04	98.93	n.a.	0.20	n.a.	< MDL (0)	44.14	2.39	3.67	10.64	113.25
28-08-17	**M (53-57 m)**	< MDL (0.16)	40.72	0.07	92.59	n.a.	0.19	n.a.	0.01	43.66	3.85	4.93	10.99	112.00

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
22-09-17	**ATES-3 28 m**	n.a.	38.28	0.06	109.89	n.a.	0.19	n.a.	0.04	43.02	1.13	3.37	10.17	113.27
22-09-17	**ATES-3 51 m**	n.a.	38.38	0.06	109.93	n.a.	0.19	n.a.	0.04	42.62	1.11	3.38	10.17	112.48
22-09-17	**Injection (28.72 m)**	n.a.	31.56	< MDL (0.01)	110.16	n.a.	0.20	4.79	0.04	44.15	3.18	4.56	10.07	112.38
22-09-17	**M (27-31 m)**	n.a.	37.94	0.06	108.85	n.a.	0.20	n.a.	0.04	42.78	1.77	4.73	10.22	110.05
22-09-17	**M (38-42 m)**	n.a.	39.77	0.10	104.13	n.a.	0.21	n.a.	0.04	45.41	1.74	2.76	11.01	110.33
22-09-17	**M (53-57 m)**	n.a.	41.83	0.11	99.53	n.a.	0.21	n.a.	0.04	47.72	1.65	3.18	11.69	114.02
13-12-17	**ATES-3 28 m**	< MDL (0.04)	39.4235	0.05	105.49	n.a.	0.20	n.a.	< MDL (0)	45.07	1.22	3.75	10.32	97.21
13-12-17	**ATES-3 51 m**	< MDL (0.02)	41.4177	0.05	98.47	n.a.	0.22	n.a.	< MDL (0)	45.44	1.22	3.68	10.57	98.75
13-12-17	**Injection (28.72 m)**	n.a.	36.214	0.01	106.51	n.a.	0.20	1.93	0.02	44.28	4.95	6.23	10.15	95.82
13-12-17	**M (27-31 m)**	< MDL (0.06)	39.7246	0.06	102.04	n.a.	0.22	n.a.	< MDL (0)	44.11	1.62	3.65	10.58	96.17
13-12-17	**M (38-42 m)**	< MDL (0.03)	43.3118	0.09	96.56	n.a.	0.23	n.a.	< MDL (0.01)	48.95	1.38	2.73	10.87	93.27
13-12-17	**M (53-57 m)**	< MDL (0.04)	40.5021	0.06	99.86	n.a.	0.21	n.a.	< MDL (0)	44.95	1.25	3.23	10.52	96.68

