EXTERNAL REPORT
SCK•CEN-ER-68
08/SLa/P-20

Essen-1 borehole of the hydro/05neb campaign: technical aspects and hydrogeological investigations

Serge Labat, Jan Marivoet, Isabelle Wemaere, and Tom Maes

Report to ONDRAF/NIRAS prepared in the frame of contract KNT 90 00 1384

July, 2008

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ABSTRACT

The drilling and core-drilling of the 508 metre deep Essen-1 borehole in the northern part of the Kempen (NE Belgium) is part of a data acquisition campaign called hydro/05neb. It aims at providing data for the various hydrogeological models that are running at SCK•CEN. This research, commissioned by ONDRAF/NIRAS, was executed for the performance assessments studies with regard to the possible disposal of high-level and long-lived radioactive waste in the Boom Clay. The investigations mainly focused on the hydraulic characterisation of the Lower-Rupelian and the Lede-Brussel aquifer.
Numerous analyses were performed in the borehole as well as in the laboratory. A detailed geological description of the borehole is given, based on cuttings, cores, and geophysical measurements. Hydraulic properties of the investigated units were determined from in situ pumping tests and laboratory experiments and compared to indirect (soft) data. Hydro geochemical analyses are also provided for both aquifers and the well is nowadays integrated in the regional piezometric network of and regularly monitored by SCK•CEN. Finally, the transferability aspects of the migration and geochemical properties of the Boom Clay are assessed, because up to now they were essentially studied at the Mol site.

EXECUTIVE SUMMARY

The drilling of the Essen-1 borehole is part of the data acquisition campaign called hydro/05neb. This borehole was drilled in 2006 and the subsequent research programme of hydrogeological investigations was realised in 2006 and 2007 as part of task 3.3 of contract CO 90 01 1467.19 performed by SCK•CEN for ONDRAF/NIRAS.

The purpose of the Essen-1 drilling was to provide data for the various hydrogeological models that are running at SCK•CEN. In a broader sense, this research fits within the framework of the hydrogeological studies and the performance assessments in Belgium with regard to the possible disposal of high-level and long-lived radioactive waste in the Boom Clay. The delimitation of the hydrostratigraphic units and the hydraulic conductivity had to be determined for the Lower-Rupelian and the Lede-Brussel aquifer. Afterwards, the borehole had to allow water level measurements in these two deeper aquifers.

The selected drilling and coring (with cutting edge and wire line) techniques appeared to be a good choice for the investigation of the Boom Clay aquitard. After all, an excellent core recovery (almost 100%) was obtained and the perturbations were limited.

Directly after the drilling, a series of geophysical loggings (gamma ray, caliper, focused electro log, deviation, spontaneous potential, short/long spacing resistivity, density, gamma spectral, and full wave sonic) were carried out in the open-hole.

The cores were conditioned in such a way to be able to carry out various types of analyses. A large part of the cores remained intact and are ready to be used for future analyses. All core manipulations are traceable.

The borehole was successfully equipped with two filters in respectively the Lower-Rupelian and the Lede-Brussel aquifer. Subsequently, groundwater samples were taken for geochemical analyses and an in situ pumping test was carried out in both piezometers. Since March 2006, the filters are also used to monitor the groundwater level in the aquifer layers and show a downwards oriented vertical hydraulic gradient between the Lower-Rupelian and the Lede-Brussel aquifer.

The hydraulic conductivity (10 Kh and 12 Kv) was measured in the laboratory and gives an indication about the vertical distribution of this property. On this basis, representative values of Kh and Kv can be assigned to the specific hydrostratigraphic units. Afterwards, grain size analyses were ordered for the Kv samples in order to characterise all sub-units in terms of grain size classification.

An in situ pumping test was performed in the Lower-Rupelian and in the Lede-Brussel aquifer in order to determine several hydraulic parameters.

Preliminary chemical analyses of the groundwater were performed for the Lower-Rupelian and the Lede-Brussel aquifer.

We may conclude that the investigations in Essen delivered valuable information with regard to the geology of the area. Furthermore, it allowed an interpretation in terms of hydrostratigraphic units that is required for the modelling. Also, the good quality cores and the geophysical measurements allowed an accurate interpretation of the deeper layers.

The borehole was successfully equipped with two piezometers that allow piezometric measurements, hydraulic testing, and sampling in the Lower-Rupelian and Lede-Brussel aquifers.

The hydraulic conductivity of the Voort aquifer, the different sublayers of the Boom Clay aquitard, as well as the top of the Lower-Rupelian was determined. For this purpose, complementary methods were applied (laboratory and in situ) that are recommended for future investigations.

1 Introduction

1.1 Framework and objectives

The drilling of the Essen-1 borehole is part of the hydro/05neb data acquisition campaign. The borehole was drilled in 2006 and the subsequent programme of hydrogeological investigations was realised in 2006 and 2007 as part of task 3.3 performed by SCK•CEN for ONDRAF/NIRAS.

The purpose of the hydro/05neb campaign was to provide data for the various hydrogeological models that are running at SCK•CEN in the framework of the hydrogeological studies and the performance assessment studies in Belgium with regard to the possible disposal of high-level and long-lived radioactive waste in the Boom Clay. The investigations mainly focussed on the hydraulic characterisation of the two aquifers underlying the Boom Clay, i.e. the Lower-Rupelian and the Lede-Brussel aquifer in north-east Belgium to improve the calibration of the regional hydrogeological model.

Indeed, only a few observation and testing points were available for these two aquifers. They were insufficient to well understand the water flow in these aquifers or to calibrate the parameter values of the model for these two layers. Therefore, it was recommended that several boreholes would be drilled through the Boom Clay down to the base of the Lede-Brussel aquifer in order to collect additional hydrogeological information. Also, it was planned to equip the boreholes with filters that allow piezometric measurements and tests for the determination of the hydraulic parameters.Furthermore, core-drilling was planned from the base of the Berchem Formation to the top of the Lower-Rupelian aquifer. That way, it was also possible to determine the hydraulic properties of the Boom Clay in order to check the transferability of these parameters.
Two sites were investigated and consisted of:

- the drilling of a borehole in Herenthout (cored from the base of the Boom Clay down to the top of the Ypresian Clay) and in Essen (cored from the base of the Berchem aquifer down to the top of the Lower-Rupelian aquifer); standard geophysical measurements such as gamma ray, caliper, resistivity, and focused electro log in each borehole; finally, equipment with filters in the Lower-Rupelian and in the Lede-Brussel aquifer for the monitoring of the water level as foreseen in task 3.1: regional piezometric measurements.
- a characterisation programme on the cores, including geological description, grain size analyses, the determination of the hydraulic conductivity in the laboratory (on small plugs taken from the cores), the calculation of migration parameters for iodide and HTO, stable isotopes, determination of the U and Th concentration, and the draw up of a helium profile in the Boom Clay
- a limited *in situ* characterisation programme that consists of hydraulic tests in each new filter for the determination of the hydraulic conductivities of the aquifers underlying the Boom Clay.

This report gives an overview of the field activities and the laboratory investigations that have been carried out for the Essen-1 borehole.

1.2 Organisation of the drilling campaign

The specifications for the drilling of the borehole and its equipment with filters was prepared by SCK•CEN in 2005. In April 2005 the call for tenders was published in the Belgian "Bulletin der aanbestedingen/Bulletin des adjudications". As a results, six companies requested the specifications yet only two of them handed over an offer. Regrettably, one offer had to be dismissed due to the fact that it was incomplete, while the second one was complete but far over the available budget. Therefore, the specifications were adjusted in order to lower the costs and sent to both companies that reacted on the first call. Again, one offer was still incomplete and therefore, Smet G.W.T. was selected as drilling contractor.

Faninbel was involved during the preparation of the drilling campaign and during the drilling activities as technical adviser and supervisor of the well site operations.

The University of Bern was involved during the cored drilling of the borehole for helium analyses on core samples.

Brunnen- und Borhlochinspektion GmbH (BBi) made the geophysical measurements in the open-hole on January 26 2006 (from 0 to 160 m below the drilling table) and on February 5 2006 (from 146 to 508 m below the drilling table).

Studiegroep Omgeving (SGO) carried out the levelling of the piezometers in May 2006.

The drilling of the borehole started mid January 2006 and was completed begin February 2006.

1.3 Organisation of the core handling and core analyses

The preliminary geological description on the site was based on the cuttings. In the cored section, cuttings were not only recovered from the drilling fluid during overcoring but also from the shoe of the core-barrel. Then, the cores were transported to the laboratories of SCK•CEN at Mol, where they were sampled and conditioned from 13 to 24 February 2006.

The Geological Survey of Belgium examined the cores at Mol during the core handling and prepared a detailed preliminary geological description with lithostratigraphic interpretation.

The determination of the hydraulic conductivity on samples was performed at SCK•CEN, while other SCK•CEN research teams received samples of the cores as well for their own specific purposes (determination of migration parameters, and geochemical composition of the Boom Clay pore water and underlying aquifers). Also, the University of Bern made a helium profile for the Boom Clay.

1.4 Organisation of in situ tests

ONDRAF/NIRAS ordered pumping tests by Ecorem to determine some hydraulic parameters *in situ*. Also, in the framework of CLAYTRAC[1] the University of Bern was asked to perform helium analyses on core samples in order to extract the diffusion properties of the Boom Clay.

