

Tijdelijk winningsplan geothermieproject WEB-2

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1. INLEIDING

Conform de vergunningensystematiek van de Mijnbouwwet bestaat voor iedere operator de verplichting tot het hebben van een winningsplan. Dit geldt ook voor het winnen van geothermie.

In onderhavig document wordt door de operator Wayland Energy B.V. (houder van de opsporingsvergunning) invulling gegeven aan deze verplichting. Hierbij wordt een korte omschrijving gegeven van de winningslocatie (zowel boven- als ondergronds), de wijze van winnen (volumes, bijvangst, techniek) en van de potentiele risico's voor de omgeving.

De wet- en regelgeving met betrekking tot aardwarmte wordt de komende jaren aangepast. Het zelfstandig winningsplan komt naar verwachting te vervallen en zal vervangen worden door een compleet geïntegreerd ontwikkelingsplan.

Tot die tijd kan gewonnen worden op basis van een tijdelijk winningsplan. Dit wordt in tijdelijk beleid vanuit het Ministerie van Economische Zaken en Klimaat vastgelegd.

1.1 WETTELIJK KADER

Het winningsplan betreft slechts die elementen die onder de Mijnbouwwet vallen en die te maken hebben met de ondergrondse winning en de gevolgen van het winnen van aardwarmte, zoals beschreven in Mbw art 35. Het bovengrondse systeem valt vergunning technisch onder de WABO.

Het winnen van delfstoffen en aardwarmte vanuit een voorkomen geschieft ex artikel 34, eerste lid, van de Mijnbouwwet overeenkomstig een winningsplan, dat bij het Ministerie van Economische Zaken en Klimaat wordt ingediend.

De minister van EZK kan zijn instemming met het opgestelde winningsplan slechts geheel of gedeeltelijk weigeren (art 36 Mbw):

- a) indien het in het winningsplan aangeduide gebied door Onze Minister niet geschikt wordt geacht voor de in het winningsplan vermelde activiteit om reden van het belang van de veiligheid voor omwonenden of het voorkomen van schade aan gebouwen of infrastructurele werken of de functionaliteit daarvan;
- b) in het belang van het planmatig gebruik of beheer van delfstoffen, aardwarmte, andere natuurlijke rijkdommen, waaronder grondwater met het oog op de winning van drinkwater, of mogelijkheden tot het opslaan van stoffen;
- c) indien nadelige gevolgen voor het milieu ontstaan, of
- d) indien nadelige gevolgen voor de natuur worden veroorzaakt.

In het winningsplan wordt onder meer aangegeven welke de voorgenomen jaarlijkse winning is gedurende de looptijd van het plan (art 35 Mbw). Als een voorgesteld winningsplan de instemming van de Minister van Economische Zaken en Klimaat heeft gekregen, zal de winning overeenkomstig het plan plaats moeten vinden. Het Staatstoezicht op de Mijnen (SodM) houdt hier toezicht op.

Voor delfstoffen wordt nadere invulling van de artikelen 34-38 Mbw gegeven in de artikelen 24 en 25 van het Mijnbouwbesluit (Mbb). Ook al zijn de artikelen in het Mbb niet gespecificeerd voor de winning van aardwarmte, kunnen ze op onderdelen wel worden gebruikt voor dit tijdelijke winningsplan.

Conform de Mijnbouwwetten en regels moet er een onderbouwd en goed gedocumenteerd plan overlegd worden waarin inzichtelijk gemaakt wordt hoe de productie in de toekomst ter hand genomen wordt.

Er dient per geothermisch systeem één winningsplan aangeleverd te worden. De voorlopige definitie van een geothermisch systeem is:

Het geheel aan geologische en technische componenten, tezamen met de besturings- en monitoringscomponenten, waardoor het warme productiewater en vervolgens het koude injectiewater stroomt waarbij het geheel als een gesloten systeem acteert, teneinde energie/warmte uit deze waterstroom te extraheren.

De duur van de winning is van vele factoren afhankelijk: juridische, economische, installatietechnische en geotechnische.

1.2 VERANTWOORDE WINNING, VEILIG VOOR MENS EN MILIEU

WEB 2 zal ten tijde van de exploitatiefase beschikken over een VG zorgsysteem waaronder aardwarmte gewonnen wordt. Onderdeel van dit systeem is een put integriteitsplan en een assetmanagement plan. Hiermee wordt een veilige, verantwoorde winning optimaal gegarandeerd.

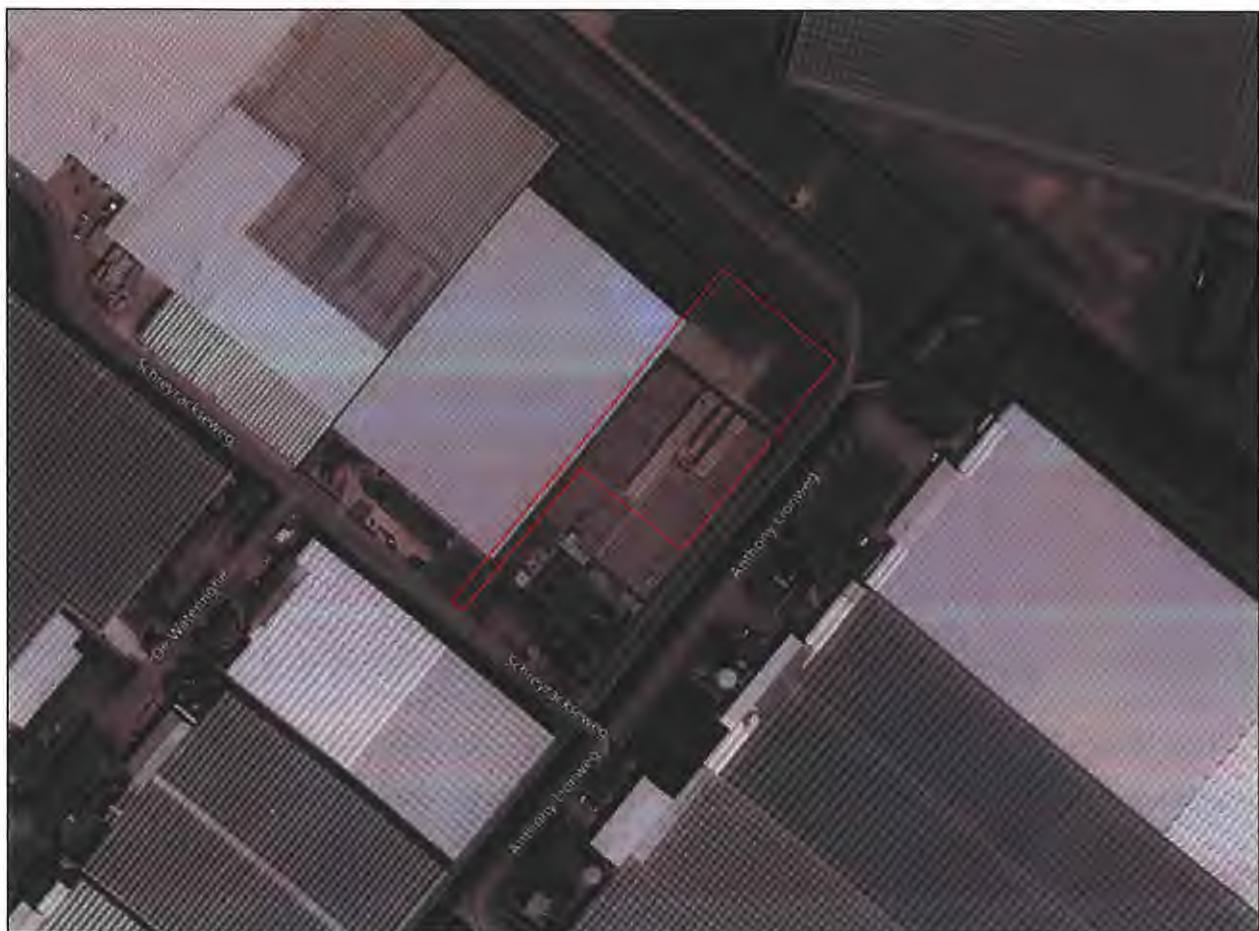
1.3 PROCEDURE EN PUBLIEKSCOMMUNICATIE

Naast de reeds bestaande wettelijke adviseurs SodM en de Technische commissie bodembescherming (hierna: Tcbb), worden op grond van de gewijzigde Mbw ook de provincie, gemeenten, waterschappen en de Mijnraad in de gelegenheid gesteld om advies te geven. Bij nieuwe winningsplannen is afdeling 3.4 van de Algemene wet bestuursrecht (AwB) van toepassing verklaard, waardoor de mogelijkheid van het indienen van zienswijzen bestaat. Op deze wijze is getracht het burgerperspectief nadrukkelijk mee te nemen in de besluitvorming. Nieuwe winningsplannen liggen (als onderdeel van de procedure ter goedkeuring) ter inzage voor het publiek.

2. LOCATIE EN BESCHRIJVING VAN HET GEOTHERMISCH SYSTEEM

2.1 LOCATIE VAN HET GEOTHERMISCH SYSTEEM

De bovengrondse locatie van het te realiseren geothermisch systeem van WEB 2 is gelegen aan de Schreyrackseweg 17 te Bergschenhoek binnen de Gemeente Lansingerland (*Figuur 1*).



Figuur 1: Locatie mijnbouwwerk (bovengronds)

Het voornemen is gefaseerd twee doubletten te realiseren ten behoeve van de verwarming van nabijgelegen glastuinbouwbedrijven en aansluiting op een regionaal warmtenet. De producer en injector van het eerste doublet zullen vanaf het opsporingsgebied 'LANSINGERLAND' naar het opsporingsgebied en 'LANSINGERLAND 4' (zie figuur 2) worden geboord tot een einddiepte van circa 1.700 meter TVD onder maaiveld tot de bodem van de Berkel/Delft Zandsteen formatie.

In maart 2018 is de SDE+ subsidie aangevraagd en in juni 2018 is de SDE+ subsidie beschikt voor het opsporingsgebied 'LANSINGERLAND 4' zoals weergegeven in *Figuur 2*. In tabel 1 zijn de RD-coördinaten van het gebied weergegeven. Het gebied heeft een oppervlakte van 6,05 km² en is gelegen binnen de gemeentes Lansingerland, Zuidplas en Rotterdam. Hierin is tevens te zien hoe dit gebied zich verhoudt tot de bovengrondse locatie.

Tabel 1: Coördinaten opsporingsvergunning

Punt	X	Y
1	96 890,78	445247,723
2	99 027,83	444487,884
3	98 240,00	442000,000
4	95 120,00	443780,000
5	95 218,10	444089,813
6	96 330,00	443690,000



Figuur 2: Locatie geothermisch systeem (ondergronds)

De opsporingsvergunning is op 9 oktober 2014 verleend door het Ministerie van Economische Zaken en Klimaat aan A + G van den Bosch B.V. De vergunning is overgedragen van A + G van den Bosch B.V. op Wayland Energy B.V. en de termijn is verlengd tot 1 oktober 2020. Op 02-07-2020 is aan EZK verzocht tot een verlenging tot 1 oktober 2022.

Ten behoeve van het 'open stuk' tussen de winningsvergunning LANSINGERLAND en opsporingsvergunning LANSINGERLAND 4 heeft reeds contact plaatsgevonden met EZK. Er zal een spontane winningsvergunning worden aangevraagd voor dat gebied.

Volgens artikel 15 lid 5 Mbw geldt voor de 'spontane' winningsvergunning een concurrentieperiode indien er andere omliggende vergunninghouders zijn, die de proceduretijd met 13 weken verlengt t.o.v. de reguliere aanvraag winningsvergunning zonder concurrentie.

In dit geval is Wayland Energy vergunninghouder van alle omliggende gebieden waardoor de proceduretijd van de reguliere winningsvergunning gelijk zal zijn aan een normale aanvraag winningsvergunning.

2.2 BESCHRIJVING VAN GEOTHERMISCH SYSTEEM

Het mijnbouwwerk van WEB 2 zal uiteindelijk bestaan uit vier bronnen (twee doubletten) die bovengronds afgewerkt zijn door middel van een wellhead welke middels leidingwerk verbonden zijn met de bovengrondse installaties. Een deel van deze installaties is buiten opgesteld, zoals de ontgassertank en de fakkel. De overige installaties zoals de filters, warmtewisselaars, pompen en WKK's zijn in de pompruimte opgesteld. Voorafgaand aan de bouw zal een volledige P&ID worden opgesteld.

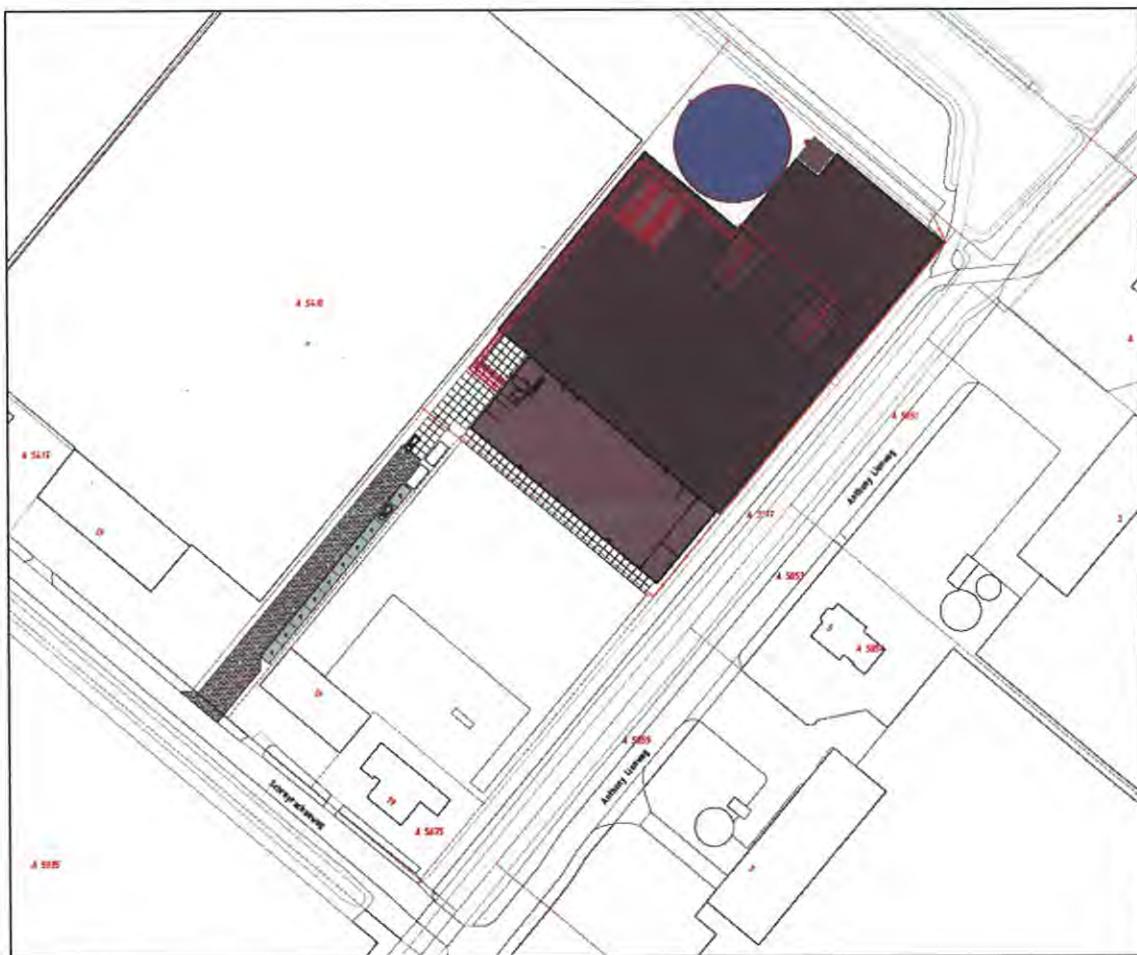
Figuur 3 en 4 betreft een weergave van de mijnbouwlocatie van Wayland Energy Bergschenhoek aan de Warmoeziersweg Bergschenhoek, figuur 5 betreft een weergave van de voorgenomen inrichting van WEB 2 inclusief de omliggende bouwwerken en terreinen.



Figuur 3: Foto mijnbouwwerk



Figuur 4: Foto wellheads



Figuur 5: Plattegrond voorgenomen inrichting

3. ONDERGROND

3.1 PUTINFORMATIE

Het voornemen is medio 2021 de putten LSL-GT-03 en LSL-GT-04 te boren en nadat dit doublet in gebruik is genomen en stabiel draait, de putten LSL-GT-05 en LSL-GT-06. Het voornemen is te boren naar de Berkel en Delft zandsteenformaties.

In Tabel 2 zijn de gegevens van de beide putten weergegeven.

LSL-GT-03	Producer	Coordinates				TVDSS (m)
		X (RD)	Y (RD)	Latitude	Longitude	
Surface location	96003	445106	51°59'28.3"N	4°31'41.7"E	-3	
Top Berkel	96277	444488	51°59'8.5"N	4°31'56.5"E	1500	
Top Delft	96379	444261	51°59'1.1"N	4°32'1.9"E	1616	
Base Reservoir	96414	444181	51°58'58.6"N	4°32'3.8"E	1657	
TD	96476	443044	51°58'54.2"N	4°32'7.7"E	1680	
KOP	96003	445106	51°59'28.3"N	4°31'41.7"E	820	
EOB	96137	444803	51°59'18.6"N	4°31'48.9"E	1339	
LSL-GT-04	Injector	Coordinates				
		X (RD)	Y (RD)	Latitude	Longitude	TVDSS (m)
Surface location	96003	445106	51°59'28.3"N	4°31'41.7"E	-3	
Top Berkel	97199	444028	51°58'53.9"N	4°32'45.0"E	1436	
Top Delft	97404	443843	51°58'48.0"N	4°32'55.9"E	1531	
Base Reservoir	97494	443762	51°58'45.4"N	4°33'0.7"E	1573	
TD	97530	443731	51°58'44.5"N	4°33'2.5"E	1589	
KOP	96003	445106	51°59'28.3"N	4°31'41.7"E	250	
EOB	96446	444706	51°59'15.6"N	4°32'5.2"E	1087	

Tabel 2: Algemene put informatie

De spud- en completiedata zijn nog niet bekend.

In de tabellen 3 en 4 zijn de voorlopige verbuizingsschema's opgenomen van de verschillende casings inclusief de posities van de liners, productietubing en screens. In bijlage 2 en 3 zijn deze gegevens gevisualiseerd.

De uiteindelijke verbuizingsschema's van beide putten zullen worden opgenomen in de End of Well Reports (EOWR).

Element Name	Size (OD)	Top (MD)	Base (MD)	Top (TVD)	Base (TVD)	Incl. (degr)	Steel	Connection Type	Weight (ppf)
Conductor	24"	0	95	0	95	0	X60	Welded	125,7
Completion Tubing (incl.x-over)	13 3/8" x 9 5/8"	0	1815	0	1505	65	L80	Vam Top	68 & 47
Prod tubing (incl.x-over)	8 5/8"	0	600	0	600	0	L80	Vam Top / Polseal-1	36
ESP	9" pump 8.75" seals 8.8" motors 4,5" sensor	600	620	600	620	0	RVS 316L	NA	NA
Inhibitor line	3/8"	0	1815	0	1505	65	Alloy 825	NA	NA
Casing 1	16"	0	830	0	830	0	L80	Dino Vam / Vam Top ND	84
Liner hanger 1	16" x 11 3/4"	780	NA	780	NA	0	NA	NA	NA
Casing 2	11 3/4"	780	1865	780	1526	0	L80	Vam Top	65
Liner hanger 2	11 3/4 x 8 5/8"	1815	NA	1505	NA	65	NA	NA	NA
Blankpipe	8 5/8"	1815	1865	1505	1526	65	L80	Vam Top / Polseal-1	36
Screen	8 5/8"	1865	2227	1526	1679	65	L80	Vam Top / Polseal-1	36

Tabel 3: Verbuizingsschema LSL-GT-03. Alle dieptes vanaf GL (Ground Level).

Element Name	Size (OD)	Top (MD)	Base (MD)	Top (TVD)	Base (TVD)	Incl. (degr)	Steel	Connection Type	Weight (ppf)
Conductor	24"	0	95	0	95	0	X60	Welded	125,7
Injection tubing (incl.x-over)	8 5/8"	0	100	0	100	0	L80	Vam Top / Polseal-1	36
Casing 1	16"	0	886	0	830	3	L80	Dino Vam / Vam Top ND	84
Liner hanger 1	16" x 11 3/4"	836	NA	785	NA	3	NA	NA	NA
Casing 2	11 3/4"	836	2442	785	1440	70	L80	Vam Top	65
Liner hanger 2	11 3/4 x 8 5/8"	2392	NA	1420	NA	70	NA	NA	NA
Blankpipe	8 5/8"	2392	2442	1420	1440	70	L80	Vam Top / Polseal-1	36
Screen	8 5/8"	2442	2897	1440	1589	70	L80	Vam Top / Polseal-1	36

Tabel 4: Verbuizingsschema LSL-GT-04. Alle dieptes vanaf GL.

3.2 GEOLOGIE IN VERGUNNINGSGEBIED

Een gedetailleerde beschrijving van de ondergrond is gegeven in het SDE+ rapport "SDE+ Bergschenhoek 2 – 2018 Update" – G1330C, PanTerra, 2018. De putpaden en downhole targets zijn sindsdien veranderd (zie bijlage 4. Geological Evaluation fot project WEB 2). In dit winningsplan zijn de huidige putpaden opgenomen en zijn de verwachte dieptes en coördinaten aangepast.

3.3.1 ALGEMENE BESCHRIJVING ONDERGROND

De projectlocatie is gelegen in het zogenaamde "West Netherlands Bekken". In dit bekken zijn in het Jura en Krijt sedimenten afgezet. Hieronder bevinden zich oudere gesteenten, zoals het Trias, Perm en Carboon. De bovenste 400 tot 500 m van de ondergrond van het doelgebied bestaat uit Tertiaire en Kwartaire afzettingen. De beoogde reservoirs van WEB 2, de Berkel en Delft Sandstone Members maken deel uit van de Rijnland en Schieland Groep en zijn gedurende het Late Jura tot Vroege Krijt afgezet. Een overzicht van de verwachte stratigrafie op de projectlocatie is gegeven in Figuur 6.

Lithostratigraphic column LSL-GT-I, LSL-GT-P						Expected Depth				Common / Expected drilling hazards		
Era	Group	Period	Formation	Member	Lithology	LSL-GT-03	LSL-GT-04	LSL-GT-05	LSL-GT-06			
Dercotic	Upper North Sea NU	Quaternary	Naaldwijk-Pelze NUNA-NUPZ		Continental deposits. Fluvial sand, silt and clays	0	0	0	0	Mudlosses in sandy topholes, sand cavings, washouts, thin layers of swelling clays	Clayballs, overpulls, stuck pipe,	
			Maassluis NUMS		Very fine to coarse calcareous sand with some clay streaks.	108	108	108	108			
		Tertiary	Oosterhout NUOT		Very fine to very coarse sand. Contains shell fragments.	253	253	253	253	Thin layers of swelling clays		
			Breda NUBA		Marine glauconitic sands with silty to sandy clays.	380	381	380	381	Pyrite, swelling clays		
	Middle North Sea NM	Rupel NMRF	Rupel Clay NMRC		Heavy dark brown marina clays. Rich in pyrite, hardly any glauconite.	415	418	415	418		Coarse chert, trace pyrite	
		Landen NLFC	Landen Clay NLFC		Dark green clay. The base can be marly and of a lighter colour.	430	434	430	434	Trace pyrite, swelling clays, tight spots, bitballing [clay+marl], stuck pipe		
	Chalk Cs.	Ekoßk CKEK			White, chalky limestones containing rare white and grey nodular and bedded chert layers, grey to green clay laminae.	448	451	435	443	Layers of chert in complete section but mainly in top and bottom sections. Mudlosses in possible karstification zones. Tight spots while POOH	Clayballs, overpulls, stuck pipe, swabbing	
		Ommelanden CKGR			Succession of white-yellowish-grey, fine grained limestones. Layers of chert nodules can be common over thick intervals.	460.0	463	451.0	456			
		Texel CKX	Plenus Marl CKTXF		Dark-grey, partly black, calcareous, laminated claystones.	784.0	787	775.0	816	Swelling clay		
			Texel Marlstone CKTM		White to light-grey, locally pinkish, limestone and marly shales.	790.0	793	781.0	822			
		Holland KNGL	Upper Holland Marl KHGLU		Light-grey and red-brown marls, characterized by a carbonate content which gradually increases towards the top.	820.0	823	811.0	860	Bitballing (marl + clay)	Cavings, overpulls, swabbing	
			Middle Holland Claystone KNGLM		Grey and/or red-brown calcareous shaly claystone with a distinctly lower lime content than the under- and overlying members.	1024.0	1030	1015.0	1171			
			Holland Greensand KNGLG		Alternation of greenish grey, very glauconitic, very fine- to fine-grained, argillaceous sandstones.	1096.0	1107	1087.0	1350	Cavings of low permeable shale fragments		
			Lower Holland Marl KNGLL		Grey and red-brown marl or calcareous, fissile claystone, frequently with intercalated bioluminescent claystone beds.	1723	1266	1207	1718			
Cretaceous	Rijnland KN	De Lier KNGSL			Alternation of thin-bedded, very fine- to fine-grained argillaceous sandstones.	1288.4	1367	1272.4	1919	Pyrite, cavings from Holland Fm, swabbing, overpulls, stuck pipe	Reservoir *	
			Vlieland Claystone KNVNC		Dark brownish-grey to grey claystones. Mica and very fine lithic matter are common. Generally, the claystones are only very slightly variegated.	1321.1	1427	1305.1	2020			
		Vlieland KNVS KNVC	Berkel Sandstone KNVSC		Light-grey, very fine- to fine- and medium- to coarse-grained sandstones. Locally gravelly, lignitic, locally glauconitic or with siderite concretions.	1500	1851	1436	2421	Clayballs, overpulls, swabbing, shale cavings, (LIR-GT-02, PLD-GT-01), stuck pipe, mudlosses (HON-GT-01)		
			Berkel Sand/Claystone KNVSC		Alternation of fine-grained, argillaceous sandstones and brown-grey silty to sandy claystones.	1528.5	1918	1464.5	2509			
			Rijswijk KNVSR		Light- to medium-grey sandstones with a very fine to medium and locally gravelly grain size.	1542.8	1952	1478.8	2553			
	Scheilander KNS	IJsseloeverbank KNSB	Rindervliet Claystone KNDCL		Medium- to dolomitic, silty to sandy, lignitic claystones with scattered laminae of dolomitic bedded, and lignite/calcite beds.	1547.5	1963	1483.5	2567	Mudlosses and/or influx of formation water in 3rd part of the member, ballooning, pyrite, cavings	Target Reservoir Section	
			Delft Reservoir KNSD		Light-grey massive dolomitic dolomite, fine to medium-grained, being dolomitized/lignite.	1616	2124	1531	2713			
			Delft Remaining section KNSD		Light-grey dolomitic dolomite, showing dolomitization to dolomite, being dolomitized/lignite.	1658	2222	1573	2842			
			Wijnschoten KNSW		Alternation of dolomitic grey, medium-grained dolomitic dolomite, showing dolomitization to dolomite, being dolomitized/lignite.	1727	2384	1645	3063			
			Werkendam ATWD		Sequence of grey, slightly marly, shaly claystones.	N/A	N/A	N/A	N/A			
Jurassic	Altena AT									shale problems: sloughing clays, cavings, overpulls, stuck pipe		

