Datum 19 juli 2018
Referentie 66238/NB
Betreft Hoogweg, update quickscan seismiciteit
Auteur [redacted]
Gecontroleerd door -

Potentie veroorzaken geïnduceerde seimiciteit

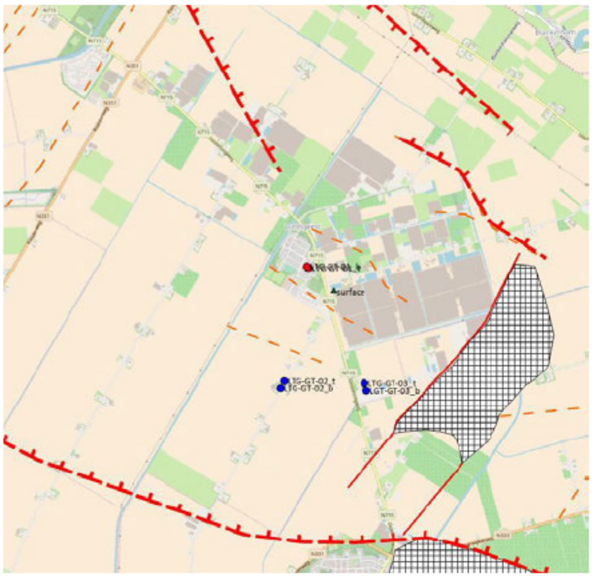
1 INLEIDING

December 2017 heeft IF Technology een quickscan uitgevoerd om te bepalen of er een gerede kans is dat geothermie systeem bij Hoogweg geinduceerde seismiciteit veroorzaakt. Uit de quickscan bleek dat deze kans klein is.

Naar aanleiding van de quick scan heeft SodM een aantal aanvullende vragen gesteld. Deze vragen konden pas beantwoord worden na het boren van de putten (zie Figuur 1) en na het uitvoeren van de puttesten. De boringen, puttesten en evaluaties zijn juni 2018 afgerond. In deze notitie zullen de resultaten van de evaluatie gebruikt worden om de vragen van SodM te beantwoorden. Voor een uitgebreide beschrijving van de puttesten wordt verwezen naar de rapportage van de puttesten. Deze rapportage is bijgevoegd in bijlage 1.

De door SodM gestelde vragen waren als volgt:
- Druk communicatie tussen de putten
- Breukorientatie

In de volgende hoofdstukken wordt op deze vragen ingegaan.

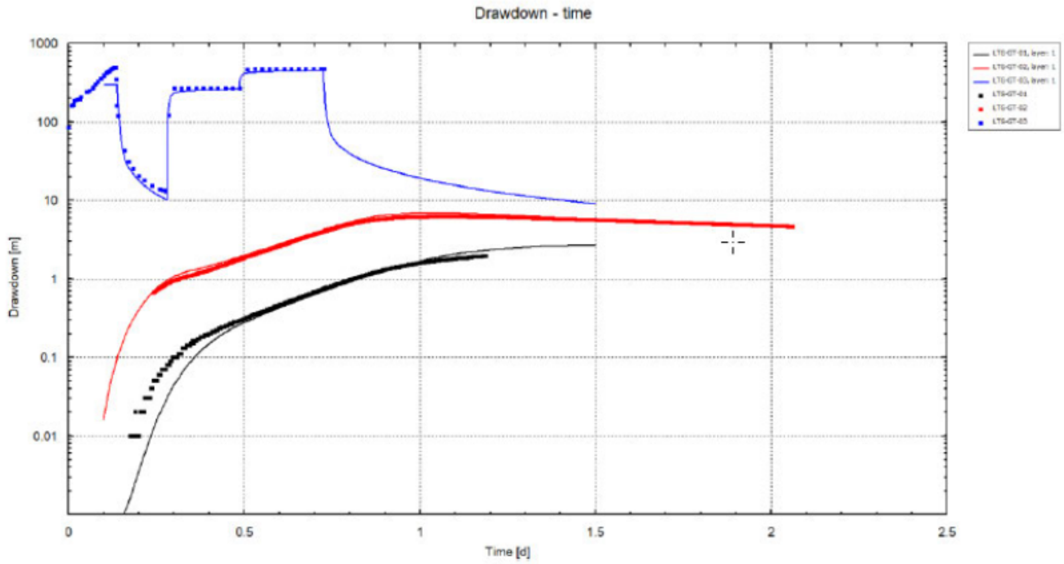


Figuur 1 | Putlocaties, belangrijkste breuken (in rood), verstoringen reservoir (oranje) en afwezigheid reservoir (gearceerd)

2 INTERWELL PRESSURE COMMUNICATION

In Figuur 1 zijn de locaties van de geboorde putten weergegeven. Het figuur geeft zowel het doorprikpunt aan de bovenkant van het reservoir, als de locatie van de put aan de onderzijde van het reservoir. In de putten zijn verschillende testen uitgevoerd. De belangrijkste testen waren: 1) productie uit LTG-GT-03 met drukmetingen in LTG-GT-01 en LTG-GT-02 en 2) productie uit LTG-GT-02 met drukmetingen in LTG-GT-01 en LTG-GT-03.

In Figuur 2 staan de resultaten van test 1. Uit het figuur blijkt duidelijk dat er een ongestoorde drukcommunicatie is tussen de verschillende putten. Verder blijkt uit de analyses dat LTG-GT-03 beïnvloed wordt door de breuk (erosievlak aan de oostzijde), maar dat dit geen volledige hydrologische barrière vormt.



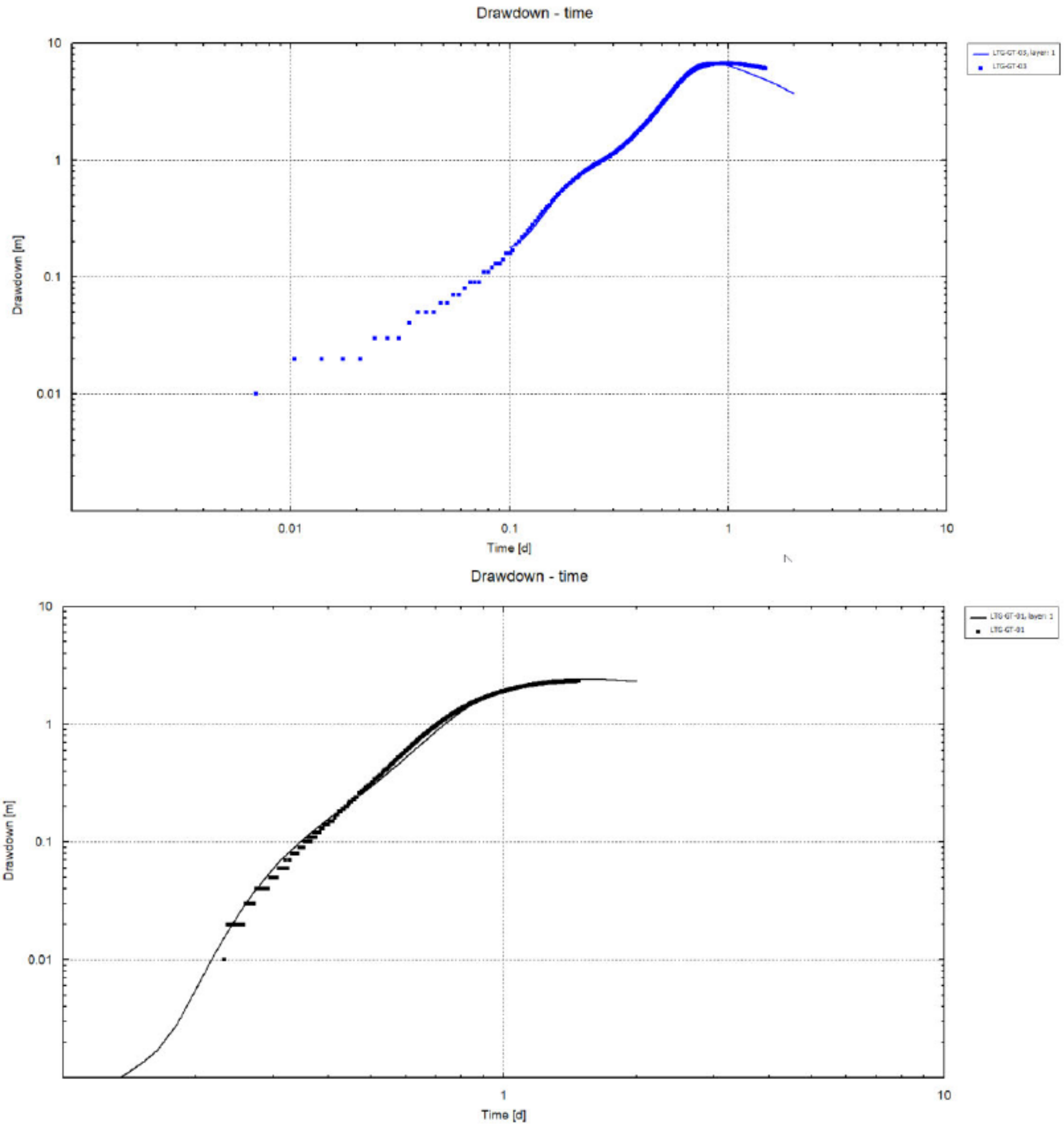
Figuur 2 | Productie test LTG-GT-03 en metingen in LTG-GT-02 en LTG-GT-01.

Op basis van de geïnterpreteerde test is een transmissiviteit van 20 Dm tussen de verschillende putten bepaald. Om te corrigeren voor de beperkte toestroming vanuit het oosten is een skin van 2.5 voor LTG-GT-03 gehanteerd. De verstoring is namelijk niet fysiek in het model opgenomen.

De resultaten van test 2 staan in Figuur 2. Ook uit deze test blijkt duidelijk dat er drukcommunicatie tussen de verschillende putten is. De interpretatie van deze test is minder eenduidig van de voorgaande test. Om een goede fit te krijgen met de drukdata op afstand was respectievelijk een transmissviteit van 21 Dm (LTG-GT-03) en 22 Dm (LTG-GT-01) benodigd. Verder week de benodigde storativity iets af. De verschillen zijn echter niet dusdanig groot dat het reden geeft om het model aan te passen. De resultaten zijn verder coherent met die van test 1.

De bovenste curve (blauw) wijkt aan het eind iets af van de meetwaarde. Dit is waarschijnlijk het gevolg van de beperktere toestroming vanuit het oosten die niet in het model is meegenomen.

De geïnterpreteerde test gaf voor de pompput (LTG-GT-02) een hogere transmissiviteit (29 Dm) dan berekend op basis van de interferentie testen. Verwacht wordt dat deze transmissiviteit lokaal rondom de put geldt. De resultaten van de interferentie testen zijn als leidend beschouwd.



Figuur 3 | Productie test LTG-GT-02 en metingen in LTG-GT-03 (boven) en LTG-GT-01 (onder).

3 BREUKORIENTATIE

Uit de uitgevoerde puttesten blijkt dat er tussen de putten geen sealende of deels sealende breuk aanwezig zijn. Dit betekent dat de oranje verstoringen aangegeven in Figuur 1 waarschijnlijk geen geen seismiciteit gaan veroorzaken. Als gevolg hiervan ligt de dichtstbijzijnde breuk bij LTG-GT-03. Door de oriëntatie van deze breuk ten opzichte van het stress veld is de slip tendency laag. Deze breuk zal hierdoor niet snel gaan schuiven.

4 HERBEREKENING SCORE

Op basis van de resultaten van de puttesten kan de scoringstabel voor het bepalen van de potentie voor het veroorzaken van geïnduceerde seismiciteit opnieuw ingevuld worden. Doordat vastgesteld is dat er een drukcommunicatie tussen de putten is, kan de “Interwel pressure communication“ op “yes” gezet worden. Verder kan “Orientation of faults in stress field” op “shearing unlikely” gezet worden. De score komt hierdoor op 0.20. Hetgeen betekent dat de potentie voor het veroorzaken van seismiciteit laag is.

Tabel 1 | Scoringstabel

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Circulation rate [m^3/h]	Epicentral distance to natural earth-quakes [km]	Epicentral distance to induced seismicity [km]	Distance to fault [km]	Orientation of fault in current stress field	Net injected volume [1000 m3]
10	Yes	no	>7	>360	<1	<1	<0.1	Favourable	>20
7	Possible	unlikely	4-7	180-360	1-5	1-5	0.1-0.5	Shearing possible	5-20
3	Unlikely	likely	1-4	50-180	5-10	5-10	0.5-1.5	Shearing unlikely	0.1-5
0	No	yes	<1	<50	>10	>10	>1.5	locked	<0.1

BIJLAGE 1 RAPPORT EVALUATIE PUTTESTEN

Well tests Hoogweg

Evaluation of clean out, step drawdown and interference tests

IF Technology **Creating energy**

Date	09 July 2018
Reference	66238
Subject	Hoogeweg
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Version	V1

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TABLE OF CONTENTS

1 Introduction

For the first phase of the Hoogweg geothermal project in Luttelgeest three wells have been drilled. In these wells several well tests (clean out, single well tests and interference test) have been carried out. In this report the evaluation of these wells tests is reported.