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
14-03-18	**B 45 (10-14 m)**	< MDL (0.06)	63.86	0.16	46.07	n.a.	0.22	n.a.	< MDL (0.01)	24.33	0.47	0.26	17.60	117.96
14-03-18	**B 45 (22-26 m)**	n.a.	46.06	0.08	71.53	n.a.	0.24	n.a.	< MDL (0.01)	45.77	2.07	3.98	12.85	126.58
14-03-18	**B 45 (34-38 m)**	n.a.	38.71	0.23	85.77	n.a.	0.26	n.a.	< MDL (0.01)	57.78	1.26	1.78	12.11	104.51
14-03-18	**B 45 (53-57 m)**	n.a.	37.96	0.04	90.46	n.a.	0.14	n.a.	< MDL (0.01)	28.47	1.28	3.82	11.49	127.76
14-03-18	**M (27-31 m)**	n.a.	45.57	0.08	92.50	n.a.	0.23	n.a.	< MDL (0.01)	47.08	1.24	2.80	10.83	110.34
14-03-18	**M (38-42 m)**	n.a.	49.41	0.10	89.74	n.a.	0.23	n.a.	< MDL (0.01)	46.69	0.94	2.02	11.51	114.90
14-03-18	**M (53-57 m)**	n.a.	51.13	0.08	93.71	n.a.	0.23	n.a.	< MDL (0.01)	49.37	1.33	2.81	11.03	108.37
14-03-18	**Injectie**	n.a.	34.03	0.04	101.57	n.a.	0.26	< MDL (0.1)	0.02	45.94	4.00	4.91	10.41	106.14
14-03-18	**Bron 3 (28.00 m)**	n.a.	53.57	0.06	79.79	n.a.	0.24	n.a.	< MDL (0.01)	42.29	1.30	2.97	11.73	117.62
14-03-18	**Bron 3 (51.00 m)**	n.a.	51.39	0.10	93.90	n.a.	0.24	n.a.	< MDL (0.01)	51.44	1.38	2.34	11.24	107.58
14-03-18	**Bron 2 (28.00 m)**	n.a.	45.42	0.10	124.88	n.a.	0.20	n.a.	< MDL (0.01)	53.13	1.35	2.47	9.45	95.98
14-03-18	**Bron 2 (51.00 m)**	n.a.	47.67	0.09	125.51	n.a.	0.21	n.a.	< MDL (0.01)	53.05	1.33	2.47	9.54	97.10
14-03-18	**Bron 1 (27.50 m)**	n.a.	47.65	0.20	111.28	n.a.	0.21	< MDL (0.07)	< MDL (0.01)	62.52	3.94	2.05	10.86	89.12
14-03-18	**Bron 1 (51.30 m)**	n.a.	54.18	0.16	121.42	n.a.	0.22	n.a.	< MDL (0.01)	65.42	2.66	2.08	9.67	89.12
04-06-18	**M (27-31 m)**	n.a.	51.01	0.09	94.91	n.a.	0.24	n.a.	< MDL (0)	57.10	1.26	3.24	10.02	104.47
04-06-18	**M (38-42 m)**	n.a.	43.62	0.11	96.27	n.a.	0.23	n.a.	< MDL (0)	54.49	1.04	2.42	10.72	106.60
04-06-18	**M (53-57 m)**	n.a.	53.15	0.10	90.34	n.a.	0.24	n.a.	0.01	53.85	1.18	3.09	11.08	105.24
04-06-18	**Injection (28.72 m)**	n.a.	52.02	0.07	96.79	n.a.	0.26	n.a.	< MDL (0.01)	57.28	1.77	3.24	11.35	91.45
04-06-18	**ATES-3 28 m**	n.a.	51.2	0.10	95.33	n.a.	0.25	n.a.	< MDL (0)	57.41	1.25	2.67	10.98	97.23
04-06-18	**ATES-3 51 m**	n.a.	50.85	0.11	94.60	n.a.	0.24	n.a.	< MDL (0)	57.11	1.36	2.60	10.92	104.22