* Wells LSL-GT-03 and LSL-GT-04 pass through the top of a fault and may encounter affected rock

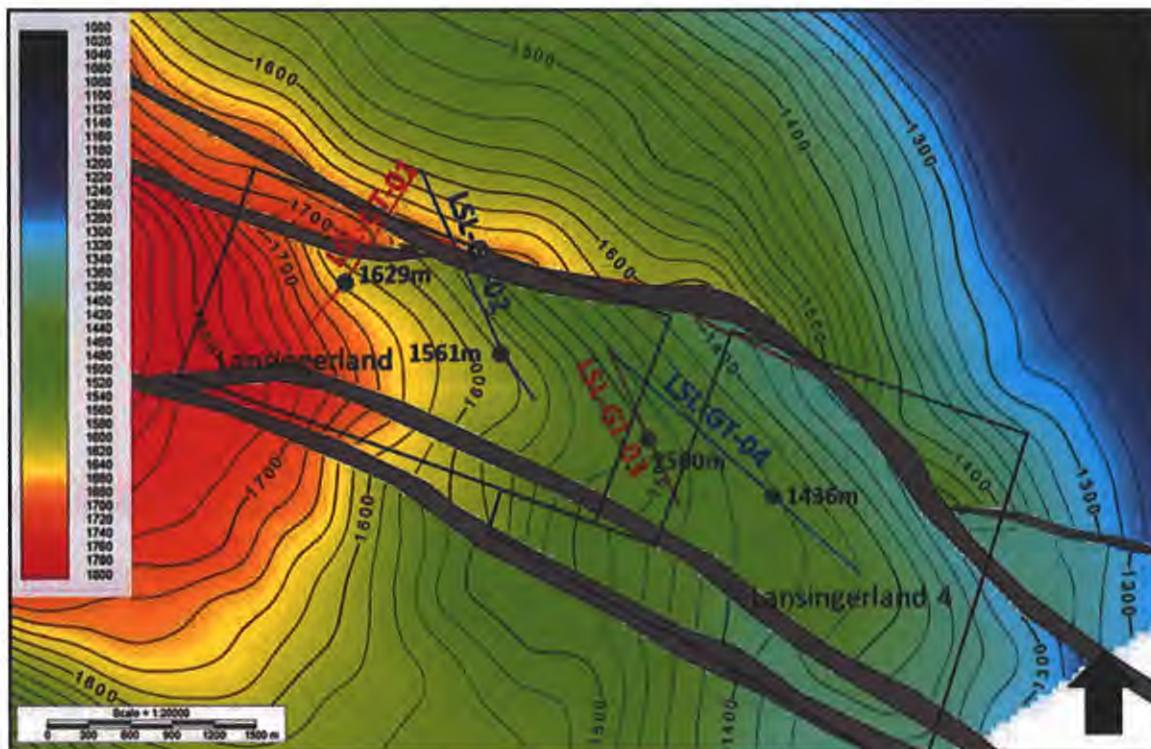
Figuur 6: Verwachte stratigrafie op de projectlocatie

3.3 RESULTATEN RESERVOIR KARAKTERISATIE

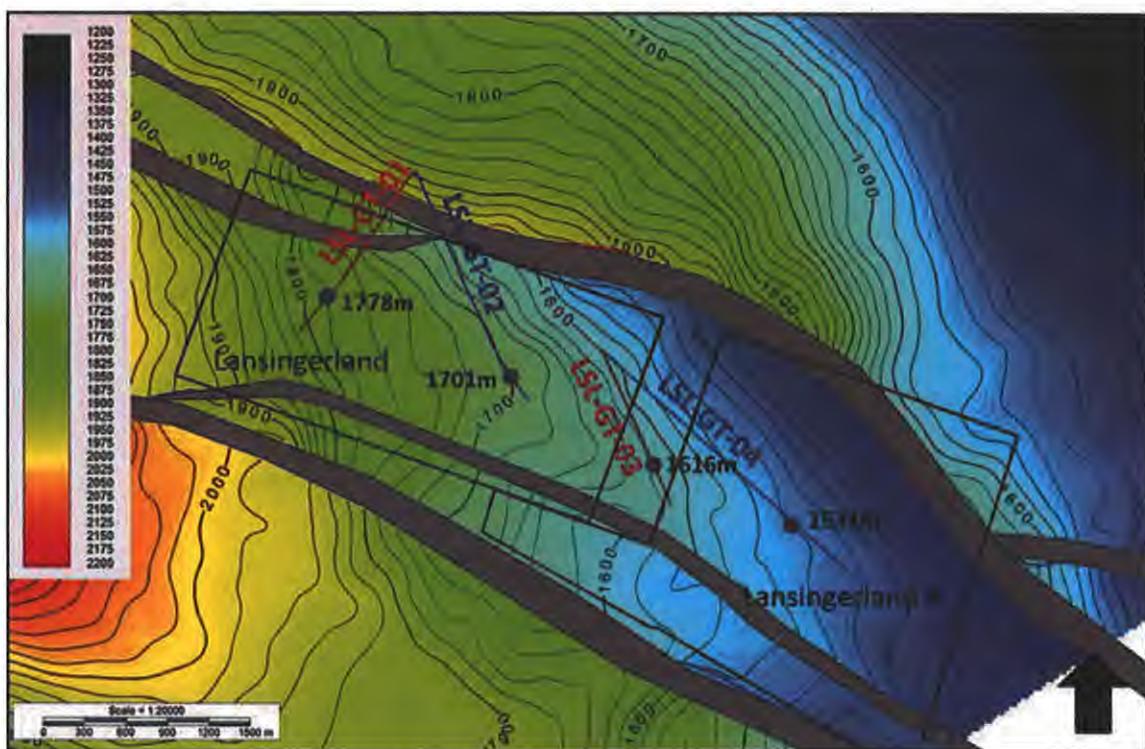
De verwachte eigenschappen van het gecombineerde reservoir is weergegeven in Tabel 5. De reservooreigenschappen van de twee afzonderlijke reservoirs en additionele details staan in het bijgevoegde SDE+ rapport. Dieptekaarten van de reservoirs zijn weergegeven in Figuur 7 en Figuur 8. De verwachte temperatuurgradiënt is afgeleid van puttestdata van WEB 1 en bedraagt circa 2.9°C/m.

Aquifer	Lage waarde	Midden waarde	Hoge waarde
Diepte top reservoir (m TVD)	-10% (1323)	1470	+10% (1617)
Diepte basis reservoir (m TVD)	-10% (1561)	1734	+10% (1907)
Bruto dikte (m)	235	264	295
Netto / bruto (%)	22	30	39
Gemiddelde permeabiliteit (mD)	211	521	780
Saliniteit (ppm)	90,000	100,000	120,000
K _h /K _v	n.v.t.	2	n.v.t.
Geothermische gradiënt (C/km)	-10% (2.6)	2.9	+10% (3.2)

Tabel 5: Verwachte reservooreigenschappen van het Berkel reservoir. Waardes betreffen gemiddelden van de twee putten.



Figuur 7: Dieptekaart van de top van de Berkel Sandstone Member.



Figuur 8: Dieptekaart van de top van de Delft Sandstone Member.

4. BEOOGDE WIJZE VAN WINNING

Op basis van de prognose van de winningsfase wordt uitgegaan van de volgende beoogde winningsparameters (systeemprestaties).

Put	Prognose waarde
Over het jaar gemiddeld debiet geproduceerd water (m ³ /h)	375
Maximaal debiet geproduceerd water (m ³ /hr)	550
Gemiddelde temperatuur van het productiewater, gewogen per volume, gemeten voor de warmtewisselaar (°C)	57
Gemiddelde druk direct onder de pomp in productieput (bar)	58
Laagste druk direct onder de pomp in productieput (bar).	52
Druk aan de putmond van de productieput (bar)	3,5
Verhouding hoeveelheid gas uit productieput indien onttrokken uit de aquifer (Nm ³ / m ³)	1,028
Verhouding hoeveelheid olie uit productieput indien onttrokken uit de aquifer (mg/l)	n.v.t.
Verhouding hoeveelheid condensaat uit productieput indien onttrokken uit de aquifer (Sm ³)	n.v.t.
Hoeveelheid in de productieput ingebrachte inhibitor (l/m ³)	0,006
Over het jaar gemiddeld debiet geinjecteerd water (m ³ /h)	375
Maximaal debiet geinjecteerd water (m ³ /hr)	550
Gemiddelde temperatuur van het injectiewater, gewogen per volume, gemeten tussen warmtewisselaar en de putmond (°C)	27
Minimale temperatuur van het injectiewater, gewogen per volume, gemeten tussen warmtewisselaar en de putmond (°C)	12
Gemiddelde druk aan de injectieputkant van de injectiepomp (bar)	15
Gemiddelde operationele injectiedruk op reservoir niveau (bar)	167
Maximale druk van aan de injectieputkant van de injectiepomp, volgens SodM protocol (bar)*	41,6
Maximale operationele injectiedruk op top reservoir niveau, volgens SodM protocol (bar)	194
Aantal vollaasturen per jaar (uur)	5536
Prognose onttrokken warmte per jaar (PJ)	0,37
Geinstalleerd vermogen installatie (MW _{th})	19

Tabel 6: Beoogde toekomstige productie

*Werkelijke maximale injectiedruk van de injectiepomp kan afwijken. Aanvullende berekeningen laten zien dat hogere injectiedrukken aan de putmond mogelijk zijn, zonder over de maximale druk op reservoir niveau te gaan. Hierbij wordt gecorrigeerd voor drukverliezen gerelateerd aan frictie.

5. PROGNOSE WINNING

5.1 BESCHRIJVING EN DUUR VAN DE WINNING

In onderstaande tabel is de verwachte jaarlijkse productie van WEB-2 per jaar weergegeven. De verwachting is dat deze gedurende het winningstermijn globaal gelijk blijft. Het mee geproduceerde gas wordt na ontgassing en nabehandeling verstoort in de WKK's en/of ketel die zich in de bedrijfsruimte zullen bevinden.

Gedurende de 6 wintermaanden zal het debiet van het doublet circa 500 m³/uur zijn met een retourtemperatuur van 22°C. Het initiële geothermische vermogen is circa 19 MW (Figuur 8 en Figuur 10). Het beoogde gemiddelde debiet gedurende de 6 zomermaanden is 250 m³/uur, met een retourtemperatuur van 27°C. Dit resulteert in een initieel geothermisch vermogen van circa 5 MW (Figuur 9 en Figuur 11). Het vermogen zal op den duur verminderen door afkoeling van het reservoir (doorbraak, zie Tabel 7 en Hoofdstuk 6).

Het verwachte aantal vollasturen is: $((\frac{1}{2} \times 19 + \frac{1}{2} \times 5) / 19) \times 8766 = 5.536$ uur
 De operationele levensduur van de installaties wordt geschat op minimaal 30 jaar. Verschillende onderdelen binnen het systeem zijn eerder aan vervanging toe zodat de levensduur van de totale installaties kan worden verlengd. Ter indicatie wordt verwacht dat de ESP elke 5 jaar moet worden vervangen. Er wordt ook een inner-tube of tie-back geïnstalleerd waardoor de stalen materialen beschermd worden tegen corrosie. Er wordt geanticipeerd op een levensduur van 15 jaar voor deze materialen en dienen dus eenmaal te worden vervangen om de totale installaties 30 jaar te laten functioneren.

Tabel 7: Verwachte productie van WEB 2 per jaar.

Jaar vanaf startdatum	Prod. Temp (oC)	Hoeveelheid water (mln m3)	Energie (GJ)	Inhibitor (m3)	Gas (mln m3)	Olie (mln m3)	Aantal vollasturen (u)	Energie-consumptie (kWh)
1	57	3,29	378.691		3,29	0	5.536	6.920.526
2	57	3,29	374.366		3,29	0	5.536	6.920.526
3	57	3,29	373.452		3,29	0	5.536	6.920.526
4	57	3,29	372.607		3,29	0	5.536	6.920.526
5	56	3,29	371.805		3,29	0	5.536	6.920.526
6	56	3,29	371.062		3,29	0	5.536	6.920.526
7	56	3,29	370.377		3,29	0	5.536	6.920.526
8	56	3,29	369.743		3,29	0	5.536	6.920.526
9	56	3,29	369.147		3,29	0	5.536	6.920.526
10	56	3,29	368.568		3,29	0	5.536	6.920.526
11	56	3,29	367.955		3,29	0	5.536	6.920.526
12	56	3,29	367.208		3,29	0	5.536	6.920.526
13	56	3,29	366.174		3,29	0	5.536	6.920.526
14	56	3,29	364.676		3,29	0	5.536	6.920.526
15	56	3,29	362.558		3,29	0	5.536	6.920.526
16	55	3,29	359.733		3,29	0	5.536	6.920.526

17	55	3,29	356.204	3,29	0	5.536	6.920.526
18	55	3,29	352.059	3,29	0	5.536	6.920.526
19	55	3,29	347.446	3,29	0	5.536	6.920.526
20	54	3,29	342.540	3,29	0	5.536	6.920.526
21	54	3,29	337.516	3,29	0	5.536	6.920.526
22	53	3,29	332.524	3,29	0	5.536	6.920.526
23	53	3,29	327.680	3,29	0	5.536	6.920.526
24	53	3,29	323.059	3,29	0	5.536	6.920.526
25	52	3,29	318.706	3,29	0	5.536	6.920.526
26	52	3,29	314.642	3,29	0	5.536	6.920.526
27	52	3,29	310.862	3,29	0	5.536	6.920.526
28	51	3,29	307.353	3,29	0	5.536	6.920.526
29	51	3,29	304.096	3,29	0	5.536	6.920.526
30	51	3,29	301.070	3,29	0	5.536	6.920.526

Op basis van de aquifer karakteristieken beschreven in voorgaande paragrafen is een reservoir model gemaakt met behulp van DoubletCalc. 2D. De onderstaande figuren geven de parameters weer waarmee gebruik is gemaakt om de reservoirmodellering op te kunnen stellen in DoubletCalc. 2D

Geotechnical input									
A) Aquifer properties									
Property	min	median	max	Property	value				
aquifer permeability (mD)	211	521	780	aquifer kh/kv ratio (-)	2				
aquifer net to gross (-)	0.22	0.3	0.39	surface temperature (°C)	10.0				
aquifer gross thickness (m)	235	264	295	geothermal gradient (°C/m)	0.029				
aquifer top at producer (m TVD)	1350.0	1500	1650.0	[mid aquifer temperature producer (°C)]	0.0				
aquifer top at Injector (m TVD)	1292.0	1436	1580.0	[Initial aquifer pressure at producer (bar)]	0.0				
aquifer water salinity (ppm)	90000	100000	120000	[initial aquifer pressure at injector (bar)]	0.0				
B) Doublet and pump properties									
Property	value								
exit temperature heat exchanger (°C)	22								
distance wells at aquifer level (m)	1120								
pump system efficiency (-)	.7								
production pump depth (m)	700								
pump pressure difference (bar)	68								
C) Well properties									
calculation length subdivision (m)		50							
Producer									
outer diameter producer (inch)	10.625								
skin producer (-)	0								
penetration angle producer (deg)	65								
skin due to penetration angle p (-)	-3.15								
Segment	pipe segment sections p (m AH)	pipe segment depth p (m TVD)	pipe inner diameter p (inch)	pipe roughness p (milli-inch)	Segment	pipe segment sections i (m AH)	pipe segment depth i (m TVD)	pipe inner diameter i (inch)	pipe roughness i (milli-inch)
1	600	600	7.921	0.0004	1	100	100	7.921	1.8
2	1004	1000	11.150	0.0004	2	775	750	15.375	1.8
3	1234	1200	9.063	0.0004	3	2050	1250	11.150	1.8
4	1614	1400	7.025	0.0004	4	2622	1436	8.097	1.8
5	1851	1500	8.097	0.0004	5				

Figuur 8: Invoerscherm DoubletCalc 1.4.3. voor de winterperiode.

Geotechnical input

A) Aquifer properties

Property	min	median	max	Property	value
aquifer permeability (mD)	211	521	780	aquifer kh/kv ratio (-)	2
aquifer net to gross (-)	0.22	0.3	0.39	surface temperature (°C)	10.0
aquifer gross thickness (m)	235	264	295	geothermal gradient (°C/m)	0.029
aquifer top at producer (m TVD)	1350.0	1500	1650.0	[mid aquifer temperature producer (°C)]	0.0
aquifer top at injector (m TVD)	1292.0	1436	1580.0	[Initial aquifer pressure at producer (bar)]	0.0
aquifer water salinity (ppm)	90000	100000	120000	[Initial aquifer pressure at injector (bar)]	0.0

B) Doublet and pump properties

Property	value
exit temperature heat exchanger (°C)	38
distance wells at aquifer level (m)	1120
pump system efficiency (-)	.7
production pump depth (m)	700
pump pressure difference (bar)	27

C) Well properties

calculation length subdivision (m) 50

Producer					Injector				
Segment	pipe segment sections p (m AH)	pipe segment depth p (m TVD)	pipe inner diameter p (inch)	pipe roughness p (milli-inch)	Segment	pipe segment sections i (m AH)	pipe segment depth i (m TVD)	pipe inner diameter i (inch)	pipe roughness i (milli-inch)
1	600	600	7.921	0.0004	1	100	100	7.921	1.8
2	1004	1000	11.150	0.0004	2	775	750	15.375	1.8
3	1234	1200	9.063	0.0004	3	2050	1250	11.150	1.8
4	1614	1400	7.025	0.0004	4	2622	1436	8.097	1.8
5	1851	1500	8.097	0.0004	5				

Figuur 9: Invoerscherm DoubletCalc 1.4.3. voor de zomerperiode.

Geotechnics (Input)				Geotechnics (Output)			
Property	min	median	max	Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer permeability (mD)	211.0	521.0	780.0	aquifer kH net (Dm)	26.6	41.0	54.71
aquifer net to gross (-)	0.22	0.3	0.39	mass flow (kg/s)	108.76	147.71	174.92
aquifer gross thickness (m)	235.0	264.0	295.0	pump volume flow (m³/h)	370.1	502.2	595.0
aquifer top at producer (m TVD)	1350.0	1500.0	1650.0	required pump power (kW)	998.7	1355.2	1605.6
aquifer top at injector (m TVD)	1292.0	1436.0	1580.0	geothermal power (MW)	14.05	19.13	23.16
aquifer water salinity (ppm)	90000.0	100000.0	120000.0	COP (kW/kW)	13.3	14.2	15.2
Property				Property			
number of simulation runs (-)	2000.0			aquifer pressure at producer (bar)	144.05	153.03	162.17
aquifer kh/kv ratio (-)	2.0			aquifer pressure at injector (bar)	138.05	146.51	154.59
surface temperature (°C)	10.0			pressure difference at producer (bar)	20.62	23.16	26.12
geothermal gradient (°C/m)	0.029			pressure difference at injector (bar)	27.55	31.02	34.91
mid aquifer temperature producer (°C)	0.0			aquifer temperature at producer * (°C)	54.92	57.34	59.76
initial aquifer pressure at producer (bar)	0.0			temperature at heat exchanger (°C)	54.62	56.98	59.39
[initial aquifer pressure at injector (bar)]	0.0			base case (median value inputs)			
exit temperature heat exchanger (°C)	22.0			base case (median value inputs)	value		
distance wells at aquifer level (m)	1120.0			aquifer kH net (Dm)	41.26		
pump system efficiency (-)	0.7			mass flow (kg/s)	148.37		
production pump depth (m)	700.0			pump volume flow (m³/h)	504.5		
pump pressure difference (bar)	68.0			required pump power (kW)	1361.4		
outer diameter producer (inch)	10.63			geothermal power (MW)	19.37		
skin producer (-)	0.0			COP (kW/kW)	14.2		
skin due to penetration angle p (-)	-3.15			aquifer pressure at producer (bar)			
pipe segment sections p (m AH)	600.0,1004.0,1234.0,1614.0,1851.0			aquifer pressure at injector (bar)	146.44		
pipe segment depth p (m TVD)	600.0,1000.0,1200.0,1400.0,1500.0			pressure difference at producer (bar)	23.08		
pipe inner diameter p (inch)	7.92,11.15,9.06,7.02,8.1			pressure difference at injector (bar)	30.87		
pipe roughness p (milli-inch)	0.0,0.0,0.0,0.0,0.0			aquifer temperature at producer * (°C)	57.33		
outer diameter injector (inch)	10.63			temperature at heat exchanger (°C)	57.01		
skin injector (-)	0.0			pressure at heat exchanger (bar)	32.51		
skin due to penetration angle i (-)	-4.04			* @ mid aquifer depth			
pipe segment sections i (m AH)	100.0,775.0,2050.0,2622.0						
pipe segment depth i (m TVD)	100.0,750.0,1250.0,1436.0						
pipe inner diameter i (inch)	7.92,15.37,11.15,8.1						
pipe roughness i (milli-inch)	1.8,1.8,1.8,1.8						

Figuur 10: Uitvoerscherm DoubletCalc 1.4.3. voor de winterperiode.

Geotechnics (Input)				Geotechnics (Output)			
Property	min	median	max	Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer permeability (mD)	211.0	521.0	780.0	aquifer kH net (Dm)	26.55	40.72	55.22
aquifer net to gross (-)	0.22	0.3	0.39	mass flow (kg/s)	52.24	73.43	91.36
aquifer gross thickness (m)	235.0	264.0	295.0	pump volume flow (m³/h)	177.4	250.0	310.4
aquifer top at producer (m TVD)	1350.0	1500.0	1650.0	required pump power (kW)	190.1	267.8	332.6
aquifer top at Injector (m TVD)	1292.0	1436.0	1580.0	geothermal power (MW)	3.52	5.05	6.62
aquifer water salinity (ppm)	90000.0	100000.0	120000.0	COP (kW/kW)	16.7	19.0	21.5
Property	value			aquifer pressure at producer (bar)	144.02	153.04	162.06
number of simulation runs (-)	2000.0			aquifer pressure at injector (bar)	138.07	146.52	154.59
aquifer kh/kv ratio (-)	2.0			pressure difference at producer (bar)	10.61	11.65	12.62
surface temperature (°C)	10.0			pressure difference at injector (bar)	11.14	12.2	13.28
geothermal gradient (°C/m)	0.029			aquifer temperature at producer * (°C)	54.9	57.3	59.78
mid aquifer temperature producer (°C)	0.0			temperature at heat exchanger (°C)	54.28	56.62	59.0
initial aquifer pressure at producer (bar)	0.0			base case (median value inputs)	value		
[Initial aquifer pressure at injector (bar)]	0.0			aquifer kH net (Dm)	41.26		
exit temperature heat exchanger (°C)	38.0			mass flow (kg/s)	74.49		
distance wells at aquifer level (m)	1120.0			pump volume flow (m³/h)	253.3		
pump system efficiency (-)	0.7			required pump power (kW)	271.4		
production pump depth (m)	700.0			geothermal power (MW)	5.19		
pump pressure difference (bar)	27.0			COP (kW/kW)	19.1		
outer diameter producer (inch)	10.63			aquifer pressure at producer (bar)	152.89		
skin producer (-)	0.0			aquifer pressure at injector (bar)	146.44		
skin due to penetration angle p (-)	-3.15			pressure difference at producer (bar)	11.59		
pipe segment sections p (m AH)	600.0,1004.0,1234.0,1614.0,1851.0			pressure difference at injector (bar)	12.16		
pipe segment depth p (m TVD)	600.0,1000.0,1200.0,1400.0,1500.0			aquifer temperature at producer * (°C)	57.33		
pipe inner diameter p (inch)	7.92,11.15,9.06,7.02,8.1			temperature at heat exchanger (°C)	56.69		
pipe roughness p (milli-inch)	0.0,0.0,0.0,0.0,0.0			pressure at heat exchanger (bar)	9.78		
outer diameter injector (inch)	10.63			* @ mid aquifer depth			
skin injector (-)	0.0						
skin due to penetration angle i (-)	-4.04						
pipe segment sections i (m AH)	100.0,775.0,2050.0,2622.0						
pipe segment depth i (m TVD)	100.0,750.0,1250.0,1436.0						
pipe inner diameter i (inch)	7.92,15.37,11.15,8.1						
pipe roughness i (milli-inch)	1.8,1.8,1.8,1.8						

Figuur 11: Uitvoerscherm DoubletCalc 1.4.3. voor de zomerperiode.

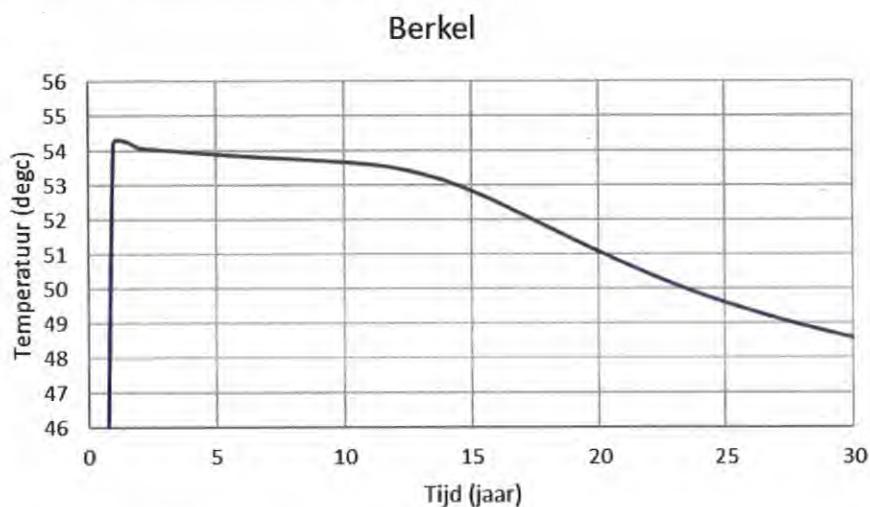
5.2 TOEKOMSTIGE ONTWIKKELING

Wayland Energy B.V. is voornemens een tweede doublet te realiseren op deze locatie.