In Figure 1.1 the well location of phase 1 are given. The figure also gives also an overview of the most important faults and areas where the reservoir is absent.

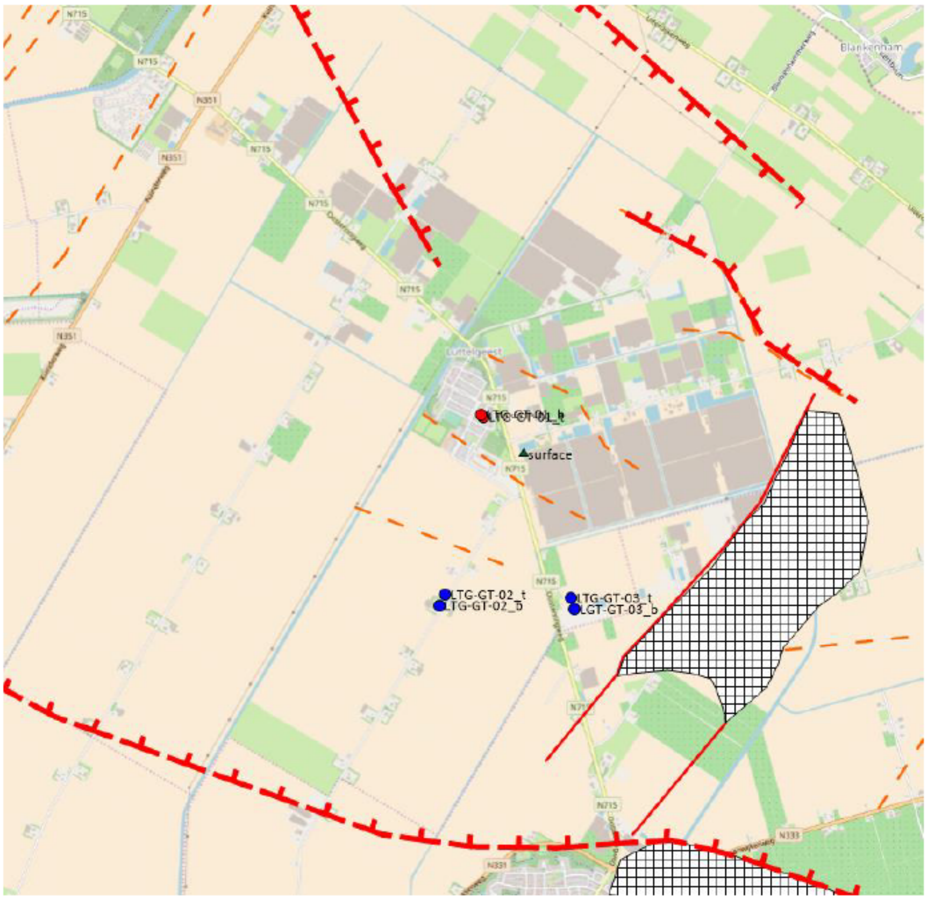

Figure 1.1 | Overview of the area: locations of the wells (top and base reservoir, blue dots are injectors, red dot is producer) of phase 1, main faults (red), minor disturbances at the bottom of the reservoir (orange dashed lines), areas where the reservoir is absent (hatched), surface location (green triangle).

The RD-coordinates of top reservoir and base reservoir of the drilled wells are given in Table 1.1. The table gives also the most relevant drilling data and measured reservoir temperature.

Table 1.1 | Well data, Coordinates top/base reservoir.

Well ID	X-RD top X-RD base [m]	Y-RD top Y-RD base [m]	Top[1] Base reservoir [mTVD]	Gross thickness Reservoir[2] [m]	Ave Inclination reservoir section [°]	Reservoir temperature [°C]
LTG-GT-01	186565	528370	1735	80	24	77.7
	186547	528388	1815			
LTG-GT-02	186292	527102	1721	66	52	76.4
	186248	527026	1787			
LTG-GT-03	187191	527079	1715	71	52	75.3
	187214	526997	1786			

1) depth is corrected for height rotary table (8.7 m)

2) based on the gamma ray it is conclude that the reservoir has got a very high N/G ratio. Therefor it is assumed that the reservoir is productive over its complete height.

A highly deviated well can have a negative skin. The value of this skin depends on the vertical anisotropy of the reservoir. If a vertical anisotropy of 5 is assumed, the negative skin for a well with a deviation angle of 52° wil be -0.75. The effect of this skin does only count for the pumped well. It will lower the pressure change in that well, remote wells are not affected by this skin. An interference test is there for not affected by this skin.

2 Well tests

2.1 GENERAL INFORMATION

In Table 2.1 some general information is given. This information is used for the interpretations of several the tests.

Table 2.1 | General information.

Parameter	unit	value	Source
Static water level	mbgl	23.39	LTG-GT-03. Only well without fresh water shut in.
Density @25°C	kg/m3	1,160	Based on density measurements, and on pressures measured with shallow pressure gauge at LTG-GT-03.
Density @25°	kg/m3	1,135	Calculated with Batzle and Wang (Batzle and wang, 1992). There is a small difference with te measured pressure. The difference is around 2%. This difference will not affect the interpretations significantly.
Initial reservoir pressure	bar	192	Pressure data offset well, see appendix 5 Calculated with density and static water level LTG-GT-03.
Salinity	g/l ppm	210 188,000	Test data LTG-GT-01, see appendix 4 Calculated.

2.2 STORATIVITY

The storativity of the reservoir plays an important role by interpreting the well tests. To get a first impression of the storativity (also used for the pre well test modelling), the equation of Jacob is used (Kruseman en de Ridder 1994).

The compressibility of the formation water was calculated with Osif's correlation (Osif, T., L. 1988). The compressibility of the reservoir matrix is based on a paper written by NAM (van Eijs en van der Wal 2017).

Table 2.2 | Input for storativity calculation.

Parameter	Unit	value	Source
Thickness	m	80	Litho-log LTG-GT-01
Temperature	°C	77	Test data LTG-GT-01
Porosity	%	20	SDE application
Density formation water @77°C	kg/m³	1,120	Measurement LTG-GT-01 & Diverted from temperature and TDS (Batzle & Wang, 1992)

Based on the input given in Table 2.2 a storativity of around 1.1 * 10^{-4} [-] is calculated. This value will be used as a start value for the test evaluations and also to check whether the storativity diverted from the tests is a reasonable value.

2.3 LTG-GT-01

This well has been cleaned out at the end of march 2018. The clean out was followed-up by a short built-up. After this short built-up the actual pumping test took place. In Figure 2.4 the flows and measured pressure chances of both the clean out and the pumping test are shown. The figure also gives the weighted average flow.

Clean out

For the interpretation of the clean out the following considerations were taken into account:

- Pressure gauge at a depth of 1,638 mTVD
- During the clean out the brine density increased from 1,145 kg/m3 to 1,160 kg/m. Due to this density increase the pressure at gauge level increased with 2.3 bar. As a result the static pressure level at the beginning and at the end of the test will not be equal.
- To account for borehole storage an effective casing radius of 0.15 m is used.
- Hole ID of 9.5 inch (see appendix 1).

For an easier interpretation the clean out pumping period was divided in 5 steps with a constant flow. The constant flow is the weighted average over the pumping time of that particularity step (see Table 2.3). As a consequence the fit of a period with a big difference between the actual flow and the averaged flow, might not as good as if the actual flow was used.

Table 2.3 | Average flow of the clean out of LTG-GT-01.

Step	End time [min]	Weighted average flow [m3/h]
1	54	257
2	110	300
3	142	338
4	208	348
5	238	282

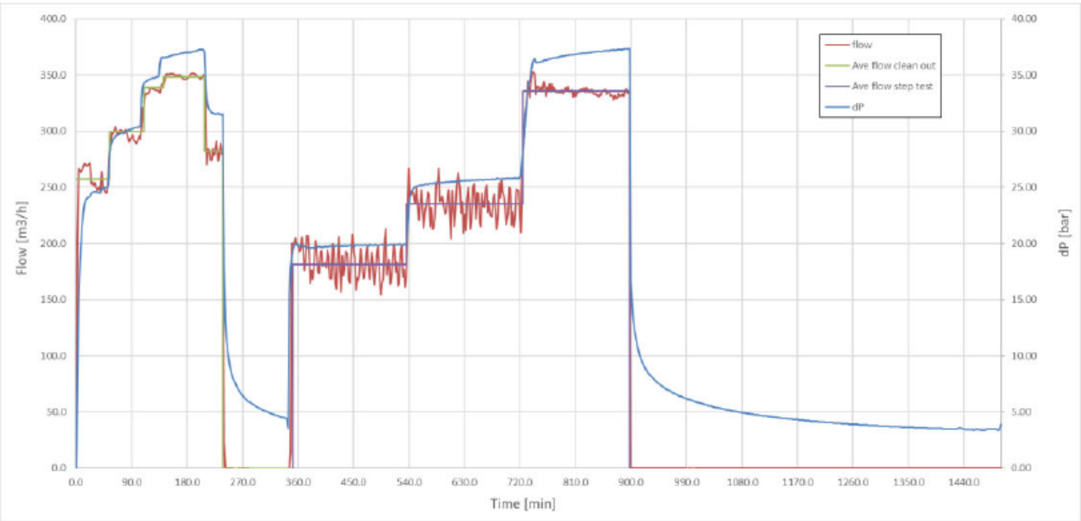

Figure 2.1 | Test data LTG-GT-01: Measured flow, calculated average flow and dP.

The test was interpreted with MLU (http://www.microfem.com/). MLU uses drawdowns in meters instead of drawdowns in bars. As a result the calculated transmissivity will be in [m^2/d] instead of [Dm]. For the conversions the correlations of Batzle and Wang (Batzle M. en Wang Z. 1992) were used. The same correlations are used in DoubletCalc (Mijnlieff e.a. 2012). The model assumes an isotropic and homogeneous reservoir with infinite extent.

The result of the interpretation in shown in Figure 2.2. Because of the density change during the test, the first step of the clean out is not taken into account. The data points of the first step are therefore not plotted in the graph. To avoid possible skin effects the fit is mainly based on the built-up data.

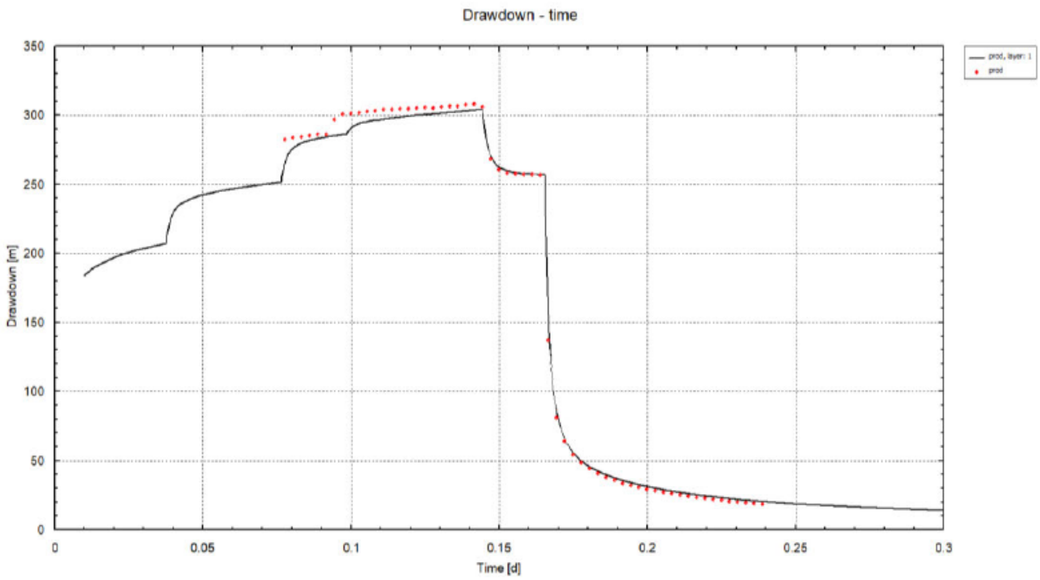

Figure 2.2 | Interpretation of well clean out LTG-GT-01.

The main results of the interpretations are:

Transmissivity	35 [m^2/d]
Storativity	0.7 10^{-4} [-]
Radius of influence	430 [m]

The calculated storativity is a little lower than the storativity calculated in paragraph 2.2.
The radius of influence of this test is calculated with the Cooper - Jacob equation (Dragoni, W. 1998). This radius is important to see whether the on the seismic lines interpreted reservoir disturbances, are within the by the test affected area. It is concluded that the interpreted disturbances are within the radius of influence (see Figure 1.1: orange dashed lines). Based on the test results no pressure effect of the disturbances is detected. This suits with the conclusions in the memo about the sealing potential of the disturbances seen on the seismic data (IF Technology 2017).

Step test

After the clean out and a short built-up, the actual pump test was carried out (Figure 2.1 from 360 min). In Table 2.4 the averaged flows for this test are given.