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
05-06-18	**M (27-31 m)**	n.a.	51.51	0.09	96.03	n.a.	0.25	n.a.	< MDL (0)	57.80	1.23	3.28	10.13	102.76
05-06-18	**M (38-42 m)**	n.a.	44.22	0.12	94.09	n.a.	0.23	n.a.	< MDL (0)	51.91	1.06	2.26	10.87	105.50
05-06-18	**M (53-57 m)**	n.a.	53.62	0.10	90.67	n.a.	0.25	n.a.	< MDL (0.01)	53.42	1.16	2.76	11.17	107.75
05-06-18	**Injection (28.72 m)**	n.a.	27.73	0.27	1757.84	n.a.	1573.69	n.a.	310.23	492.66	3.46	5.81	15.79	170.09
05-06-18	**ATES-3 28 m**	n.a.	51.13	0.11	95.26	n.a.	0.25	n.a.	< MDL (0.01)	57.17	1.30	2.65	10.96	104.36
05-06-18	**ATES-3 51 m**	n.a.	49.15	0.10	90.99	n.a.	0.27	n.a.	< MDL (0)	57.61	1.29	2.66	10.93	99.62
06-06-18	**M (27-31 m)**	n.a.	51.2	0.09	95.15	n.a.	0.25	n.a.	< MDL (0)	57.64	1.25	3.25	10.18	106.17
06-06-18	**M (38-42 m)**	n.a.	44.34	0.12	97.79	n.a.	0.23	n.a.	< MDL (0)	54.27	1.06	2.36	10.86	104.40
06-06-18	**M (53-57 m)**	n.a.	54.04	0.10	92.40	n.a.	0.24	n.a.	< MDL (0)	54.75	1.16	2.84	11.23	108.60
06-06-18	**Injection (28.72 m)**	n.a.	30.11	0.28	1271.16	n.a.	1118.91	< MDL (7.81)	238.88	403.13	2.99	5.19	9.16	99.71
06-06-18	**ATES-3 28 m**	n.a.	50.89	0.11	94.60	n.a.	0.24	n.a.	< MDL (0)	57.33	1.33	2.67	10.93	106.44
06-06-18	**ATES-3 51 m**	n.a.	51.45	0.11	95.71	n.a.	0.25	n.a.	< MDL (0)	57.63	1.30	2.66	10.89	100.83
07-06-18	**M (27-31 m)**	n.a.	50.82	0.09	94.54	n.a.	0.24	n.a.	< MDL (0.01)	57.34	1.29	3.25	10.30	105.56
07-06-18	**M (38-42 m)**	n.a.	44.12	0.12	101.05	n.a.	0.24	n.a.	< MDL (0)	55.75	1.08	2.34	10.61	102.69
07-06-18	**M (53-57 m)**	n.a.	52.55	0.10	90.90	n.a.	0.24	n.a.	< MDL (0)	53.54	1.21	2.74	11.12	108.55
07-06-18	**Injection (28.72 m)**	n.a.	46.02	0.30	218.07	n.a.	116.75	21.73	53.45	128.85	1.30	1.96	4.01	46.65
07-06-18	**ATES-3 28 m**	n.a.	51.09	0.10	94.83	n.a.	0.25	n.a.	< MDL (0)	56.87	1.33	2.67	10.92	100.44
07-06-18	**ATES-3 51 m**	n.a.	50.65	0.11	94.25	n.a.	0.25	n.a.	< MDL (0)	56.49	1.38	2.59	10.95	105.81
08-06-18	**M (27-31 m)**	n.a.	51.32	0.09	95.28	n.a.	0.24	n.a.	< MDL (0)	57.19	1.29	3.26	10.22	104.48
08-06-18	**M (38-42 m)**	n.a.	43.85	0.12	101.65	n.a.	0.23	n.a.	< MDL (0.01)	54.42	1.14	2.24	10.59	102.18
08-06-18	**M (53-57 m)**	69.85	52.85	0.08	89.74	n.a.	n.a.	n.a.	< MDL (0)	54.11	1.24	2.88	11.04	108.50
08-06-18	**Injection (28.72 m)**	n.a.	44.53	0.18	117.09	n.a.	22.52	11.59	19.97	106.84	1.48	2.46	5.42	55.35
08-06-18	**ATES-3 28 m**	n.a.	50.49	0.10	94.27	n.a.	0.24	n.a.	< MDL (0)	56.51	1.36	2.64	10.96	104.89
08-06-18	**ATES-3 51 m**	n.a.	50.93	0.10	94.67	n.a.	0.25	n.a.	< MDL (0)	56.61	1.38	2.62	10.91	104.04
09-06-18	**M (27-31 m)**	n.a.	50.46	0.09	94.20	n.a.	0.26	n.a.	< MDL (0)	57.56	1.31	3.26	10.42	105.76
09-06-18	**M (38-42 m)**	n.a.	46.46	0.15	108.60	n.a.	0.24	n.a.	< MDL (0)	59.51	1.06	2.44	10.26	100.29
09-06-18	**M (53-57 m)**	n.a.	52.36	0.10	93.36	n.a.	0.26	n.a.	< MDL (0)	55.49	1.23	2.80	11.05	107.94
09-06-18	**Injection (28.72 m)**	n.a.	46.8	0.14	103.86	n.a.	9.17	3.21	9.95	88.36	1.57	2.74	7.30	74.00
09-06-18	**ATES-3 28 m**	n.a.	50.28	0.10	93.67	n.a.	0.26	n.a.	< MDL (0)	56.45	1.38	2.65	10.92	105.27
09-06-18	**ATES-3 51 m**	n.a.	50.35	0.10	94.05	n.a.	0.26	n.a.	< MDL (0)	56.60	1.39	2.61	10.97	105.36