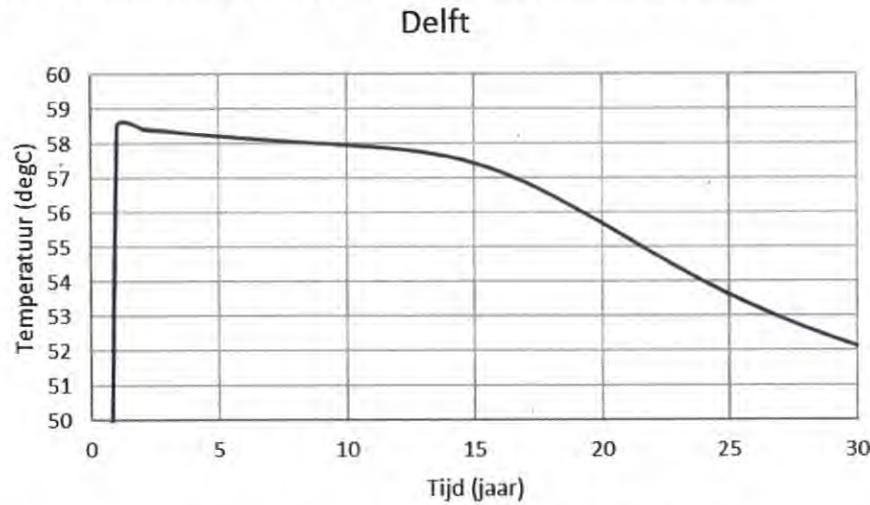
Voor de geplande ontwikkelingen willen wij verwijzen naar de jaarlijkse update van het 5-jarenplan.

5.3 DOORBRAAKTIJD

De doorbraaktijd van WEB 2 is gemodelleerd met het DoubletCalc2D. Details over het model staan paragraaf 5.1. De gemodelleerde temperatuur van het productiewater gedurende de winningsperiode is weergegeven in Figuur 12 en Figuur 13. In beide reservoirs is er doorbraak (1°C afkoeling ten opzichte van initiële temperatuur) na circa 15 jaar. Dit vormt echter geen belemmering voor de aardwarmtewinning en/of afzet.



Figuur 12: Gemodelleerde temperatuur van het productiewater uit het Berkel reservoir.



Figuur 13: Gemodelleerde temperatuur van het productiewater uit het Delft reservoir.

6. INTERFERENTIE MET ANDER GEBRUIK (DIEPE ONDERGROND)

De temperatuur en druk in de reservoirs gedurende de winningsperiode is gemodelleerd met DoubletCalc2D (TNO). Screenshots van de input parameters zijn opgenomen in bijlage 1. De gebruikte reservoir parameters zijn gebaseerd op het SDE+ rapport (PanTerra, 2018). Omdat de aardwarmtewinning uit 2 reservoirs zal plaatsvinden, is een model gemaakt van zowel het Berkel als het Rijswijk reservoir. Diepte en temperatuur inputs zijn op basis van grids om de laterale variatie in het model te bouwen. Overige geologische parameters (dikte, porositeit en permeabiliteit) variëren naar verwachting weinig en zijn als constant aangenomen. Omdat het verzet van de gekarteerde breuken op reservoir niveau over het algemeen groter is dan de reservoirdikte, zijn de breuken als niet-doorlatend gemodelleerd (permeabiliteit van 1 mD).

Het gemiddelde jaardebiet van WEB2 is 375 m³/uur, retourtemperatuur is circa 27°C (6 maanden 250 m³/uur, 38°C en 6 maanden 500 m³/uur, 22°C). Op basis van de permeabiliteit-hoogte van beide reservoirs, is de verwachting dat 42% van het water door het Berkel reservoir zal stromen en 58% door het Delft reservoir. Gehanteerde debieten in DoubletCalc zijn dan ook:

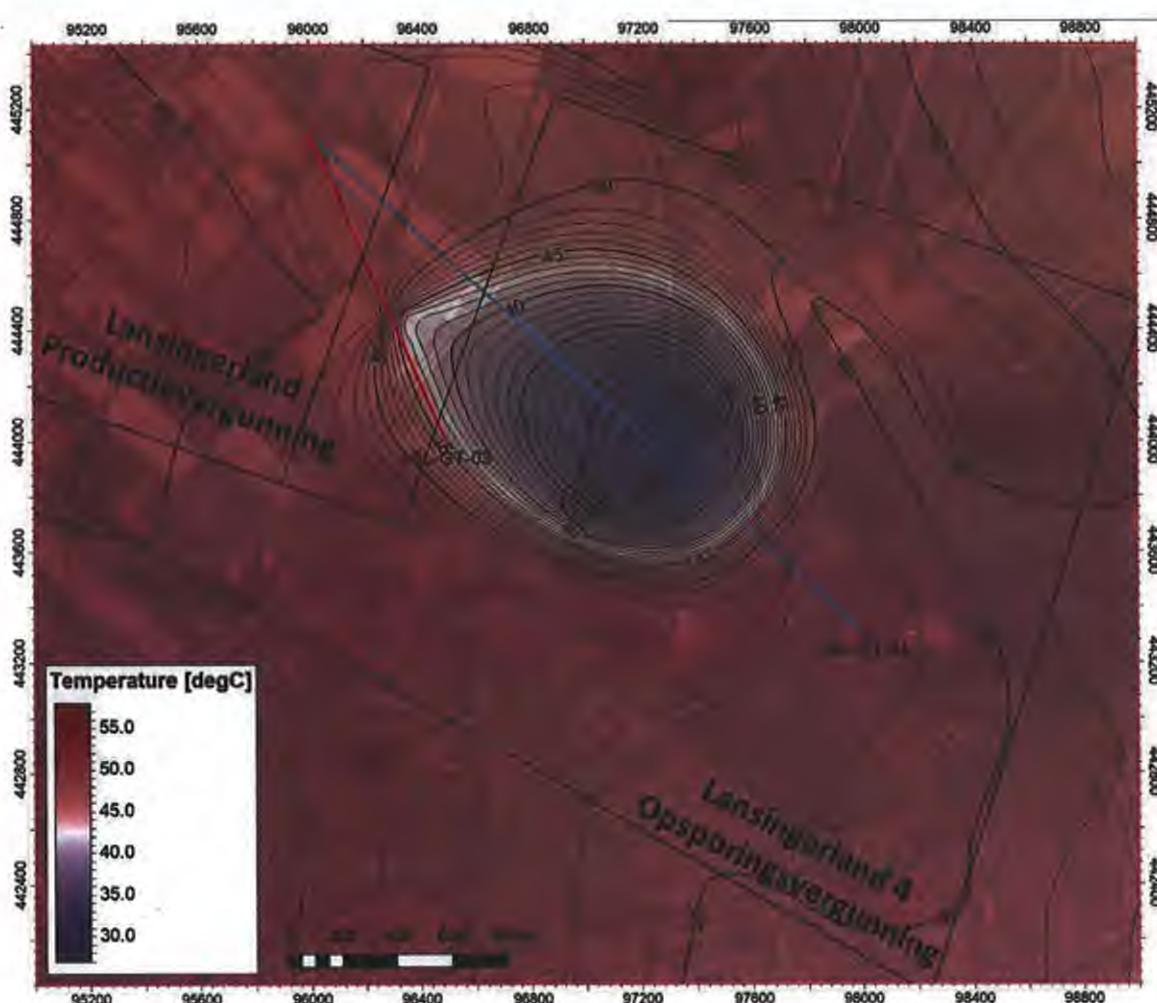
Berkel: 0.42 x 375 = 157 m³/uur

Delft: 0.58 x 375 = 218 m³/uur

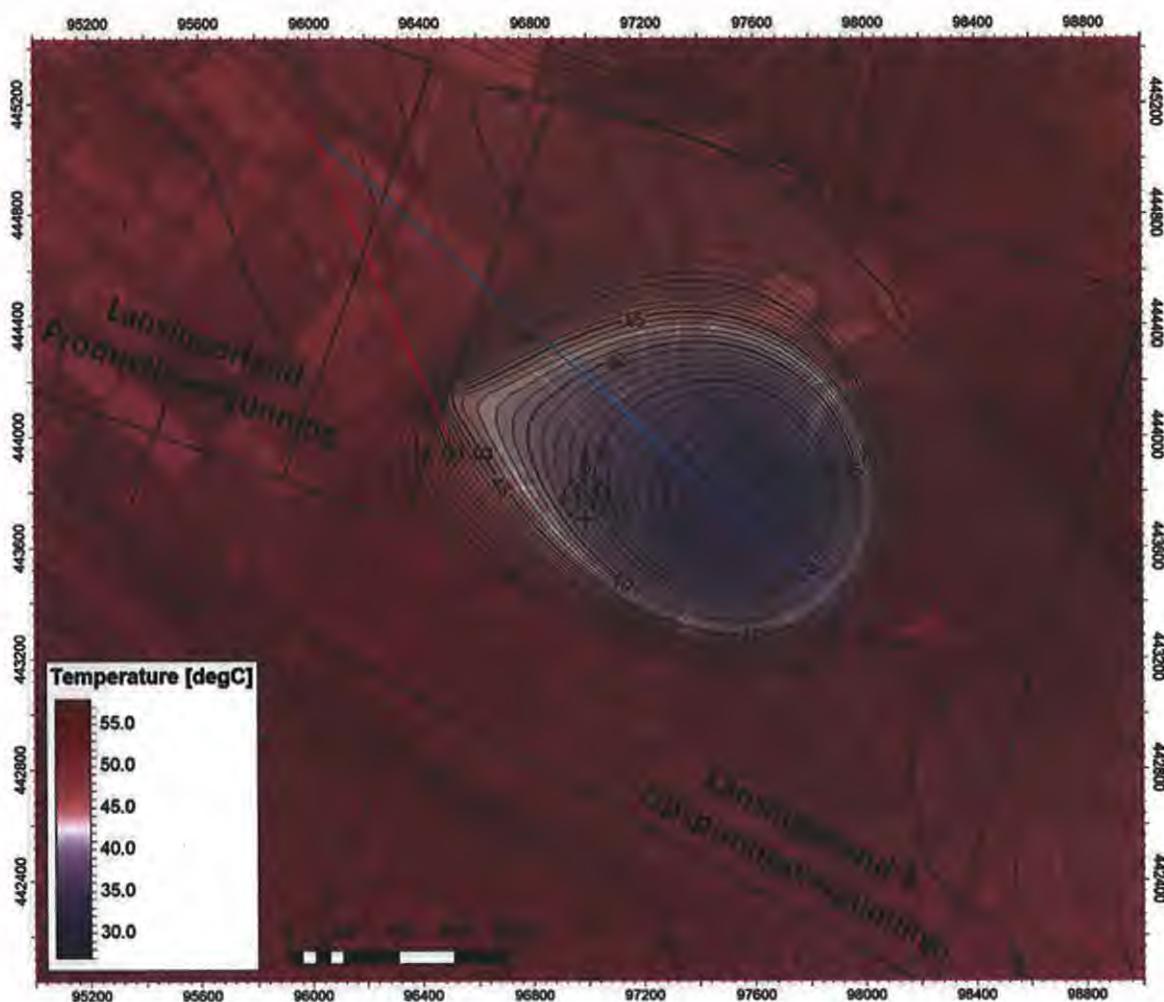
Gemodelleerde temperatuur- en drukkaarten van de reservoirs zijn afgebeeld in Figuur 14 t/m Figuur 17.

Na 30 jaar aardwarmtewinning is er in beide reservoirs een koude "pluim" ontstaan die de productieput reeds bereikt heeft. De pluim blijft binnen de exploratievergunning Lansingerland 4 en het open gebied tussen de exploratievergunning Lansingerland 4 en winningsvergunning Lansingerland. De pluim blijft op ruime afstand van winningsvergunning Lansingerland en andere geothermische projecten in de regio. Als gevolg van de productie en injectie van WEB2 ontstaat er een drukverschil in de reservoirs (Figuur 16 en Figuur 17). Omdat de breuken als niet-doorlatend zijn gemodelleerd, blijft het drukverschil binnen het breukblok waarin WEB2 en WEB1 zich bevinden. Het drukverschil is circa 20 bar ter plaatse van de putten en vermindert daarbuiten. In de winningsvergunning Lansingerland, zal de onderdruk van circa 5 tot 8 bar, veroorzaakt door productie van LSL-GT-03, een positief effect hebben op de injectiviteit van LSL-GT02.

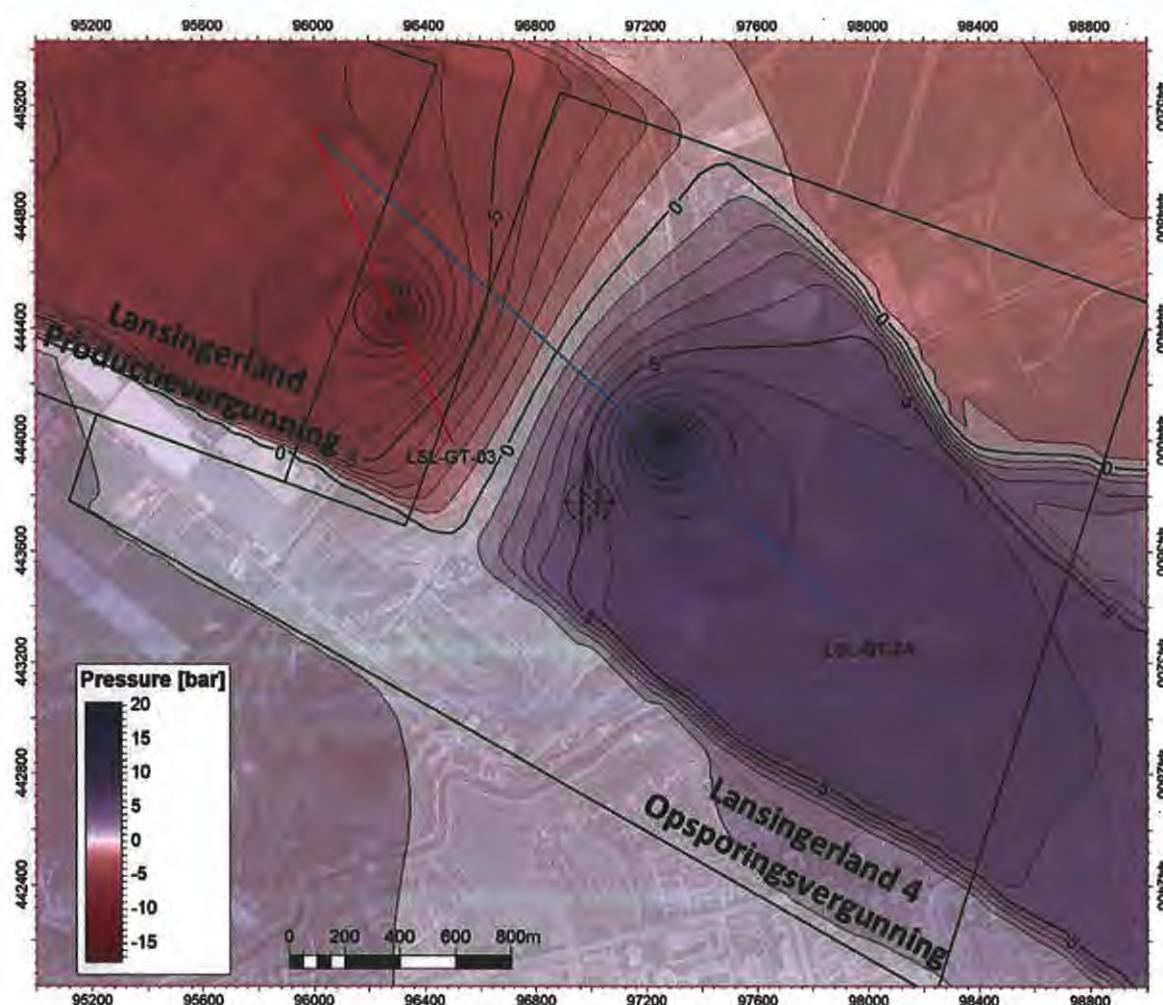
Er bevinden zich geen olie- of gasvelden in de nabijheid van WEB2 waarmee interferentie kan optreden.



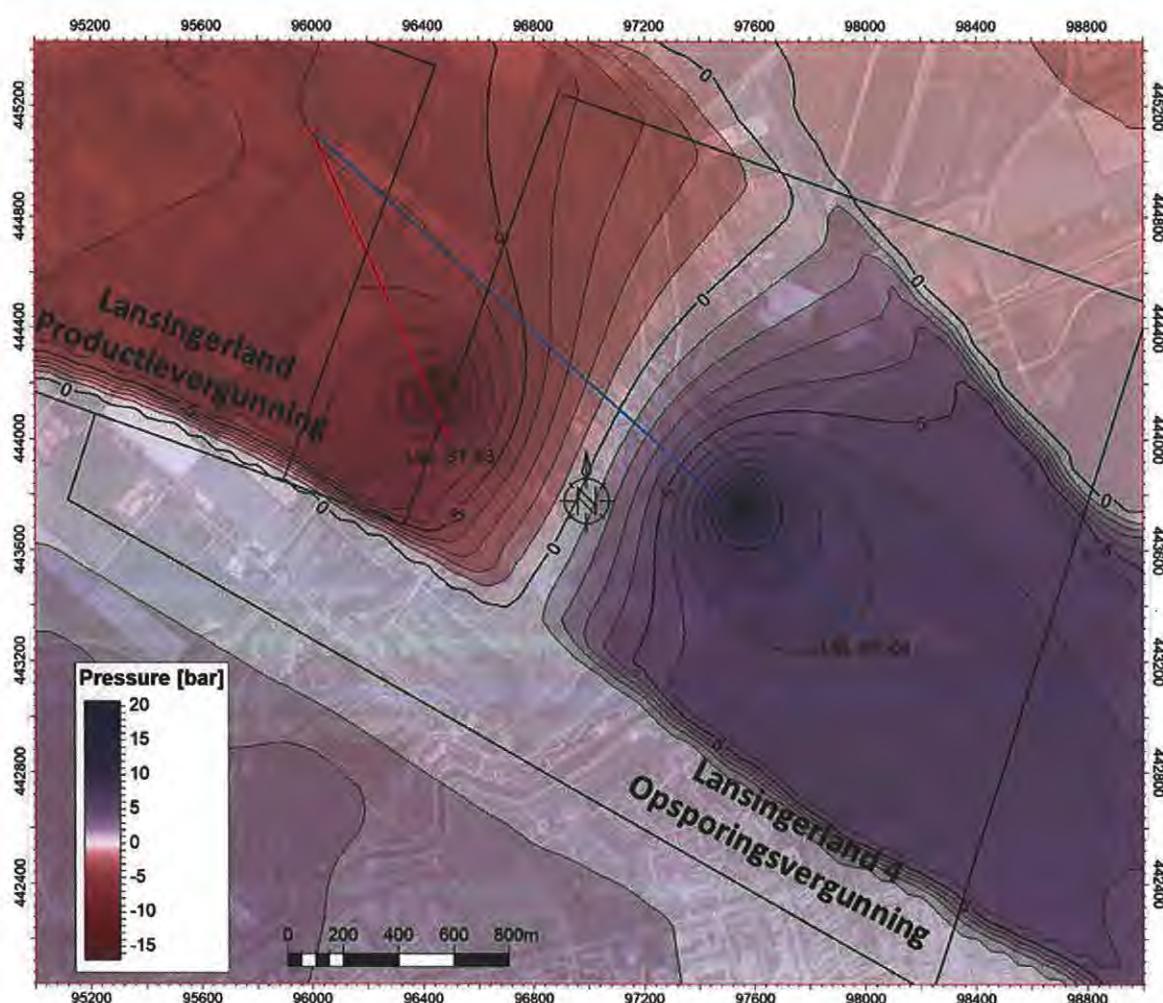
Figuur 14: Temperatuur distributie in het Berkel reservoir na 30 jaar aardwarmtewinning



Figuur 15: Temperatuur distributie in het Delft reservoir na 30 jaar aardwarmtewinning



Figuur 16: Delta druk distributie in het Berkel reservoir na 30 jaar aardwarmtewinning.



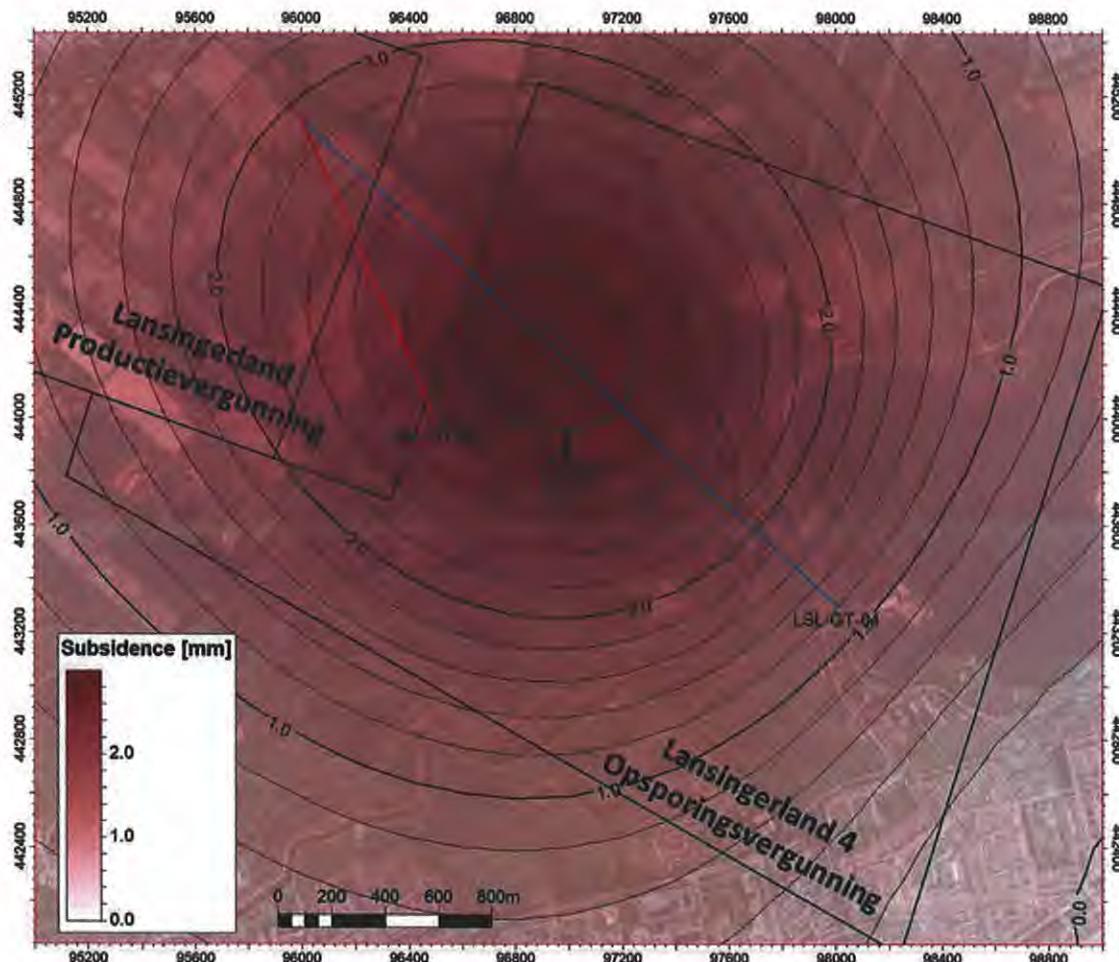
Figuur 17: Delta druk distributie in het Delft reservoir na 30 jaar aardwarmtewinning.

7. BODEMBEWEGING

7.1 BODEMDALING OF -STIJGING

Als gevolg van de aardwarmtewinning van WEB2 zal er afkoeling plaatsvinden van de Berkel en Delft reservoirs. Hierdoor kan er ter plaatse van het doublet geringe bodemdaling plaatsvinden. De omvang van de bodemdaling is berekend door middel van DoubletCalc2D (TNO). Hieruit blijkt dat de bodemdaling na 30 jaar productie uit de Berkel en Delft reservoirs tot circa 3 mm bedraagt (Figuur 19). Volgens de Klimaateffectatlas (www.klimaateffectatlas.nl) is er in een deel van het gebied sprake van natuurlijke bodemdaling (Figuur 19). Deze bodemdaling staat los van eventuele geothermische activiteiten. De verwachting bodemdaling in de periode 2016 – 2050 varieert tussen 0 en 60 cm.

De eventuele bodemdaling als gevolg van geothermische winning van WEB2 is zeer gering en zal geen nadelige gevolgen hebben voor mens en natuur. Bovendien valt de mogelijke bodemdaling als gevolg van aardwarmtewinning van WEB2, in het niet bij de verwachte, natuurlijke, bodemdaling in een groot deel van het gebied.



Figuur 18: Natuurlijke bodemdaling in de periode 2016 – 2050 (bron (www.klimaateffectatlas.nl)). De locatie van WEB2 is met geel aangegeven.



Figuur 19: Natuurlijke bodemdaling in de periode 2016 – 2050 (bron (www.klimaateffectatlas.nl)). De locatie van WEB2 is met geel aangegeven.

7.2 BODEMTRILLING

Bodemtrillingen ontstaan door het plotseling vrijkomen van energie in de ondergrond. Vanuit het punt waar de energie vrijkomt, het hypocentrum, beweegt de energie zich in golfbewegingen voort. De meeste bodemtrillingen zijn van natuurlijke aard; ze worden veroorzaakt door beweging van aardplaten, bijvoorbeeld in subductiezones. Geïnduceerde bodemtrillingen worden veroorzaakt door menselijk handelen, o.a. door winning van delfstoffen. Door een verandering in de lokale stress (druk) situatie kunnen bodemtrillingen optreden. Het lokale stressveld wordt beïnvloed door poro-elastische en thermo-elastische effecten. De drukverandering gerelateerd aan de poro-elastische effecten, treedt voornamelijk op nabij de productieput (drukafname) en de injectieput (druktoename) en neemt snel af naarmate de afstand tot de putten groter wordt. Na initiële productie treedt een evenwicht op omdat de geïnjecteerde en geproduceerde volumes gelijk zijn. Als tijdens deze initiële periode geen seismiciteit optreedt, is het geassocieerde risico zeer klein geworden.