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[1] The CLAYTRAC project has been launched by the NEA Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations (known as "Clay

1.5 Location of and general information on the borehole and piezometers

The drilling site is located on a terrain of PIDPA[2] besides the Oude Baan (see Figures 1 and 2), while the co-ordinates of the well are given in Table 1.

The borehole of Essen was registered at the Geological Survey of Belgium (GSB) and received the archive number 1E071.

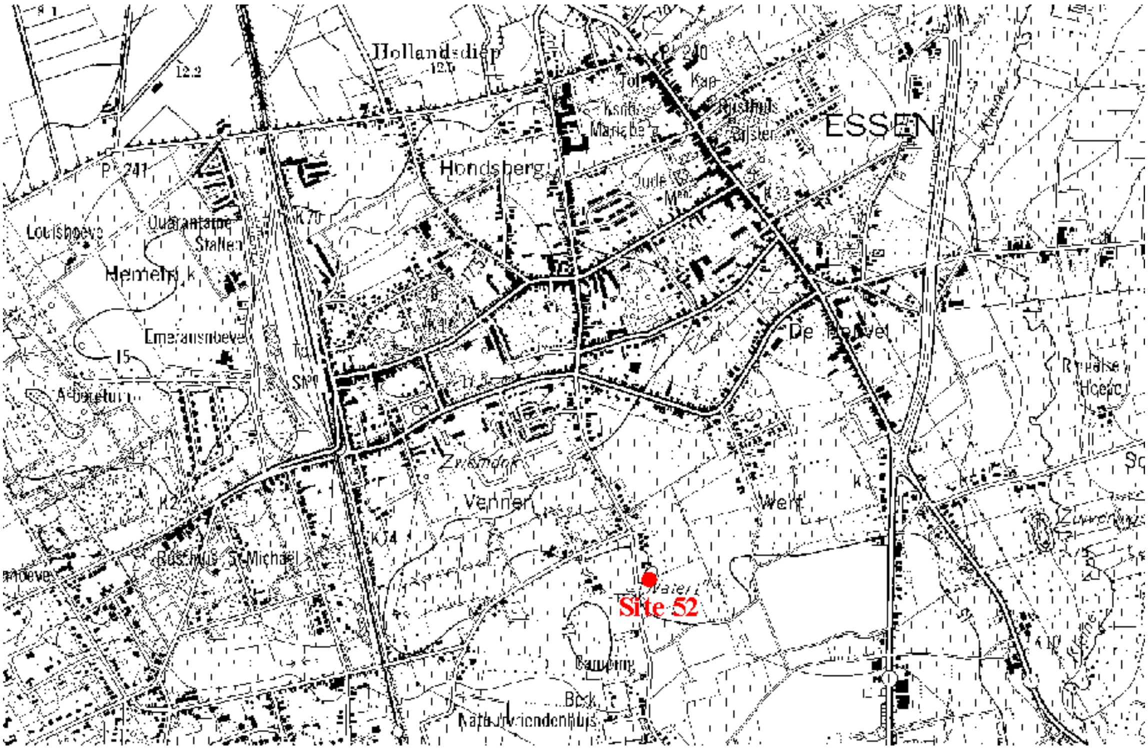

Figure 1: Location of the Essen-1 borehole (Site 52) on a topographic map

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Club" at the beginning of 2005. It examines natural tracers in geological formations through detailed (re)evaluation and integration of existing measurements (from a variety of formations) and evidence documented in literature

[2] PIDPA: Provinciale en Intercommunale Drinkwatermaatschappij der Provincie Antwerpen

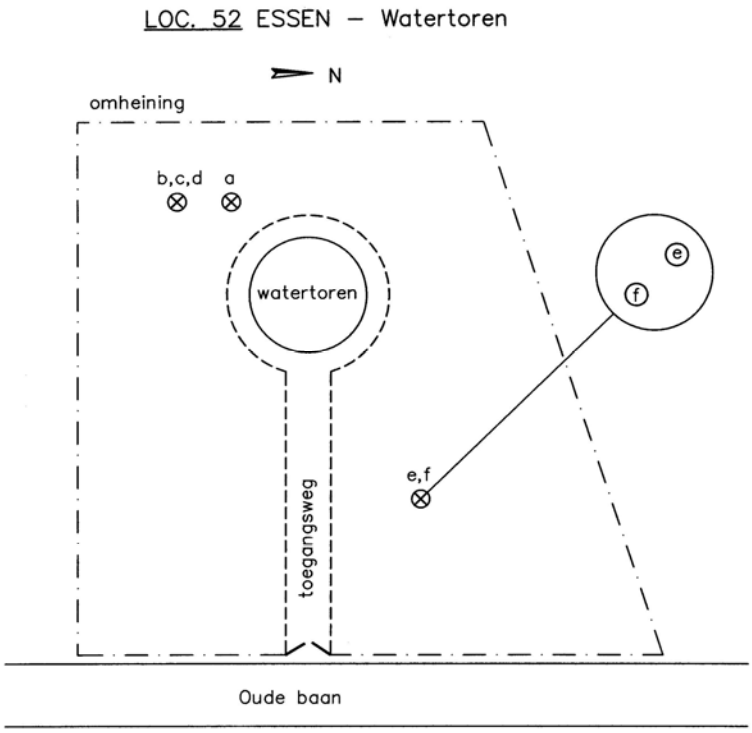

Figure 2: Location of the Essen-1 borehole with piezometers e and f (site 52)

Table 1: Co-ordinates of the Essen-1 borehole and piezometers

Point	X Lambert (m)	Y Lambert (m)	Z ground level (m a.s.l.)[3]	Z reference (m a.s.l.)
Essen-1 borehole	156662.511	238672.197	14.871	
Piezometer 52e[4]	156662.511	238672.197	14.871	15.25
Piezometer 52f[3]	156662.511	238672.197	14.871	15.30

More information about the above mentioned topics can be found in Annex 1: Technical datasheet site 52 (only available on the accompanying CD-ROM entitled "05neb Essen").

[3] **a.s.l.**: above sea level according to Belgian reference.

[4] The identification code refers to the number that was appointed to this site and piezometers within the regional piezometric network of SCK•CEN.

2 Drilling operations and equipment of the Essen-1 borehole

The field activities that were planned at the Essen site are illustrated in Figure 3.

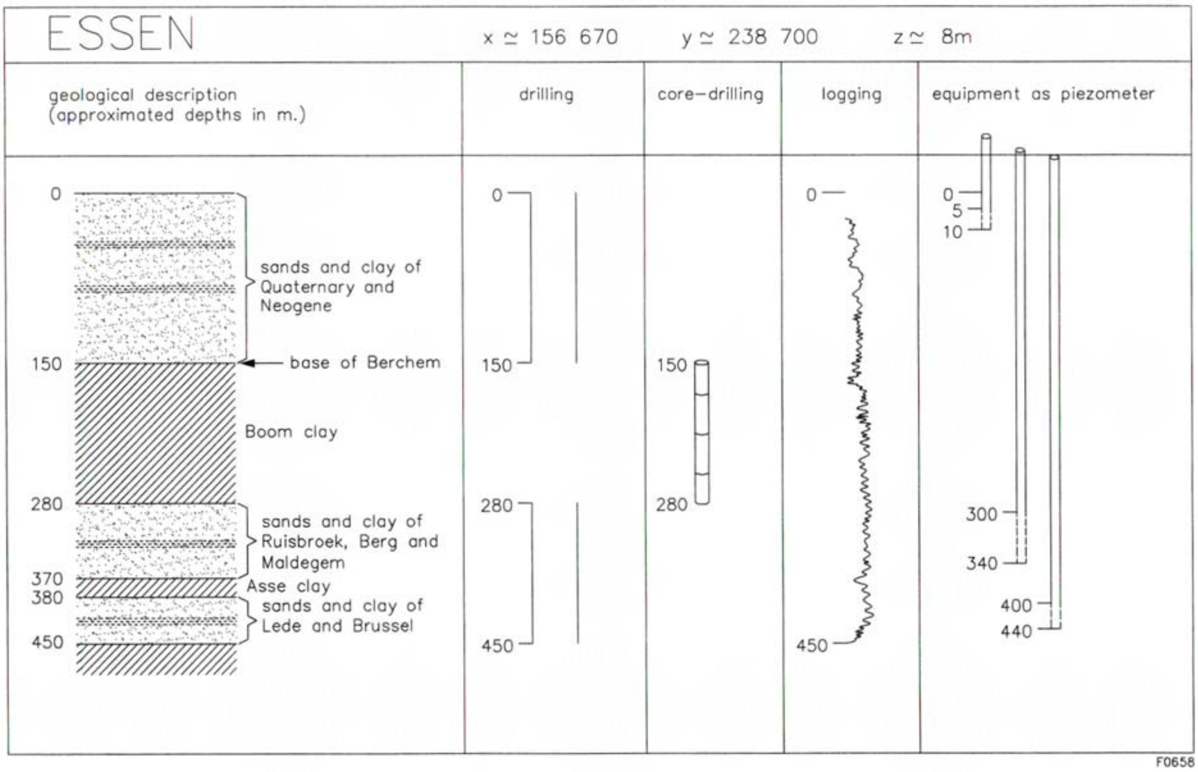

Figure 3: Drilling operations planned for the Essen borehole

The drilling of the Essen-1 borehole started on 23 January 2006 and coring was started on 25 January 2006 at a depth of 145 m. On 26 January 2006 the top of the Boom Clay formation was reached and the coring was temporarily stopped to allow a first set of geophysical loggings. Subsequently, a steel casing (outer/inner diameter: 323/308 mm) was installed and its shoe was set at a depth of 156.55 m, i.e. in the top of the Boom Clay formation to ensure a good sealing. Then, the space between the borehole and this casing was filled with cement that was allowed to harden until 30 January 2006. Once the cement and the filling gravel in the casing were drilled out coring was resumed at a depth of 161.12 m and lasted until 3 February 2006 at a depth of 301.94 m. Finally, destructive drilling was resumed on 3 February 2006 and the borehole reached its final depth of 508.55 m on 4 February 2006.