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
10-06-18	**M (27-31 m)**	n.a.	48.35	0.10	193.65	n.a.	95.37	n.a.	2.30	69.93	1.50	4.03	15.24	152.78
10-06-18	**M (38-42 m)**	n.a.	44.53	0.17	108.13	n.a.	0.27	n.a.	< MDL (0.01)	53.68	1.06	2.16	10.70	103.18
10-06-18	**M (53-57 m)**	n.a.	52.39	0.10	94.90	n.a.	1.25	n.a.	< MDL (0.01)	54.85	1.25	2.80	10.96	107.86
10-06-18	**Injection (28.72 m)**	n.a.	47.97	0.07	100.34	n.a.	6.01	< MDL (0.3)	4.55	71.66	1.75	3.07	9.04	91.02
10-06-18	**ATES-3 28 m**	n.a.	50.3	0.16	93.75	n.a.	0.26	n.a.	< MDL (0)	56.34	1.39	2.67	10.90	105.24
10-06-18	**ATES-3 51 m**	n.a.	50.2	0.16	93.94	n.a.	0.27	n.a.	< MDL (0)	56.01	1.39	2.65	10.90	105.17
11-06-18	**M (27-31 m)**	n.a.	49.85	0.05	188.09	n.a.	90.03	n.a.	3.80	68.77	1.40	3.95	14.65	137.31
11-06-18	**M (38-42 m)**	n.a.	45.14	0.08	110.35	n.a.	0.23	n.a.	< MDL (0)	54.19	1.03	2.23	10.60	96.07
11-06-18	**M (53-57 m)**	n.a.	52.91	0.06	95.66	n.a.	3.26	n.a.	0.01	53.61	1.18	2.77	11.33	104.03
11-06-18	**Injection (28.72 m)**	n.a.	47.24	0.03	102.31	n.a.	8.08	< MDL (0.14)	4.61	70.20	1.86	3.12	9.26	86.54
11-06-18	**ATES-3 28 m**	n.a.	49.76	0.06	93.90	n.a.	0.23	n.a.	< MDL (0)	56.02	1.36	2.65	10.92	98.39
11-06-18	**ATES-3 51 m**	n.a.	49.70	0.06	93.60	n.a.	0.23	n.a.	< MDL (0)	56.14	1.37	2.69	10.88	98.12
12-06-18	**M (27-31 m)**	n.a.	48.65	0.06	204.89	n.a.	106.99	n.a.	15.64	73.82	1.36	3.82	12.88	119.54
12-06-18	**M (38-42 m)**	n.a.	46.68	0.11	114.07	n.a.	0.28	n.a.	< MDL (0.01)	54.59	1.03	2.22	10.58	95.48
12-06-18	**M (53-57 m)**	n.a.	53.41	0.10	106.21	n.a.	9.18	n.a.	0.80	56.54	1.20	2.82	11.53	105.15
12-06-18	**Injection (28.72 m)**	n.a.	47.62	0.03	98.82	n.a.	4.93	n.a.	3.03	65.69	1.84	3.17	9.71	90.17
12-06-18	**ATES-3 28 m**	n.a.	49.42	0.06	93.43	n.a.	0.23	n.a.	< MDL (0)	55.90	1.35	2.68	10.82	98.36
12-06-18	**ATES-3 51 m**	n.a.	49.79	0.06	93.83	n.a.	0.23	n.a.	< MDL (0)	56.19	1.35	2.67	10.92	98.59
13-06-18	**M (27-31 m)**	n.a.	50.45	0.06	171.38	n.a.	73.41	n.a.	14.26	70.22	1.28	3.60	11.52	106.96
13-06-18	**M (38-42 m)**	n.a.	47.92	0.08	115.22	n.a.	0.39	n.a.	0.02	54.93	1.02	2.24	10.56	95.41
13-06-18	**M (53-57 m)**	n.a.	54.53	0.06	104.97	n.a.	8.74	n.a.	1.29	55.31	1.16	2.76	11.45	104.41
13-06-18	**Injection (28.72 m)**	n.a.	47.44	0.03	100.42	n.a.	6.20	n.a.	3.11	64.71	1.95	3.26	9.82	90.75
13-06-18	**ATES-3 28 m**	n.a.	49.62	0.06	93.48	n.a.	0.23	n.a.	< MDL (0)	55.57	1.36	2.67	10.89	98.20
13-06-18	**ATES-3 51 m**	n.a.	49.44	0.11	93.35	n.a.	0.23	n.a.	< MDL (0)	55.66	1.36	2.66	10.90	98.22
14-06-18	**M (27-31 m)**	n.a.	59.34	0.06	152.52	n.a.	48.77	< MDL (0.27)	12.79	73.12	1.36	3.54	12.41	117.16
14-06-18	**M (38-42 m)**	n.a.	49.38	0.08	113.87	n.a.	0.38	n.a.	0.02	56.13	1.05	2.22	10.45	101.75
14-06-18	**M (53-57 m)**	n.a.	54.83	0.06	100.92	n.a.	7.41	n.a.	1.23	56.18	1.21	2.92	11.25	111.27
14-06-18	**Injection (28.72 m)**	n.a.	48.22	0.03	97.52	n.a.	4.49	n.a.	2.46	63.36	1.88	3.15	9.96	98.42
14-06-18	**ATES-3 28 m**	n.a.	50.38	0.06	92.93	n.a.	0.23	n.a.	< MDL (0)	56.75	1.35	2.69	10.92	105.50
14-06-18	**ATES-3 51 m**	n.a.	50.35	0.07	93.08	n.a.	0.23	n.a.	< MDL (0)	57.01	1.36	2.66	10.96	105.54