Table 2.4 | Average flow of the step test of LTG-GT-01.

Step	End time [min]	Weighted average flow [m3/h]
1	352	0
2	536	181
3	725	235
4	898	335

The interpretation of this test in shown in Figure 2.3. Again this fit is mainly based on the recovery period. At the beginning of the first step (0.2 to 0.25 d) there is a misfit between the calculated drawdown and the measured drawdown. This is due to the fact that an averaged flow instead of actual flow is used. At the beginning of this period the actual flow is for a short period of time much higher than the averaged flow.

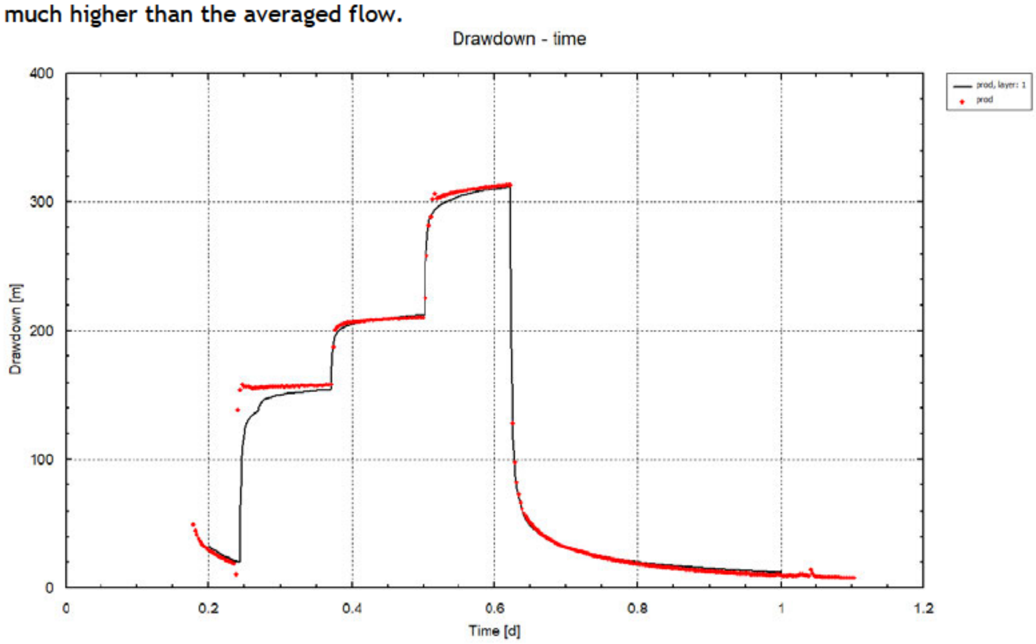

Figure 2.3 | Step test LTG-GT-01.

The main results of the interpretations are:

Transmissivity	34 [m^2/d]
Storativity	0.7 10^{-4} [-]
Radius of influence	1000 [m]

The clean out and the step test give similar results for both the transmissivity and storativity. Also both tests don't indicate a pressure boundary within the affected radius.

2.4 LGT-GT-03

These tests are carried out at te beginning of June 2017 on June. In appendix 3 the data of the data logger in LTG-GT-03 are shown. The manual measurements are shown in Figure 2.4.

Clean out

The interpretation of the clean out of this well is based on manual registered data (0 to 200 min). The measurements are shown in Table 2.5 and Figure 2.4.

Table 2.5 | Clean out of LTG-GT-03.

Step	End time [min]	Weighted average flow [m3/h]
1	22	64
2	77	143
3	146	251
4	195	330

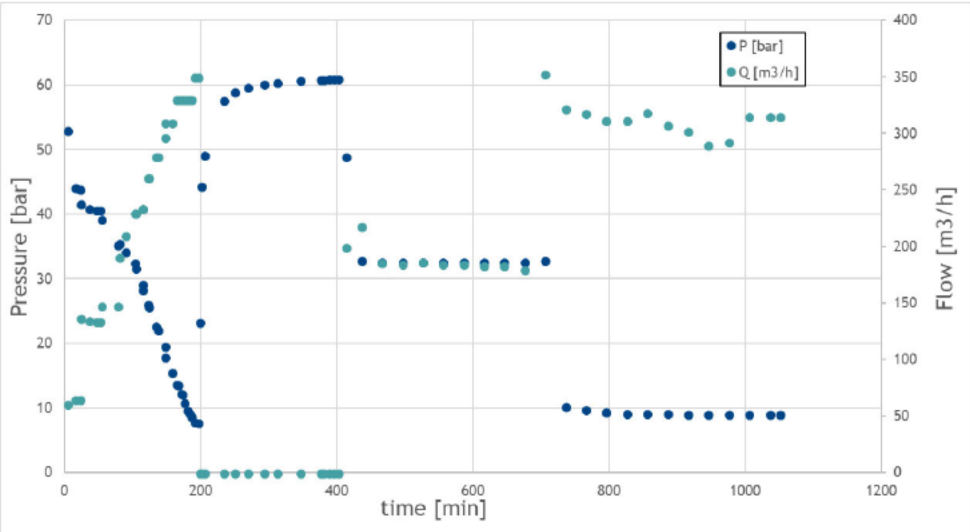

Figure 2.4 | Clean out LTG-GT-03: manual registered flow and pressures.

In Figure 2.5 the result of the interpretation of the clean out is shown.

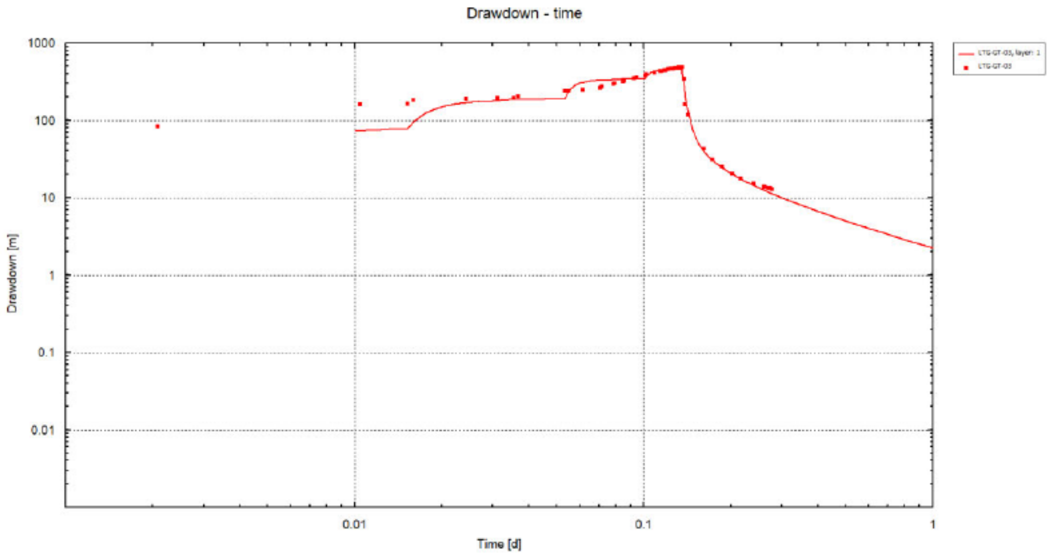

Figure 2.5 | Interpretation of well clean out LTG-GT-03.

To get a good fit on the built-up data shown in Figure 2.5 a skin of 2.5 was used. This skin is probably needed to account for the effect of the fault and the absence of the reservoir east of LTG-GT-03. Due to software limitations it is not possible to implement this fault directly in the MLU-model. The distance between the fault and the well is around 500 m. If no flow at all comes from the east a higher skin is expected. The skin for a now flow condition can analytically be calculated with: Skin = - 0.5 * ln (r_well/ L)

L is the distance to the fault (500 m) and r is the well radius (0.11 m). Based on these numbers the skin representing a complete sealing barrier at the east, will be around 4.2. Because the skin needed to get a good fit on the data is lower than the skin representing no flow at all, it is concluded that some water must come from the south-east. Based on the used geological model this seems to be logic, see Figure 2.7.

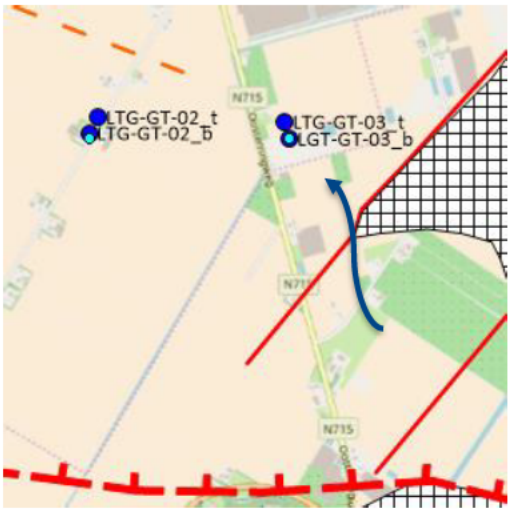

Figure 2.6 | Possible flow path to LTG-GT-02.

The main results of the interpretations are:

Transmissivity	28 [m2/d]
Storativity	$0.7\ 10^{-4}$ [-]
Skin	2.5 [-]
Radius of influence	350 [m]

Step test and interference test

After the clean out a step test and interference test were carried out. The results of the interpretation of these tests are shown in Figure 2.7. The flows of the step test are given in Table 2.6.

Table 2.6 | Step test flows LTG-GT-03.

Step	End time [min]	Weighted average flow [m3/h]
1	700	188
2	1045	317

Because only a pressure gauge directly under the ESP was available, the interpretation is mainly based on the pressures measured in LTG-GT-02 and LTG-GT-01. These pressure are corrected for the atmospheric pressure. The data for this correction is taken from the KNMI station in Stavoren. During the test period this pressure was fairly constant at 1015 mbar.

The interpretation of the data measured in remote wells gives by far the best insight in the reservoir properties because no corrections for e.g. friction losses, temperature and density changes or bore hole damage have to be made. Also it gives the reservoir properties in between the wells and not only around the pumped well. For the interpretations the pressures measured with the deepest logger are used (see appendix 1, 2 and 3; registratie formulier Fugro).

The figure makes clear that the model gives a good fit with LTG-GT-03 and LTG-GT-02. The fit with the LTG-GT-01 is a little less. The well responds is a little too late and at the end the predicted pressure changes are a little too high. Probably this has something to do with changing reservoir properties between LTG-GT-03 and LTG-GT-01. A higher transmissivity around LTG-GT-01 will cause a quicker response and a lower change at the end. The interpretation of LTG-GT-01 shows indeed a higher transmissivity than the interpretation of LTG-GT-03.

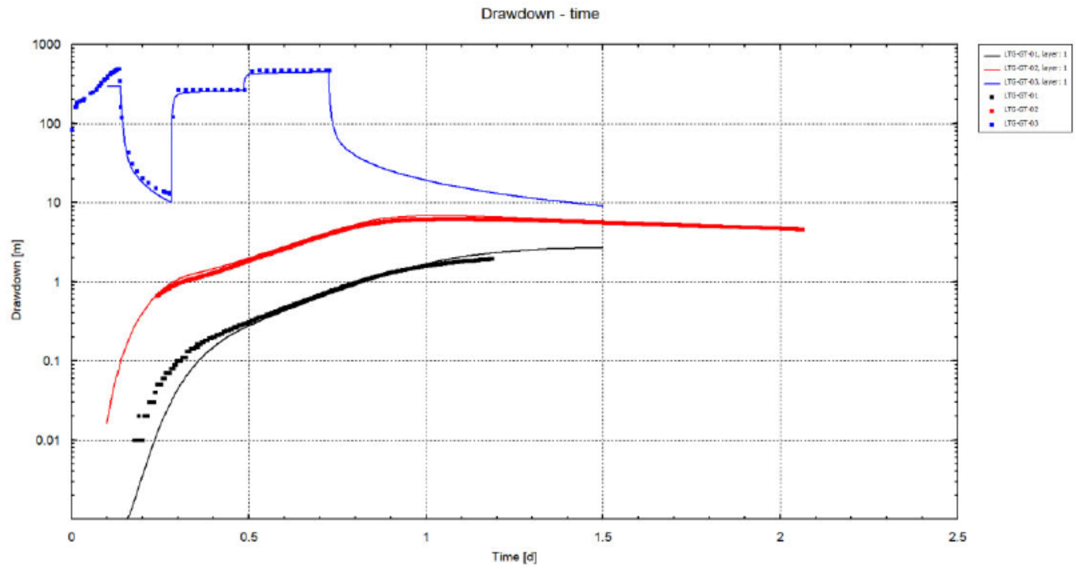

Figure 2.7 | Step test LTG-GT-03 and interference with LTG-GT-02.

The main results of the interpretations are:

Gross thickness	69 [m] Average of LTG-GT-02 and LTG-GT-03
Transmissivity	30 [m2/d] (0.42 m/d)
Storativity	0.70 10^{-4} [-]
Skin	2.5 [-] Only for the pumped well (LTG-GT-03) and because of a disturbed flow to the well
Radius of influence	distance between the wells

The clean out, the step test and interference test give similar results for both the transmissivity and storativity. For LTG-GT-03 a skin was needed to get a good fit with the measured data. This skin is probably needed to compensate for a limited flow from the east.