2.1 Drilling techniques

The drilling rig used by Smet G.W.T. was a GSB60 with a mast height of 13.2 m (working height: 11 m) and a maximum pull capacity of 60 ton. Drill pipes with a diameter of 6" were used.

The destructive drilling was performed by a chisel bit with a diameter of 15" until a depth of 161.12 m and a chisel bit with a diameter of 10 ¾" from 301.94 until 508.55 m, while the coring was performed with the cutting-edge wire line technique that is developed by Smet G.W.T.. The drilling assembly is in both cases the same and remains in the hole during the

core-drilling. A core-barrel[5] is lowered into the drill pipes and hydraulically pushed into the sediment with the drill pipes once it reaches the end of the bottom-hole assembly (BTA). Subsequently, it is removed with the wire line and emptied at the surface, where the PVC tube is recovered, sealed at both ends with paraffin, PVC covers, and tape.
After the hole is reamed over one metre with the BTA, the core-barrel can be lowered down again for a next sampling.

Smet G.W.T. did not use a mud circuit, but pumped fresh water from a nearby shallow well (especially drilled for that purpose) and flushed it into the borehole. When the fluids came back on the surface they were pumped into the first out of three containers in which the particles could precipitate. Via the last container, the water was pumped back into the borehole.

2.2 Sequence of drilling operations

Table 3 summarises the evolution of the drilling activities.

Table 3: Evolution of the drilling activities

Date	Description
18 to 20 January 2006	Start of the site preparation: delivery and installation of material
23 January 2006	Destructive drilling of the Essen-1 borehole until a depth of 12.20 m and installation of a conductor pipe (outer/inner diameter: 508/488 mm)
24 January 2006	Destructive drilling until a depth of 145.00 m
25 to 26 January 2006	Cored drilling and reaming until a depth of 161.12 m
26 to 29 January 2006	Logging by BBi (gamma ray, caliper, focused electro log, deviation, spontaneous potential, short/long spacing resistivity, density, and full wave sonic); installation of steel casing (outer/inner diameter: 323/308 mm) until a depth of 156.55 m; cementing the void between the borehole and the steel casing; hardening of the cement
30 January to 3 February 2006	Drilling out of cement and filling gravel from inside the casing; cored drilling from 161.12 m until a depth of 301.94 m
3 to 4 February 2006	Destructive drilling until a depth of 508.55 m
5 February 2006	Logging by BBi (gamma ray, caliper, focused electro log, deviation, spontaneous potential, short/long spacing resistivity, density, and full wave sonic)
5 to 7 February 2006	Installation of two piezometers (e and f) with a filter in the Lower-Rupelian (e) and the Lede-Brussel (f) aquifer (4 piezometers, referred to as a to d, of VMM[6] were already installed on the drilling site)
16 February 2006	Pump test in piezometers e and f by the drilling contractor, followed by the taking of a water sample for chemical analysis at SCK•CEN and for He-analysis at the University of Bern (Switzerland)
16 February 2006	Completion of well by the installation of a metal cylinder that covers the head of piezometers e and f

[5] The core-barrel contains a PVC inner tube with a length of 1 metre and a diameter of 100 mm and is mounted with a shoe with a slightly different diameter depending on the type of sediment.
[6] VMM: Vlaamse MilieuMaatschappij

IMPORTANT REMARK

The wellhead cellar collapsed between the installation of the steel casing and the second part of the destructive drilling (i.e. between 27 and 30 January 2006). As a result, the conductor pipe slid down for about 20 cm and had to be pulled up again. According to the drilling company it was repositioned at its original level, but according to the well-site geologists it was about 10 cm below its original level. Therefore, the reference level from January 30 onward might not be precisely the same as before.

2.3 Technical characteristics of the Essen-1 borehole

The technical characteristics of the well are shown in Figure 4.

A conductor pipe was placed in the first 12.20 m below ground level.

The borehole has a diameter of 280 mm, in which 2 PVC piezometers with an outside diameter of 90 mm and an inside diameter of 76.6 mm were installed. They are composed of a series of blind and screened segments joined together by glue. The deepest piezometer (52f) has a length of about 502 m and its screened parts have a length of 70.40 m situated between 400 and 470.4 m below ground level and 24.60 m situated between 475.40 and 500 m below ground level. The second piezometer (52e) has a length of about 383.70 m with its filters between 298 and 283 m, between 305 and 340 m, between 355 and 362 m, and between 377 and 381 m below ground level. In both cases, a multifilter was chosen to differentiate between the aquifers above and below a thin clay layer.

The spares around the filters were filled with calibrated gravel (grain size of 0.8-1.25 mm), i.e. between 394.70 and 508.55 m for the Lede-Brussel aquifer and between 276.40 and 348.00, between 350.50 and 368.00 m, and between 372.00 and 383.70 m for the Lower-Rupelian aquifer.

The space between the filters is filled with a clay plug (MIKOLIT 300) to avoid any communication between the different aquifers. For the same reason, two clay plugs are placed above the highest filter.

The remaining part of the annulus in contact with the blind tube was filled up with coarse uncalibrated grind.

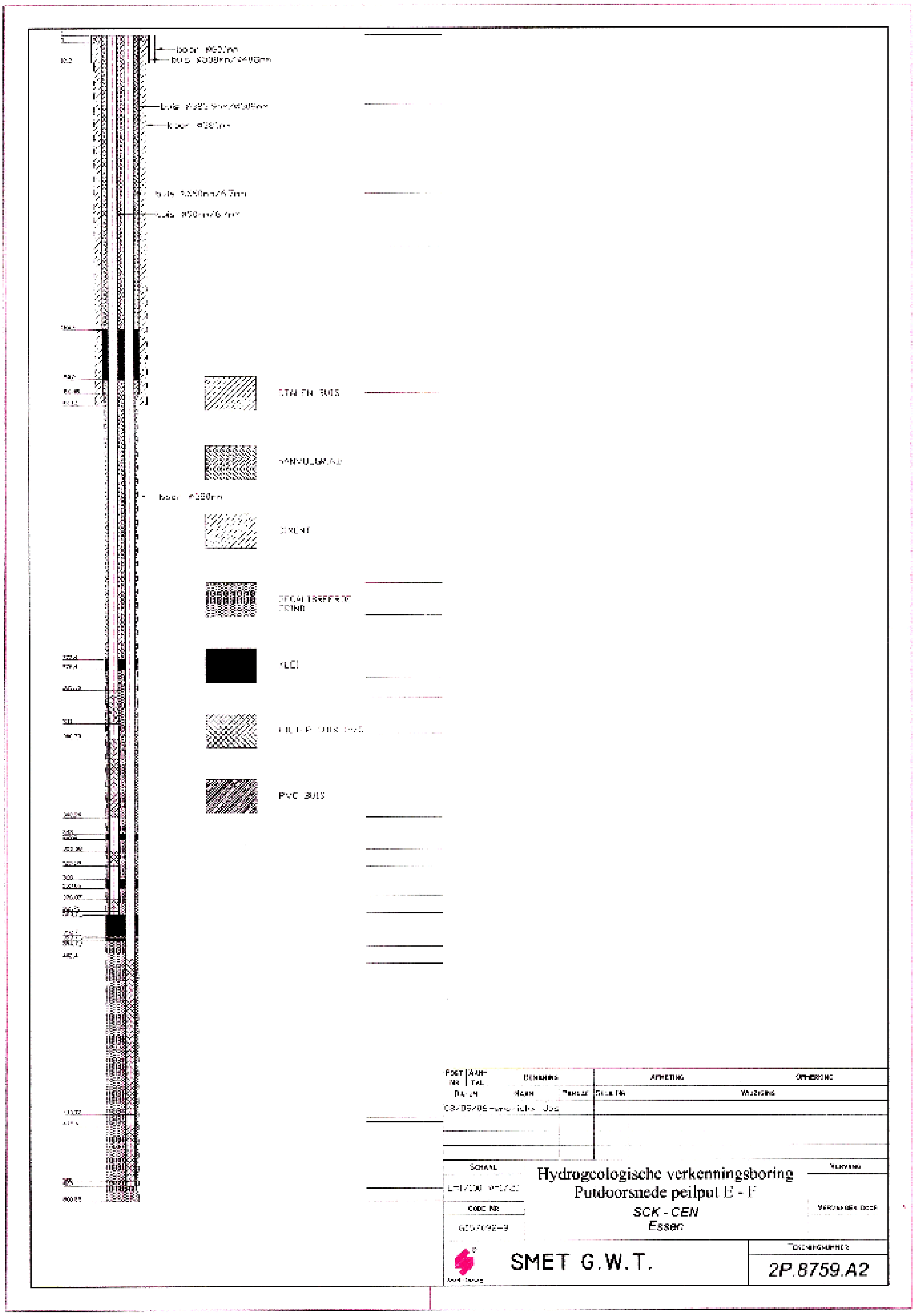

Figure 4: Technical description of the Essen-1 borehole and its piezometers (depths are expressed in m below ground level)

More detailed information can be found in Annex 2a: Drilling report Faninbel and Annex 2b: Annex to the drilling report Faninbel (only available on the accompanying CD-ROM entitled "05neb Essen").