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
15-06-18	**M (27-31 m)**	n.a.	49.95	0.06	101.39	n.a.	8.69	n.a.	7.18	66.40	1.27	3.04	9.38	89.65
15-06-18	**M (38-42 m)**	n.a.	53.45	0.08	108.45	n.a.	0.29	n.a.	0.01	59.56	1.08	2.30	9.90	97.97
15-06-18	**M (53-57 m)**	n.a.	54.15	0.06	99.94	n.a.	4.31	n.a.	1.77	56.81	1.18	2.66	10.59	105.04
15-06-18	**Injection (28.72 m)**	n.a.	48.72	0.03	94.68	n.a.	2.69	n.a.	1.53	60.29	1.84	3.12	10.09	100.83
15-06-18	**ATES-3 28 m**	n.a.	49.87	0.06	91.62	n.a.	0.23	n.a.	< MDL (0)	55.64	1.37	2.62	10.79	105.21
15-06-18	**ATES-3 51 m**	n.a.	50.04	0.06	91.95	n.a.	0.23	n.a.	< MDL (0)	56.22	1.37	2.59	10.80	104.86
04-07-18	**B45 10-14 m**	n.a.	61.91	0.13	55.18	n.a.	0.28	n.a.	< MDL (0)	31.79	0.61	0.44	18.43	123.81
04-07-18	**B45 22-26 m**	n.a.	41.50	0.06	73.74	n.a.	0.25	n.a.	< MDL (0)	47.61	1.98	4.29	12.71	129.73
04-07-18	**B45 34-38 m**	n.a.	42.12	0.19	93.53	n.a.	0.27	n.a.	< MDL (0)	62.76	1.21	1.93	11.27	100.97
04-07-18	**B45 57-59 m**	n.a.	37.47	0.05	94.13	n.a.	0.15	n.a.	< MDL (0.01)	35.14	1.28	4.02	11.36	128.53
04-07-18	**M 27-31 m**	n.a.	50.29	0.07	93.23	n.a.	0.25	n.a.	0.03	57.22	1.31	2.92	11.62	107.80
04-07-18	**M 38-42 m**	n.a.	51.70	0.08	94.80	n.a.	0.25	n.a.	< MDL (0.01)	66.75	1.09	2.29	10.09	99.74
04-07-18	**M 53-57 m**	0.88	54.40	0.07	90.47	0.03	0.25	n.a.	0.01	57.04	1.20	2.67	11.17	109.79
04-07-18	**Injectie 28 m**	n.a.	49.28	0.05	92.99	n.a.	0.44	n.a.	0.21	56.81	1.72	3.04	11.63	107.53
04-07-18	**Bron 1 27 m**	n.a.	54.04	0.12	121.22	n.a.	0.23	n.a.	< MDL (0)	71.41	2.77	2.24	9.58	89.92
04-07-18	**Bron 1 51 m**	n.a.	54.05	0.12	121.17	n.a.	0.23	n.a.	< MDL (0)	72.43	2.73	2.30	9.50	89.77
04-07-18	**Bron 2 28 m**	n.a.	47.16	0.07	126.07	n.a.	0.21	n.a.	< MDL (0)	59.71	1.31	2.76	9.27	98.10
04-07-18	**Bron 2 51 m**	n.a.	47.38	0.07	126.26	n.a.	0.22	n.a.	< MDL (0)	60.73	1.33	2.77	9.27	98.22
04-07-18	**Bron 3 28 m**	n.a.	50.27	0.07	92.52	n.a.	0.24	n.a.	< MDL (0)	55.77	1.35	2.82	11.41	107.99
04-07-18	**Bron 3 51 m**	n.a.	50.38	0.07	92.39	n.a.	0.24	n.a.	< MDL (0)	56.87	1.35	2.82	11.62	107.99