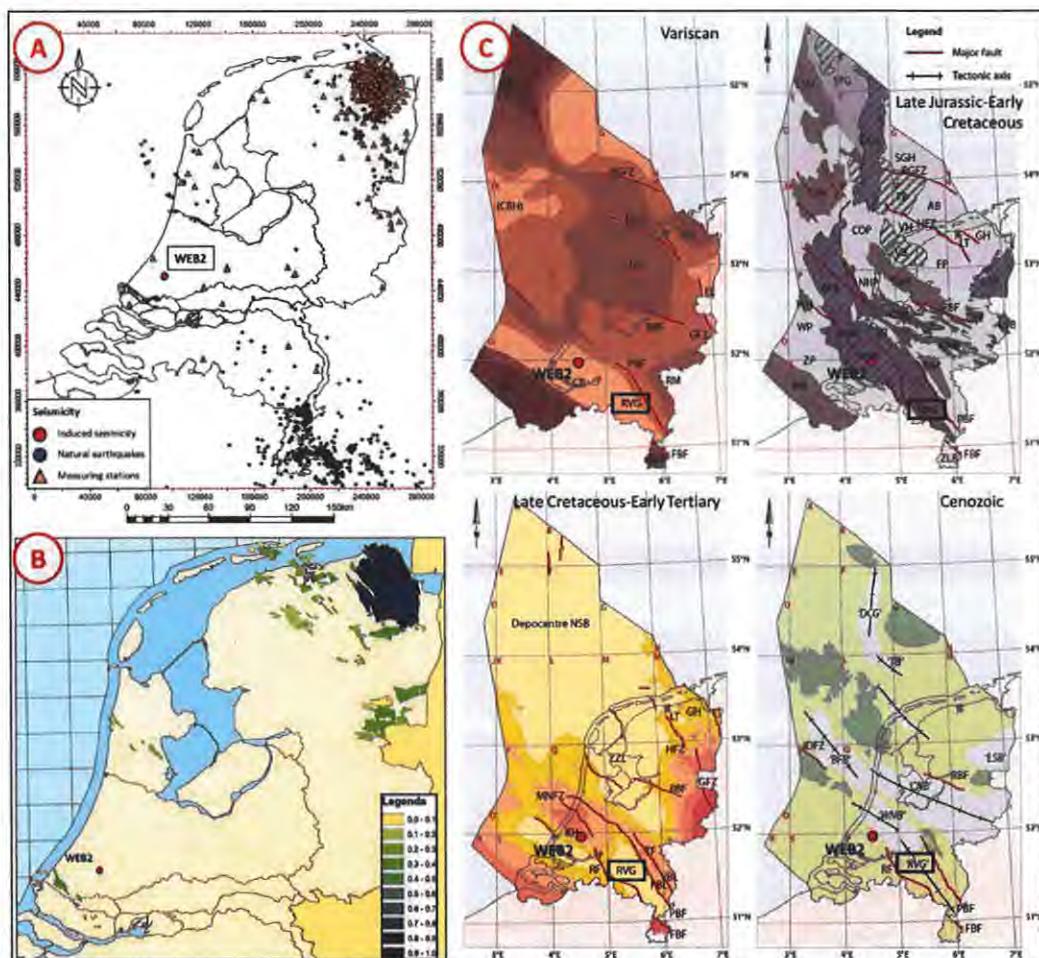
Op basis van het protocol "Defining the Framework for Seismic Hazard Assessment in Geothermal Projects 5 V0.1" (IF Technology B.V. en Q-con GmbH) en de leidraad opgesteld door SodM in 2016 ("Methodiek voor risicoanalyse omtrent geïnduceerde bevingen door gaswinning, tijdelijke leidraad

voor adressering") is een SHA level 1 uitgevoerd voor WEB2. Het rapport is bijgevoegd als bijlage. De genormaliseerde score voor WEB2 is 0.30 en wordt geassocieerd met een laag risico (Tabel 10). Voor WEB2 moeten de boringen nog plaats vinden, maar bij productie binnen de gestelde productierichtlijnen van SodM, worden geen problemen verwacht. De effecten van de afkoeling van

het reservoir, de thermo-elastische effecten zoals compactie, zijn niet meegenomen in de methodieken van IF/QCON en SodM en als zodanig niet onderzocht in deze studie. Hieronder volgen enkele conclusies en de scoringstabel uit de SHA.

Tabel 8. Eerste set beslisboom vragen

Decision tree questions	Answer (Y/N)	Argumentation or Reference to relevant paragraph
Distance to major fault zone < 100m or circulation through existing faults?	N	Zie SHA rapport in de bijlage
Project in tectonically active area of Roer Valley Graben?	N	Zie SHA rapport in de bijlage
Influenced by Groningen Field?	N	Zie SHA rapport in de bijlage



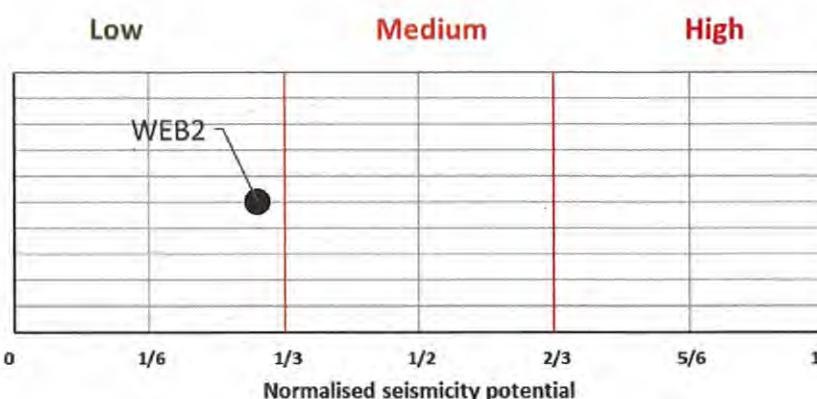
Figuur 20: A) Kaart met locatie van natuurlijke en geïnduceerde aardbevingen (KNMI), B) Locatie van het Slochteren gasveld (blauw) ten opzichte van WEB2 en C)locatie van grootschalige breuken en het Roer Valley Graben ten opzichte van WEB2.

Tabel 9: Quickscan resultaten voor WEB2

Decision tree questions	Answer / Value	Argumentation or reference to relevant paragraph of this report
Basement connected: <ul style="list-style-type: none"> separation reservoir <=> X-line basement 	no, score: 0	Zie SHA rapport in de bijlage
inter-well pressure communication: <ul style="list-style-type: none"> lateral separation vertical separation 	Yes, score: 0	Zie SHA rapport in de bijlage
re-injection pressure [Mpa]	1-4 MPa, score: 3	Zie SHA rapport in de bijlage
circulation rate [m^3/h]	> 360 m^3/h , score: 10	Zie SHA rapport in de bijlage
epicentral distance to natural earth-quakes [km]*	> 10 km, score: 0	Zie SHA rapport in de bijlage
epicentral distance to induced seismicity [km]*	> 10 km, score: 0	Zie SHA rapport in de bijlage
distance to natural fault [km] <ul style="list-style-type: none"> quality of seismic data 	0.1 – 0.5 km, score: 7	Zie SHA rapport in de bijlage
Orientation of fault in current stress field <ul style="list-style-type: none"> Orientation stress field Orientation strike of fault 	Shearing possible, score: 7	Zie SHA rapport in de bijlage
net injected volume [x1000 m3]	< 0.1 m^3 , score: 0	Zie SHA rapport in de bijlage

Tabel 10: Scoringstabel quickscan.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Flow 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 m ³]	Sum of column scores	Normalized score
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		
Column Score	0	0	3	10	0	0	7	7	0	27	0.30



Figuur 21 Resultaat van de quickscan

7.3 NADELIGE GEVOLGEN OMGEVING

Bovengrondse gevolgen voor de omgeving op het gebied van veiligheid en milieu zullen geborgd worden in de diverse vergunningen en in het VG zorgsysteem. Zo zijn er voorschriften van kracht voor wat betreft onder ander uitstoot, geluid en bodembescherming. In de VG documentatie zal onder andere aandacht besteed worden aan explosieveiligheid, werkvergunningen, risico-inventarisaties en onderhoud.

Ook zal de ondergrondse integriteit opgenomen worden in het VG zorgsysteem, zoals in het putintegriteitsdocument dat toeziet op onderhoud en monitoring van de ondergrondse installatie.

In de navolgende figuren is de locatie van het mijnbouwwerk van WEB 2 weergegeven in relatie tot beschermd gebieden. In figuur 22 betreft dit het Natura 2000 gebied en in figuur 23 betreft dit de drinkwaterwingebieden.

De stikstof uitstoot is in de normale bedrijfssituatie zeer gering en gezien de afstand tot het Natura 2000 gebied is de depositie nihil. De afstand van het mijnbouwwerk tot de drinkwaterwingebieden is tevens dermate groot, dat de invloed daarop eveneens nihil is.

Het grondwater in het winningsgebied is overigens brak, waardoor dit niet direct geschikt is voor drinkwaterwinning..



Figuur 19: Natura 2000 gebieden



Figuur 20: Grondwaterwingegebieden



BLJULAGE 1

Bijlage 1. Details DoubletCalc2D

Berkel Reservoir

REGION OF INTEREST

xmin	0.0	m	nx	100
xmax	2000.0	m	ny	100
ymin	-1000.0	m		
ymax	1000.0	m		
grid geometry	TopDepth_DC2D_Berkel		use values	view

AQUIFER PROPERTIES

initial temperature	17.0	C	Temperature_DC2D_Berkel	use value	view
aquifer depth	1.0	m	TopDepth_DC2D_Berkel	use value	view
(cell) thickness	34.0	m	Thickness_DC2D_Berkel	use grid	view
porosity	0.19	-	poros.	use grid	view
net to gross	1.0	-	netto	use grid	view
actnum	1.0	-	actnum	use grid	view
permeability in xdir	400.0	mDarcy	perm_DC2D_Berkel	use value	view
permeability in ydir	400.0	mDarcy	perm_DC2D_Berkel	use value	view
water salinity	100000.0	ppm			

CALCULATION SETTINGS

time end production	50.0	yr
time end analysis	50.0	yr
output interval	1.0	yr
output/calculation interval after production	250.0	yr

name	Well 0		Well 1	
	x	y	x	y
well diameter	10.6	inch	10.6	inch
well skin	-3.0	-	-4.0	-
well excess pressure	30.0	bar	30.0	bar
well (inj) temperature	-1.0	C	27.0	C
well flow rate	-157.0	m ³ /h	157.0	m ³ /h
pressure constraint	no			

ADVANCED ROCK PROPERTIES

rock conductivity	2.0	W K ⁻¹ m ⁻¹
heat capacity	1000.0	J kg ⁻¹ K ⁻¹
rock density	2200.0	kg m ⁻³
Young's modulus	9.0E9	Pa
Poisson's ratio	0.35	-
compaction coefficient	1.0E-5	bar ⁻¹
thermal compaction coefficient	2.0E-5	C ⁻¹

OUTPUT SETTINGS

output fileformat	ZYCOR
output VTK (ParaView) fileformat	no
write debug output grids	no

CALCULATION SETTINGS

cooling 3D	yes
calculate subsidence	yes
no flow boundary	yes

Delft Reservoir
REGION OF INTEREST

xmin	96427.0	m	nx	100000.0
xmax	97528.0	m	ny	100000.0
ymin	-11257.0	m		
ymax	89052.0	m		

grid geometry

AQUIFER PROPERTIES

initial temperature	17.0	C	Temperature_DC2D_Delft	use value	view
aquifer depth	1800.0	m	TopDepth_DC2D_Delft	use value	view
(cell) thickness	46.0	m	Thickness_DC2D_Delft	use grid	view
porosity	0.19	-	none	use grid	view
net to gross	1.0	-	none	use grid	view
actnum	1.0	-	none	use grid	view
permeability in xdir	100.0	mDarcy	perm_DC2D_Delft	use value	view
permeability in ydir	100.0	mDarcy	perm_DC2D_Delft	use value	view
water salinity	100000.0	ppm			

CALCULATION SETTINGS

time end production	50.0	yrs
time end analysis	50.0	yrs
output interval	1.0	yrs
output/calculation interval after production	250.0	yrs

name	Well 0		Well 1	
	x	y	x	y
x	96427.0	97528.0	m	
y	444154.0	443733.0	m	
well diameter	10.6	10.6	inch	
well skin	-3.0	-4.0	-	
well excess pressure	-0.0	-0.0	bar	
well (inj) temperature	-1.0	27.0	c	
well flow rate	-218.0	218.0	m ³ /h	
pressure constraint	no			

ADVANCED AQUIFER PROPERTIES

storage capacity	1.0E-9	m ³ Pa ⁻¹
water conductivity	0.6	W K ⁻¹ m ⁻¹
temperature dependent viscosity	yes	✓
viscosity	0.001	Pa s
temperature dependent density	yes	✓

ADVANCED ROCK PROPERTIES

rock conductivity	2.0	W K ⁻¹ m ⁻¹
heat capacity	1000.0	J kg ⁻¹ K ⁻¹
rock density	2200.0	kg m ⁻³
Young's modulus	9.0E9	Pa
Poisson's ratio	0.35	-
compaction coefficient	1.0E-5	bar ⁻¹
thermal compaction coefficient	2.0E-5	C ⁻¹

OUTPUT SETTINGS

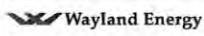
output Netformat	ZYCOR	▼
output VTK (ParaView) Netformat	no	▼
write debug output grids	no	▼

CALCULATION SETTINGS

cooling 3D	yes	▼
calculate subsidence	yes	▼
no flow boundary	yes	▼



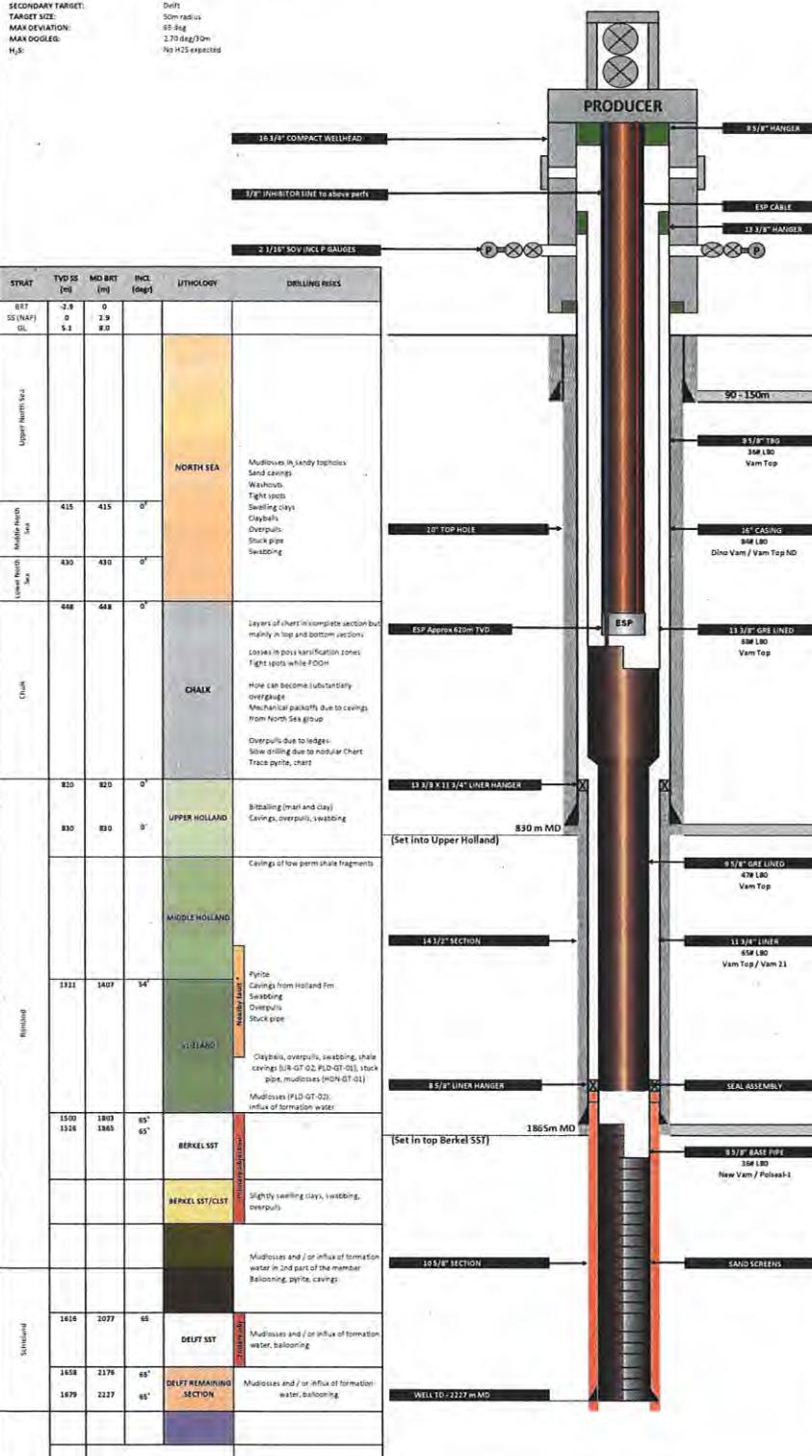
BIJLAGE 2



LSL-GT-03 GEOTHERMAL PRODUCER

VANGUARD ENERGY MANAGEMENT

RIG:	LOC4010
WELL TYPE:	Deviated geothermal producer
TOP BHT DEPTH:	1670 ft TVD 1517 ft MD
DATAFILE:	51mm borehole diameter
RKS ABOVE SS:	3 km (10,000 ft above ground level)
TO CHTERIA:	Exit base Delt formation 50m to that shoe doesn't cover any reservoir
OBJECTIVE:	Drill geothermal production well into Berkel and Del formations
DESIRED PROD:	550 m³/day
CAP PROD SALINITY:	90,000-100,000 ppm
BHT DEGREES:	51.0 degrees C (31.0 degrees C / 100m = 10% surface temp.)
FINAL WELL STATUS:	Producer
PRIMARY TARGET:	Berkel
SECONDARY TARGET:	Delt
TARGET KZ:	50m radius
MAX DEVIATION:	±5 deg
MAX DOBLEG:	2.70 deg/30m
H:S:	No H2S expected



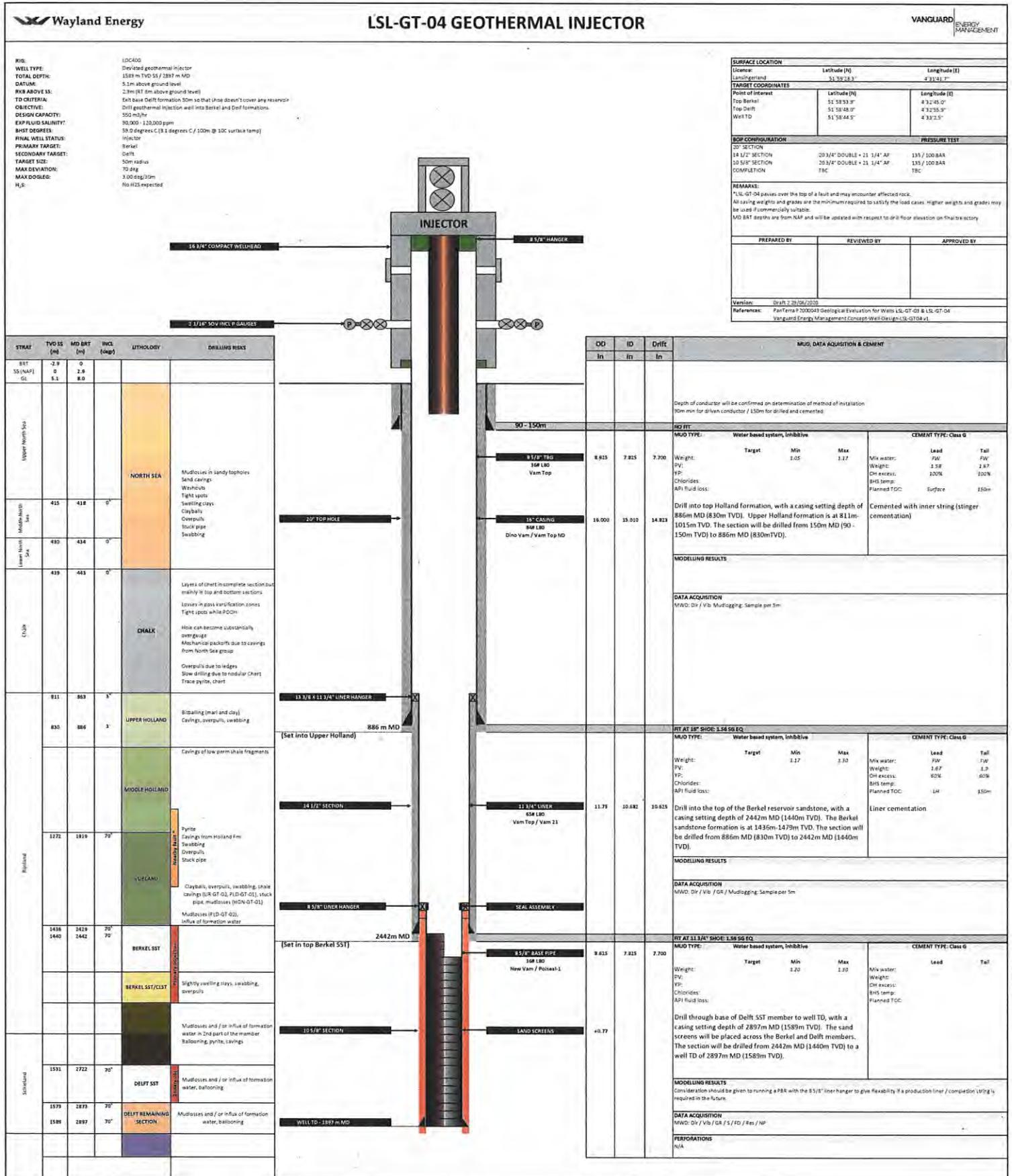
SURFACE LOCATION		
License:	Latitude [N]	Longitude [E]
Lansingland	51°39'16.3"	4°31'41.7"
TARGET COORDINATES		
Point of Interest	Latitude [N]	Longitude [E]
Top Borehole	51°39'5.5"	4°31'55.5"
Top Drift	51°39'11.1"	4°31'59.9"
Well Top	51°39'54.1"	4°32'7.7"
BOP CONFIGURATION		PRESSURE TEST
BOP SECTION		
14 1/2" SECTION	20 3/4" DOUBLE + 11 1/4" API	185 / 100 BAR
10 5/8" SECTION	20 3/4" DOUBLE + 11 1/4" API	135 / 100 BAR
COMPLETION	TBC	TBC
REMARKS:		
115L-GT-02 passes over the top of a fault and may encounter affected rock.		
Weights and grades are the minimum required to satisfy the load cases. Higher weights and grades may be used if commercially available.		
MD SET depths are from NAF and will be updated with respect to drill floor elevation on final trajectory.		
PREPARED BY		REVIEWED BY
APPROVED BY		
Version: Draft 12/06/2020		
Reference: EastTexas200903 Geometrical Evaluation for Well 115L-GT-02		

STRAT	TVD SS [m]	MD MFT [m]	INC [deg]	LITHOLOGY	DRILLING RECS
BET SE (NAF) GL	-2.8 5.2	0 #30			
Upper Norm. Sea				NORTH SEA	Mudstones (K) sandy lamproles Sand cavings Washouts Tight pyrite Swelling clays Clayballs Overpulls: Stuck pipe Swabbing
Lower North Sea	415	415	0°		
	430	430	0°		
Chalk	448	448	0°	CHALK	Layers of chalk (incomplete section b) mainly in top and bottom sections Losses in poro karstification zones; Tight spots while PDCB Holes can become suddenly overpulls Mechanical packoffs due to cavings from North Sea group
					Disturbances due to ledges; low drilling due to nodular Chalk Trace pyrite, craze
	820	820	0°		
	830	830	0°	UPPER HOLLAND	Bioturbation (main and clay) Cavings, overpulls, swabbing
				MIDDLE HOLLAND	Cavings of low perm shale fragments
Rijnland	1321	1407	54°	(IJSLAND)	Pyrone Cavings from Holland Fm. Swabbing Overpulls Stuck pipe
					Clayballs, overpulls, swabbing, shale cavings (IJ-GT-02, PLD-GT-01), stuck pipe, mudlosses (HON-GT-01)
	1500	1803	65°	BERKEL SST	Mudlosses (PLD-GT-02); influx of formation water
	1526	1865	65°		
				BERKEL SST/CST	Slightly swelling clays, overpulls
Sint Maart					Mudlosses and / or influx of formation water in 2nd part of the member Ballooning, pyrite, cavings
	1616	2077	65	DEFLT SST	Mudlosses and / or influx of formation water, ballooning
	1638	2176	65°	DEFLT REMAINING SECTION	Mudlosses and / or influx of formation water, ballooning
	1679	2217	65°		



BLILAGE 3

LSL-GT-04 GEOTHERMAL INJECTOR





BLJLAGE 4

Geological Evaluation for project WEB2

Wells:

- LSL-GT-03
- LSL-GT-04

August 2021 v2

PanTerra Project P2000043-02a

Geological Evaluation for project WEB2

Wells:

- LSL-GT-03
- LSL-GT-04

Volume 8 (v2)

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Version 2 is an update with a Dutch summary on request of Wayland.

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1 Introduction

The purpose of this report is to provide geological input for drilling 2 geothermal wells near Bergschenhoek (project *Wayland Energy Bergschenhoek 2* or **WEB2**). In 2017 two geothermal wells (LSL-GT-01 and LSL-GT-02) have been drilled successfully in production license Lansingerland 1, operated by Wayland Energy. Wayland Energy is now planning to drill two new wells towards the East, that will consist of producer LSL-GT-03 and injector LSL-GT-04 (Figure 1-1). The produced heat will be used for greenhouse heating.

This Geological Evaluation report was written to act as input to the well design process of both wells. The information gathered from drilling the first well may be incorporated, either as an addendum to, or as an updated version of this document for the second well. The main reservoir parameters in this document can be considered valid for the entire fault block. Reservoir target depths are specified as an Appendix per well to be drilled. The reservoir targets are the sandstones of the Berkel and Delft, at a depth of approximately 1,400--1650m TVDss.