3 Geological description of the borehole

3.1 Geophysical loggings

To ensure the stability of the borehole the installation of a steel casing from ground level until the top of the Boom Clay formation was necessary. Therefore, the geophysical measurements were performed on 2 different days, but an overlap of about 15 m was foreseen to facilitate their interpretation. In both cases, the measurements were performed during several independent trips:

- Trip 1: caliper
- Trip 2: gamma ray and focused electro log (FEL)
- Trip 3: short/long spacing resistivity, spontaneous potential
- Trip 4: density
- Trip 5: deviation
- Trip 6: full wave sonic
- Trip 7: cement bond log
- Trip 8: gamma spectral

The gamma spectral tool (needed to provide the University of Bern with the U and Th contents in order to calculate the production of He in the host fromation) did not work properly on 26 January 2006 and the trip had to be cancelled. Also, although coring stopped at a depth of 161.12 m, the tools could not be lowered below 158 m.
On 5 February 2006 a similar phenomenon was noticed when the logging tools could not go below 506 m, while the total depth of the borehole was 508.55 m. Additionally, an extra trip (cement bond log) was made to check the bond of the cement plug against the steel casing.

Annex 3 contains the original records of the various loggings that were performed in the Essen-1 borehole (only available on the accompanying CD-ROM entitled "05neb Essen").

3.2 Geological information

On the basis of the geophysical loggings and the core description the Geological Survey of Belgium made a geological description of the borehole. The core log is not complete due to the fact that several core sections were sampled as a whole (see Figure 6) for planned analyses (hydraulic conductivity, geomechanical tests, and migration experiments).

Table 4 summarises the lithostratigraphy of the Essen-1 borehole using the core as well as the logging information, while Figure 5 shows the stratigraphical log of the Essen-1 borehole.

Table 4: Stratigraphical interpretation of the Essen-1 borehole

Stratigraphy		Depth (m BDT)		Depth (m a.s.l.)	
Formation	**Member**	**Top**	**Basis**	**Top**	**Basis**
Kempen		0	46.00	14.87	-31.13
Merksplas		46.00	66.00	-31.13	-51.13
Lillo		66.00	84.60	-51.13	-69.73
	Luchtbal	80.70	84.60	-65.83	-69.73
Kattendijk		84.60	95.00	-69.73	-80.13
Diest		95.00	125.00	-80.13	-110.13
	Dessel	115.00	125.00	-100.13	-110.13
Berchem		125.00	142.00	-110.13	-127.13
Voort (?)		142.00	153.45	-127.13	-138.58
Boom	W0 to W3	153.45	200.00	-138.58	-185.13
	Putte	200.00	237.62	-185.13	-222.75
	Terhagen	237.62	259.50	-222.75	-244.63
	Belsele-Waas	259.50	281.08	-244.63	-266.21
Zelzate	Ruisbroek	281.08	287.33	-266.21	-272.46
	Wintham	287.33	299.00	-272.46	-284.13
	Watervliet	299.00	304.00	-284.13	-289.13
	Bassevelde	304.00	340.00	-289.13	-325.13
Maldegem	Onderdijke	340.00	355.00	-325.13	-340.13
	Buisputten	355.00	362.00	-340.13	-347.13
	Zomergem	362.00	377.00	-347.13	-362.13
	Onderdale	377.00	383.00	-362.13	-368.13
	Ursel	383.00	396.00	-368.13	-381.13
	Asse	396.00	400.00	-381.13	-385.13
	Wemmel	400.00	410.00	-385.13	-395.13
Lede		410.00	426.00	-395.13	-411.13
Brussel or Gent		426.00	437.50	-411.13	-422.63
Gent	Vlierzele	437.50	448.00	-422.63	-433.13
	Pittem	448.00	470.00	-433.13	-455.13
	Merelbeke	470.00	476.00	-455.13	-461.13
Tielt	Egem	476.00	505.00	-461.13	-490.13

B.D.T.: below drilling table
a.s.l.: above sea level according to Belgian reference

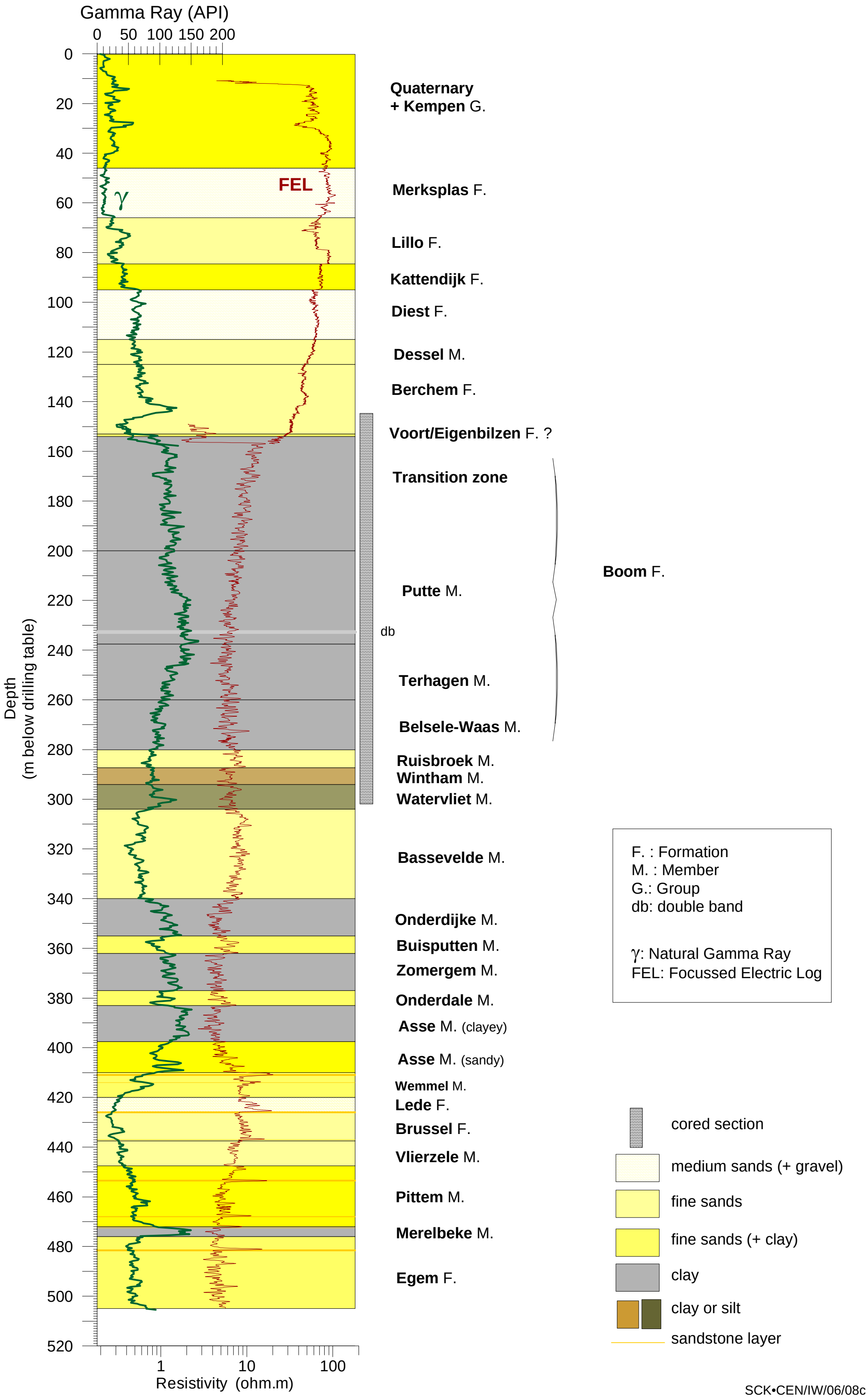

Figure 5: Stratigraphical log of the Essen-1 borehole

The final report of the Geological Survey of Belgium can be found in Annex 4: Description and interpretation (only available on the accompanying CD-ROM entitled "05neb Essen").

4 Core handling and selection

A total of 158 cores of one metre each were taken from the base of the Voort Formation to the top of the Lower-Rupelian. Shortly after their delivery at SCK•CEN they were all systematically sampled and conditioned for various planned analyses or storage to ensure a good preservation over a long time period (thus also enabling further research on cores from these boreholes).