2.5 LTG-GT-02

LTG-GT-02 was tested mid-June 2017. In appendix 2 the data of the logger in LTG-GT-02 are shown. The used averaged flows are given in Table 2.7.

Table 2.7 | step test flows LTG-GT-02.

Step	End time [min]	Weighted average flow [m3/h]
1	120	276
2	290	0
3	490	231
4	785	368

Besides the step test also the interference with LTG-GT-01 and LTG-GT-03 has been analysed. It was not possible to get a reasonable fit for all wells with the same parameter set. Therefor the wells have been analysed separately. The step test gave a transmissivity of 44 m^2/d and a storativity of 0.70 10^{-4}. These values are considered to be only valid to close to the pumped well.

The results of the interpretation of the interference data of LTG-GT-03 and LTG-GT-01 are given in Figure 2.8 and Figure 2.9, respectively. Figure 2.8 show that the modelled recovery is faster than the actual recovery. This is probably the effect of the reduced flow from the east.

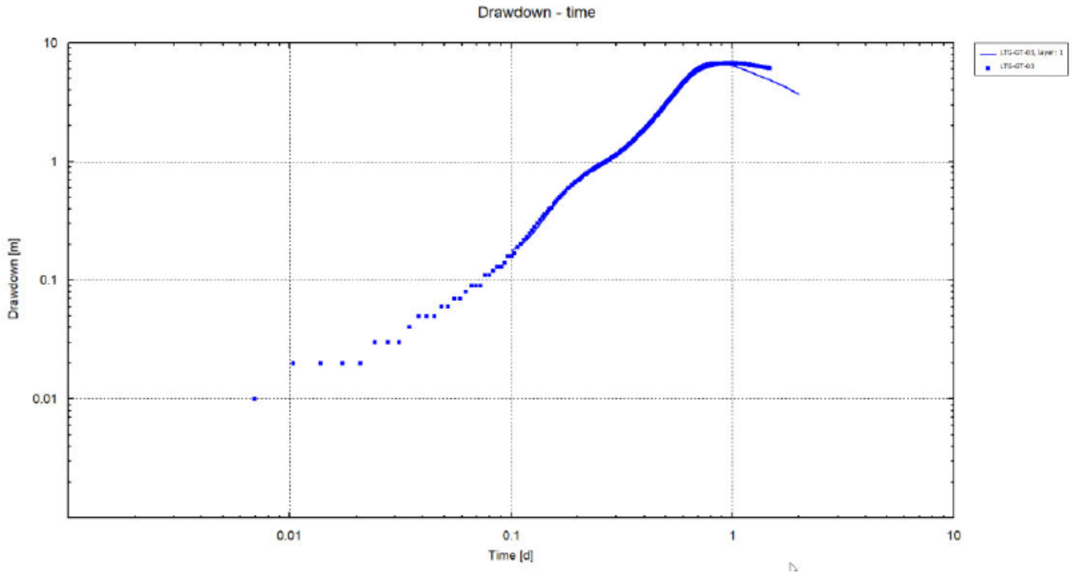

Figure 2.8 | Interference with LTG-GT-03

The diverted reservoir properties are:

Gross thickness 70 [m]
Transmissivity 32 [m^2/d]
Storativity 0.64 10^{-4} [-]

To get a good fit with the data of LTG-GT-01 a slightly higher storativity is needed

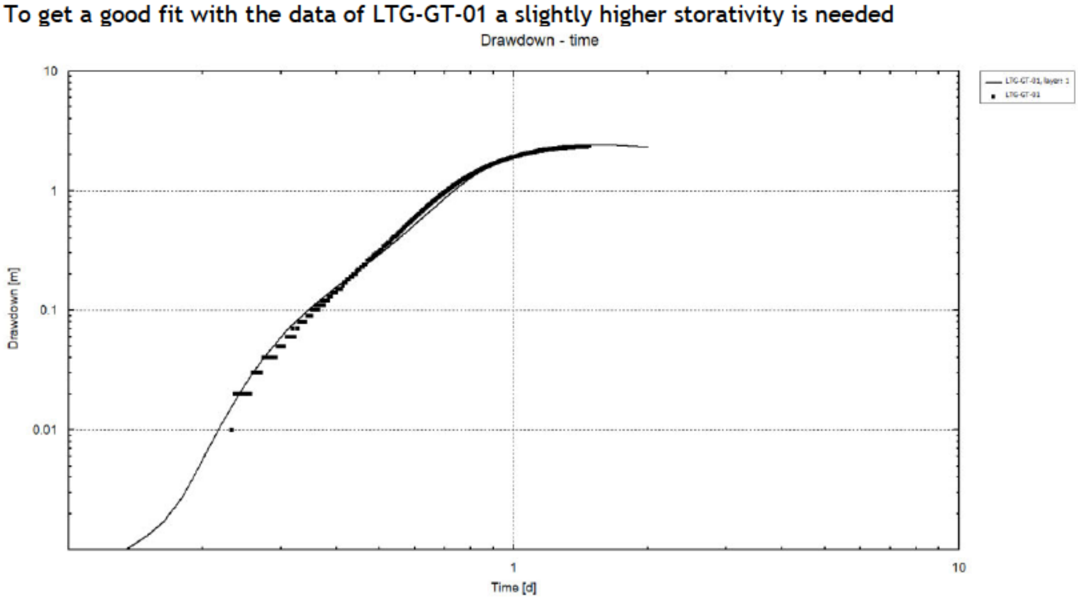

Figure 2.9 | interference with LTG-GT-01.

The diverted reservoir properties are:

Transmissivity	33 [m^2/d]
Storativity	0.90 10^{-4} [-]

The interference test give similar results for both the transmissivity and storativity. The interpretation of the pumped well itself gives a higher transmissivity.

3 Summary and conclusion

In Table 3.1 a summary of the test results is given. From the table it is clear that the average reservoir transmissivity in between the well is around 32 m^2/d (21 Dm). Based on the interference well test results it is concluded that no hydraulic barriers are situated in between the wells.

The transmissivity around LTG-GT-01 is slightly higher that the average reservoir transmissivity, the transmissivity around LTG-GT-02 is much higher and the transmissivity around LTG-GT-03 is slightly lower. LTG-GT-03 is also influenced by the fault eastern of this well. This variation in transmissvity and the flow barrier east the east have to be taken in to account in the reservoir model that will be made for the field development plan.

Table 3.1 | Summary test results.

Well	Test	Gross Thickness [m]	Transmissivity [m2/d] / [Dm]	Permeability [mD]	Storativity 10^{-4} [-]	Skin
LTG-GT-01	Clean out	80	35 / 23	292	0.70	-
	Step test		34 / 23	284	0.70	-
LTG-GT-02	Step test	66	44 / 29	445	0.70	-
	Interference with LTG-GT-03		32 / 21	324	0.64	-
	Interference with LTG-GT-01		33 / 22	334	0.90	-
LTG-GT-03	Clean out	71	28 / 19	263	0.70	2.5
	Step + interference with LTG-GT-02 and LTG-GT-01		30 / 20	282	0.70	2.5

4 Literature

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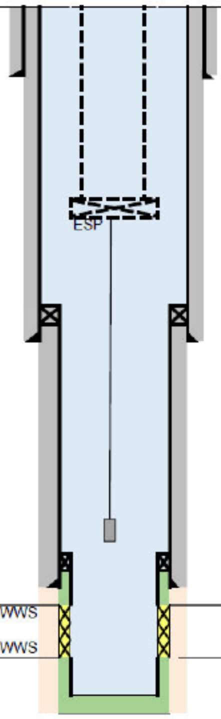
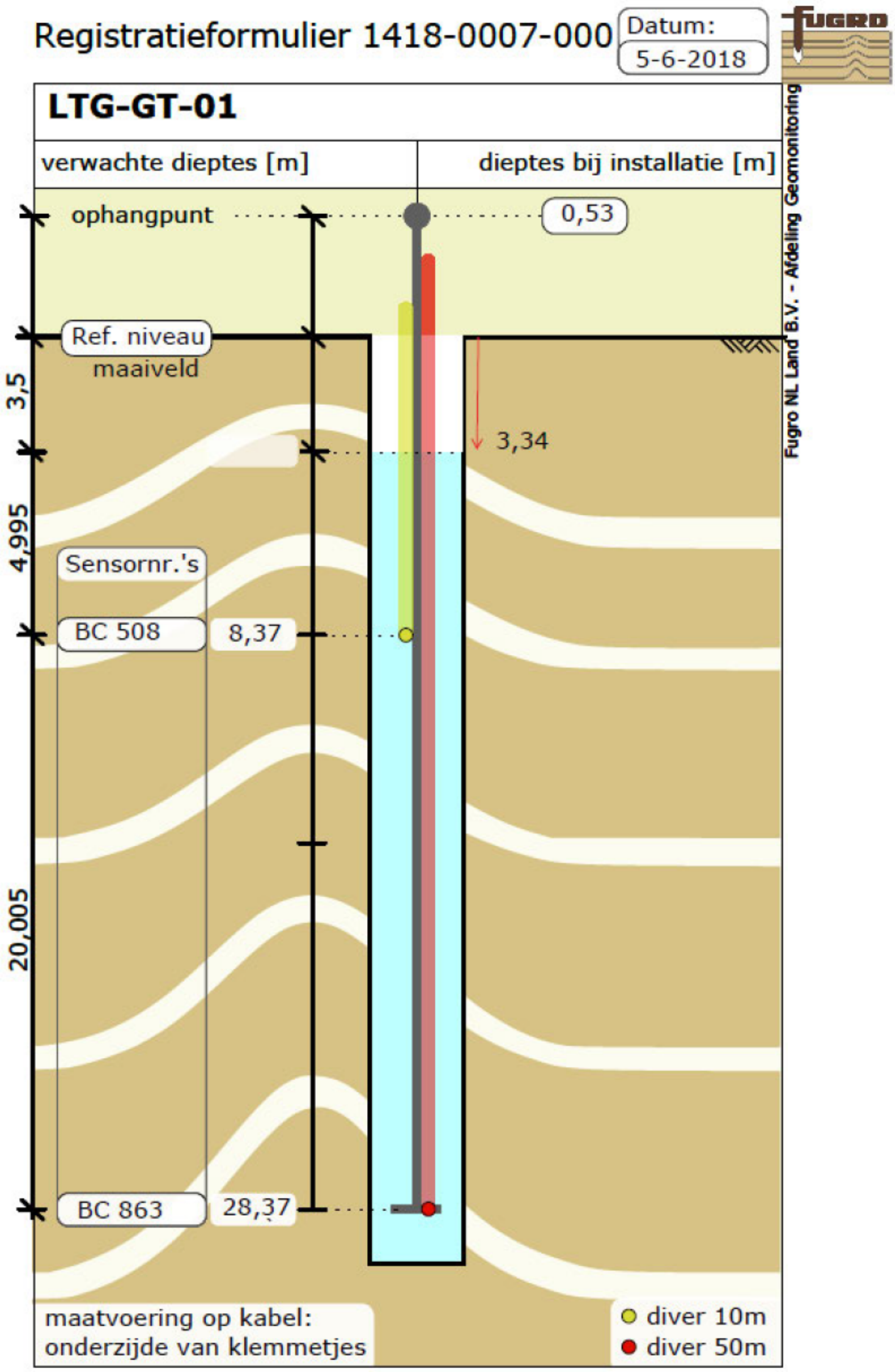
Appendix 1 LTG-GT-01

Nr.	Item Description Geothermal Production Well **All depths from RT** RT = 8,70m above GL RT = 5,08m above NAP	Wellhead and Xmas Tree **LTG-GT-01**	Depth m tvd	Depth m ah	Hole ID in	Pipe OD in	Collar OD in (nom)	Pipe ID in	Pipe ID in (drift)
1	24" welded conductor		229	229		24.000	welded	23.000	
	for testing: *ESP on 8 5/8" 32# L80* HC Polseal-1 *production tubing*	ESP	766.7	766.7		8.625	9.650	7.921	7.796
	Kick off Point		778	778					
	13 3/8 x 9 5/8" Liner Hanger + Packer		889	889					
2	13 3/8" 72# L80 VAM TOP		980	981	16.000	13.375		12.347	**12.25 SD**
			981	983	section TD				
	End of build to 26°		1089	1100					
			1638	1711	Pressure & temperature gauge				
	9 5/8" x 7 5/8" Liner Hanger + Packer		1657	1734					
3	9 5/8" 53.5# L80 VAM TOP		1704	1784	12.250	9.625		8.535	**8.5 SD**
			1705	1785	section TD				
	Top Slochteren SST: 1743m TVD / 1827m AH	WWS	1750	1835					
	Base Slochteren 1822m TVD / 1910m AH	WWS	1831	1918					
	Pack-off / Seal-sub collar		1855	1943					
4	7 5/8" 26.4# L80 HC Polseal-1 SC Base Pipe		1863	1951	9.500	7 ¾ / 8.23	**8.141 SC**	6.969	6.844
	Open hole 9 1/2" Bi-Centre bit (TD) - **Incl. 9.7°**		1864	1952	9.500	TD			