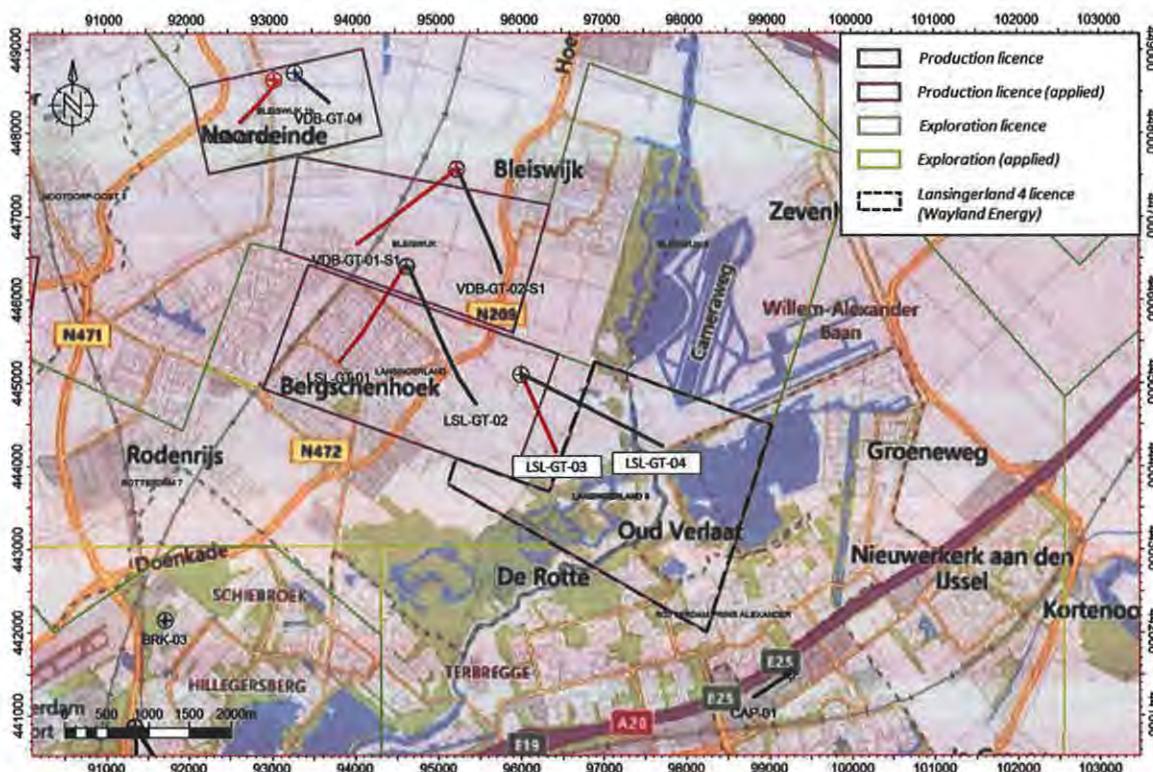


Figure 1-1 Map view of the area, the existing doublet in production licence Lansingerland 1 and the planned doublet in license Lansingerland 4. Well trajectories of producers are shown as red, trajectories of injectors as blue.

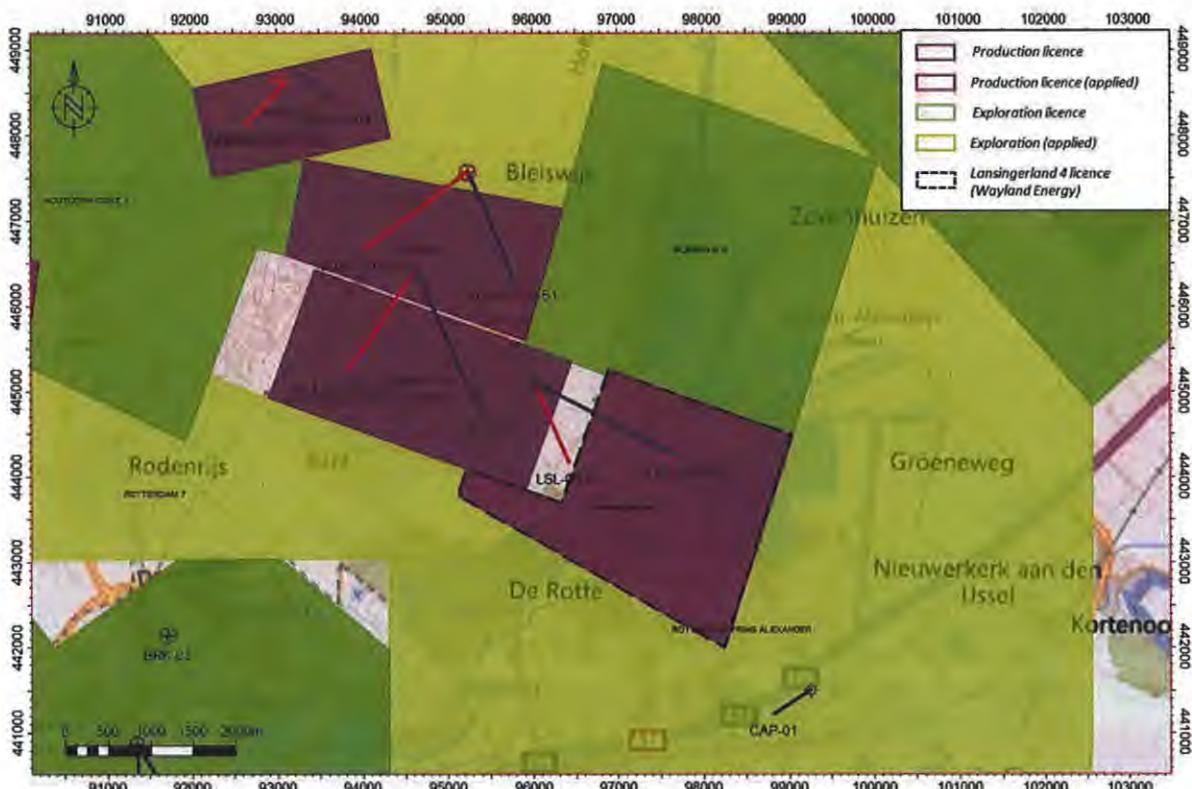


Figure 1-2 Map view of the area with planned doublet in license Lansingerland 4 and adjacent exploration and production licenses. The producer is partly drilled into an open area that Wayland will apply for. There are a number of geothermal planned wells to be drilled nearby which are not included on this map for clarity.

2 Surface location and downhole targets

2.1 Surface location

The surface location of both wells is located in the municipality of Lansingerland, in a greenhouse area east of the village of Bergschenhoek (Figure 1-1).

2.2 Subsurface targets geothermal wells and target tolerances

The planned well configuration will consist of two wells: producer LSL-GT-03 and injector LSL-GT-04. The planned locations of the wells are displayed in Figure 1-1. They will be situated east of the two existing wells LSL-GT-01 (producer) and LSL-GT-02 (injector). Overview of other geothermal projects nearby is given in Figure 1-2.

It is not yet determined which well will be drilled first. On completion of the first well, subsurface targets may be revised and well trajectories adjusted accordingly. The targets for all wells are reported in Appendix A and B.

3 Geological prognosis and pressure data

The planned wells are to be drilled in a fault block in the West Netherlands Basin, previously drilled in to by offset wells LSL-GT-01 and LSL-GT-02. The wells will intersect the Tertiary and Quaternary North Sea Supergroup, Cretaceous Chalk Group and the Cretaceous Rijnland Group before reaching the target reservoirs in the Schieland Group.

The wells will drill sediments ranging in age from Tertiary to Jurassic which are overlying Triassic and pre-Mesozoic sediments. In the Late Cretaceous, during the deposition of the Chalk Group, the West Netherlands Basin was inverted. This was accompanied by compressional movements and resulted in convergent oblique-slip faulting, general uplift, erosion and basin inversion, during which pre-existing normal faults were reactivated. The well is to be located in a structural low position in a horst block. The structure is bound by a number of faults, which are discussed in detail in section 3.2.1. The target reservoirs are briefly described from top to bottom in Figure 3-1, with the two targets being the Berkel and Delft sandstones, which are separated by a thin interval containing: thin interval of Berkel claystone and sandstone, thin interval of Rijswijk sandstone (which could form part of the reservoir interval or could be absent at this location, note that the Rijswijk interval was only a few meters thick in LSL-GT-01 and LSL-GT-02 wells) and the Rodenrijs shales (see schematic of the regional stratigraphy in Figure 3-2).

Era	Group	Period	Lithostratigraphic column LSL-GT-03 and LSL-GT-04			Expected Depth (RTE)		Common / Expected drilling hazards		Faults	Expected drilling hazards	
			Formation	Member	Lithology	LSL-GT-03 m	LSL-GT-04 m	LSL-GT-03 ft	LSL-GT-04 ft			
Upper North Sea NU	Quaternary	Naldwijk-Peize NU-NUPZ			Continental deposits. Fluvial sand, silt and clays.	-3	0	-3	0	Clayballs, overpulls, stuck pipe, swabbing	No drilling hazards reported in well reports for PNA-GT-01 & -02 and VUB-GT-03 & -04	
		Maasvluis NU-NS			Very fine to coarse calcareous sand with some clay streaks.	105	108	105	108			
		Oosterhout NUOT			Very fine to very coarse sand. Contains shell fragments.	250	253	250	253			
		Breda NUBA			Marine glauconitic sands with silty to sandy clays.	377	380	377	380			
	Tertiary	Rupei Clay NMRC	Rupei Clay	NMRC	Heavy dark brown marine clays. Rich in pyrite, hardly any glauconite.	412	415	412	415	Coarse chert, trace pyrite	No OH-1 (GT-03) - equivalent in LSL-GT-04 and -02 (possibly due to weathering effects)	
		Landen NLLFC	Landen Clay	NLLFC	Dark green clay, the base can be marly and of a lighter colour.	427	430	427	430			
		Ekofisk CXE			White, chalky limestone containing rare white and grey nodules and bedded chert layers, grey to green clay laminae.	431	433	430	433	Trace pyrite, swelling clays, tight spots, bitubling (clay-marl), stuck pipe, gas		
		Ommelanden OOGA			Succession of white-yellowish-grey, fine grained limestones. Layers of chert nodules can be common over thick intervals.	457	470	461	464			
		Terschell CTTC	Pleins Maal CTCP		Dark grey to black, micaceous, iron-stained clays.	737	740	769	804			
		Terschell CTTC	Terschell Marlstone CTTM		White to light grey, locally pebbly, limestone and marly dolomite.	742	745	774	811			
Chalk CK	Cretaceous	Holland KNGL	Upper Holland Marl KNGLU		Light grey and red-brown marls, characterized by a carbonate content which gradually increases towards the top.	757	770	803	851	Bitubling (marl + clay)	Westerly Fault	
			Middle Holland Claystone KNGLM		Grey and/or red-brown calcareous shaly claystone with a distinctly lower lime content than the under- and overlying members.	973	978	996	1258			
			Holland Greensand KNGUG		Alternation of greenish grey, very glauconitic, very fine- to fine-grained, siliceous sandstones.	1046	1056	1064	1436	Cavings of low permeable shale fragments		
			Lower Holland Marl KNGLL		Grey and red-brown marl or calcareous, fissile claystone, frequently with intercalated bioclastic claystone beds.	1225	1228	1179	1796			
		Vlieland KNVS	De Uer KNVS		Alternation of thin-bedded, very fine- to fine-grained argilaceous sandstones.	1301	1382	1242	1904	Pyrite, cavings from Holland Fm, bitubling, overpulls, stuck pipe	T-600 - pyrite spots in VLI-02	
			Vlieland Claystone KNVC		Dark greyish-green to grey claystones. Micritic and very fine lignitic matter are common. Generally, the claystones are only very slightly calcareous.	1342	1450	1274	1988			
			Berkel Sandstone KNVS	Target	Light grey, very fine- to fine- and medium- to coarse-grained sandstones. Locally pebbly, sparry, mottled glauconitic or with siderite concretions.	1495	1509	1402	2326	Clayballs, overpulls, swabbing, shale cavings, (LUR-GT-02, PLD-GT-01), stuck pipe, mudlosses (HUN-GT-01)		
			Berkel Sand/Claystone KNVS		Alternation of fine-grained argillaceous sandstones and brownish grey to ferruginous dolomites.	1510	1528	1449	2334			
			Hijswijk crystall.		Light- to medium-grey sandstones with varying fine- to medium-grained locally pebbly grain size.	1566	1966	1457	2469	Slightly swelling clays, swabbing, overpulls		
			Rodderwijkstra Claystone SLGHT		Medium- to dark grey, very silty argillites. Alternations with common intercalations of dolomite, pebbles and lignite/coal lenses.	1572	1980	1462	2482			
Schiaam SL	Miocene	Delft Sandstone SLGTC	Target	Light grey medium- to massive, fine- to medium-grained dolomitic sandstones, lignitic.	1618	2088	1483	2388	Mudlosses and/or influx of formation water, bitubling, pyrite, cavings	No drilling hazards reported in well reports for PNA-GT-01 & -02 and VDB-GT-03 & -04		
		Upper Alblasdien SLGTH		Thickens of dark grey to light grey dolomitic clay and dolomite with dolomitic interbeds and dolomitic dolomite. Thickness up to 10 meters.	1670	2232	1830	2858				
		Lower Alblasdien SLGTL		Sequence of dark grey to light grey dolomitic clay and dolomite with dolomitic interbeds. Thickness up to 10 meters.	1691	2262	1559	2746				
Altena AT	Jurassic	Werkendam ATWD			Sequence of grey, slightly marly, shaly claystones.	N/A	N/A	N/A	N/A	Shale problems: sloughing clays, cavings, overpulls, stuck pipe		

* Wells LSL-GT-03 and LSL-GT-04 pass through a fault and may encounter affected rock

Figure 3-1 Lithostratigraphic column according to Van Adrichem Boogaert & Kouwe (1993 – 1997) adapted from [1]. The Target Reservoir Sections are indicated in Orange. Drilling hazards adapted from the Drilling Program for well LSL-GT-02 [1] and added to by PanTerra and VEM.

3.1 Target reservoirs

The main targets are the sands of the Berkel and Delft reservoir. Both the Berkel and Delft sandstone have proven to be a reliable reservoir for geothermal operations. The top reservoir target for wells both wells is the Top Berkel.

It is expected that the stratigraphy of the planned wells will resemble wells LSL-GT-01 and LSL-GT-02 (Figure 3-2). The key parameters of each reservoir are briefly described below:

- **Berkel sandstone (Rijnland Group):** very fine- to medium-grained sandstones. The Berkel sandstone is underlain by an alternation of fine-grained sandstones and silty to sandy claystones, called the Berkel Sand-Claystone Member. Based on the results from LSL-GT-01 and LSL-GT-02 wells, planned wells are expected to penetrate very thin layer of Rijswijk Sandstone Member (base of Rijnland Group), which may form part of the target reservoir section. The wells will then drill through Rodenrijs Claystone Member (Schieland Group) characterised by silty to sandy claystones with occasional sand and coal layers.
- **Rijswijk Sandstone:** light- to medium-grey sandstones with a very fine to medium and locally gravelly grain size. In the main offset wells LSL-GT-01 and -02 the Rijswijk Sandstone was only a few meters thick.
- **Delft Sandstone (Schieland Group):** light-grey massive sandstone sequence, fine to coarse-gravelly with good reservoir properties.
- **Alblasserdam sandstone:** Transition of dark to light grey, red clay- and brownish siltstones - Fine to medium grained sandstones up to a few metres - Massive, thick-bedded, coarse grained sandstones. The sandstones in the Alblasserdam are of average quality, expectedly less than the Delft Sandstone.

Age		Stratigraphy				
Early Cretaceous	Albian	Rijnland Group	Vlieland Fm.	Holland Fm.	post-rift	
	Aptian					
	Barremian					
	Hauterivian					
	Valanginian	Schieland Group	Nieuwpoort Fm.	Delft Sandstone Member		
	Ryazanian					

Figure 3-2 Regional geothermal aquifer layout of the Target reservoir section (Schieland and Rijnland). In the target location only a very thin Rijswijk Sandstone Member is present.

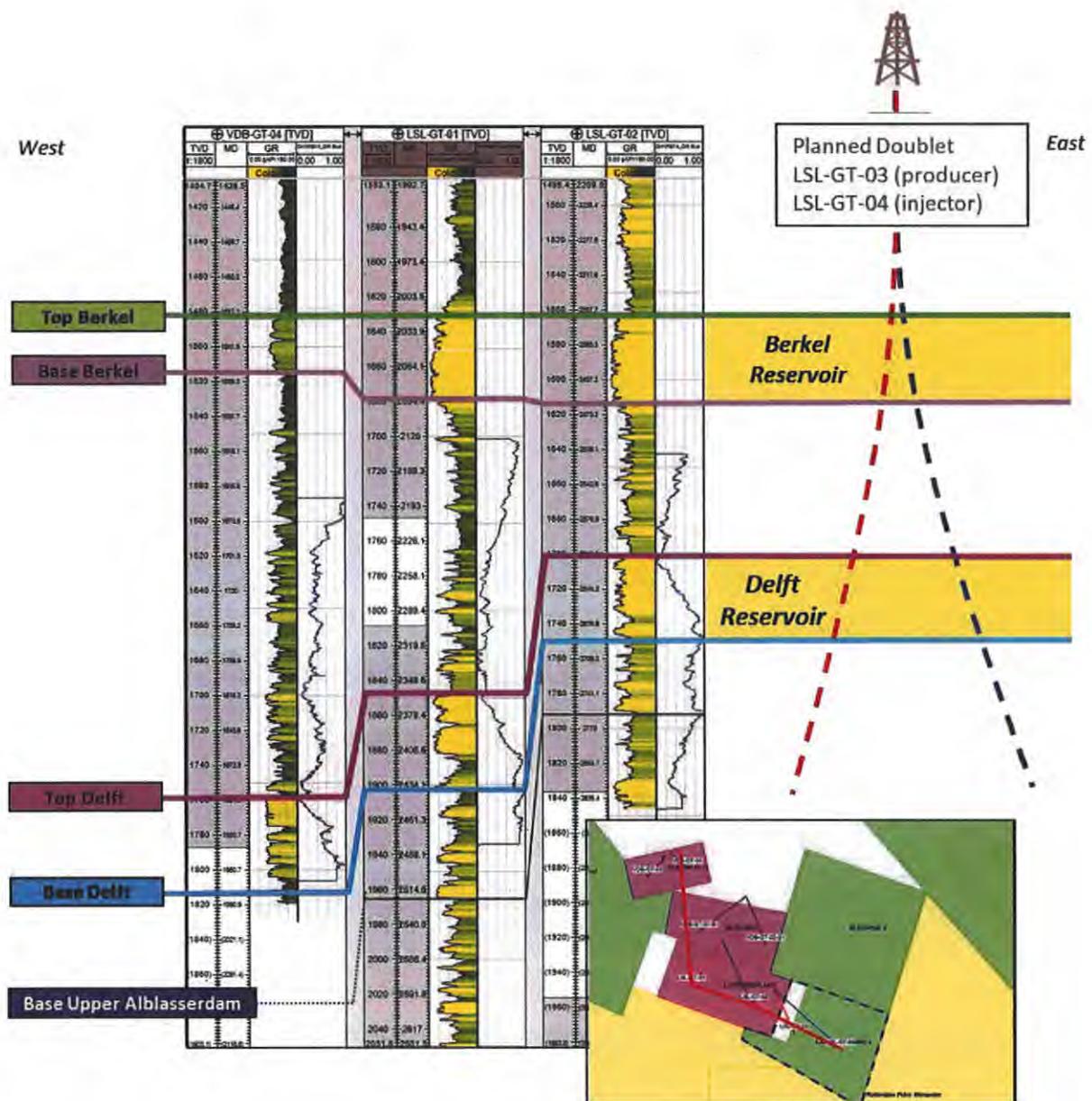


Figure 3-3 Regional correlation panel showing the gamma ray logs and derived INPEFA curves, flattened on the Top Delft. The Berkel and Delft reservoirs are the main targets, where most of the sands of the Delft stratigraphic interval are accumulated.

3.2 Depth prognosis and uncertainties – deeper subsurface

Figure 3-4 shows the planned wells on the top reservoir depth map. The two seismic lines are plotted in Figure 3-5 and Figure 3-6.

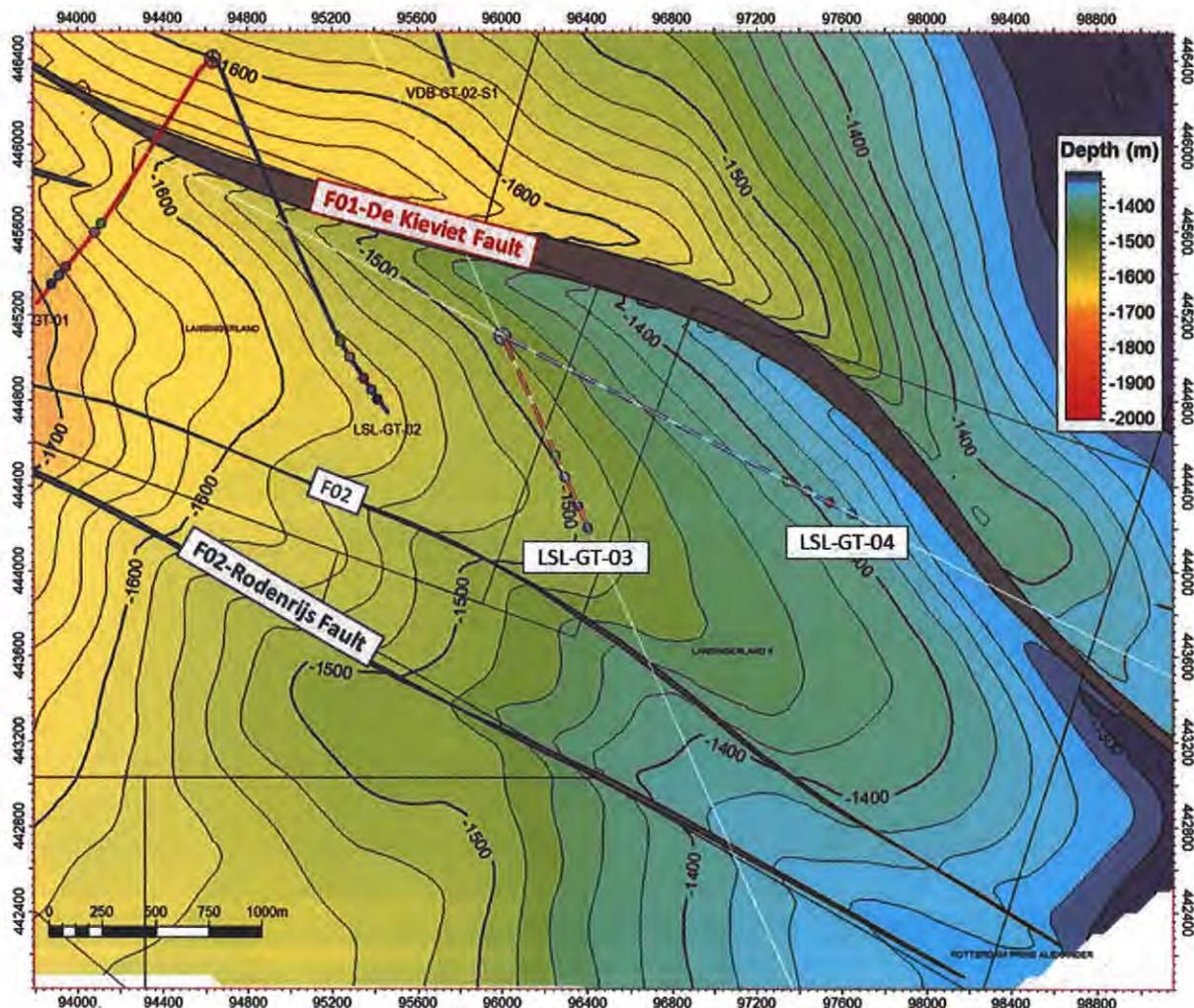
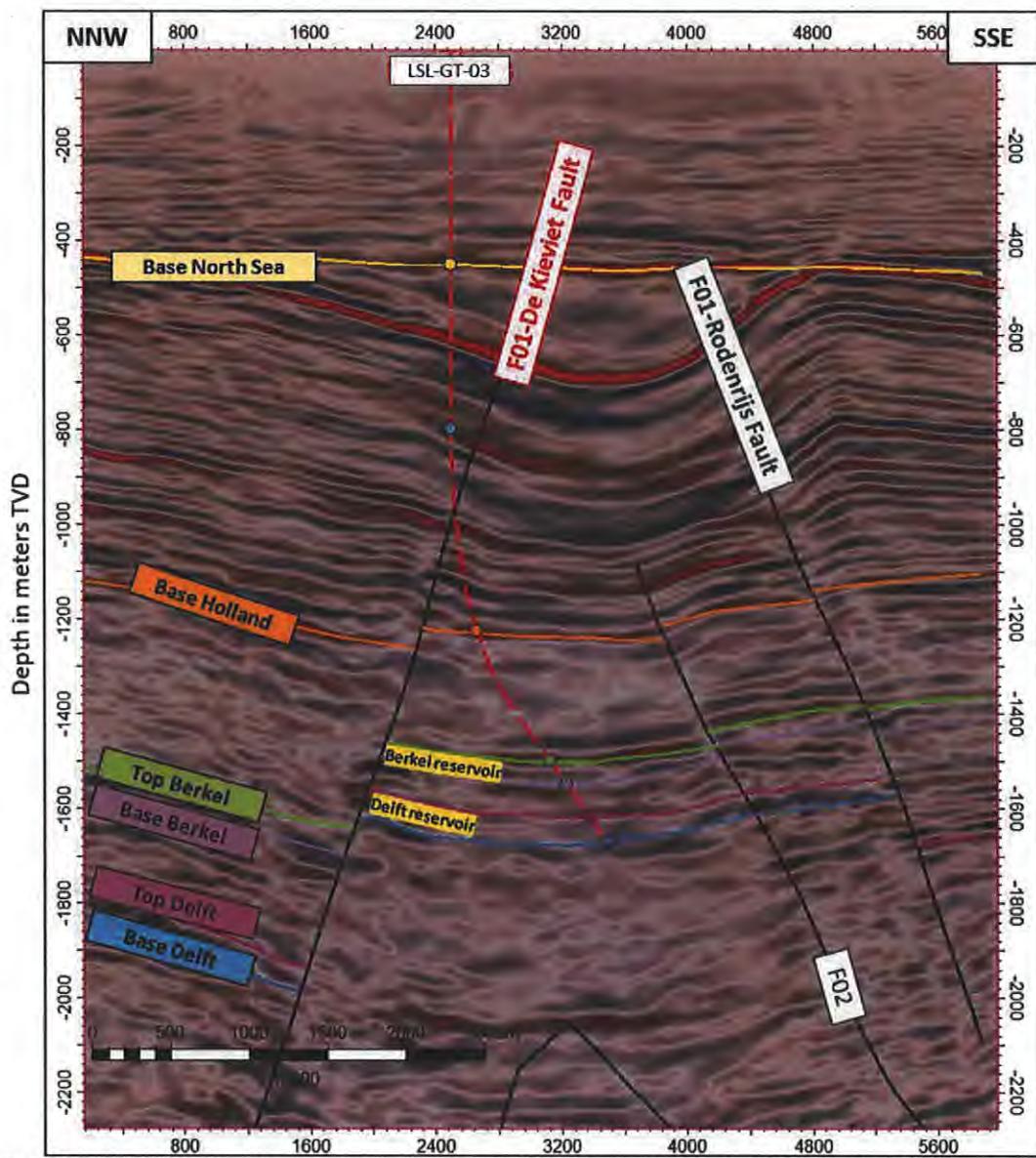


Figure 3-4 Intersections of the planned wells at Top Berkel reservoir (indicated by green circles). The seismic lines of Figure 3-5 and Figure 3-6 are indicated with the black dashed lines.