The samples that were conditioned for hydraulic conductivity (K) measurements were left unopened in order to limit their swelling. Therefore, a transverse slice of about 20 cm length was sawed from nearly half of the cores, sealed at both ends with a PVC cap, and immediately packed in a film (12 µm polyester, 8 µm alumina, and 70 µm polyethylene) under vacuum conditions. The samples that were conditioned for migration experiments and geomechanical tests were treated in the same way, only in this case the length of the transverse slice is respectively limited to about 10 and 40 cm. Finally, 7 cores were left unopened for geomechanical tests at ULg (these results will be reported in a different note).
Once these cylindrical sections were sawn off, the remaining part or whole core was sawn longitudinally into two unequal segments, namely a large lower longitudinal segment and a much smaller upper longitudinal segment (see Figure 6).

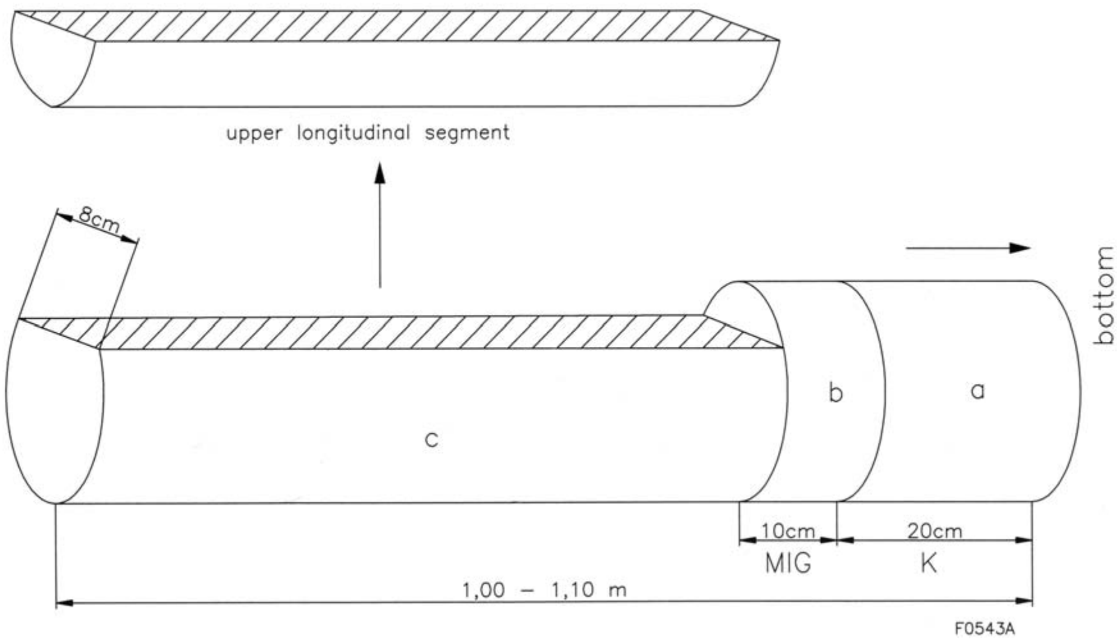

Figure 6: Schematic representation of the sampling procedures and the various types of samples

The upper segment was used for the geological description and for taking small samples that do not require any preservation. On the other hand, the lower segment was packed as soon as possible in a film under vacuum and stored in a core box after being photographed and labelled. So, further sampling and analyses remain possible despite the fact that a perfect sealing can not be guaranteed after several years (oxidation can, for example, not be excluded after two years).

The list of analyses performed on samples taken from the different cores of the Essen-1 drilling are given in Table 5.

Table 5: Non-exhaustive list of analyses performed on cores from the Essen-1 borehole

Analysis	Main laboratory	Number of samples
hydraulic conductivity	SCK•CEN	Kh: 10; Kv: 12
He analysis	University of Bern	19
natural analogues	SCK•CEN	14
geomechanical tests	ULg	7
grain size	K.U.Leuven	12 (all Kv samples)
water chemistry	SCK•CEN	2

5 Hydraulic conductivity measurements performed in the laboratory

5.1 Introduction

Measurements of the hydraulic conductivity have been carried out in the laboratory on 22 plugs (10 Kh and 12 Kv) that were taken from 12 core-slides spread over the whole cored profile.

5.2 Description of the applied methods

5.2.1 Horizontal hydraulic conductivity Kh

The sampling technique and the design of the experimental set-up (see Figure 7) have been developed within an internal R&D project of SCK•CEN. Thin wall tubes (internal diameter: 38 mm; wall thickness: 2 mm; length: 100 mm) with a cutting edge at one side are pressed vertically in the core. The position of the core on the hydraulic press determines the orientation of the sample and therefore wether it is Kh or Kv that will be measured. Subsequently, the plug is transferred from this tube into the actual measuring tube (length: 50 mm) and both ends are cut off. Finally, the measuring tube is mounted in a permeameter cell with a sintered stainless steel filter (average pore diameter: 10 µm) at both ends.
De-ionised water is injected under constant pressure at the bottom of the sample with a cylinder that is connected to a displacement transducer. The pressure is controlled by a pressure reducer that is connected to an inert gas bottle and measured by means of a pressure transmitter. The water flowing out of the cell is collected in a flask that is placed on a precision balance.

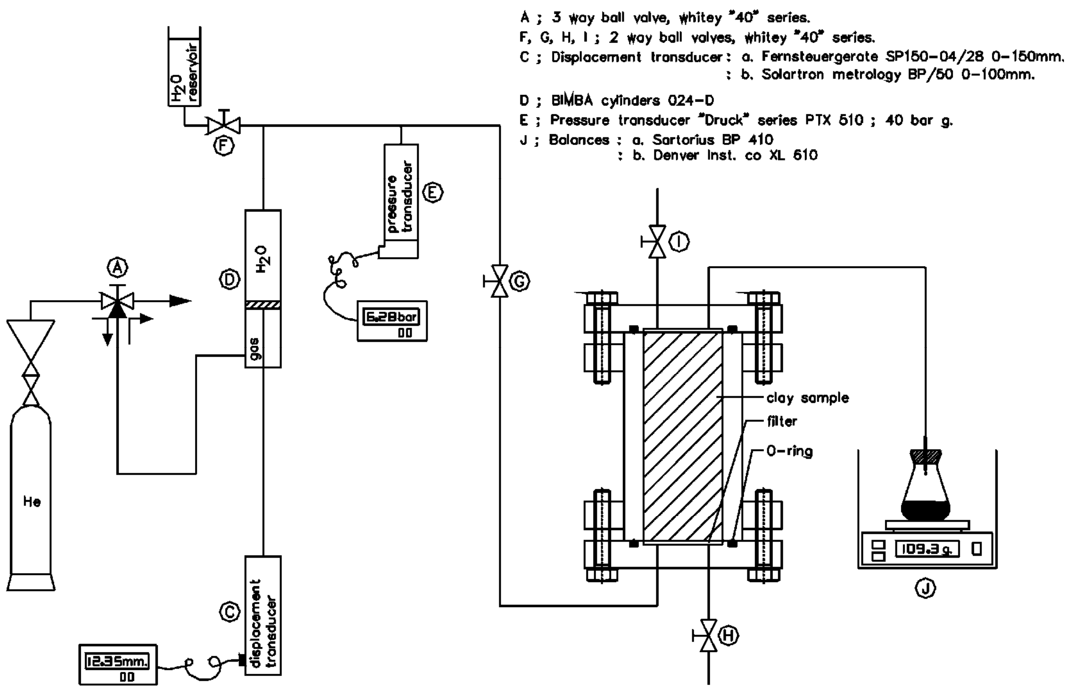

Figure 7: Scheme of SCK•CEN's experimental set-up for the measurement of low hydraulic conductivities

The hydraulic conductivity K (m/s) is determined by applying Darcy's law:

K= (Q*dl)/(S*dh)

where Q: flow rate (m^3/s)
S: surface area perpendicular to the flow rate (m^2)
dh/dl: hydraulic gradient

5.2.2 Vertical hydraulic conductivity Kv and transport parameters

ONDRAF/NIRAS has asked SCK•CEN to analyse the migration parameters of 10 core samples, i.e. the vertical hydraulic conductivity Kv, but also the product of the porosity with the retardation coefficient ηR, and the diffusion coefficient Dapp for I^- and HTO. Therefore, a plug with a diameter of 38 mm and a height of 72 mm is mounted in a stainless steel and confined percolation cell. Then, clay water is injected at a pressure of 0.55 MPa to permit the determination of the vertical hydraulic conductivity. Finally, once stabilisation is obtained, HTO and later ^{125}I are injected in the center of the plug (i.e. at a height of 36 mm) for the diffusion experiment.
This method however, could not be applied on cores 110, 118, and 133, due to a too high permeability. Using a pure diffusion experiment in order to determine their transport parameters was considered impossible, because problems were foreseen to cut the sample in very thin slices in order to determine the quantity and location of the ^{125}I. Ultimately, it was decided to take a plug with a height of 50 mm for the determination of the vertical hydraulic conductivity via a permeameter cell (see Chapter 5.2.1: Horizontal hydraulic conductivity Kh).
Previously, two extra plugs were already taken from cores 119 and 133 in order to determine their Kv by means of a permeameter cell. The results suggest a clayey sample, which is in contradiction with the Kh values that were already obtained in the same manner (see Table 6).