Lithostratigraphic Column Luttelgeest LTG-GT-01 J.Smulders

Era	Group	Period	Formation	Epoch (Age)	Member	Lithology definition	Expected depth (m)		Actual depth (m)	
							TV-RT	AH-RT	TV-RT	AH-RT
Cenozoic	Upper North Sea NU	Quaternary	"Diverse"	Holocene-Pleistocene		Diverse continental deposits, mostly fluvial sands and silts intercalated by some thin layers of grey or greenish-grey, silty clays.	8,7	**8,7**	8,7	**8,7**
			Maassluis NUMS	Early Pleistocene		Deposits of coastal sands, very fine to medium coarse, calcareous, shell and wood bearing, mica rich. Silty to sandy, grey to dark grey clay containing shells, lignite and mica.	192	**192**	no gamma ! 24" conductor shoe @ 229m	
		Tertiary	Oosterhout NUOT	Pliocene		Succession of sands, sandy clays, and grey and greenish clays. The lower part of the formation often consists of sands that are extremely rich in shells and bryozoans.	280	**280**	352	**352**
			Breda NUBA	Miocene		Sequence of marine, glauconitic sands, sandy clays and clays. In places a glauconite-rich layer occurs at the base.	509	**509**	456	**456**
	Middle North Sea NM		Rupel NMRF	Oligocene (Rupelian - Early Chattian)	Rupel Clay NMRFC	Clays that become more silty towards basis and top. It is rich in pyrite, contains hardly any glauconite and calcium carbonate tends to be concentrated in the septaria layers.	622	**622**	531,5	**531,5**
				Eocene -Oligocene (Priabonian - Rupelian)	Vessem NMRFV	Silty to clayey sands with a low glauconite content, flint pebbles or phosphorite nodules commonly occur at the base.	676	**676**	666	**666**
	Lower North Sea NL		Dongen NLFF	Middle - Late Eocene (Lutetian to Bartonian)	Asse NLFFB	Dark greenish-grey and blue-grey, plastic clays. The unit locally shows indications of bioturbation, and may be glauconitic and somewhat micaceous.	678	**678**	668	**668**
				Early to Middle Eocene (Ypresian to Lutetian)	Brussels Sand NLFFS	Succession of green-grey, glauconitic, very fine-grained sand with, mainly in the upper part, a number of hard, calcareous sandstone layers. Towards the base of the unit the clay content increases, and the calcium carbonate content and amount of glauconite decreases.	718	**718**	792	**792**
				Early Eocene (Ypresian)	Ieper NLFFI	A soft, tough and sticky to hardened and friable clay. The lower part is characterised by its brown-grey colour, tending to beige or red-brown locally. The upper two-thirds have a green-grey colour. It has a sandy upper part.	826	**826**	889	**889** 13 3/8" shoe depth @ 983m
					Basal Dongen Tuffite NLFFT	Tuffaceous clays, blue to violet-grey in colour, alternating with dark-grey and red-brown clays.	1015	**1020**	1073	**1082**
			Landen NLLF	Late Paleocene (Thanetian)	Landen Clay NLLFC	Generally dark-green, hard, flaky clay, somewhat silty, containing glauconite, pyrite and mica. The basal part of the member can be marly and of a lighter colour.	1025	**1031**	1077,5	**1087**
Mesozoic	Chalk CK	Cretaceous	Ekofisk CKEK	Upper Cretaceous (Danian)		White, chalky limestones containing rare white and grey nodular and bedded chert layers, and thin, grey to green clay laminae. Some glauconite can occur in the basal interval.	-	-	1117,5	**1131**
			Ommelanden CKGR	(Turonian to Maastrichtian)		Succession of white, yellowish-white or light-grey, fine grained limestones, in places argillaceous. Layers of chert can be very common over thick intervals, especially at the base section. Along the basin edge coarse, bioclastic limestones and tongues of sandstone occur.	1085	**1096**	1164,5	**1183,5**
			Texel CKTX	(Cenomanian)	Plenus Marl CKTXP	Dark-grey, partly black, calcareous, laminated claystone. Its thickness generally does not exceed a couple of metres.	1595	**1659**	1601	**1669,5**
					Texel Marlstone CKTXM	White to light-grey (locally pinkish) limestones, marls and marly chalks. Firm to moderately hard but locally silty, plastic, soft, and sticky!	1597	**1661**	1603,5	**1672**
	Rijnland KN		Holland KNGL	Lower Cretaceous (Late Albian)	Upper Holland Marl KNGLU	Light to medium grey and red-brown marls, characterised by a carbonate content which gradually increases towards the top. Locally silty, plastic, soft, and sticky! Trace Pyrite.	1640	**1709**	1663	**1739** 9 5/8" shoe @ 1784m
	Lower Germanic Trias RB	Triassic	Lower Buntsandstein RBSH	Latest Permian - early Scythian	Rogenstein RBSHR	A succession of red-brown to green silty, sometimes anhydritic claystones with regular intercalation of up to 1 m thick oolite beds in the small-scale cycles. (Note: some pieces of iron oölites were found indicating the presence of the Rogenstein Mb)	-	-	1719,5	**1801**
Paleozoic	Zechstein ZE	Permian	Zechstein 1 (Werra) ZEZ1	Upper Permian (Thuringian)	Coppershale ZEZ1K	A microlaminated, brownish-black bituminous shale with a thickness of 0,5 to 1 m. It is characterized by a high gamma-ray reading.	1749	**1829**	1741,5	**1825**
	Upper Rotliegend RO		Slochteren ROSL	Lower Permian (Saxonian)		Sequence of white to pink and pale red-brown (occ. yellow or grey) sandstones with subordinate amounts of intercalated dark red, red-brown or green-grey silty claystones. Unconsolidated to hard (siliceous cement). Locally a conglomeratic base is present.	1750	**1830**	1743,5	**1827**
	Limburg DC	Carboni-ferous	Ruurlo DCCR	Middle Carboniferous (Late Westphalian A - Early Westphalian B)		Succession of light to dark-grey or black, silty claystones, mudstones and shales containing a variable number of coal seams, and grey or buff, very fine- to fine-grained, fairly- to poorly-sorted, argillaceous or silty sandstone beds. At the top a dark red, sandy claystone sequence is present.	1825	**1913**	1823,5	**1911**
RT to GL = 8,7m; GL = 3,62m below NAP						TD (15-03-2018)	*1838*	***1928***	*1863,5*	***1952***


Registratieformulier 1418-0007-000
Datum:
5-6-2018
FUGRO
Fugro NL Land B.V. - Afdeling Geomonitoring
LTG-GT-01
verwachte dieptes [m]
dieptes bij installatie [m]
ophangpunt
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Ref. niveau
maaiveld
3,5
3,34
4,995
Sensornr.'s
BC 508
8,37
20,005
BC 863
28,37
maatvoering op kabel:
onderzijde van klemmetjes
diver 10m
diver 50m

Appendix 2 LTG-GT-02

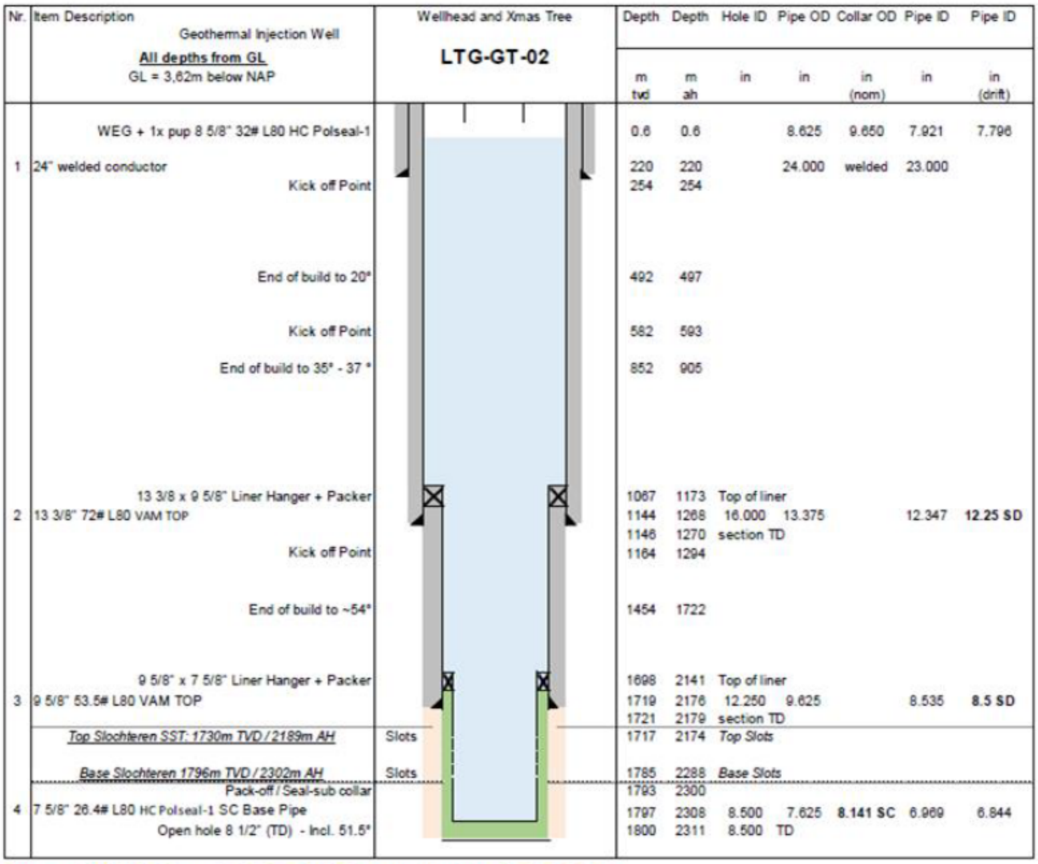
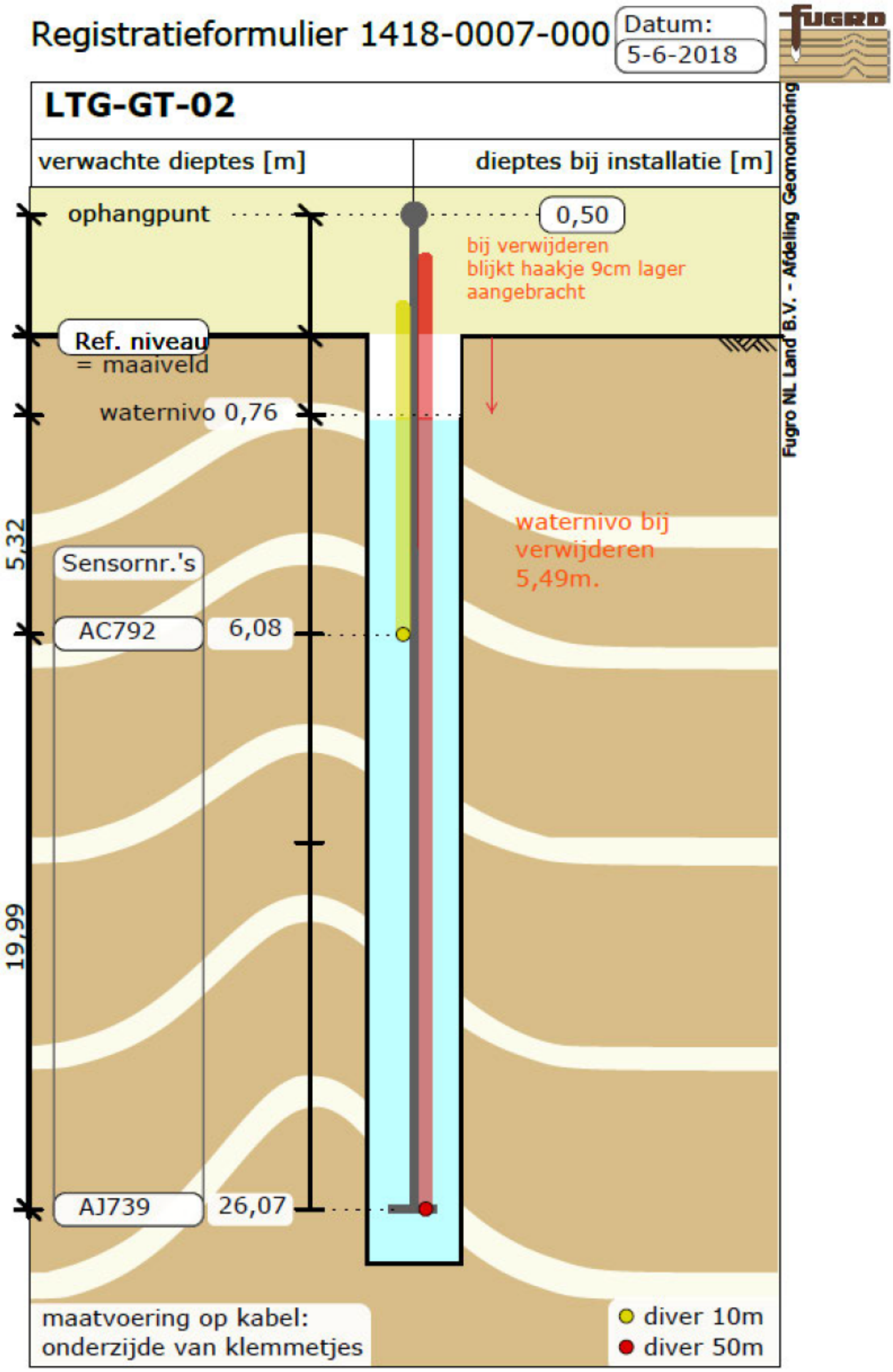