Producer LSL-GT-03 is located to the northwest of the planned injector LSL-GT-04. The subsurface mid reservoir distance between the wells is approximately 1,200 m. The doublets are situated parallel to the main fault direction in order to minimize the chance of the presence of faults between the wells.

Faults are present near all wells. The distance between these faults and the wells is approximately 500m to minimise risk of fault seismicity. The northern fault has a relative vertical displacement of approximately 80 m. Minor faults may also be present near the wells, but they cannot be distinguished on seismic. Because these faults are so small it is not expected that they form a significant barrier to flow or cause geomechanical problems.

The target reservoir in the Delft formation is expected to sit in the section as indicated in Figure 3-1. Combined with the uncertainty in the depth interpretation (± 30 m) an uncertainty of ~ 100 m is applicable on the top of the Delft as well as TD prognosis.



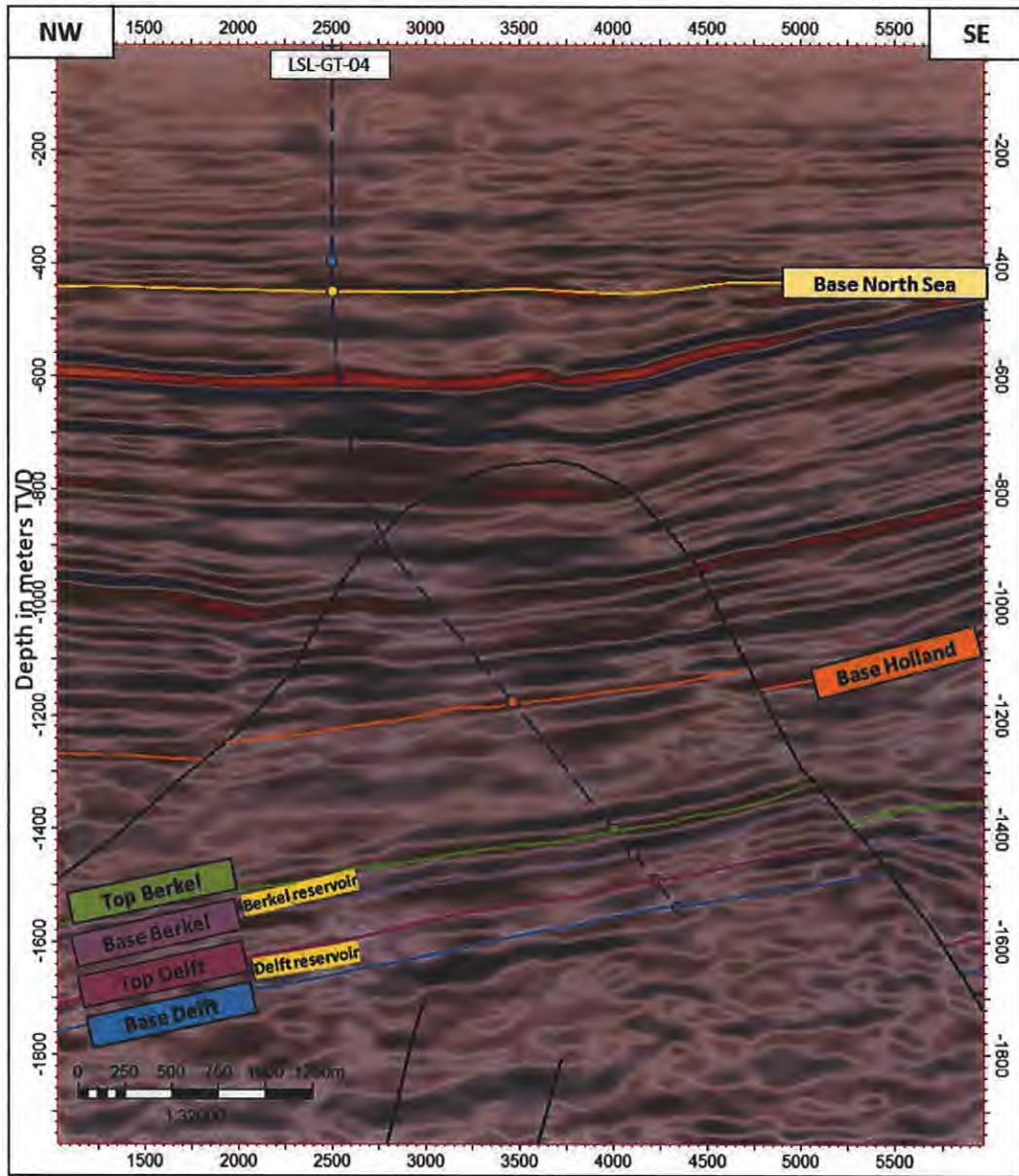


Figure 3-6 Seismic intersection through the fault block, perpendicular to the wells. Only the planned injector is displayed. The location of the line is indicated in Figure 3-4.

3.2.1 Faults

Before reaching the top of the Berkel reservoir wells LSL-GT-03 and LSL-GT-04 will pass through the top of an interpreted fault ("De Kievit Fault") in the Holland Formation (Figure 3-1).

The fault is identified by offset in the reflectors. This offset becomes smaller and diminishes in the shallower regions. Based on the seismic interpretation, the current trajectory of the producer will pass through the fault where the offset is not/hardly visible. The estimated fault offset is approximately 5-10m. After determining the final well trajectories the angle between well and fault and estimate the depth of the fault can be calculated.

While drilling deeper towards the reservoir the distance between the well and the fault increases. When reaching top reservoir, the distance is larger than 500m for both wells. All other sections of the planned trajectories for the planned wells are clear of any nearby faults.

3.2.2 Depth map of the top and base reservoir

Maps of the top Berkel, top Delft and base reservoir are displayed in Figure 3-7, Figure 3-8 and Figure 3-9 respectively. A series of NW-SE trending normal and thrust faults are present in the study area. The target locations of the planned wells are located near the axis of the structural high, parallel to the local fault trend, minimizing the risk of faults between the injector and producer.

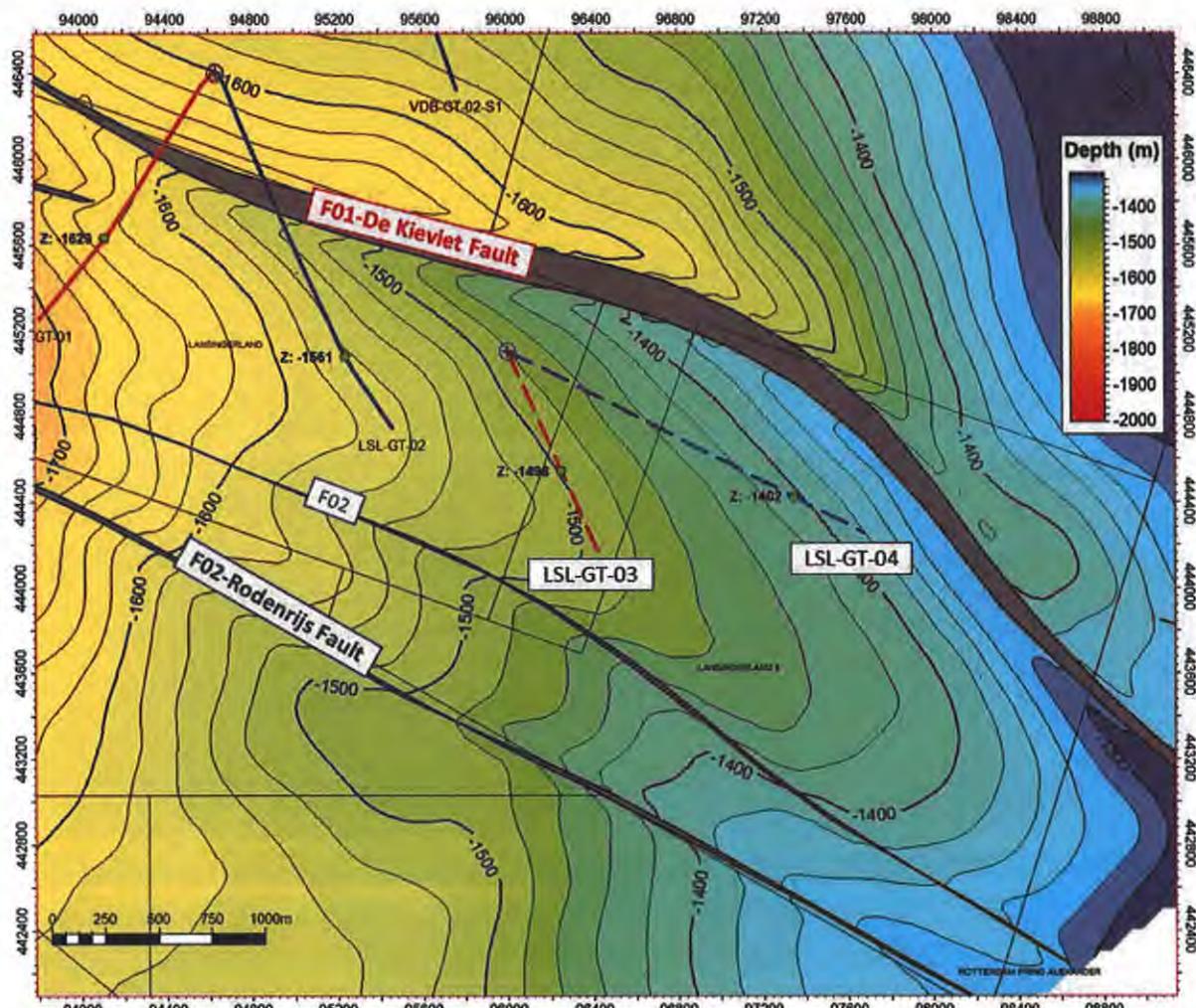


Figure 3-7 Depth map of Top Berkel with the well trajectories of the planned wells. The point where the wells penetrate the Top Berkel are marked by green circles.

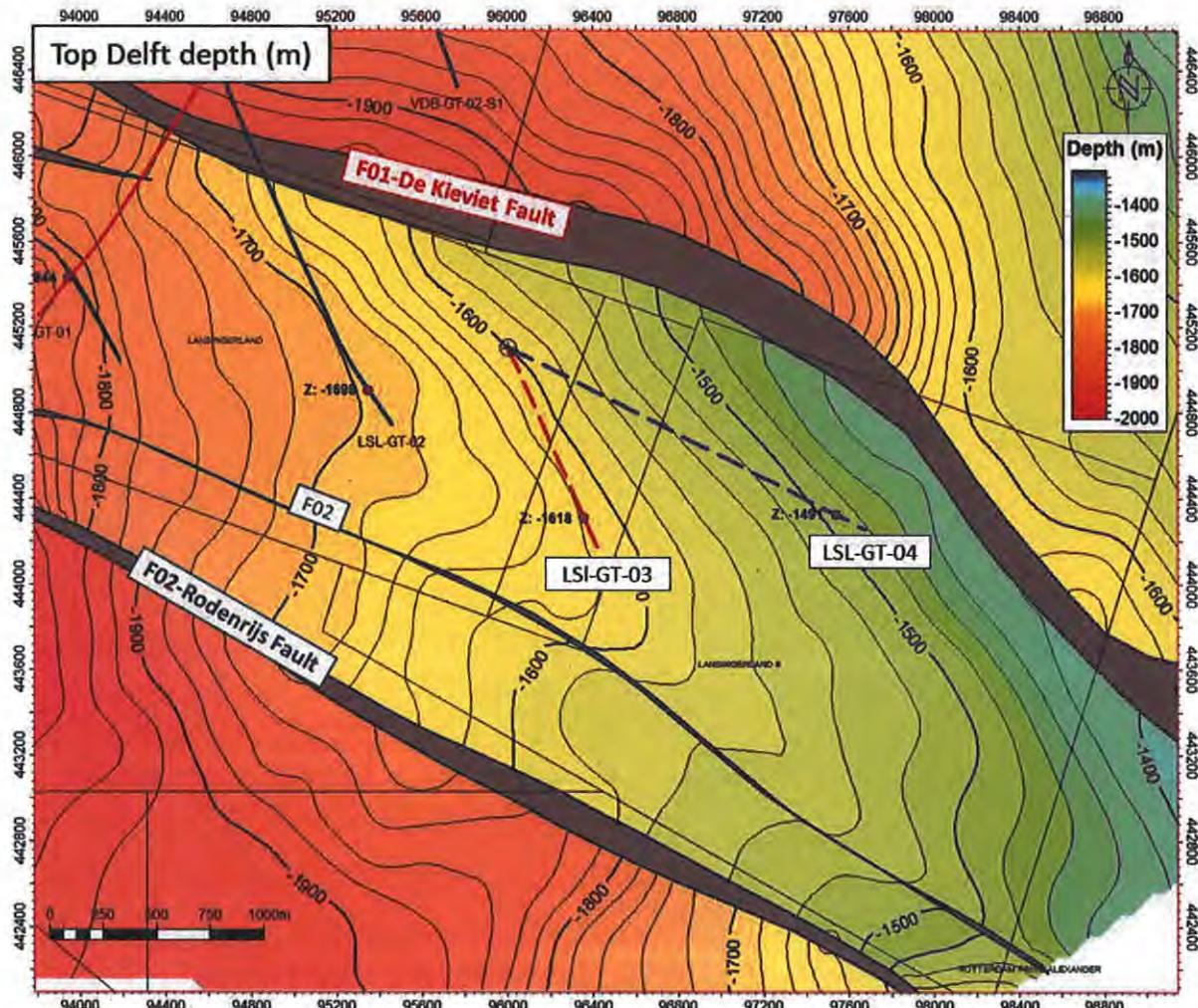


Figure 3-8 Depth map of Top Delft with the well trajectories of the planned wells. The point where the wells penetrate the Top Delft are marked by pink circles.

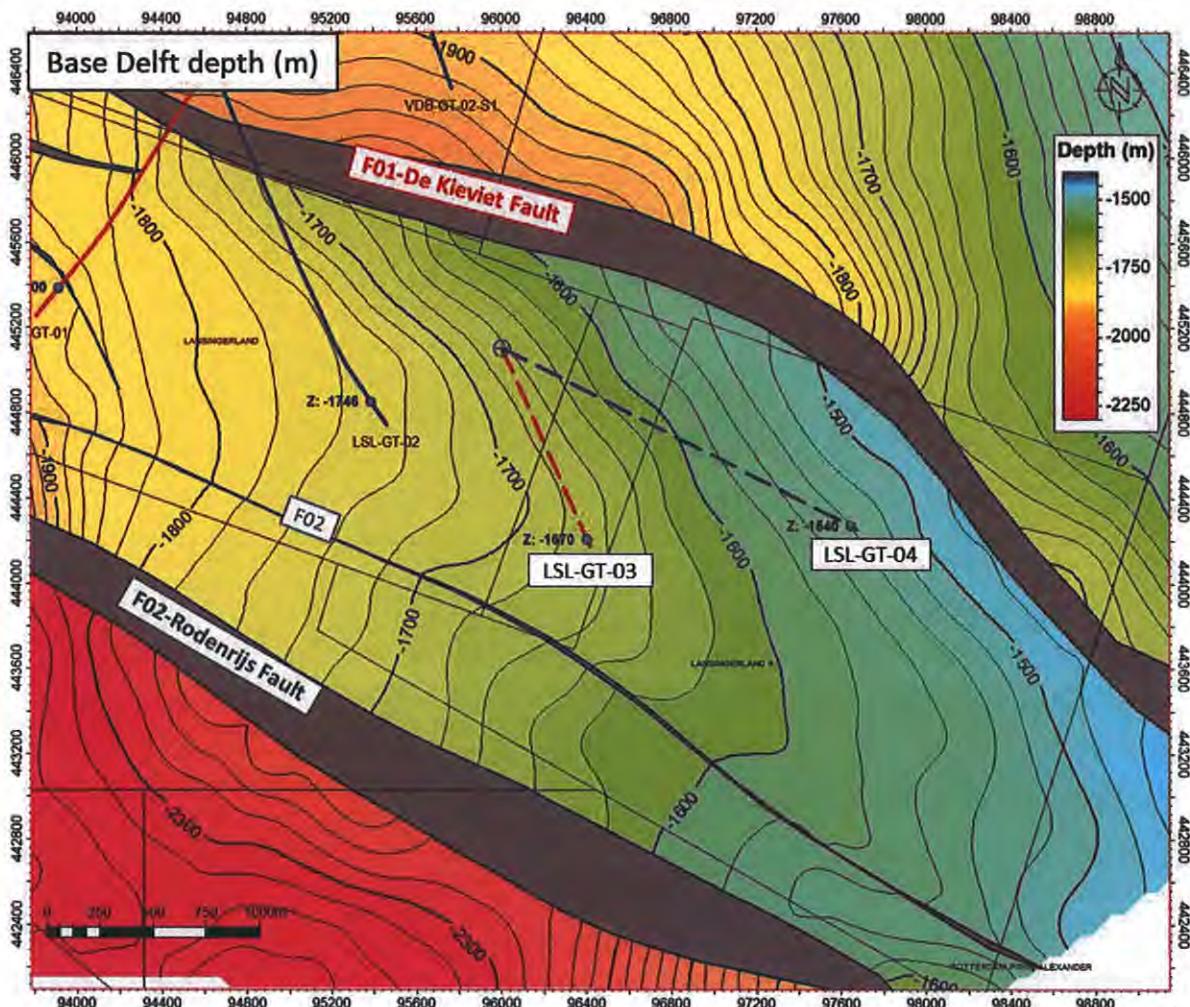


Figure 3-9 Depth map of Base Reservoir with the well trajectories of the planned wells. The point where the wells penetrate the Base Reservoir are marked by blue circles.

3.2.3 Expected Reservoir Parameters

The expected [2] reservoir parameters with uncertainty ranges are summarized in Table 3-1, Table 3-2. The P50 parameters are mainly based on recently drilled wells LSL-GT-01 and (to a lesser extent) LSL-GT-02. Given the close proximity of wells LSL-GT-01 and -02 and the extensive dataset (logs, well tests, good quality seismic data), the uncertainty of the reservoir parameters is relatively minor.

Table 3-1 Min, median and max estimates for the Berkel Reservoir. Petrophysical averages derived from the GGO Oostland [3].

Parameter	Min	Median	Max
Gross thickness (m)	41	48	55
N/G (dec)	0.8	0.9	1
Average permeability (mD)	86	371	500
K_h/K_v	-	10	-
Average Reservoir Temperature ($^{\circ}\text{C}$)	-	3.1	-

Table 3-2 Min, median and max estimates for the Delft reservoir. Petrophysical averages derived from the GGO Oostland [3].

Parameter	Min	Median	Max
Gross thickness (m)	40	50	60
N/G (dec)	0.5	0.75	0.9
Average permeability (mD)	105	800	1500
Kh/Kv	-	10	-
Average Reservoir Temperature (°C)	-	3.1	-

3.2.3.1 Temperature

A temperature gradient of 3.10°C/100m is used for the area of interest, based on the following analysis.

In the surface facilities of the VDB-GT-03 and -04 doublet, the formation water temperature in the producing well VDB-GT-03 is 64°C. As the water is expected to cool approximately 1°C to 2°C when pumped from the reservoir up to the surface, the reservoir temperature at VDB-GT-03 is approximately 65°C. Assuming this temperature corresponds to the best reservoir depth of approximately 1820 m TVD s, the linear temperature gradient is 3.02 °C/100 m with a surface temperature of 10°C. VEEGEO reported on the geothermal gradient in well LSL-GT-01 [4]. They concluded a geothermal gradient between 0.0293 and 0.0304 °C/m, which is in line with the gradient from the VDB wells. The temperature of 76.2 °C produced at the PNA-GT-01 well, assuming a mid-reservoir depth of 2175m (Delft formation), results in a temperature gradient of 3.05°C/100 m.

The well tests of VDB-GT-03/04 and LSL-GT-01/02 are performed on a combined reservoir, which has possibly caused a slight underestimation of the thermal gradient. As a comparison, a gradient of 3.10°C/100 m is reported for the nearby VDB-GT-01 well.

Temperature gradient is expected to be similar in the rest of the AOI. Therefore, to produce Temperature maps at Mid-reservoir depth of Berkel and Delft, a linear temperature gradient of 3.10°C/100m is used, and surface temperature is assumed to be 10°C resulting in mid-reservoir temperature for Berkel at 57°C and Delft 61°C (see Table 3-1 and Table 3-2).

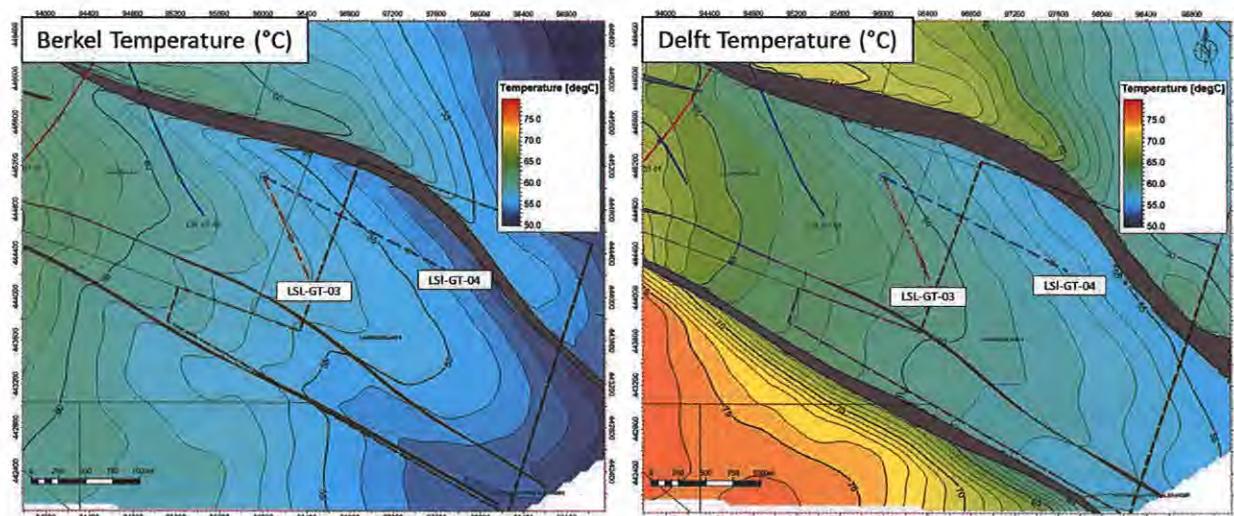


Figure 3-10 Temperature maps (°C) of Berkel and Delft at mid reservoir intervals. Green and pink dots are intersection points with the top Berkel and Delft respectively

3.2.3.2 Salinity

The composition of the formation water produced from LSL-GT-01 was measured [5]. The well produced from the Berkel Sandstone, Delft Sandstone and Alblasserdam Member. The chloride concentration in the formation water sample is 60,000 ppm which corresponds to 99,000 ppm NaCl equivalent. The measured resistivity of the water sample confirms a salinity of approximately 100,000 ppm NaCl equivalent. The well test analysis for LSL-GT-01 refers to a potential salinity over 120,000 ppm.

Formation water samples were also analysed in the four VDB-GT wells (communication by Van den Bosch, 2013). The salinity of the formation water in the Berkel and Rijswijk Sandstones is approximately 97,000 to 98,000 ppm, in the Delft Sandstone Member 104,000 to 109,000 ppm in well VDB-04. Based on these values the following salinity range is estimated for the combined Berkel and Delft Sandstone reservoir in the target area:

Table 3-3 Estimated salinities of the formation water.

	Min	Median	Max
Salinity (ppm)	90,000	100,000	120,000

3.2.3.3 Aquifer pressure

The aquifer pressure is hydrostatic; this is the experience from other geothermal doublets in the nearby area, also found in LSL-GT-01 and LSL-GT-02.

3.2.4 Pore Pressure and Fracture Gradients

The expected pore pressure and fracture gradients are based on data taken from nearby wells. LOT and pore pressure data points are from wells in the West Netherlands Basin [7] and FIT data was taken from LST-GT-01/02 and PNA-GT-05/06. The FIT data is representative of the depth and not correlated to the formations. No lateral transfer has been performed to the new location. The expected gradients can be seen in Figure 3-11. No abnormal pore or fracture pressure is expected.