Date	Well	NO3 (mg/l)	SO4 (mg/l)	F (mg/l)	Cl (mg/l)	NO2 (mg/l)	Br (mg/l)	PO4 (mg/l)	Li (mg/l)	Na (mg/l)	NH4 (mg/l)	K (mg/l)	Mg (mg/l)	Ca (mg/l)
11-09-18	**B45 10-14 m**	n.a.	60.99	0.18	46.38	n.a.	0.22	n.a.	< MDL (0)	26.80	0.58	0.22	16.33	98.82
11-09-18	**B45 22-26 m**	n.a.	48.05	0.08	74.17	n.a.	0.25	< MDL (0.14)	< MDL (0)	44.52	1.98	3.91	12.72	140.98
11-09-18	**B45 34-38 m**	n.a.	43.89	0.20	102.02	n.a.	0.26	< MDL (0.42)	< MDL (0)	59.41	1.31	1.83	11.31	105.15
11-09-18	**B45 57-59 m**	n.a.	39.68	0.03	104.01	n.a.	0.14	n.a.	< MDL (0.01)	34.19	1.42	3.65	11.78	138.06
11-09-18	**M 27-31 m**	n.a.	44.17	0.05	98.43	n.a.	0.22	n.a.	< MDL (0.01)	47.12	1.38	2.75	10.86	122.27
11-09-18	**M 38-42 m**	n.a.	48.28	0.07	93.31	n.a.	0.23	n.a.	< MDL (0)	50.88	1.19	2.08	11.21	111.02
11-09-18	**M 53-57 m**	n.a.	50.38	0.06	91.39	n.a.	0.23	n.a.	< MDL (0.01)	48.49	1.26	2.55	11.28	114.91
11-09-18	**Injectie 28.50 m**	n.a.	42.98	0.03	99.21	n.a.	0.20	< MDL (0.13)	0.02	46.82	1.55	3.21	10.60	118.29
11-09-18	**Bron 1 27 m**	n.a.	53.90	0.11	126.25	n.a.	0.22	< MDL (0.14)	< MDL (0)	67.68	2.65	2.11	9.53	96.56
11-09-18	**Bron 1 51 m**	n.a.	56.70	0.11	126.30	n.a.	0.22	< MDL (0.14)	< MDL (0)	69.12	2.70	2.16	9.30	92.23
11-09-18	**Bron 2 28 m**	n.a.	48.85	0.06	128.16	n.a.	0.20	n.a.	< MDL (0)	57.24	1.44	2.77	9.17	96.93
11-09-18	**Bron 2 51 m**	n.a.	48.59	0.07	129.49	n.a.	0.21	n.a.	< MDL (0)	57.95	1.53	2.78	9.21	98.50
11-09-18	**Bron 3 28 m**	n.a.	43.63	0.04	100.53	n.a.	0.21	n.a.	< MDL (0)	46.25	1.30	3.21	10.43	101.08
11-09-18	**Bron 3 51 m**	n.a.	53.01	0.05	100.45	n.a.	0.24	n.a.	< MDL (0)	50.56	1.30	3.19	10.39	111.92