5.3 Results

Table 6 summarises the results of the hydraulic conductivity measurements, while Table 7 summarizes the calculated migration parameters on the basis of the different percolation tests.

Table 6: Horizontal and vertical hydraulic conductivities (Kh and Kv) determined on cores of the Essen-1 borehole in the laboratory at SCK•CEN

Drilling & core number	Stratigraphy[7]	top section (m BDT)	bot section (m BDT)	Kh depth (m BDT)	Kh (m/s)	Log(Kh)	Kv depth (m BDT)	Kv (m/s)	Log(Kv)	Kh/Kv
Essen-1 core 14	W0 to W3	158.94	159.12	159.08	6.81E-11	-10.167	158.99	6.2E-12	-11.208	10.98
Essen-1 core 36	W0 to W3	180.90	181.08	181.04	1.33E-11	-10.876	180.95	8.4E-12	-11.076	1.58
Essen-1 core 60	Boom (Putte)	204.70	204.88	204.84	1.04E-11	-10.983	204.75	5.0E-12	-11.301	2.08
Essen-1 core 79	Boom (Putte)	223.69	223.87	223.83	1.18E-11	-10.928	223.74	4.4E-12	-11.357	2.68
Essen-1 core 88	Boom (Putte)	232.20	232.40	232.35	6.65E-12	-11.177	232.25	3.4E-12	-11.469	1.96
Essen-1 core 90	Boom (Putte)	234.41	234.59	234.55	1.08E-11	-10.967	234.46	3.5E-12	-11.456	3.09
Essen-1 core 97	Boom (Terhagen)	241.33	241.53	241.48	6.96E-12	-11.157	241.38	6.7E-12	-11.174	1.04
Essen-1 core 110	Boom (Terhagen)	254.71	254.89	254.85	3.51E-10	-9.4547	254.76	1.0E-10	-10.000	3.51
Essen-1 core 118	Boom (Belsele-Waas)	262.85	263.03	262.99	6.22E-10	-9.2062	262.90	5.43E-10	-9.2652	1.15
Essen-1 core 133	Boom (Belsele-Waas)	277.86	278.04	278.00	1.15E-08	-7.9393	277.91	1.00E-11	-11.000	1150
Essen-1 core 119	Boom (Belsele-Waas)	263.05	263.15				263.10	4.74E-11	-10.324	
Essen-1 core 133	Boom (Belsele-Waas)	277.76	277.86				277.81	5.55E-12	-11.256	

n.m.: not measured

Table 7: Calculated migration parameters for iodide and HTO

Drilling & core number	Stratigraphy[8]	top section (m BDT)	bottom section (m BDT)	mean depth (m BDT)	Iodide		HTO	
					ηR	Dapp (m^2/s)	ηR	Dapp (m^2/s)
Essen-1 core 14	W0 to W3	158.94	159.12	158.99	0.24	2.46E-10	0.38	2.13E-10
Essen-1 core 36	W0 to W3	180.90	181.08	180.95	0.23	3.36E-10	0.39	2.69E-10
Essen-1 core 60	Boom (Putte)	204.70	204.88	204.75	0.26	1.98E-10	0.42	2.09E-10
Essen-1 core 79	Boom (Putte)	223.69	223.87	223.74	0.26	1.76E-10	0.47	1.90E-10
Essen-1 core 88	Boom (Putte)	232.20	232.40	232.25	0.26	1.51E-10	0.49	1.70E-10
Essen-1 core 90	Boom (Putte)	234.41	234.59	234.46	0.25	1.69E-10	0.47	1.85E-10
Essen-1 core 97	Boom (Terhagen)	241.33	241.53	241.38	0.24	2.80E-10	0.35	2.68E-10

More detailed information about the migration experiments can be found in the report entitled "Vertical distribution of Iodide and HTO transport parameters in Boom Clay in the Essen-1 borehole (Essen, Belgium)" (ER-67 ; N. Maes et al., 2008, in preparation).

[7] Based on the stratigraphic interpretation made by the Geological Survey of Belgium
[8] Based on the stratigraphic interpretation made by the Geological Survey of Belgium

6 Grain size analyses

The laboratory of Historical Geology of the Katholieke Universiteit Leuven (K.U.Leuven) performed the grain size analyses on pieces of the samples that were used to determine the vertical hydraulic conductivity Kv. This will allow to compare both parameters and determine the best correlation.

The 12 analyses were performed with a sedigraph after eliminating the carbonates by acidification, the organic matter by oxygenation, and the particles larger than 250 µm by sieving. The results of the grain size analyses are given as the percentage of particles that are smaller than a given diameter and are directly calculated by the sedigraph. These percentages were provided for 19 grain size intervals ranging from 0.49 µm to 250 µm. Additional percentages were given for the carbonate content ($CaCO_3$) and the amount of particles larger than 250 µm.

The 19 measured fractions of particles smaller than 250 µm are expressed as percentage of the sample weight that remains after the removal of the carbonates, the organic matter, and the fraction larger than 250 µm. Generally, all percentages are weight percentages, but different reference total weights are used that might require some correction of the data. Indeed, the carbonate content is expressed as a percentage against the initial weight of the sample, while the proportion of particles larger than 250 µm is given against the sample weight after extraction of the carbonate content and the organic matter.

As can be seen in Table 8, the sedigraph results did not always end with 100 % for the cumulated percentages smaller than 250 µm. These imperfections are most probably due to an insufficient homogenisation of the suspension in the sedigraph.

Table 8: Overview of the grain size analyses

Drilling	**Core**	**Mean depth (m B.D.T.)**	**%<0.49**	**%<0.69**	**%<0.98**	**%<1.38**	**%<1.95**	**%<2.76**	**%<3.91**
Essen-1	14	158.99	8.0	10.2	11.7	13.5	15.8	18.6	21.5
Essen-1	36	180.95	9.9	13.0	16.2	19.0	21.7	25.8	30.1
Essen-1	60	204.75	10.5	14.5	17.5	20.7	24.5	29.3	34.4
Essen-1	79	223.74	29.8	34.5	38.4	42.7	47.2	52.6	58.9
Essen-1	88	232.25	14.2	16.9	20.3	23.8	27.6	31.8	36.7
Essen-1	90	234.46	19.3	23.6	27.6	31.7	36.2	41.4	47.5
Essen-1	97	241.38	11.8	14.6	17.1	19.4	22.3	25.6	29.5
Essen-1	110	254.76	6.3	7.3	8.6	10.0	11.4	13.2	15.1
Essen-1	118	262.90			5.0	13.8	21.9	26.8	28.2
Essen-1	133	277.91		31.5	35.4	37.7	39.9	42.2	44.7
Essen-1	119	263.10	6.6	8.4	10.5	12.7	14.8	16.6	18.7
Essen-1	133	277.81	8.4	10.6	12.6	14.7	17.0	19.1	21.8

Drilling	**Core**	**Mean depth (m B.D.T.)**	**%<5.52**	**%<7.81**	**%<11.05**	**%<15.62**	**%<22.1**	**%<31.25**	**%<44.19**
Essen-1	14	158.99	25.3	30.4	37.1	46.7	59.1	73.7	87.2
Essen-1	36	180.95	34.8	40.6	47.7	57.1	69.9	83.9	93.4
Essen-1	60	204.75	40.6	47.6	55.7	64.6	73.1	80.8	87.7
Essen-1	79	223.74	66.0	73.5	79.7	85.6	90.0	93.3	95.7
Essen-1	88	232.25	42.5	48.9	54.9	61.3	68.6	76.1	84.2
Essen-1	90	234.46	54.7	62.8	70.1	77.1	83.0	89.5	95.4
Essen-1	97	241.38	33.8	38.2	43.7	50.7	60.1	74.4	89.8
Essen-1	110	254.76	17.7	20.9	24.4	28.9	35.0	44.6	66.1
Essen-1	118	262.90	29.6	30.2	31.0	32.1	34.1	37.1	46.4
Essen-1	133	277.91	46.9	48.5	50.5	53.3	57.7	65.0	75.6
Essen-1	119	263.10	21.2	23.9	26.9	30.4	34.0	39.5	54.7
Essen-1	133	277.81	25.6	29.9	36.7	43.2	52.0	61.8	73.5

Drilling	**Core**	**Mean depth (m B.D.T.)**	**%<62.5**	**%<88.39**	**%<125**	**%<176.78**	**%<250**	**%>250**	**%CaCO3**
Essen-1	14	158.99	95.4	98.7	99.6	99.9	**100.1**		0.92
Essen-1	36	180.95	97.0	98.4	99.3	99.8	**100.1**		0.00
Essen-1	60	204.75	94.1	98.4	**100.1**	**100.6**	**100.8**		0.00
Essen-1	79	223.74	96.9	97.7	98.0	98.0	98.1		0.00
Essen-1	88	232.25	91.9	96.6	98.6	99.4	99.9		0.00
Essen-1	90	234.46	97.9	98.8	99.1	99.1	99.0		0.00
Essen-1	97	241.38	97.3	98.9	99.0	99.0	99.0		0.78
Essen-1	110	254.76	88.8	98.4	**100.2**	**100.4**	**100.4**		0.00
Essen-1	118	262.90	71.9	92.7	98.1	99.2	100		5.40
Essen-1	133	277.91	87.5	96.3	99.8	**101.2**	**101.9**		6.40
Essen-1	119	263.10	78.0	94.5	99.9	**100.6**	**100.6**		3.23
Essen-1	133	277.81	85.3	93.8	97.8	99.2	99.9		4.39

7 Other laboratory investigations

7.1 Geochemical analyses of Boom Clay pore water and underlying aquifers

Samples for pore water analyses were selected in the Berchem Sands, the Boom Clay, and the Ruisbroek Sands. The pore water itself was collected by means of mechanical squeezing of the selected core samples under a hydraulic press (COMPAC HP100) at a constant pressure of 30 MPa. Next, the pore water samples were analysed at SCK•CEN using classical techniques, i.e. ICP-AES for the analyses of the cations, and Ion Chromatography for the anion analyses (except for F^- that was analysed by the Ion selective Electrode).The trace elements were analysed by the ICP-MS method, while the total organic carbon content (TOC) was measured with a high-temperature TOC analyser. An overview of the results is presented in Table 9a.
Finally, the stable hydrogen isotopes were analysed at the Leibniz Institute for Applied Geosciences (GGA) S3: Geochronology and Isotopehydrology, Hannover, Germany and the results are presented in Table 9b.