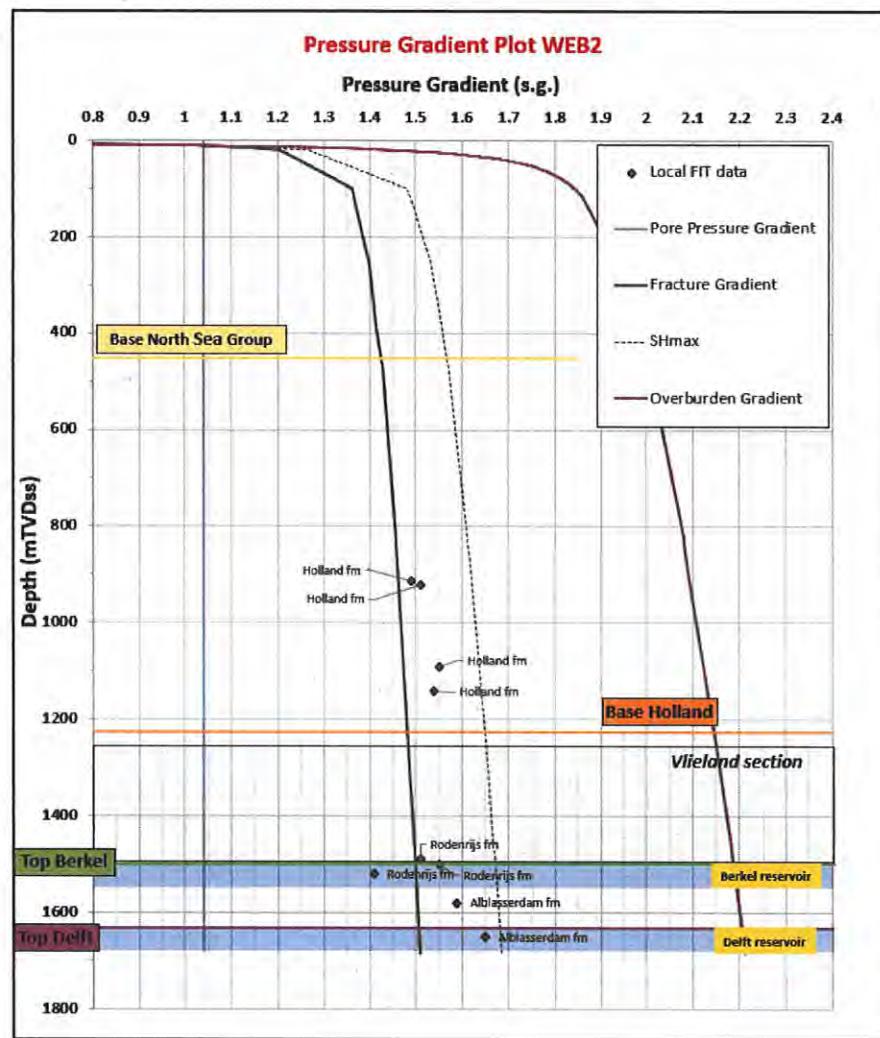


Figure 3-11 Expected pressure gradients at the target location.

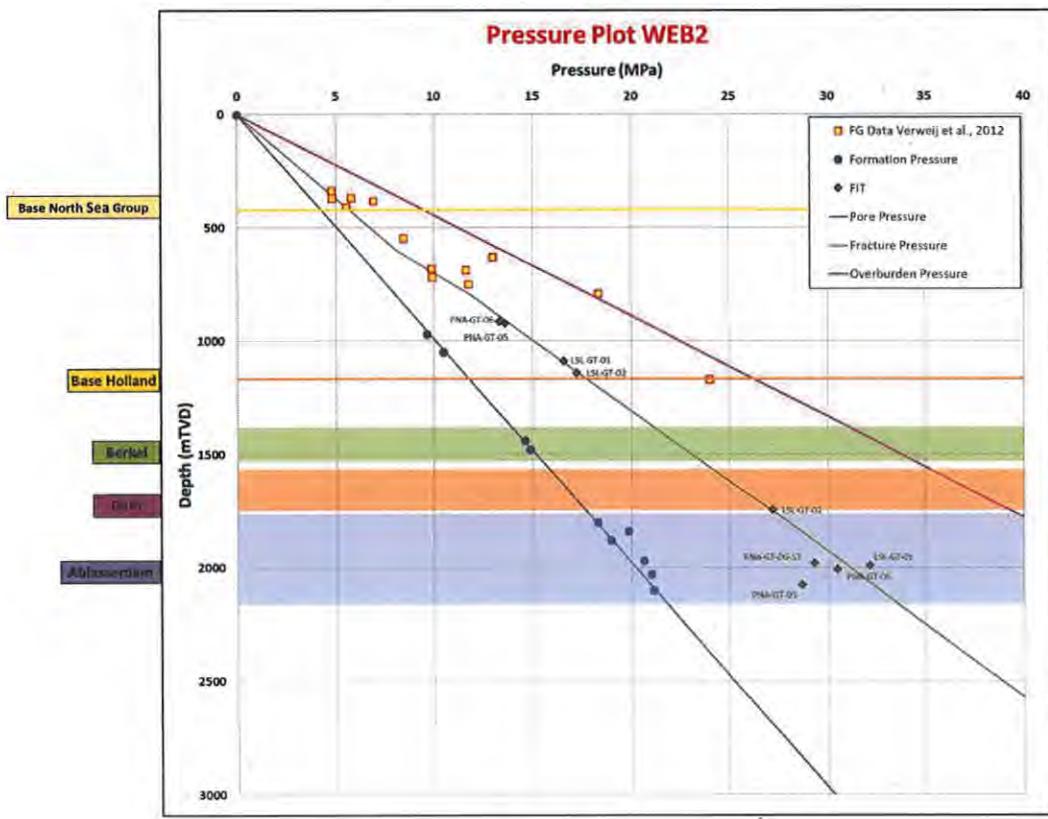


Figure 3-12 Pressure plot of the target location.

4 Conductor installation depth

A detailed investigation of the hydro-geology of the shallow subsurface (< 400 m depth below NAP, Upper North Sea Group) was carried out to define a safe conductor setting depth which isolates the wellbore from fresh water zones and which cases off the soft sediment formations which are a risk for potential washouts and cavings.

4.1 Hydrogeological properties of the shallow subsurface

A lithostratigraphic column of the Upper North Sea Group at the surface location is presented in Table 4-1. Figure 4-1 shows a NW-SE geological cross-section across the surface location. Figure 4-2 shows a detailed hydro-geological cross-section across the surface location. Figure 4-3 shows the hydrogeological properties of the shallow subsurface at the surface location. Finally, Table 4-2 shows an overview of the percentages of fresh-brackish-salt water in five aquifers in Zuid Holland.

Fresh water is expected in Aquifer 1 and 2. The first Salt dominated aquifer is the Peize/Waalre Formation with a percentage of 12% fresh water. In addition, potential washout formations occur in this zone. The first impermeable layer below fresh-water containing zones is the Second clayey unit of the Maassluis formation (MSz2, Figure 4-3). The depth of this layer is between 135 and 150 m TVDss.

Analysis of the offset wells show that the conductor depth ranges between 51 and 102m in most of the recently drilled geothermal wells (VDB-GT-01 to 04 and PNA-GT-01 to 06). The nearby wells in the Pijnacker field also had the conductor placed at 51 to 85m depth. There are no indications that these depths were unsuitable for the conductor.

Setting the conductor below the fresh water and in the bottom of the Peize/Waalre Formation at circa 100m below NAP will seal off the shallower fresh water formations. With the conductor shoe at this depth in a very low hydraulic-conductivity confining unit, there are at least two impermeable units present between the shoe and the possible freshwater aquifer. Note that the first salty aquifer is absent in the WEB2 area (Figure 4-2).

Protecting and monitoring the protection of the geohydrological base is of most importance. SodM suggests to use a double casing with a preferably monitorable annulus. If not present, an adequate monitoring should be provided. Whether the double casing found in LSL-GT-03 is fully protective of the geohydrological base and the annulus monitorable is currently under discussion. The same goes for the presence of double casing for LSL-GT-04 and the monitoring plan. This section may be updated in a future iterations of this report.

Table 4-1 Lithostratigraphic column of the Upper North Sea Group at the surface location [7].

Lithostratigraphic column upper North Sea Group							Depth (TVD)	
Era	Period	Epoch	Group	Formation	Abbreviation	Lithology	From	To
Cenozoic	Quaternary	Holocene	Upper North Sea	Naaldwijk	NA	Very fine to medium coarse sand and silty calcareous to sandy clay	0	10
				Kreftenheye	KR	Medium to coarse calcareous sand. Contains gravel	10	31
		Urk		Urk	UR	Fine to very coarse sand and gravel. Plant and wood remains	31	40
		Waalre		Waalre	WA	Cycles of silty to sandy clay. Interfingers with sandy Peize formation	40	108
	Pleistocene	Peize		Peize	PZ	Coarse to very coarse sand. Interfingers with clayey Waalre formation	108	253
		Maassluis		Maassluis	MS	Very fine to coarse calcareous sand with some clay streaks	253	380
	Tertiary	Oosterhout		Oosterhout	OO	Very fine to very coarse sand. Contains shell fragments	380	410
		Breda		Breda	BR	Marine glauconitic sands with silty to sandy clays		

Table 4-2 Overview of fresh – brackish – salt water in five aquifers in Zuid Holland [8].

Aquifer N°	Stratigraphic position	Water proportions per aquifer in 2004 (South-Holland)		
		Fresh	Brackish	Salt
1	Holocene (Naaldwijk)	-	-	-
2	Kreftenheye/Urk	40%	31%	29%
3	Peize/Waalre	12%	27%	61%
4	Maassluis	9%	16%	75%
5	Oosterhout	2%	8%	90%

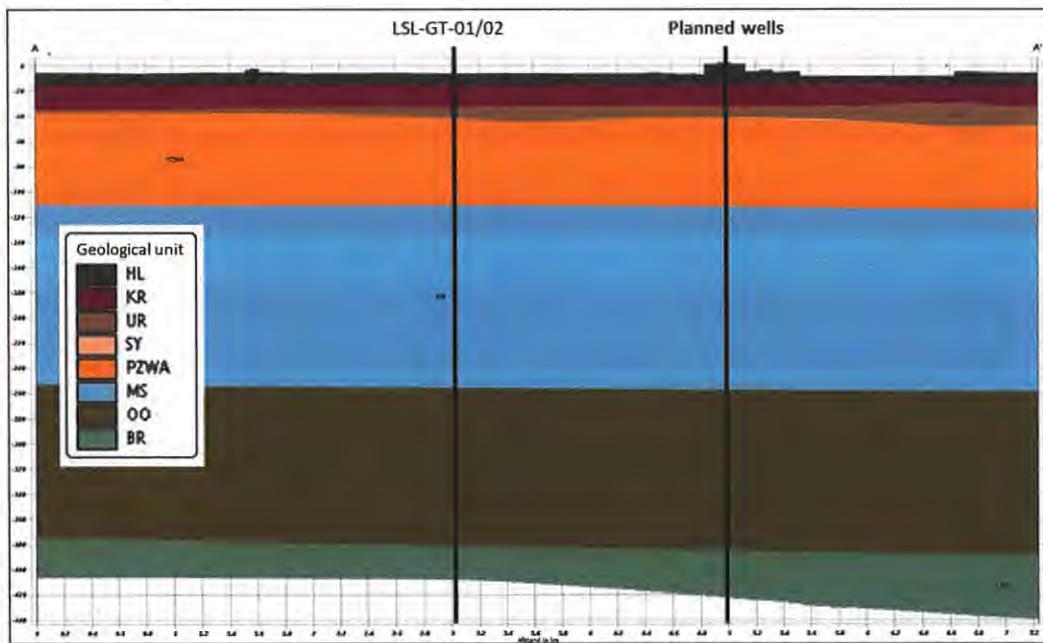


Figure 4-1 NW-SE geological cross-section (maximum depth 500m below NAP) across the surface location [9].

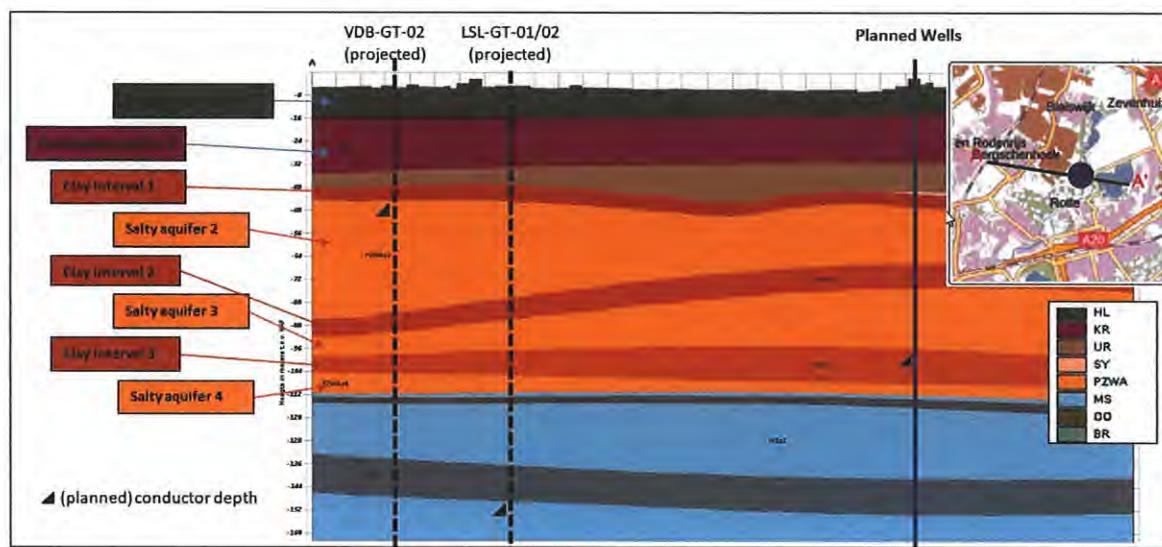


Figure 4-2 Detailed hydro-geological cross-section across the surface location [10].

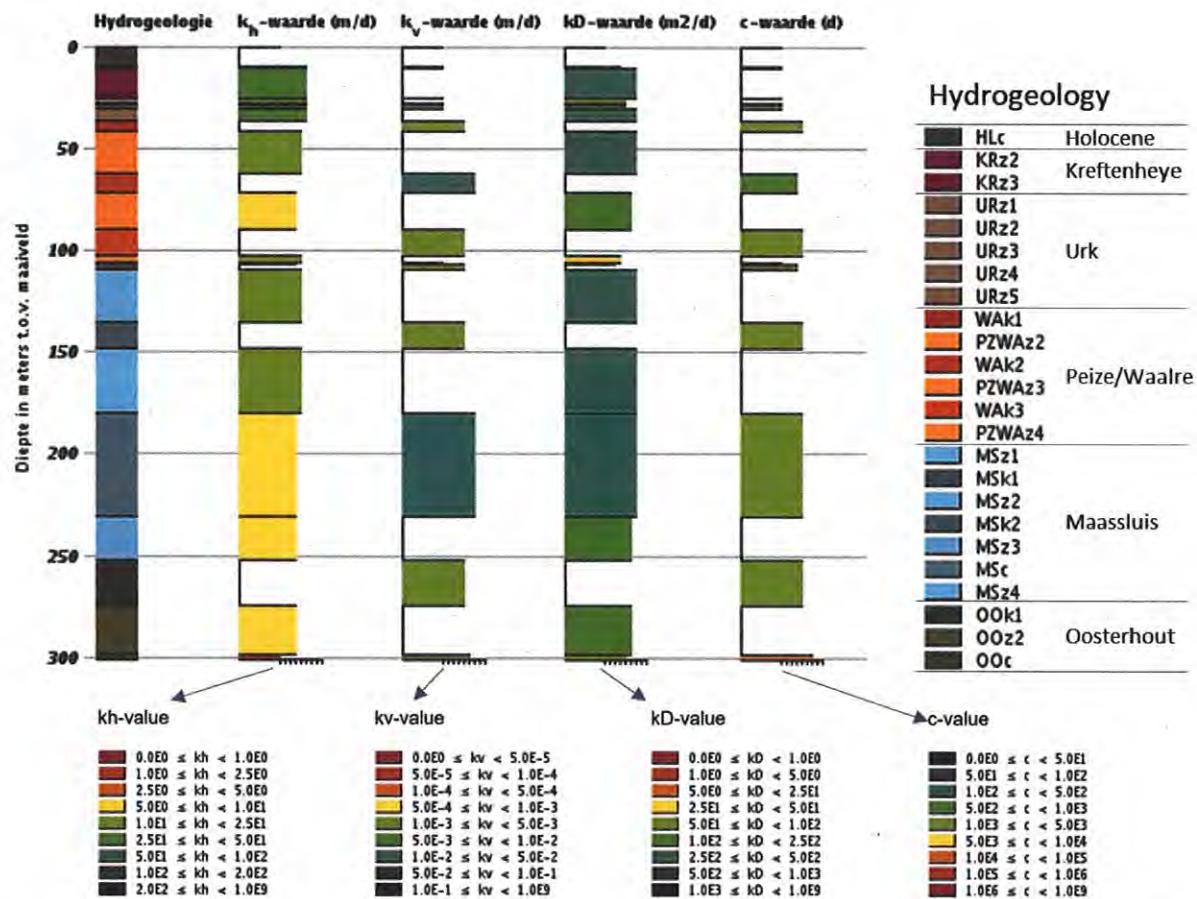


Figure 4-3 Hydro-geological properties of the shallow subsurface at the LSL-GT-03 & LSL-GT-04 surface location [10]. The shallow subsurface prediction is accurately based on abundant nearby wells.

5 Formation evaluation requirements

The development strategy of the entire fault block depends on the reservoir quality found in the first well to be drilled. Therefore, it is vital to gather sufficient data from the first well. The following chapter indicates the general concept of logging requirements. It is to be determined in more detail at a later stage.

5.1 Mud Logging

A mudlogging service provider is to be contracted to perform the standard logging of drilling parameters while drilling.

The cuttings sample interval will be:

- Once per 5 meters in the overburden
- Once per 2 meters in the reservoir section

Wet and dry samples will be packed, labelled and stored for future use:

- 2 x 0.25 kg wet
- 2 x 0.1 kg dry samples.

Formation spot samples shall be recovered on:

- Wellsite Geologist / drilling supervisor demand,
- drill breaks
- bottoms up prior and after each bit or BHA trip, and casing run
- Approaching the top of the reservoir (increasing sampling rate to at least once per 2 meter)

Total gas and gas chromatography will be continuously monitored. All gas equipment must be calibrated and checked prior each trip in hole. The calibration sheet must be available for local consultation. A master log will be digitally prepared based on measured depth (mAH); and shall include the following composite lines and text information:

- Lithology description
- Interpreted stratigraphy
- Cuttings %
- Formation tops including System – Epoch – Group – Formation – Member
- Total gas
- Gas chromatography
- ROP
- WOB
- Calcimetry
- Fluorescence
- Surveys data
- Gamma ray (from MWD)
- Drilling fluids info every 150m with: Mud weight (sg); KCl (kg/m³); Glycol (%)
- Drilling parameters info every 100m with: Flow rate (lpm); SPP (bar)
- Drill bit info every new bit, with: bit make, type, serial number (SN), IADC code, TFA, dull grading

- Casing shoe depths
- Remarks on significant drilling problems, if occurring

The master log will be updated and submitted daily to the operator representative. A TVD based master log with the same parameters will also be prepared.

The scale of the master log will be 1:1000. The reservoir section interval will be additionally plotted on a scale of 1:200.

One wet sample set is required to be sent to TNO by governmental regulations. These are to be sent to: NITG - TNO Department of Deep subsurface / Oil & Gas in Zeist.

5.2 Well Site Geology Services

In the operational phase, a wellsite geologist can provide on- or offsite support if so requested. The scope for a well site geologist can include picking casing setting depths, log analysis, quality control of the mudlogging/LWD data or completion of the End of Well Report(s).

5.3 Open Hole Logging Requirements

In the overburden no open hole logging is planned during the drilling operations (above Berkel Sandstone), except for Gamma-ray while drilling to facilitate casing setting points. Open hole logging over the reservoir sections is required to calculate the difference in quality and contribution to flow between individual sand layers. This information is essential to understand the observed behaviour while producing commingled from the entire reservoir section.

Over the reservoir sections open hole logging will be performed to evaluate the following parameters to calculate reservoir quality and interpretation of the well tests. The method of logging (LWD, pipe conveyed, wireline) will be determined at a later stage.

- Gamma Ray
- Sonic
- Formation Density
- Resistivity
- Neutron Porosity

5.4 Coring

No coring is required in this well.

5.5 Testing

Well testing will be performed after the release of the drilling rig. It will follow a dedicated Well Test Program. Separate testing of the reservoir intervals is advised to gain insight in the productivity (or injectivity) of the reservoirs.

6 Hydrocarbon risk assessment and drilling hazards

The study area is in a basin with a mature oil and gas source, the Posidonia Formation (De Jager et al. 1996) that has generated large quantities of oil and gas. Oil and gas fields are present in close proximity of the fault block (Figure 6-1). Hydrocarbons can be present in two forms: 1) oil and gas accumulations or 2) gas dissolved in formation water and oil dispersed in formation water.

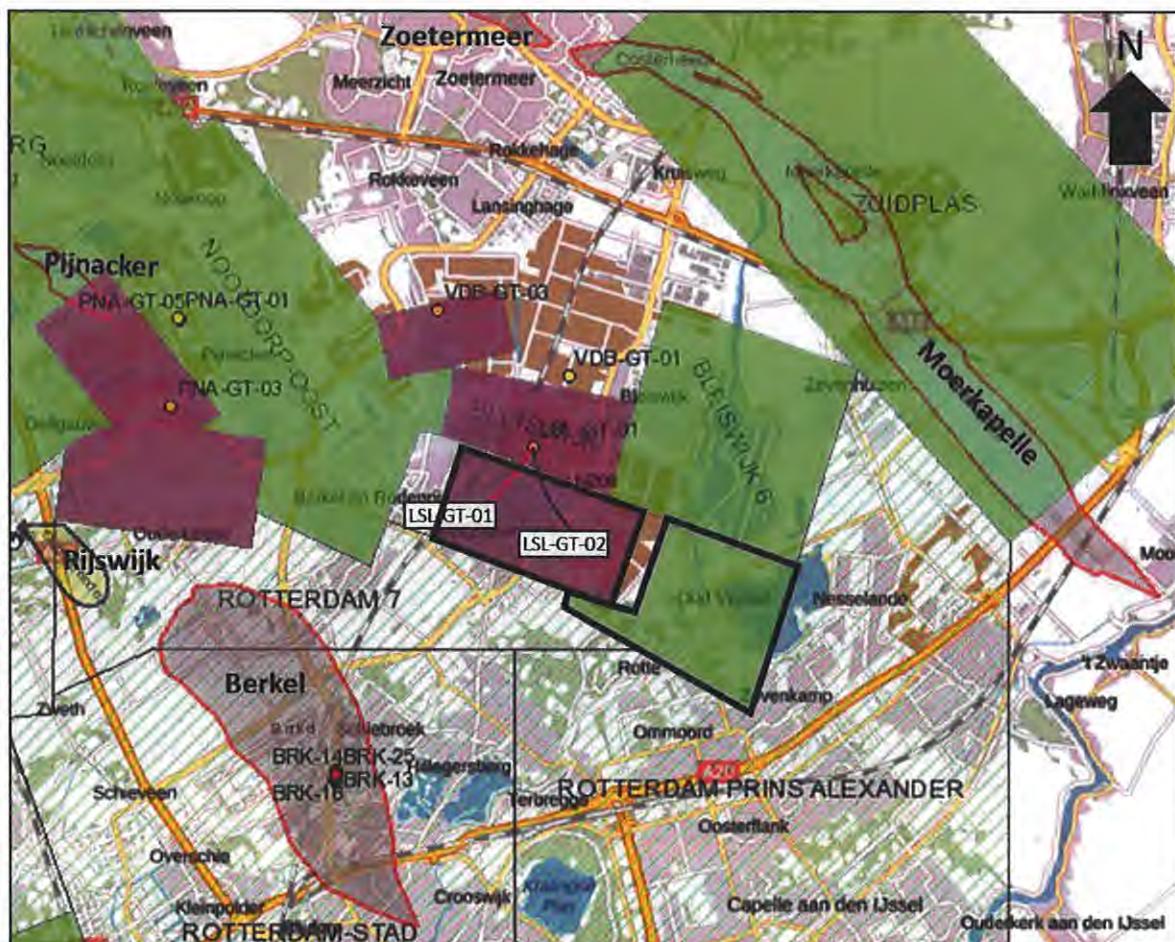


Figure 6-1 Location of the Lansingerland 1 concession (left black outline) and the Lansingerland 4 concession (right black outline) with respect to oil and gas fields (www.nlsg.nl). Pijnacker is the abandoned oil field in the Rijswijk Sandstone Member on the crest of the Pijnacker structure. Rijswijk is the abandoned oil field that produced from the Rijswijk Sandstone on the crest of the Rijswijk structure. The abandoned oilfield Moerkapelle produced from the Rijswijk Sandstone Member. The abandoned Berkel oil field produced from the Berkel Sandstone Member.

6.1 Traps with accumulations of free oil and/or gas

Several oil and gas fields exist in close proximity to the planned wells.

Table 6-1 and Figure 6-1 show the fields and the producing reservoirs. All these oil and gas discoveries were found in structural traps. Near the doublet there is no apparent structural trap and chances for finding trapped hydrocarbons are minimal.

Table 6-1 Oil- and gas fields near the Lansingerland 1 and -4 concessions.

Field	Content	Status	Reservoir
Pijnacker	Oil & Gas	Not producing	Rijswijk Sst Mbr
Rijswijk	Oil & Gas	Not producing	Rijswijk Sst Mbr & Delfland Group
Berkel	Oil & Gas	Producing	Berkel Sst Mbr & De Lier Mbr
Moerkapelle	Oil	Not producing	Rijswijk Sst Mbr & Delfland Group
Zoetermeer	Oil & Gas	Not producing	Rijswijk Sst Mbr & Delfland Group
Leidschendam	Gas	Not producing	Rijswijk Sst Mbr

The Rijswijk Member is an oil productive reservoir in the Rijswijk and Pijnacker Fields. The Berkel Member is productive in the Berkel field. In Oude Leede gas is present in the argillaceous sandstones of the De Lier Member. The De Lier Member has produced some oil and gas in the former Delft field. DEL-07 drilled in 1955 and abandoned probably in 1968 is located close to the project. It was perforated and tested in the De Lier Member. DEL-08 drilled in 1994 has oil shows in the De Lier Member and minor shows in the Rijswijk Member.

It is noted that NAM has identified a prospect over the Lansingerland concession. Wells LSL-GT-01 and LSL-GT-02 have not found any free hydrocarbons but this does not exclude the possibility of finding oil and/or gas accumulations updip, towards LSL-GT-03 & LSL-GT-04. Nevertheless, hydrocarbon accumulations near the target location are not expected since this would require a very high column to trap. In addition, no hydrocarbon indicators are seen on seismic.

6.2 Hydrocarbons dissolved dispersed in formation water

In most surrounding geothermal wells, oil and/or gas is present in the produced formation water from both the Rijswijk and the Delft Sandstone reservoirs. The sandstones of the Delft and Rijswijk Members can be carrier beds for migrating hydrocarbons. Four out of the six doublets (listed in Table 6-2) co-produce gas in quantities between 1 and 1.5 Nm³ for each produced m³ of formation water. One of the six had oil. After the completion of the first Ammerlaan doublet, production was halted temporarily in 2011 because of the presence of small amounts of oil in the production fluids (~7m³ in three weeks). Preliminary data from the new PNA-GT-05/06 doublet also shows between 1 and 1.5 Nm³. For the new doublet the chances of producing dissolved gas is significant, but the volumes will be minor. Oil is not expected. The welltest analysis of LSL-GT-01 showed 1 Nm³/m³ which was also confirmed by the downhole samples.