Appendix 7: Total organic carbon

Date	Well	Depth	DOC (mg/L)
12-07-17	Bron-3 (Nulmeting)	28 m	4.702
12-07-17	Bron-3 (Nulmeting)	51 m	4.135
12-07-17	injectie (Nulmeting)		4.695
12-07-17	monitor (Nulmeting)	27/31 m	4.797
12-07-17	monitor (Nulmeting)	38/42 m	4.995
12-07-17	monitor (Nulmeting)	53/57 m	5.128
28-07-17	Bron-3 (T=1)	28 m	4.136
28-07-17	Bron-3 (T=1)	51 m	4.148
28-07-17	injectie (T=1)		45.31
28-07-17	monitor (T=1)	27/31 m	4.861
28-07-17	monitor (T=1)	38/42 m	4.788
28-07-17	monitor (T=1)	53/57 m	5.313
31-07-17	Bron-3 (T=2)	28 m	4.029
31-07-17	injectie (T=2)		8.097
31-07-17	monitor (T=2)	27/31 m	4.523
31-07-17	monitor (T=2)	38/42 m	4.751
31-07-17	monitor (T=2)	53/57 m	5.097
31-07-2017	Bron-3 (T=2)	51 m	4.125
02-08-17	Bron-3 (T=3)	28 m	4.265
02-08-17	Bron-3 (T=3)	51 m	4.143
02-08-17	injectie (T=3)		4.417
02-08-17	monitor (T=3)	27/31 m	36.88
02-08-17	monitor (T=3)	38/42 m	6.877
02-08-17	monitor (T=3)	53/57 m	5.678
02-08-17	B-45 (T=3)	10-14m	2.788
02-08-17	B-45 (T=3)	22-26 m	9.107
02-08-17	B-45 (T=3)	34-38 m	4.962
02-08-17	B-45 (T=3)	57-59 m	4.919
04-08-17	Bron-3 (T=4)	28 m	4.284
04-08-17	Bron-3 (T=4)	51 m	4.16
04-08-17	injectie (T=4)		10.68
04-08-17	monitor (T=4)	27/31 m	117.6
04-08-17	monitor (T=4)	38/42 m	9.313
04-08-17	monitor (T=4)	53/57 m	30.54
07-08-17	Bron-3 (T=5)	28 m	4.049
07-08-17	Bron-3 (T=5)	51 m	4.048
07-08-17	injectie (T=5)		12.31
07-08-17	monitor (T=5)	27/31 m	15.91
07-08-17	monitor (T=5)	38/42 m	6.397
07-08-17	monitor (T=5)	53/57 m	10.4
10-08-17	Bron-3 (T=6)	28 m	4.198
10-08-17	Bron-3 (T=6)	51 m	4.293
10-08-17	injectie (T=6)		6.521
10-08-17	monitor (T=6)	27/31 m	9.019
10-08-17	monitor (T=6)	38/42 m	5.431
10-08-17	monitor (T=6)	53/57 m	7.805