More detailed information about the various geochemical analyses, the results, and the conclusions can be found in Annex 5: Geochemical analyses (only available on the accompanying CD-ROM entitled "05neb Essen").

Table 9a: Analytical results on Boom Clay and underlying aquifers pore water samples

Core number	Mean depth (m B.D.T.)	Stratigraphy[9]	TIC (mg C/l)	TOC (mg C/l)	B (mg/l)	Ca (mg/l)	Fe (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	Si (mg/l)	Sr (mg/l)	Al (mg/l)
1	145.52	Voort	34.97	4.64	1.3	42	<0.02	32	7.9	44	8.2	0.31	0.007
6	150.37	Voort	28.62	4.40	1.5	24	0.47	32	6.5	49	6.9	0.18	0.185
17	162.01	Boom Clay (W0 to W3)	58.71	20.60	5.6	19	1.11	21	18.7	440	9	0.38	0.008
27	171.93	Boom Clay (W0 to W3)	69.87	27.02	5.0	29	3.8	40	29	570	7.5	0.56	0.072
39	183.91	Boom Clay (W0 to W3)	73.46	15.44	7.9	25	0.08	49	34	900	4.2	0.68	n.a.
52	196.82	Boom Clay (W0 to W3)	72.64	21.40	8.5	18.7	1.09	22	29	1100	6.5	0.54	<0.005
64	208.72	Boom Clay (Putte)	87.28	16.93	9.9	15.3	0.26	22	30	1300	7.5	0.55	n.a.
76	220.50	Boom Clay (Putte)	85.88	27.66	9.4	20	2.2	22	33	1500	7.5	0.69	<0.005
87	231.38	Boom Clay (Putte)	90.13	29.37	9.2	22	1.03	26	36	1770	7.3	0.90	<0.005
99	243.40	Boom Clay (Terhagen)	83.27	19.73	8.5	23	0.73	23	41	1890	7.2	1.04	<0.005
111	255.24	Boom Clay (Terhagen)	84.96	14.27	8.0	26	0.37	24	44	1970	7.5	1.20	<0.005
124	268.78	Boom Clay (Belsele-Waas)	109.20	14.06	9.6	36	0.39	55	52	2500	7.7	2	n.a.
138	282.77	Ruisbroek	n.a.	n.a.	9.0	40	1.41	52	49	2500	9.8	2	0.7
151	294.83	Wintham	109.30	13.41	9.0	45	1.21	57	56	2700	7.4	2.4	0.036

[9] Based on the stratigraphic interpretation made by the Geological Survey of Belgium

Table 9a: Analytical results on Boom Clay and underlying aquifers pore water samples (continued)

Core number	Mean depth (m B.D.T.)	Stratigraphy[7]	F^- (mg/l)	Cl^- (mg/l)	Br^- (mg/l)	I^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	$S_2O_3^{2-}$ (mg/l)	HCO_3^- [10] (mg/l)	alkalinity (meq/l)	salinity[11] (mg/l)
1	145.52	Voort	0.5	53	<0.25	<0.1	<0.25	52	<1	177.764	2.84	419
6	150.37	Voort	0.74	31.2	0.4	<0.1	<0.25	60	<1	145.485	2.47	298
17	162.01	Boom Clay (W0 to W3)	1.12	510	1.9	0.21	1.38	125	18.6	298.443	5.27	1470
27	171.93	Boom Clay (W0 to W3)	1.72	660	2.4	0.36	<1	190	24	355.173	5.54	1918
39	183.91	Boom Clay (W0 to W3)	1.74	1070	3.9	n.a.	0.66	324	13.5	373.422	6.56	2807
52	196.82	Boom Clay (W0 to W3)	1.26	1250	4.2	0.55	(1.6)	390	13.8	369.253	6.98	3214
64	208.72	Boom Clay (Putte)	1.16	1580	5.6	n.a.	<0.25	373	5.1	443.673	7.41	3794
76	220.50	Boom Clay (Putte)	1.23	1840	6.2	0.73	<1	450	7.2	436.557	7.30	4336
87	231.38	Boom Clay (Putte)	1.10	2180	7.3	0.80	<1	550	5.8	458.161	8.12	5075
99	243.40	Boom Clay (Terhagen)	1.07	2360	7.8	0.79	<1	580	6.0	423.289	7.22	5373
111	255.24	Boom Clay (Terhagen)	1.01	2540	8.4	0.78	<1	610	22	431.880	7.46	5694
124	268.78	Boom Clay (Belsele-Waas)	0.99	3100	11.0	n.a.	<0.25	790	129	555.100	9.99	7249
138	282.77	Ruisbroek	n.a.	3400	11.7	0.90	0.46	600	29			>6704
151	294.83	Wintham	n.a.	3700	12.8	0.99	0.89	630	43	555.608	9.42	7819

[10] Calculated from the total inorganic carbon content (TIC)
[11] Calculated as the sum of all ions and cations present in the water

Table 9b: Stable isotope composition of hydrogen (δ^2H or δD) and oxygen ($\delta^{18}O$)

Core number	Mean depth (m B.D.T.)	Stratigraphy[12]	δO (‰ VSMOW)	δD (‰ VSMOW)
1	145.52	Voort	-6.07	-42.8
6	150.37	Voort	-5.99	-42.6
17	162.01	Boom Clay (W0 to W3)	-6.08	-44.9
27	171.93	Boom Clay (W0 to W3)	-6.41	-47.5
39	183.91	Boom Clay (W0 to W3)	-6.31	-46.2
52	196.82	Boom Clay (W0 to W3)	-6.25	-44.9
64	208.72	Boom Clay (Putte)	-6.19	-44.2
76	220.50	Boom Clay (Putte)	-6.04	-42.9
87	231.38	Boom Clay (Putte)	-6.01	-42.0
99	243.40	Boom Clay (Terhagen)	-6.15	-40.9
111	255.24	Boom Clay (Terhagen)	-5.89	-40.0
124	268.78	Boom Clay (Belsele-Waas)	-5.74	-39.3
138	282.77	Ruisbroek	-5.69	-39.1
151	294.83	Wintham	-5.61	-37.7

7.2 He, U, and Th analyses

Within the CLAYTRAC project different potential argillaceous host formations for radwaste disposal are compared and examined in order to evaluate their diffusion properties based on natural tracers (i.e. non-reactive anions, water isotopes, or noble gases). It is mainly carried out and co-ordinated by the Rock-Water Interaction Group of the Institute of Geological Sciences, University of Bern (Ubern), Switzerland. The necessary input is provided by the representatives of the countries that are involved in this project and, in the case of Belgium, it is provided by SCK•CEN and ONDRAF/NIRAS.

Although the Mol-1 borehole is used as the reference borehole for the Mol site, no ideal tracer profile was already available for the Boom Clay. Therefore, the Essen-1 borehole was exerted to study various natural tracer profiles in the Boom Clay.

Helium was measured on a number of core samples from the Essen-1 borehole at the Ubern and the results are presented in Table 10. These samples were conditioned (sawed, put in stainless steel cells, flushed with nitrogen, and vacuum packed) at the Essen site during the core drilling and transferred to Switzerland.