Figure 4. Well schematic LTG-GT-02 - Actual status LTG-GT-02

Lithostratigraphic Column Luttelgeest LTG-GT-02

J.Smeulders

Era	Group	Period	Formation	Epoch (Age)	Member	Lithology definition	Expected depth (m)		Actual depth (m)	
							TV-RT	AH-RT	TV-RT	AH-RT
Cenozoic	Upper North Sea NU	Quaternary	"Diverse"	*Holocene-Pleistocene*		Diverse continental deposits, mostly fluvial sands and silts intercalated by some thin layers of grey or greenish-grey, silty clays.	8,7	**8,7**	8,7	**8,7**
			Maassluis NUMS	*Early Pleistocene*		Deposits of coastal sands, very fine to medium coarse, calcareous, shell and wood bearing, mica rich. Silty to sandy, grey to dark grey clay containing shells, lignite and mica.	192	**192**	no gamma ! 24" conductor shoe @ 228m	
		Tertiary	Oosterhout NUOT	*Pliocene*		Succession of sands, sandy clays, and grey and greenish clays. The lower part of the formation often consists of sands that are extremely rich in shells and bryozoans.	280	**280**	314,5	**314,5**
			Breda NUBA	*Miocene*		Sequence of marine, glauconitic sands, sandy clays and clays. In places a glauconite-rich layer occurs at the base.	509	**515**	458	**460**
	Middle North Sea NM		Rupel NMRF	*Oligocene (Rupelian - Early Chattian)*	Rupel Clay NMRFC	Clays that become more silty towards basis and top. It is rich in pyrite, contains hardly any glauconite and calcium carbonate tends to be concentrated in the septaria layers.	622	**612**	534,5	**541,5**
				Eocene -Oligocene (Priabonian - Rupelian)	Vessem NMRFV	Silty to clayey sands with a low glauconite content, flint pebbles or phosphorite nodules commonly occur at the base.	666	**684**	667	**684**
	Lower North Sea NL		Dongen NLFF	*Middle - Late Eocene (Lutetian to Bartonian)*	Asse NLFFB	Dark greenish-grey and blue-grey, plastic clays. The unit locally shows indications of bioturbation, and may be glauconitic and somewhat micaceous.	668	**687**	668,5	**686**
				Early to Middle Eocene (Ypresian to Lutetian)	Brussels Sand NLFFS	Succession of green-grey, glauconitic, very fine-grained sand with, mainly in the upper part, a number of hard, calcareous sandstone layers. Towards the base of the unit the clay content increases, and the calcium carbonate content and amount of glauconite decreases.	792	**831**	788,5	**826**
				Early Eocene (Ypresian)	Ieper NLFFI	A soft, tough and sticky to hardened and friable clay. The lower part is characterised by its brown-grey colour, tending to beige or red-brown locally. The upper two-thirds have a green-grey colour. It has a sandy upper part.	889	**950**	896,5	**957,5**
					Basal Dongen Tuffite NLFFT	Tuffaceous clays, blue to violet-grey in colour, alternating with dark-grey and red-brown clays.	1074	**1176**	1067,5	**1170.5**
			Landen NLLF	*Late Paleocene (Thanetian)*	Landen Clay NLLFC	Generally dark-green, hard, flaky clay, somewhat silty, containing glauconite, pyrite and mica. The basal part of the member can be marly and of a lighter colour.	1076	**1179**	1070,5	**1175**
Mesozoic	Chalk CK	Cretaceous	Ekofisk CKEK	*Upper Cretaceous (Danian)*		White, chalky limestones containing rare white and grey nodular and bedded chert layers, and thin, grey to green clay laminae. Some glauconite can occur in the basal interval.	-	-	1114,5	**1229** 13 3/8" shoe @ 1276m
			Ommelanden CKGR	*(Turonian to Maastrichtian)*		Succession of white, yellowish-white or light-grey, fine grained limestones, in places argillaceous. Layers of chert can be very common over thick intervals, especially at the base section. Along the basin edge coarse, bioclastic limestones and tongues of sandstone occur.	1117	**1229**	1155	**1280**
			Texel CKTX	*(Cenomanian)*	Plenus Marl CKTXP	Dark-grey, partly black, calcareous, laminated claystone. Its thickness generally does not exceed a couple of metres.	1602	**1966**	1585,5	**1941**
					Texel Marlstone CKTXM	White to light-grey (locally pinkish) limestones, marls and marly chalks. Firm to moderately hard but locally silty, plastic, soft, and sticky!	1604	**1969**	1588	**1945**
	Rijnland KN		Holland KNGL	*Lower Cretaceous (Late Albian)*	Upper Holland Marl KNGLU	Light to medium grey and red-brown marls, characterised by a carbonate content which gradually increases towards the top. Locally silty, plastic, soft, and sticky! Trace Pyrite.	1644	**2038**	1648,5	**2049**
	Lower Germanic Trias RB	Triassic	Lower Buntsandstein RBSH	*Latest Permian - early Scythian*	Rogenstein RBSHR	A succession of red-brown to green silty, sometimes anhydritic claystones with regular intercalation of up to 1 m thick oolite beds in the small-scale cycles. (Note: top of high gamma peak at base was at 2185m, base at 2189m; 12 1/4" section TD was at 2188m)	1680	**2099**	1706	**2148** 9 5/8" casing shoe @ 2185m
Paleozoic	Upper Rotliegend RO	Permian	Slochteren ROSL	*Lower Permian (Saxonian)*		Sequence of white to pink and pale red-brown (occ. yellow or grey) sandstones with subordinate amounts of intercalated dark red, red-brown or green-grey silty claystones. Unconsolidated to hard (siliceous or anhydritic cement). Locally a conglomeratic base is present.	1705	**2142**	1730	**2189**
	Limburg DC	Carboni-ferous	Ruurlo DCCR	*Middle Carboniferous (Late Westphalian A - Early Westphalian B)*		Succession of light to dark-grey or black, silty claystones, mudstones and shales containing a variable number of coal seams, and grey or buff, very fine- to fine-grained, fairly- to poorly-sorted, argillaceous or silty sandstone beds. At the top a dark red, sandy claystone sequence is present.	1770	**2253**	1796	**2302**
RT to GL = 8,7m; GL = 3,62m below NAP						*TD* (13-04-2018)	*1779*	***2268***	*1806*	***2320***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5-6-2018
LTG-GT-02
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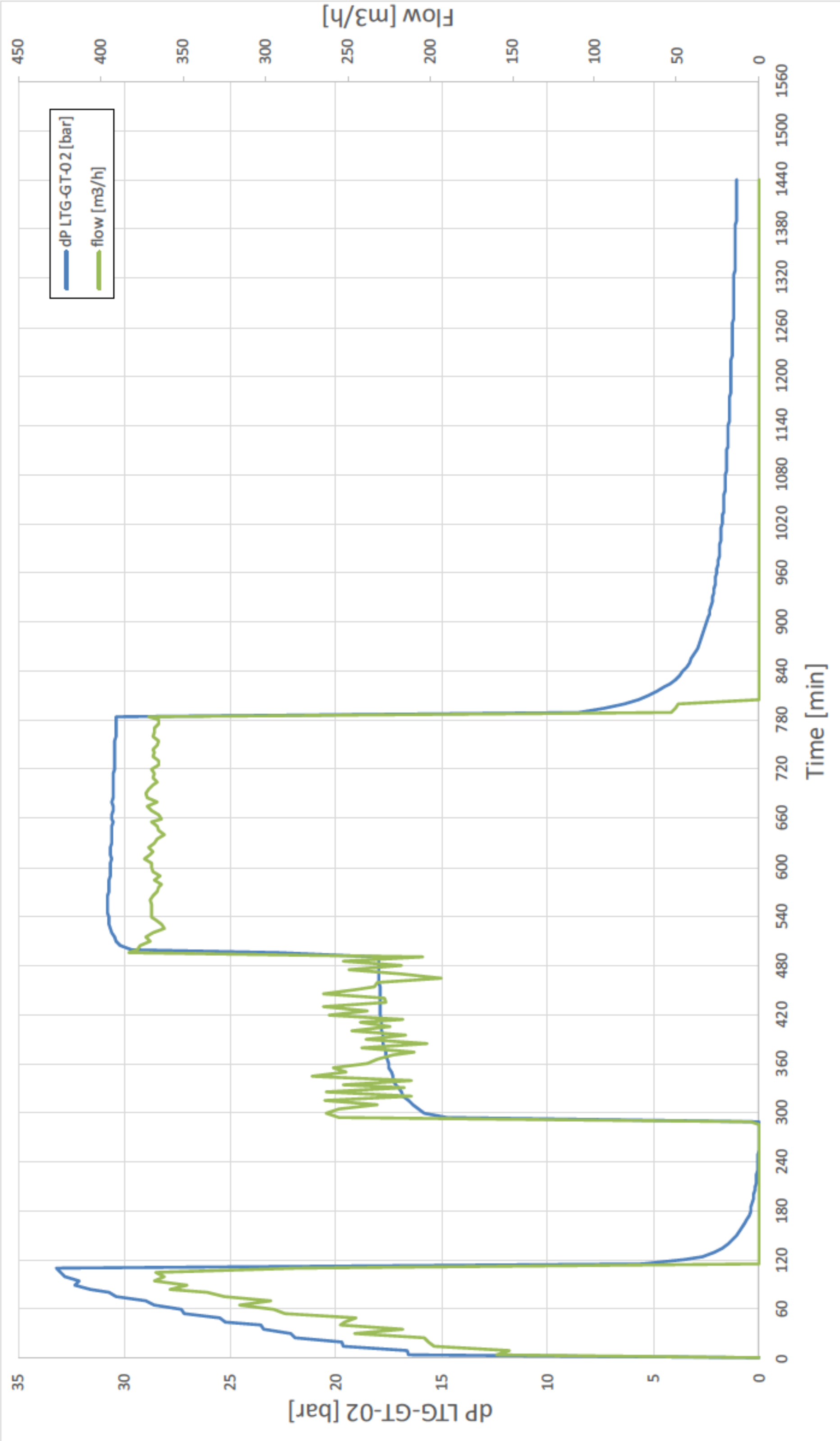
dieptes bij installatie [m]
ophangpunt
0,50
bij verwijderen
blijkt haakje 9cm lager
aangebracht
Ref. niveau
= maaiveld
waternivo 0,76
waternivo bij
verwijderen
5,49m.
5,32
Sensornr.'s
AC792
6,08
19,99
AJ739
26,07
maatvoering op kabel:
onderzijde van klemmetjes
diver 10m
diver 50m
Fugro NL Land B.V. - Afdeling Geomonitoring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dP LTG-GT-02 [bar]
flow [m3/h]
Time [min]
dP LTG-GT-02 [bar]