Date	Well	Depth	DOC (mg/L)
17-08-17	Bron-3 (T=7)	28 m	5.222
17-08-17	Bron-3 (T=7)	51 m	4.23
17-08-17	injectie (T=7)		3.727
17-08-17	monitor (T=7)	27/31 m	5.274
17-08-17	monitor (T=7)	38/42 m	4.933
17-08-17	monitor (T=7)	53/57 m	5.359
28-08-17	Bron 3 (T=8)	28 m	5.109
28-08-17	Bron-3 (T=8)	51 m	4.733
28-08-17	injectie (T=8)		3.871
28-08-17	monitor (T=8)	27/31 m	5.089
28-08-17	monitor (T=8)	38/42 m	4.963
28-08-17	monitor (T=8)	53/57 m	5.296
14-03-18	B 45 (10-14 m)		2.976
14-03-18	B 45 (22-26 m)		8.657
14-03-18	B 45 (34-38 m)		7.137
14-03-18	B 45 (53-57 m)		4.449
14-03-18	M (27-31 m)		4.653
14-03-18	M (38-42 m)		4.819
14-03-18	M (53-57 m)		4.603
14-03-18	Injectie		4.464
14-03-18	Bron 3 (28.00 m)		5.356
14-03-18	Bron 3 (51.00 m)		4.651
14-03-18	Bron 2 (28.00 m)		3.637
14-03-18	Bron 2 (51.00 m)		3.752
14-03-18	Bron 1 (27.50 m)		4.304
14-03-18	Bron 1 (51.30 m)		3.831
04-07-18	B45 10-14 m		3.51
04-07-18	B45 22-26 m		9.42
04-07-18	B45 34-38 m		6.66
04-07-18	B45 57-59 m		5.01
04-07-18	M 27-31 m		5.14
04-07-18	M 38-42 m		5.08
04-07-18	M 53-57 m		5.13
04-07-18	Injectie		4.46
04-07-18	Bron 1 27 m		4.08
04-07-18	Bron 1 51 m		4.21
04-07-18	Bron 2 28 m		3.96
04-07-18	Bron 2 51 m		3.87
04-07-18	Bron 3 28 m		5.24
04-07-18	Bron 3 51 m		5.02

Date	Well	Depth	DOC (mg/L)
11-09-18	B45 10-14 m		2.849
11-09-18	B45 22-26 m		8.148
11-09-18	B45 34-38 m		5.931
11-09-18	B45 57-59 m		4.932
11-09-18	M 27-31 m		4.57
11-09-18	M 38-42 m		5.26
11-09-18	M 53-57 m		5.995
11-09-18	Injectie 27 m		4.446
11-09-18	Bron 1 27 m		4.042
11-09-18	Bron 1 51 m		3.946
11-09-18	Bron 2 28 m		3.561
11-09-18	Bron 2 51 m		3.923
11-09-18	Bron 3 28 m		8.317
11-09-18	Bron 3 51 m		10.22

Appendix 8: Groundwater displacement calculations

To provide an estimate of the possible groundwater displacement of the ATES in comparison to the bioaugmentation, the front of displacement is calculated based on the reported injection volumes for the 2017 summer season and the injected volume during the DHC inoculation. Assuming radial flow, the front of displacement can be calculated as follows:

$$Front\ (F) = \sqrt{\frac{V}{\pi D \varphi}}$$

Where:

F = maximum displacement (m)

V = Seasonal injection volume of the ATES (m^3)

D = thickness of the aquifer (in this case the aquifer is taken as 10-40 m thick)

Φ = porosity (taken as 0.35 for sand)

Results are listed in Table A7-1, and show that an injection of 4 m^3 will induce a front of 0-1 m approximately, whereas the front of displacement of the ATES system is much larger, approximately 15-30 m.

Table A7-1: Estimates of the front of displacement (m) of the bioaugmentation and ATES system

		Pumped volumes (m^3)	
		Bioaugmentation	Total season injected in warm well
		4	10000
Aquifer thickness (m)	10	**0.6**	**30.2**
Aquifer thickness (m)	40	**0.3**	**15.1**