[12] Based on the stratigraphic interpretation made by the Geological Survey of Belgium

Table 10: Overview of all clay core samples of the Essen-1 borehole that were taken for a He analysis at Ubern

Core	Top section (m B.D.T.)	Bottom section (m B.D.T.)	Mean depth (m B.D.T.)	Stratigraphy[13]	He core cc STP/g water
1	145.57	145.67	145.62	Voort	4.71E-08
2	146.85	146.93	146.89	Voort	2.52E-07
6	150.42	150.50	150.46	Voort	
15	159.31	159.39	159.35	Boom Clay (W0 to W3)	
16	160.97	161.05	161.01	Boom Clay (W0 to W3)	3.70E-06
27	171.98	172.06	172.02	Boom Clay (W0 to W3)	
39	183.96	184.04	184.00	Boom Clay (W0 to W3)	
52	196.87	196.96	196.92	Boom Clay (W0 to W3)	1.88E-05
64	208.77	208.85	208.81	Boom Clay (Putte)	1.96E-05
76	220.54	220.62	220.58	Boom Clay (Putte)	2.50E-05
87	231.43	231.51	231.47	Boom Clay (Putte-db?)	2.99E-05
99	243.45	243.53	243.49	Boom Clay (Terhagen)	3.36E-05
111	255.29	255.37	255.33	Boom Clay (Terhagen)	3.33E-05
124	268.83	268.91	268.87	Boom Clay (Belsele-Waas)	2.38E-05
135	279.93	280.01	279.97	Boom Clay (Belsele-Waas)	2.02E-05
138	282.82	282.90	282.86	Ruisbroek Sands	4.89E-05
143	287.17	287.25	287.21	Ruisbroek Sands	
151	294.88	294.96	294.92	Watervliet Clay	2.69E-05
157	300.79	300.87	300.83	Watervliet Clay	1.32E-05

For more detail about the He analyses: see Annex 6: Helium raw data report Essen (only available on the accompanying CD-ROM entitled "05neb Essen").

Also, a gamma-ray spectral log was carried out in open-hole to provide the uranium and thorium contents needed by Ubern to calculate the helium production in the host formation. Therefore, the calculated helium concentrations can be compared with the helium concentrations that are measured on the different core samples. Finally, the helium profile is used to extract the diffusion properties of the Boom Clay.

Regrettably, the U and Th concentrations that were derived from the open-hole geophysical measurements appeared to be much higher than expected. It was therefore decided to verify and calibrate these measurements by analyses performed on the solid phase of the core samples.

The samples that were used for the determination of the U and Th concentration in the solid phase were selected from a series of 14 core samples that were already used for the pore water extraction and geochemical analyses. Five of them are located in the Boom Clay formation, while the 2 deepest samples are located at the limit of the Boom Clay with the underlying aquifer. Special attention was given to the latter 2 samples, because there was uncertainty in locating the base of the Boom Clay formation. Also, a higher variability was already observed with respect to the He values in this section.

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[13] Based on the stratigraphic interpretation made by the Geological Survey of Belgium

Table 11: Results of the U and Th analyses on the solid phase of core samples

Core number	Mean depth (m B.D.T.)	Stratigraphy[14]	U (µg/g)	Th (µg/g)
16	160.92	Boom Clay (W0 to W3)	9.2	3.1
39	183.91	Boom Clay (W0 to W3)	8.0	3.0
64	208.72	Boom Clay (Putte)	12.7	4.2
87	231.43	Boom Clay (Putte)	12.3	3.4
111	255.24	Boom Clay (Terhagen)	9.9	3.5
138	282.77	Ruisbroek	6.0	2.32
151	294.83	Wintham	6.0	1.8

On this basis, it was obvious that the concentrations that were derived from the gamma spectral logs were overestimated. After a re-calibration of the curves with the U-Th values obtained via analyses on solid core samples more appropriate U and Th logs could be drawn up.

Annex 7: U and Th analyses contains a more detailed overview of the U and Th analyses (only available on the accompanying CD-ROM entitled "05neb Essen").

[14] Based on the stratigraphic interpretation made by the Geological Survey of Belgium

8 *In situ* measurements

8.1 Development and sampling of the piezometers e (Lower-Rupelian) and f (Lede-Brussel)

After their installation both piezometers were rinsed several times by the drilling contractor. This is called the well development and is done in order to remove a) dirt from the piezometers that was introduced during their installation and b) the fine sediments along the well screen-aquifer contact.

The drilling contractor also performed a small pumping test in both piezometers on 16 February 2006. Pumping in **piezometer e** (Lower-Rupelian aquifer) lasted for 1 hour and 30 minutes at a rate of about 2.4 m^3/h. During the test, its water level dropped with 13.40 m, while the level in piezometer f remained constant all the time. In other words, no indication for an interaction between both deep piezometers was found and a water sample was taken at the end of the test to be chemically analysed in a laboratory at SCK•CEN.

For **piezometer f** (Lede-Brussel aquifer) pumping lasted for about 1 hour and 30 minutes at a rate of about 2.4 m^3/h (similar to the time and rate that was applied in piezometer e), yet here its level dropped down with only 8.97 m. Meanwhile, the level in piezometer e still rose as it was still recovering from the pumping test. Hence, this test confirmed (again) that there is no indication for an interaction between both piezometers. Again, a water sample was taken at the end of the test and chemically analysed in a laboratory of SCK•CEN.

Table 12 summarises the chemical composition of the water samples that were taken at the end from both piezometers/aquifers.

Table 12: Major ions, pH, and carbon content of the Lower-Rupelian (52e) and Lede-Brussel (52f) aquifer sampled in February 2006

	Piezometer 52e	Piezometer 52f
Ca (mg/l)	50	73
Fe (mg/l)	0.86	0.45
K (mg/l)	48	55
Mg (mg/l)	53	57
Na (mg/l)	2800	3300
Si (mg/l)	5.6	12.4
F^- (mg/l)	0.69	0.70
Cl^- (mg/l)	3800	4900
Br^- (mg/l)	12.7	16.6
NO_3^- (mg/l)	<0.25	<0.25
HPO_4^{2-} (mg/l)	<0.5	<0.5
SO_4^{2-} (mg/l)	520	171
TIC (ppm C)	141.6	190.4
TOC (ppm C)	12.6	10.7

8.2 Sampling for He analysis

An additional hour and 20 minutes was pumped in both piezometers to take an extra sample for He analysis. The water sample was collected in a copper tube with a length of approximately 1 m that was carefully sealed with clamps that were screwed on at both ends.

8.3 Pumping tests

Prior to the actual pumping tests the piezometers were further developed during 5.5 (piezometer e) and 4.5 hours (piezometer f). That way, the results would not be influenced by an insufficient well development, all the more because there was uncertainty about the well development (see also Chapter 8.1: Development and sampling of the piezometers e (Lower-Rupelian) and f (Lede-Brussel)). Subsequently, a pumping test with a constant flow rate was launched at each piezometer and the drawdown was followed in both piezometers by means of automatic digital pressure transmitters (so-called Divers). Once equilibrium was reached the pump was stopped and the recovery phase was followed as well using the same equipment. Finally, a step-drawdown test was performed in both piezometers, because this type of test with gradual increase of the flow rate allows an estimation of the well resistance.

Based on the obtained values for the transmissivity and the total recovery, the hydraulic conductivity and the specific storage capacity can be calculated, which are summarised in Table 13.

Table 13: Overview of the hydraulic parameters obtained on the basis of the *in situ* pumping tests

Method	Transmissivity T (m^2/day)	Hydraulic conductivity K (m/d)		Permeability k (m^2)		Total recovery S	Specific storage capacity S_f (1/m)	
Lower-Rupelian aquifer								
		D=103 m	Deff=70 m	D=103 m	Deff=70 m		D=103 m	Deff=70 m
Jacob	10.586	0.1028	0.1512	9.72E-04	1.43E-03			
Theis	15.122	0.1468	0.2160	1.39E-03	2.04E-03			
Eden-Hazel	14.057	0.1365	0.2008	1.29E-03	1.90E-03			
Model	11.33	0.11	0.1619	1.04E-03	1.53E-03	0.1	9.7E-04	1.4E-03
Lede-Brussel aquifer								
		D=105 m		D=105 m			D=105 m	
Jacob	36.508	0.3477		3.15E-03				
Eden-Hazel	13.811	0.1315		1.19E-03				
Model	14.70	0.14		1.27E-03		0.025	2.4E-04	

Reference: Ecorem, Single well pomptests in boringen Herenthout-2 en Essen-1, Eindrapport pomptesten, Dossiernr. B01/1503.009R1, September 2006

Annex 8: Report Ecorem contains a detailed explanation of the applied in situ pumping tests and the collected results (only available on the accompanying CD-ROM entitled "05neb Essen").

9 Conclusion

The partially cored Essen-1 borehole was realised to extend the regional characterisation of the Boom Clay and to enhance the hydraulic characterisation of the Lower-Rupelian and the Lede-Brussel aquifer.

The applied coring technique delivered cores from the base of the Voort aquifer until the top of the Lower-Rupelian aquifer. They were all of high quality and a recovery of almost 100% was obtained.

The borehole Essen-1 was successfully logged, but the uranium and thorium concentration that was derived from the gamma spectral log was higher than expected. Therefore, the concentration was also determined for the solid phase of several core samples, which allowed a recalibration of the *in situ* measurements.
The borehole was also equipped with two piezometers that allow periodically piezometric measurements, hydraulic testing, and sampling in the Lower-Rupelian and Lede-Brussel aquifer. Finally, the geophysical loggings and the cores made it possible to draw up a detailed lithostratigraphical interpretation.

Finally, the planned laboratory and *in situ* investigations were carried out without any problem. They delivered a representative value of the hydraulic conductivity K for the Voort aquifer, the different sublayers of the Boom Clay aquitard, and the top of the Lower-Rupelian aquifer, while the complementary techniques (lab and *in situ* tests) are certainly recommended for future investigations.

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