Appendix 3 LTG-GT-03

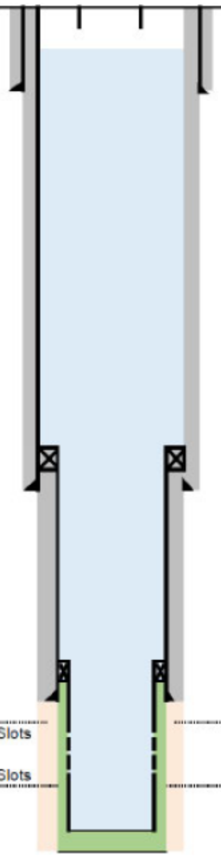
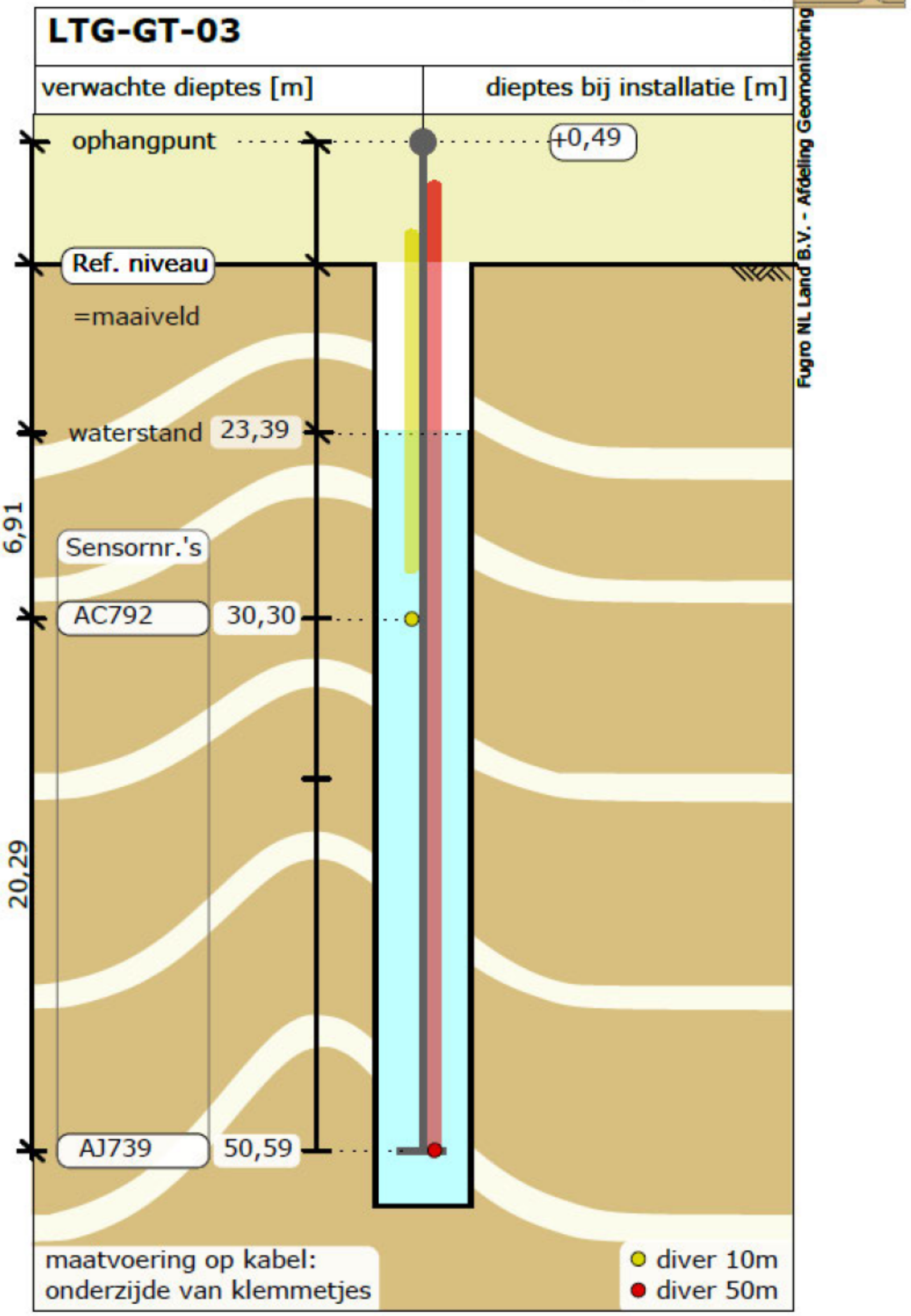
Nr.	Item Description Geothermal Injection Well **All depths from GL** GL = 3,62m below NAP	Wellhead and Xmas Tree **LTG-GT-03**	Depth m tvd	Depth m ah	Hole ID in	Pipe OD in	Collar OD in (nom)	Pipe ID in	Pipe ID in (drift)
	1x joint 8 5/8" 32# L80 HC Polseal-1		6.3	6.3		8.625	9.650	7.921	7.796
1	24" welded conductor		211	211		24.000	welded	23.000	
	Kick off Point		256	256					
	End of build to 20°		493	497					
	Kick off Point		577	586					
	End of build to 35-37°		758	790					
	13 3/8 x 9 5/8" Liner Hanger + Packer		1050	1150	Top of liner				
2	13 3/8" 72# L80 VAM TOP		1149	#####	16.000	13.375		12.35	**12.25 SD**
			1152	1276	section TD				
	Kick off Point		1161	1288					
	End of build to ~45°		1263	1425					
	Kick off Point		1383	1588					
	End of build to ~53°		1474	1723					
	9 5/8" x 7 5/8" Liner Hanger + Packer		1660	2029	Top of liner				
3	9 5/8" 53.5# L80 VAM TOP		1689	2077	12.250	9.625		8.535	**8.5 SD**
			1690	2079	section TD				
	Top Slochteren SST: 1723.5m TVD / 2128m AH	Slots	1708	2109	*Top Slots*				
	Base Slochteren 1795m TVD / 2244m AH	Slots	1785	2234	*Base Slots*				
	Pack-off / Seal-sub collar		1793	2247					
4	7 5/8" 26.4# L80 HC Polseal-1 SC Base Pipe		1798	2255	8.500	7.625	**8.141 SC**	6.969	6.844
	pen hole 8 1/2" pilot hole **x 12 1/4" (TD)** - Incl. 51.2°		1799	2256	12.250	TD			

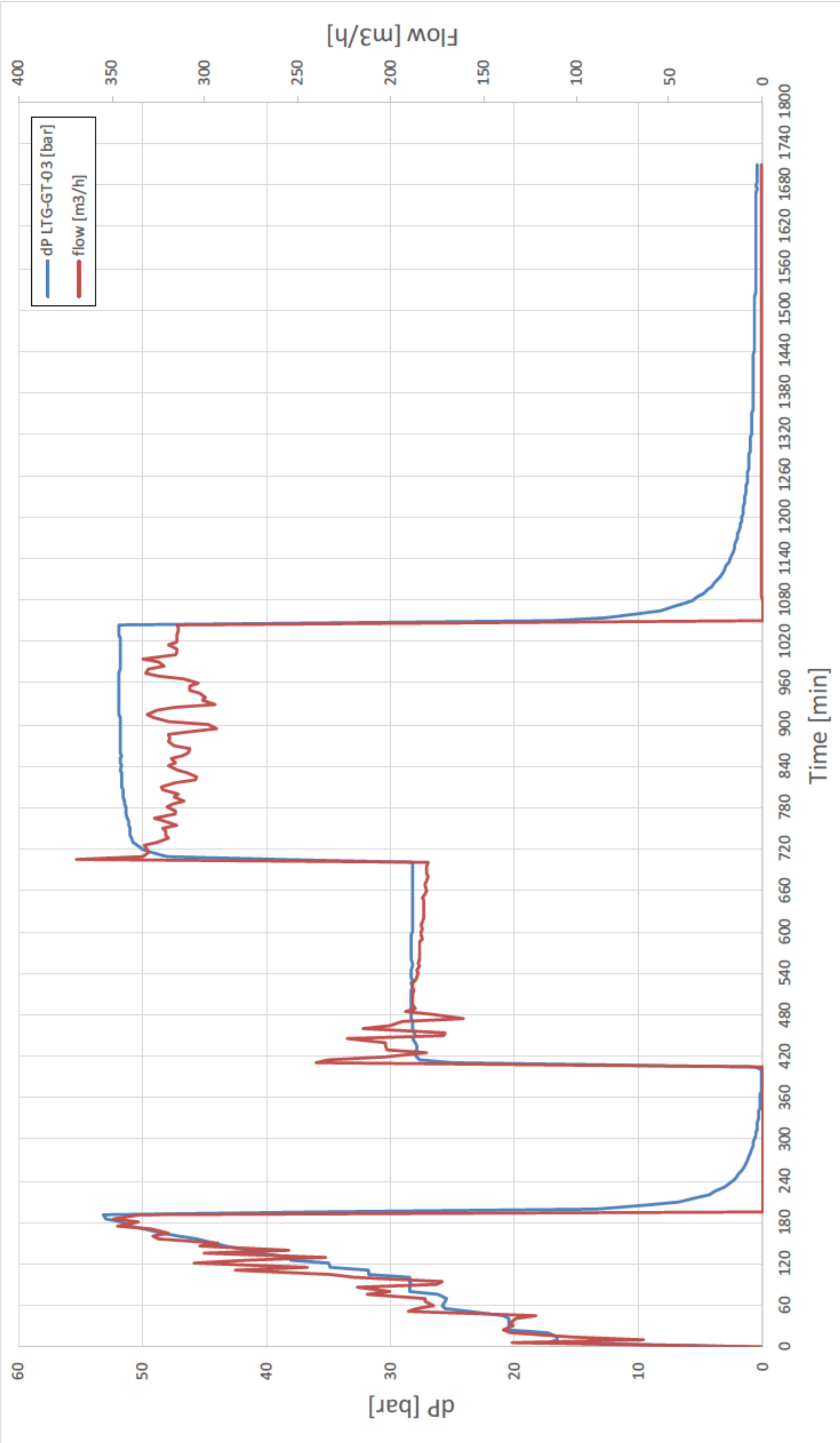
Figure 7: Well schematic LTG-GT-03 - Actual status LTG-GT-03

Lithostratigraphic Column Luttelgeest LTG-GT-03

Era	Group	Period	Formation	Epoch (Age)	Member	Lithology definition	Expected depth (m)		Actual depth (m)	
							TV-RT	AH-RT	TV-RT	AH-RT
Cenozoic	Upper North Sea NU	Quaternary	"Diverse"	*Holocene-Pleistocene*		Diverse continental deposits, mostly fluvial sands and silts intercalated by some thin layers of grey or greenish-grey, silty clays.	8,7	8,7	8,7	8,7
			Maassluis NUMS	*Early Pleistocene*		Deposits of coastal sands, very fine to medium coarse, calcareous, shell and wood bearing, mica rich. Silty to sandy, grey to dark grey clay containing shells, lignite and mica.	192	192	no gamma ! 24" conductor shoe @ 229m	
		Tertiary	Oosterhout NUOT	*Pliocene*		Succession of sands, sandy clays, and grey and greenish clays. The lower part of the formation often consists of sands that are extremely rich in shells and bryozoans.	315	315	331,5	331,5
			Breda NUBA	*Miocene*		Sequence of marine, glauconitic sands, sandy clays and clays. In places a glauconite-rich layer occurs at the base.	435	437	458	460
	Middle North Sea NM		Rupel NMRF	*Oligocene (Rupelian - Early Chattian)*	Rupel Clay NMRFC	Clays that become more silty towards basis and top. It is rich in pyrite, contains hardly any glauconite and calcium carbonate tends to be concentrated in the septaria layers.	535	542	532,5	538,5
				Eocene -Oligocene (Priabonian - Rupelian)	Vessem NMRFV	Silty to clayey sands with a low glauconite content, flint pebbles or phosphorite nodules commonly occur at the base.	667	684	665,5	681,5
	Lower North Sea NL		Dongen NLFF	*Middle - Late Eocene (Lutetian to Bartonian)*	Asse NLFFB	Dark greenish-grey and blue-grey, plastic clays. The unit locally shows indications of bioturbation, and may be glauconitic and somewhat micaceous.	669	686	668	684
				Early to Middle Eocene (Ypresian to Lutetian)	Brussels Sand NLFFS	Succession of green-grey, glauconitic, very fine-grained sand with, mainly in the upper part, a number of hard, calcareous sandstone layers. Towards the base of the unit the clay content increases, and the calcium carbonate content and amount of glauconite decreases.	789	828	787	824
				Early Eocene (Ypresian)	Ieper NLFFI	A soft, tough and sticky to hardened and friable clay. The lower part is characterised by its brown-grey colour, tending to beige or red-brown locally. The upper two-thirds have a green-grey colour. It has a sandy upper part.	897	960	894	954
					Basal Dongen Tuffite NLFFT	Tuffaceous clays, blue to violet-grey in colour, alternating with dark-grey and red-brown clays.	1068	1169	1065	1167
			Landen NLLF	*Late Paleocene (Thanetian)*	Landen Clay NLLFC	Generally dark-green, hard, flaky clay, somewhat silty, containing glauconite, pyrite and mica. The basal part of the member can be marly and of a lighter colour.	1071	1172	1071	1173,5
Mesozoic	Chalk CK	Cretaceous	Ekofisk CKEK	*Upper Cretaceous (Danian)*		White, chalky limestones containing rare white and grey nodular and bedded chert layers, and thin, grey to green clay laminae. Some glauconite can occur in the basal interval.	-	-	1110	1122 13 3/8" shoe @ 1285m
			Ommelanden CKGR	*(Turonian to Maastrichtian)*		Succession of white, yellowish-white or light-grey, fine grained limestones, in places argillaceous. Layers of chert can be very common over thick intervals, especially at the base section. Along the basin edge coarse, bioclastic limestones and tongues of sandstone occur.	1115	1226	1161	1286
			Texel CKTX	*(Cenomanian)*	Plenus Marl CKTXP	Dark-grey, partly black, calcareous, laminated claystone. Its thickness generally does not exceed a couple of metres.	1586	1908	1573,5	1880,5
					Texel Marlstone CKTXM	White to light-grey (locally pinkish) limestones, marls and marly chalks. Firm to moderately hard but locally silty, plastic, soft, and sticky!	1588	1911	1575,5	1884
	Rijnland KN		Holland KNGL	*Lower Cretaceous (Late Albian)*	Upper Holland Marl KNGLU	Light to medium grey and red-brown marls, characterised by a carbonate content which gradually increases towards the top. Locally silty, plastic, soft, and sticky! Trace Pyrite.	1649	2007	1635,5	1983
	Lower Germanic Trias RB	Triassic	Lower Buntsandstein RBSH	*Latest Permian - early Scythian*	Rogenstein RBSHR	A succession of red-brown to green silty, sometimes anhydritic claystones with regular intercalation of up to 1 m thick oolite beds in the small-scale cycles.	1706	2097	1697,5	2085,5 9 5/8" shoe @ 2186m
Paleozoic	Zechstein ZE	Permian	Zechstein 1 (Werra) ZEZ1	*Upper Permian (Thuringian)*	Z1 Carbonate ZEZ1C	Zechsteinkalk' commonly grades from argillaceous limestone at the base into crystalline dolomite at the top. The unit contains variable amounts of anhydrite.	-	-	1717	2117
					Coppershale ZEZ1K	A microlaminated, brownish-black bituminous shale with a thickness of 0,5 to 1 m. It is characterized by a very high gamma-ray peak.	-	-	1722,5	2126,5
	Upper Rotliegend RO		Slochteren ROSL	*Lower Permian (Saxonian)*		Sequence of white to pink and pale red-brown (occ. yellow or grey) sandstones with subordinate amounts of intercalated dark red, red-brown or green-grey silty claystones. Unconsolidated to hard (siliceous or anhydritic cement). Locally a conglomeratic base is present.	1729	2133	1723,5	2128
	Limburg DC	Carboni-ferous	Ruurlo DCCR	*Middle Carboniferous (Late Westphalian A - Early Westphalian B)*		Succession of light to dark-grey or black, silty claystones, mudstones and shales containing a variable number of coal seams, and grey or buff, very fine- to fine-grained, fairly- to poorly-sorted, argillaceous or silty sandstone beds. At the top a dark red, sandy claystone sequence is present.	1810	2260	1795	2244
RT to GL = 8,7m; GL = 3,62m below NAP						*TD* (09-05-2018)	*1820*	*2276*	*1808*	*2265*

Registratieformulier 1418-0007-000 Datum: 11-06-2018




Flow [m3/h]
dP LTG-GT-03 [bar]
flow [m3/h]
Time [min]
dP [bar]

Appendix 4 Water quality

Customer Analytical Services

P.O. Box 627 2300 AP Leiden

Phone: +31715241100   Email: customeranalyticalservices@nalco com

Interim - Report Number: 2311339

Geothermie Hoogweg
Kalenbergerweg 1
Luttelgeest - 8315 PD - NETHERLANDS
Representative: [redacted]

Sample Number	EW105391
Date Sampled	20-Mar-2018
Date Received	26-Mar-2018
Date Completed	5-Apr-2018
Date Authorised	

Analytical Report

This sample was analysed as received, the results being as follows:

Sampling point: Geothermo Well 1-2

Water

Cations - Metals	**Test Method**	**Filtered**	**Total**
Aluminium (Al)	AMW0013	<0.5 mg/L	<0.5 mg/L
Antimony (Sb)	AMW0013	<0.5 mg/L	<0.5 mg/L
Barium (Ba)	AMW0013	5.3 mg/L	5.5 mg/L
Boron (B)	AMW0013	21 mg/L	21 mg/L
Cadmium (Cd)	AMW0013	0.1 mg/L	0.1 mg/L
Calcium (Ca)	AMW0013	17000 mg/L	17000 mg/L
Calcium (CaCO3)	AMW0013	43000 mg/L	43000 mg/L
Chromium (Cr)	AMW0013	<0.1 mg/L	<0.1 mg/L
Copper (Cu)	AMW0013	<0.1 mg/L	<0.1 mg/L
Iron (Fe)	AMW0013	83 mg/L	100 mg/L
Lead (Pb)	AMW0013	8.4 mg/L	8.9 mg/L
Lithium (Li)	AMW0013	2 mg/L	2 mg/L
Magnesium (Mg)	AMW0013	1900 mg/L	1900 mg/L
Magnesium (CaCO3)	AMW0013	7700 mg/L	7800 mg/L
Manganese (Mn)	AMW0013	8.8 mg/L	8.8 mg/L
Molybdenum (Mo)	AMW0013	<0.5 mg/L	<0.5 mg/L
Nickel (Ni)	AMW0013	<0.1 mg/L	<0.1 mg/L
Potassium (K)	AMW0013	1000 mg/L	1000 mg/L
Silicon (Si)	AMW0013	5 mg/L	6 mg/L
Silica (SiO2)	AMW0013	12 mg/L	14 mg/L
Sodium (Na)	AMW0013	61000 mg/L	65000 mg/L
Sodium (CaCO3)	AMW0013	130000 mg/L	140000 mg/L
Strontium (Sr)	AMW0013	750 mg/L	750 mg/L
Vanadium (V)	AMW0013	0.9 mg/L	0.9 mg/L
Zinc (Zn)	AMW0013	51 mg/L	51 mg/L
Arsenic (As)	NEN-ISO 17294-2		55 µg/L
Mercury (Hg)	NEN-EN 1483		<0.02 µg/L

Quality System Certified to ISO 9001

Authorised by

Customer Analytical Services
P.O. Box 627 2300 AP Leiden
Phone: +31715241100 Email: customeranalyticalservices@nalco com

NALCO Water
An Ecolab Company

Interim - Report Number: 2311339

Geothermie Hoogweg
Kalenbergerweg 1
Luttelgeest - 8315 PD - NETHERLANDS
Representative: [redacted]

Sample Number	EW105391
Date Sampled	20-Mar-2018
Date Received	26-Mar-2018
Date Completed	5-Apr-2018
Date Authorised	

Analytical Report

This sample was analysed as received, the results being as follows:

Sampling point: Geothermo Well 1-2

Anions Test Method: AMW0002	**Filtered**
Fluoride (F)	<50 mg/L
Chloride (Cl)	>100000 mg/L
Nitrite (NO2)	<50 mg/L
Bromide (Br)	<50 mg/L
Nitrate (NO3)	<50 mg/L
Ortho Phosphate (PO4)	<50 mg/L
Sulfate (SO4)	270 mg/L

Alkalinity Test Method: AMW0111	**Total**
Total Alkalinity (CaCO3)	<100 mg/L
Phenolphthalein Alkalinity (CaCO3)	<100 mg/L
Bicarbonate (CaCO3)	<100 mg/L

Phosphate Test Method: AMW0121	**Total**
Total Phosphate (PO4)	<1 mg/L

Other Analytes	**Test Method**	**Filtered**	**Total**
Conductivity at 25 C	AMW0111		360000 µS/cm
Ammonia (NH3-N)	AMW0120	79 mg/L	
pH @ 25 C	AMW0111		5.9 pH Units
Total Suspended Solids @ 105 C	AMW0007		75 mg/L
Total Dissolved Solids @ 180 C	AMW0024		210000 mg/L

Note that the pH and Conductivity were measured on a diluted sample. Conductivity has been calculated back to the original sample and reported. Measuring in this way could affect the result and should be borne in mind for result interpretation.

Quality System Certified to ISO 9001

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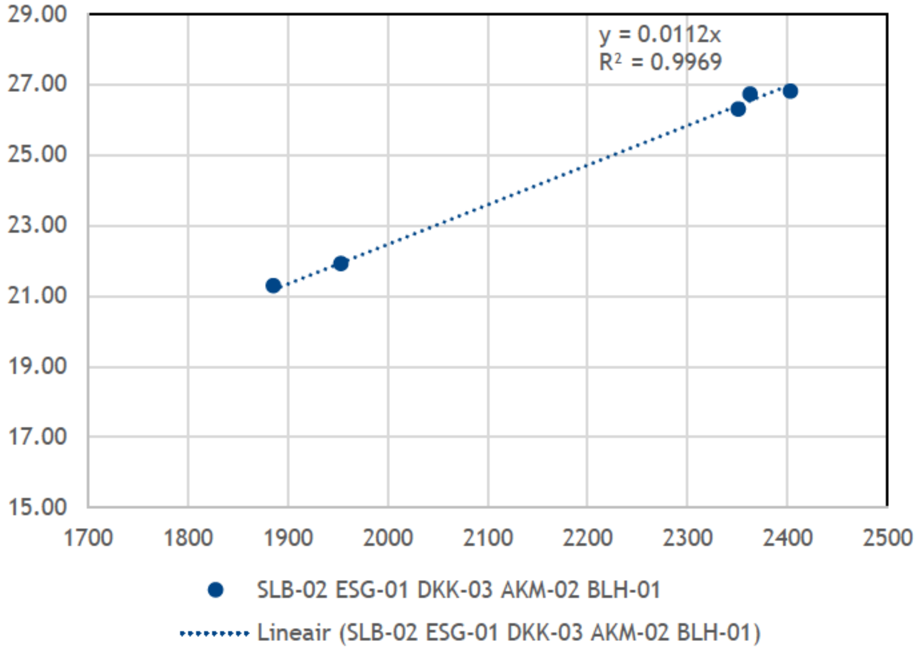
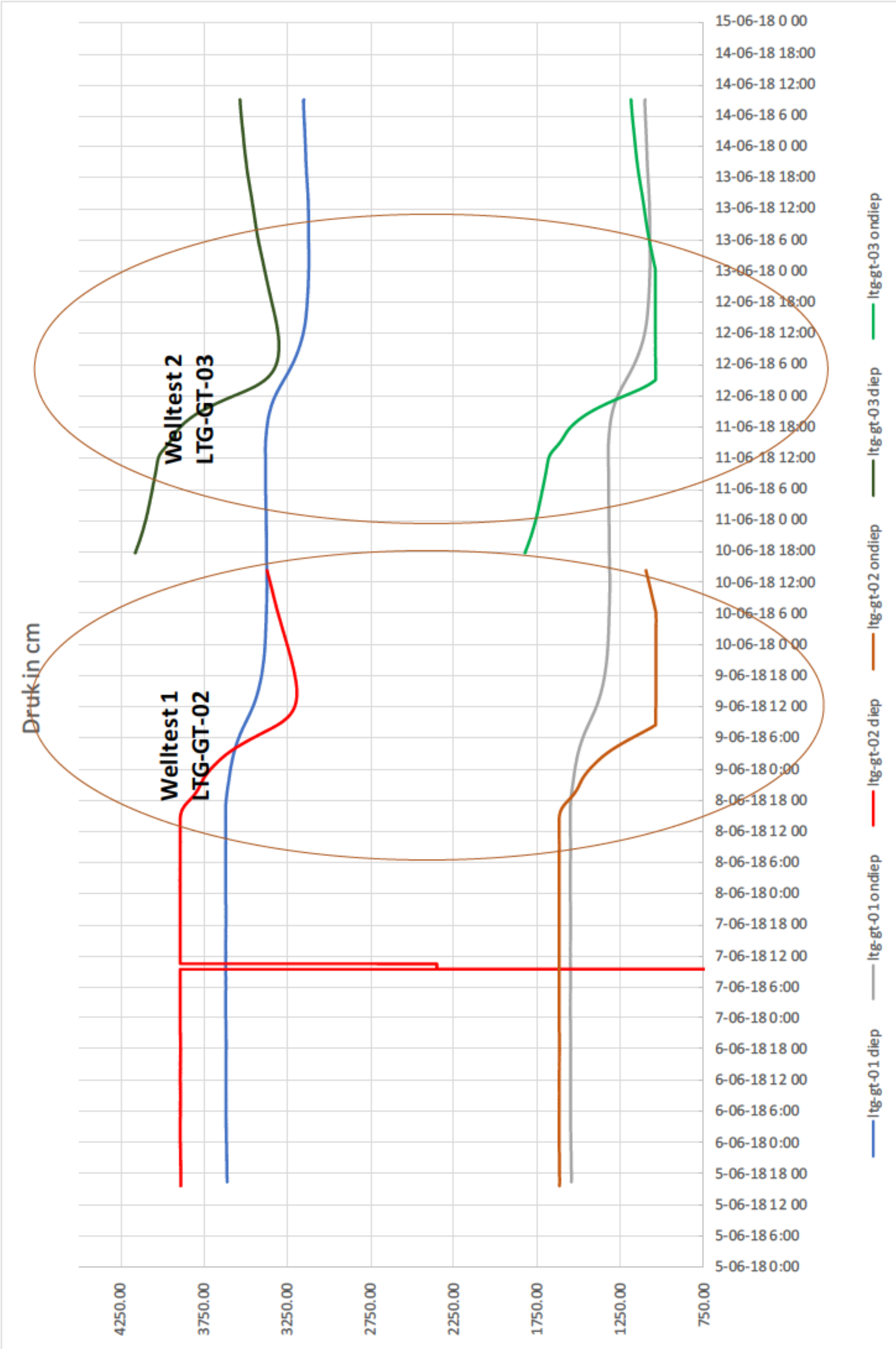
Appendix 5 Reservoir pressure



Appendix 6 Pressure data



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