Table 6-2 Hydrocarbon observations in nearby geothermal doublets. Data from Bakker (2010) and other sources (including personal communication Ammerlaan). *Preliminary result

Geothermal doublet	Normalized volume of gas per volume of produced water
Den Haag	1.5 Nm ³ /m ³
PNA-GT-01 and -02	0.5 Nm ³ /m ³ ; small amounts of oil are present
PNA-GT-03 and -04	1 Nm ³ /m ³
PNA-GT-05 and -06*	1-1.5 Nm ³ /m ³
VDB-01, -02, 03, 04	Traces
HON-GT-01 and -02	1 to 1.5 Nm ³ /m ³
LSL-GT-01 and -02	1 Nm ³ /m ³

6.3 Drilling hazards

Figure 3-1 lists potential drilling hazards that could be incurred while drilling LSL-GT-03 and -04 wells. Review of the available well reports of the nearby geothermal wells has concluded that majority of the wells have been drilled without encountering drilling problems. It is noted that while drilling well PNA-GT-03-S2 there have been mud losses reported at 945m (MD) within Texel marlstone Member formation. However this may not be the case in WEB2 wells as those are located in the fault block further north from the PNA-GT-03-S2 well. Wells LSL-GT-01 and -02 experienced some tight spots while drilling, which could be linked to swelling clays.

The well path for both wells is crossing a fault in the Holland Formation. The fault crossings might give problems with losses or hole stability. A study to investigate the stability of the borehole is currently in its final stages and the conclusions will be used to update this report in the future.

7 Stress Regime

7.1 Current stress field

The map in Figure 7-1 shows the location of the WEB2 area with respect to the nearest in-situ stress measurements interpreted in the Netherlands. These measurements represent the orientation of the maximum horizontal stress, SH, interpreted from well data in a number of formations.

Only one stress measurement is available from the Schieland Group; 340 ± 20 degrees (Figure 7-1). The average SH from all measurements available surrounding the target area is about 320 ± 20 degrees.

Major faults in the WEB2 area as displayed in Figure 3-4 to Figure 3-9 strike 310 ± 20 degrees (NW). The angle between fault lineaments and maximum horizontal stresses in the WEB2 area is thus 10 ± 40 degrees and hereby covers the range in which stress orientation on faults is suitable for reactivation (10 to 30 degrees; (Nieuwland, 2012)).

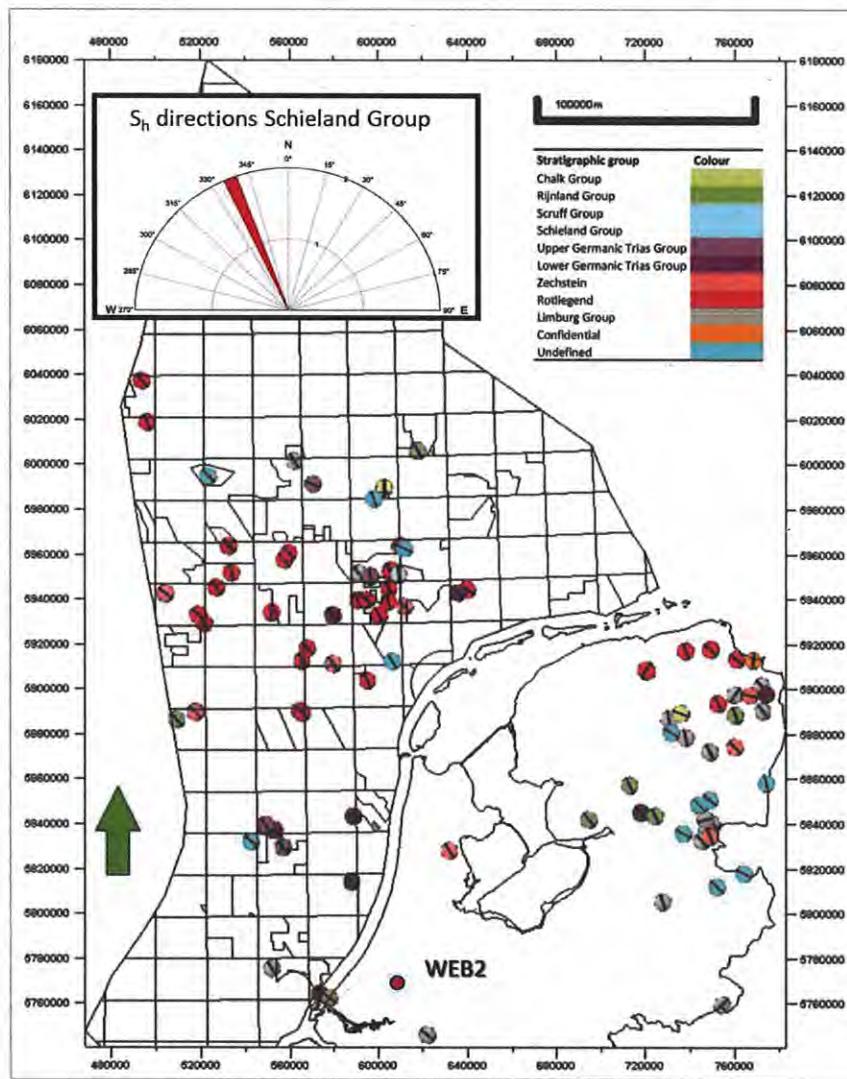


Figure 7-1 Dutch Stress Map data (DSM) presented by Mechelse (2017). The coloured circles show the orientation of average S_H per stratigraphic Group. The inlay shows the rose diagram of all the Dutch Schieland measurements.

8 Seismic risk

The risk of induced seismicity in relation to geothermal exploration is influenced by a number of factors. These primarily include pressure management of the (doublet) system, the vicinity and properties of local faults and the stress state of the subsurface. A Level-1 SHA assessment based on the IF & Q-Con a [10] and SodM [11] has been performed for which the risk of the WEB2 doublet is assessed as **low** [12].

When seismicity occurs, it originates at a local point of weakness i.e. a fracture or fault. Larger faults (length of more than ~ 1 km) can be identified on seismic. Smaller faults may still be related to seismicity, but the possible magnitudes involved decrease. For the target reservoirs a number of significant faults have been mapped. However, the target location is situated between the two main faults, greatly diminishing the related risk.

As long as a pressure balance is maintained, the associated risk will also be low. This will roughly mean that injection rate equals production rate. The injection pressure is prognosed to exceed the standards set by SodM and additional fracture containment studies are being performed, prognosed to be finalised in March 2020. Based on the seismic interpretation at the target location also no faults or other barriers are expected which needs to be confirmed by an interference test.

In summary, based on the criteria generally applied to assess seismic risk, the risk for the Berkel and Delft under Bergschenhoek is **low**.

9 Nederlandse samenvatting

Dit rapport geeft inzicht in de geologische aspecten die van belang zijn bij het boren van twee geothermische putten bij Bergschenhoek in het project Wayland Energy Bergschenhoek 2 (WEB2). In 2017 zijn er twee geothermische putten (LSL-GT-01 en LSL-GT-02) succesvol geboord in de naastliggende productie licentie Lansingerland 1 door Wayland Energy. Wayland Energy heeft plannen voor twee nieuwe putten iets verderop in oostelijke richting, namelijk productie put LSL-GT-03 en injectie put LSL-GT-04 (Figure 1-1). Het Geologische Evaluatie rapport, welke is geschreven ter voorbereiding van aardwarmte winning in dit gebied, ligt ten grondslag aan het put ontwerp proces. De geproduceerde warmte zal worden gebruikt voor het verwarmen van kassen.

De geplande putten worden geboord in een breukblok in het West Nederland Bekken, net als de nabijgelegen putten LSL-GT-01 en LSL-GT-02. De putten boren door sedimenten van Tertiaire tot Jura ouderdom. De doublets zullen parallel aan de oriëntatie van de grote breuken geplaatst worden om de kans op breuken tussen de putten te verkleinen en daarmee een goede connectie tussen de putten te waarborgen. De reservoirs waaraan de warmte onttrokken zal worden zijn de zandstenen van de Berkel en Delft Formaties, welke beide betrouwbare reservoirs zijn voor geothermie. De Berkel en Delft zandstenen liggen relatief diep in het breuk blok en zijn te vinden op een diepte van ongeveer 1400-1650m TVDss (zie Figure 3-5 en Figure 3-6). Deze twee reservoirs worden gescheiden door een dun interval dat bestaat uit de Berkel klei en zandsteen en de Rodenrijs schalie (zie Figure 3-2). De Rijswijk zandsteen kan aanwezig zijn als een dunne zandsteen, maar is moeilijk te onderscheiden van de Berkel klei en zandsteen en daarom in dit pakket meegenomen. De beoogde coördinaten in het reservoir voor beide putten zijn terug te vinden in de Appendices A en B.

De reservoir parameters in dit document gelden voor het gehele breukblok en zijn terug te vinden in Table 3-1 en Table 3-2. Een temperatuur gradiënt van $3.10^{\circ}\text{C}/100\text{m}$ is gebruikt in de ondergrond gebaseerd op de nabijgelegen VDB-GT-01 put. Deze gradiënt is iets hoger in vergelijking met de gradiënt in putten LSL-GT-01/02 en VDB-GT-03/04. Dit komt doordat in de twee laatst genoemde doublets er geproduceerd wordt uit verschillende reservoir combinaties wat een exacte bepaling van de temperatuur gradiënt moeilijk maakt. De verwachtte saliniteit ligt tussen de 90 en 120 kppm NaCl equivalent gebaseerd op data van LSL-GT-01 en de vier nabijgelegen VDB-GT putten. Er wordt geen afwijkende hydrostatische druk verwacht na analyse van de lokale LOT en FIT data (zie Figure 3-11 en Figure 3-12).

Na analyse van de hydro-geologie van de ondiepe ondergrond is een optimale conductor diepte vastgesteld om de put van schoon oppervlakte water te scheiden en om risico's met uitspoelingen en verontreiniging in de bovenliggende zachte sedimenten te vermijden (Figure 4-2). SodM heeft een dubbele casing met een te monitoren annulus voorgesteld.

Het toekomstige geothermisch potentieel in dit breukblok hangt af van de resultaten van de eerste put, en daarom is het cruciaal dat voldoende gegevens worden verzameld tijdens het boren (zie hoofdstuk 5 voor meer details).

In de nabijheid van beide putten bevinden zich verschillende gedepleteerde olie- en gasvelden

Table 6-1 en Figure 6-1). Deze velden bevinden zich in opgeheven structuren in de ondergrond (d.w.z. 'structural traps'), maar in de omgeving van het geplande doublet zijn deze afwezig. Ook de structurele dieptekaarten die van de verschillende reservoirs zijn gemaakt rondom het geplande doublet laten geen structural traps zien. Daarom wordt de kans op het vinden van olie- of gas accumulaties klein geacht. Olie en gas kan echter ook opgelost in water voorkomen. In vier van de zes doublets genoemd in Table 6-2 werd 1-1.5 Nm³ gas geproduceerd per 1 m³ geproduceerd water. Daarom wordt verwacht dat ook gas geproduceerd zal worden door de geplande doublet in ongeveer dezelfde kleine hoeveelheden. Ter vergelijking, uit gegevens van put LSL-GT-01 blijkt dat deze rond de 1 Nm³/m³ gas produceert.

Uit de gegevens van de beschikbare rapporten van de nabijgelegen geothermische putten komt naar voren dat er geen problemen zijn ondervonden tijdens het boren die schade zouden kunnen aanrichten aan het milieu. In Figure 3-1 zijn de potentiële risico's die kunnen voorkomen tijdens het boren van LSL-GT-03 en -04 aangegeven. Het tracé van beide putten kruist een breuk in de Holland Formatie. Ook is er rekening gehouden met de maximale horizontale stress oriëntatie in de WEB2 omgeving bij het plannen van beide putten om risico's bij mogelijke breuk re-activatie te vermijden (Figure 7-1). Daarnaast is het risico op geïnduceerde seismiciteit laag voor het WEB2 doublet [12]. Dit komt naar voren uit de Level-1 SHA assessment uitgevoerd volgens het IF & Q-Con [10] en SodM [11] protocol.

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- [12] PanTerra, "Seismic Hazard Analysis (Quick-Scan)," 2020.
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- [14] PanTerra, Petrophysical evaluation LSL-GT-01, (PanTerra project G1335).

Appendix A – Downhole target LSL-GT-03

Well LSL-GT-03 will be the producer. Together with well LSL-GT-04 (injector) it will form a doublet. Coordinates are listed in Table 10-1. Well TD is 50m MD below the base reservoir.

Table 10-1 Coordinates of the surface location, the top and base reservoir, and TD location of the planned well LSL-GT-03.

LSL-GT-03 Producer (Planned)	Coordinates		Depths	
	X (RD)	Y (RD)	TVDss (m)	MD (m)
Surface location	96003.00	445106.00	-3	0
Base North Sea Group	96003.00	445106.00	450	453
Base Holland	96069.38	444956.90	1225	1268
Top Berkel	96254.98	444540.04	1498	1805
Base Berkel	96298.76	444441.72	1548	1923
Top Delft	96359.75	444304.73	1618	2089
Base Delft	96404.82	444203.49	1670	2212
TD	96422.93	444162.83	1691	2262
KOP	96003.00	445106.00	500	800.00
EOB	96179.65	444709.24	1100	1600.00

Table 10-1 shows the surface and subsurface coordinates for the planned well. On completion of the first well, subsurface targets may be revised and well trajectories adjusted accordingly.

Appendix B – Downhole target LSL-GT-04

Well LSL-GT-04 (injector) is the second well to be drilled. Together with well LSL-GT-03 (producer) it will form a doublet. Coordinates are listed in Table 10-2. Well TD is 50m MD below the base reservoir.

Table 10-2 Coordinates of the surface location, the top and base reservoir, and TD location of the planned well LSL-GT-04.

LSL-GT-04 Injector (Planned)	Coordinates		Depths	
	X (RD)	Y (RD)	TVDss (m)	MD (m)
Surface location	96003.00	445106.00	-3	0
Base North Sea Group	96005.23	445104.86	450	453
Base Holland	96861.39	444668.63	1178	1736
Top Berkel	97346.40	444421.50	1402	2324
Base Berkel	97437.64	444375.02	1444	2434
Top Delft	97539.49	444323.12	1491	2558
Base Delft	97645.42	444269.15	1540	2686
TD	97686.61	444248.16	1559	2736
KOP	96003.00	445106.00	397	400
EOB	96337.89	444935.36	935	1099

Table 10-2 shows the surface and subsurface coordinates for the planned well. On completion of the first well, subsurface targets may be revised and well trajectories adjusted accordingly.



BILAGE 5



Seismic Hazard Analysis (Quick-Scan) WEB2

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PanTerra Project 2000043

WEB2 SHA

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1 Samenvatting

Wayland Energy B.V. (**Wayland**) heeft PanTerra Geoconsultants B.V. (**PanTerra**) gevraagd een Level-1 (Quick-Scan of **QS**) Seismic Hazard Analysis (**SHA**) uit te voeren waarin de risico's op seismiciteit bij geothermische exploratie worden omschreven en gekwantificeerd. In deze SRA worden de risico's op seismiciteit bij geothermische exploratie omschreven en gekwantificeerd. Dit wordt gedaan op basis van het protocol "Defining the Framework for Seismic Hazard Assessment in Geothermal Projects 5 V0.1" (IF-Technology & Q-con, 2016) en de leidraad "Methodiek voor risicoanalyse omtrent geïnduceerde bevingen door gaswinning, tijdelijke leidraad voor adressering" (SodM, 2016). Dit rapport beschrijft de resultaten uitgerekend voor WEB2, bestaande uit producer LSL-GT-03 en injector LSL-GT-04. Het is gebaseerd op de seismische interpretatie zoals beschreven in "Geological Study Oostland, PanTerra, 2020", de reservoir parameters uit het SDE+ rapport (PanTerra, SDE+ Bergschenhoek 2 – 2018 Update, G1330C, 2018) en de meest recente putpaden (PanTerra, Geological Evaluation for project WEB2, 2020). Het eventuele seismische risico dat wordt toegeschreven aan de afkoeling van het geothermisch reservoir wordt in dit rapport niet behandeld.

Het IF/Q-CON protocol beschrijft een aantal criteria die bepalend zijn voor seismisch risico. Deze parameters zijn voor WEB2 beoordeeld en zijn een score toegewezen. In de scoringsmatrix, gepresenteerd in tabel 1-1, staan de resultaten. De genormaliseerde score is 0.30 en wordt geassocieerd met een laag risico. Ook op basis van de leidraad van SodM kan worden geconcludeerd dat het risico voor WEB2 zeer klein is en geen verder onderzoek vereist is.

Geïnduceerde seismiciteit wordt veroorzaakt door een verandering in de lokale stress (druk) situatie. Deze stresssituatie wordt beïnvloed door poro-elastische en thermo-elastische effecten. De drukverandering gerelateerd aan de poro-elastische effecten, treedt voornamelijk op nabij de productieput (drukafname) en de injectieput (druktoename) en neemt snel af naarmate de afstand tot de putten groter wordt. Na initiële productie treedt een equilibrium op omdat de geïnjecteerde en geproduceerde volumes gelijk zijn. Als tijdens deze initiële periode geen seismiciteit optreedt, is het geassocieerde risico zeer klein geworden. Voor WEB2 moeten de boringen nog plaats vinden, maar bij productie binnen de gestelde productierichtlijnen van SodM, worden geen problemen verwacht. De effecten van de afkoeling van het reservoir, de thermo-elastische effecten zoals compactie, zijn niet meegenomen in de methodieken van IF/QCON en SodM en als zodanig niet onderzocht in deze studie.

Tabel 1-1. SRA score kaart voor WEB2. De score resultaten zijn met rood aangegeven.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Flow rate [m³/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]	Sum of column scores	Normalized score
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		
Column Score	0	0	3	10	0	0	7	7	0	27	0.30

Voor WEB2 is het noodzakelijk massabalans (gelijke injectie en productie) te handhaven en om te monitoren gedurende productie. Daarnaast is het van belang om de nieuwe putten zo ver mogelijk van de gekarteerde breuken te plannen en om na boring interferentietests uit te voeren. Hiermee kan worden bepaald of er mogelijk onvoorziene drukverschillen in het reservoir kunnen optreden. Het is mogelijk dat een of meer breuken met een klein (sub-seismisch) verzet niet in kaart zijn gebracht.

2 Summary

Wayland Energy B.V. (**Wayland**) has requested PanTerra Geoconsultants B.V. (**PanTerra**) to perform a Level-1 (Quick-Scan or **QS**) of the Seismic Hazard Analysis (**SHA**) to assess and quantify the risks of seismicity during geothermal exploration. This has been done on the basis of the protocol “Defining the Framework for Seismic Hazard Assessment in Geothermal Projects 5 V0.1” (IF-Technology & Q-con, 2016) and the guideline “Methodiek voor risicoanalyse omtrent geïnduceerde bevingen door gaswinning, tijdelijke leidraad voor adressering” (SodM, 2016). This SRA report describes the results as they have been established for the project WEB2, consisting of producer LSL-GT-03 and injector LSL-GT-04. It is based on the seismic interpretation of the “Geological Study Oostland”, PanTerra, 2020, the reservoir parameters as described in the SDE+ report (PanTerra, SDE+ Bergschenhoek 2 – 2018 Update, G1330C, 2018) and most recent well trajectories (PanTerra, Geological Evaluation for project WEB2, 2020). The risk associated to the effects of cooling of the geothermal reservoir have not been addressed in this report.

The IF/Q-CON framework describes a number of criteria which control seismic risk. For WEB2, each of these parameters have been evaluated. The results are presented in a scoring table where the scores for the individual criteria are normalised (Table 2-1). The resulting weighted score is 0.30 which, according to the IF/QCON framework is associated with low risk. Similarly, the SodM criteria indicate low risk and do not warrant further investigation.

Induced seismicity is triggered by a change in the in-situ stress state. The stress state of the geothermal reservoir is affected by poroelastic and thermoelastic effects. The pressure changes related to poroelastic effects occur mainly near the production (decrease) and injection (increase) well and decreases rapidly away from the wells. After initial production an equilibrium will be established because there is a balance between the injected and produced volumes. If no seismicity has occurred during that initial stage, risk is greatly reduced. Operation within the guidelines set by SodM is not expected to result in problems. The risk of seismicity related to the thermoelastic effects in geothermal applications has not been considered in the IF/QCON and SodM methodologies and have therefore not been investigated in this report.

Table 2-1 SRA scoring scheme for WEB2. The applicable scores are highlighted in red.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Flow 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 [$1000 m^3$]	Sum of column scores	Normalized score
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		
Column Score	0	0	3	10	0	0	7	7	0	27	0.30

It is key for WEB2 to maintain mass balance as to not build up or reduce reservoir pressure. The wells should be situated as far away from any known faults as possible. Interference well tests are also recommended for the new wells. Well tests can show whether intra-well communication is good (which avoids pressure differentials). It is possible that one or more lower-offset faults have not been mapped. Seismic monitoring will remain key, during initial production of new doublets, but also over the lifespan of the doublets.

3 Introduction

Wayland has commissioned PanTerra Geoconsultants to execute a quickscan study on the risk of induced seismicity by geothermal operations of the WEB2 doublet. The doublet will be drilled east of the existing WEB1 doublet (SL-GT-01 and -02), in the Lansingerland 4 exploration licence (Figure 3-1). The target reservoir comprises the Berkel and Delft sandstones in the Rijnland and Schieland Groups.



Figure 3-1. Location of the planned WEB2 doublet (LSL-GT-03 and -04) with respect to geothermal licenses Lansingerland and Lansingerland 4 and doublet WEB1 (LSL-GT-01 and -02).

3.1 Guidelines for geothermal projects

A decision tree has been made by IF/Q-CON (IF-Technology & Q-con, 2016) which is presented in Figure 3-2. The decision tree contains three levels where the highest level is applicable to the highest risk category. This report will touch upon all the aspects described under Level 1 for the geothermal area. In case the conclusions of this report warrant a progression to Level 2, further work is needed, but this will then be worked out in a separate report.

For WEB2, the first three considerations described in Level 1 as well as the last do not need extensive explanation. As Figure 3-4 shows, no major fault zones are present within 100 m of the doublets. Also,

the Roer Valley Graben (RVG) and the Groningen gasfield are far removed from WEB2. Lastly, as will also be described below, no previous seismicity, natural or induced, previously occurred in the geothermal project area.

The criteria on the QS scoring table are individually discussed in section 4.1 to justify the scores given in Table 4-1.

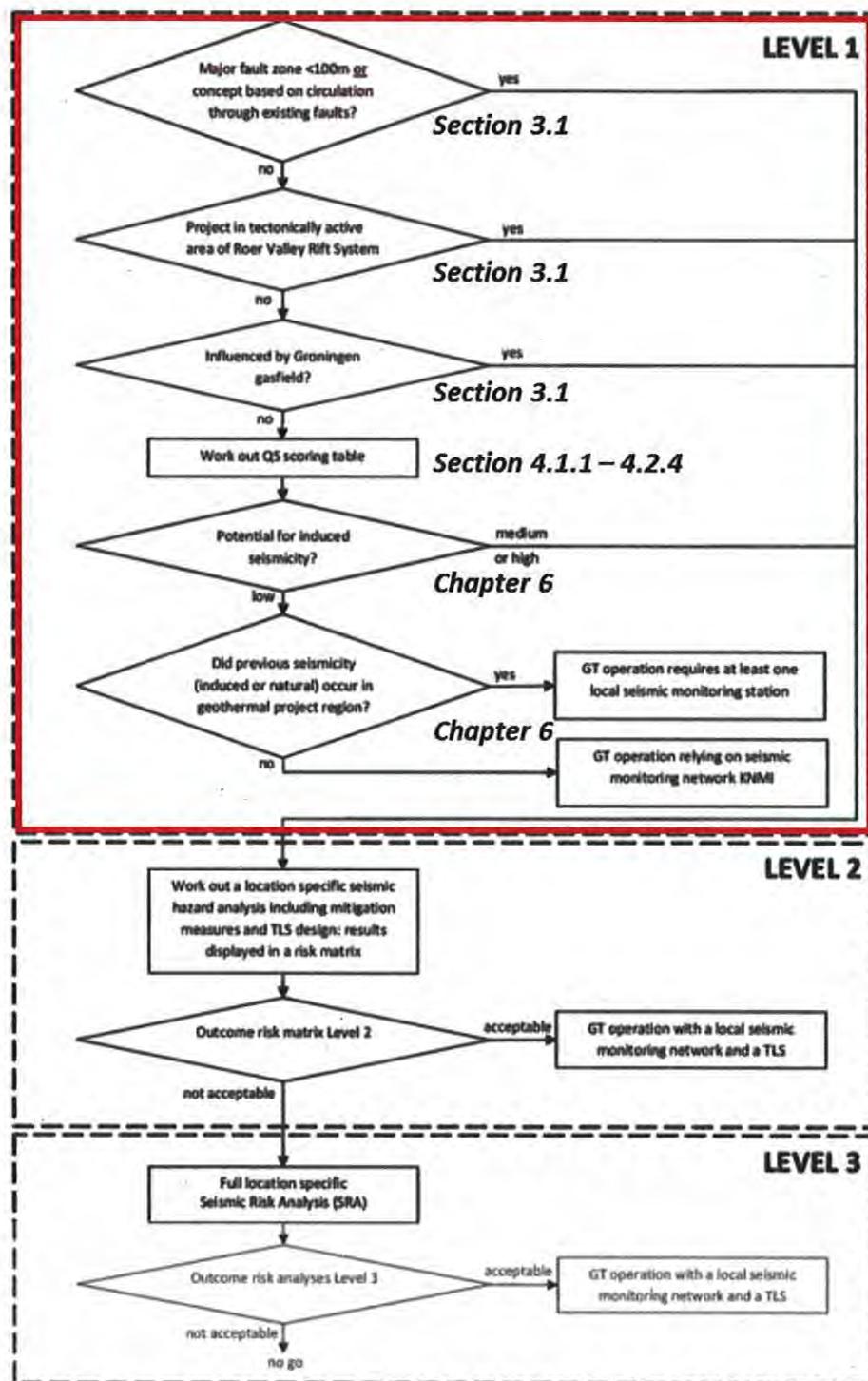


Figure 3-2. Decision tree as presented in the report by IF/Q-CON. In this report only Level 1 (red outline) is covered. The sections in which each of the elements are discussed are added in the figure. TLS stands for Traffic Light System.

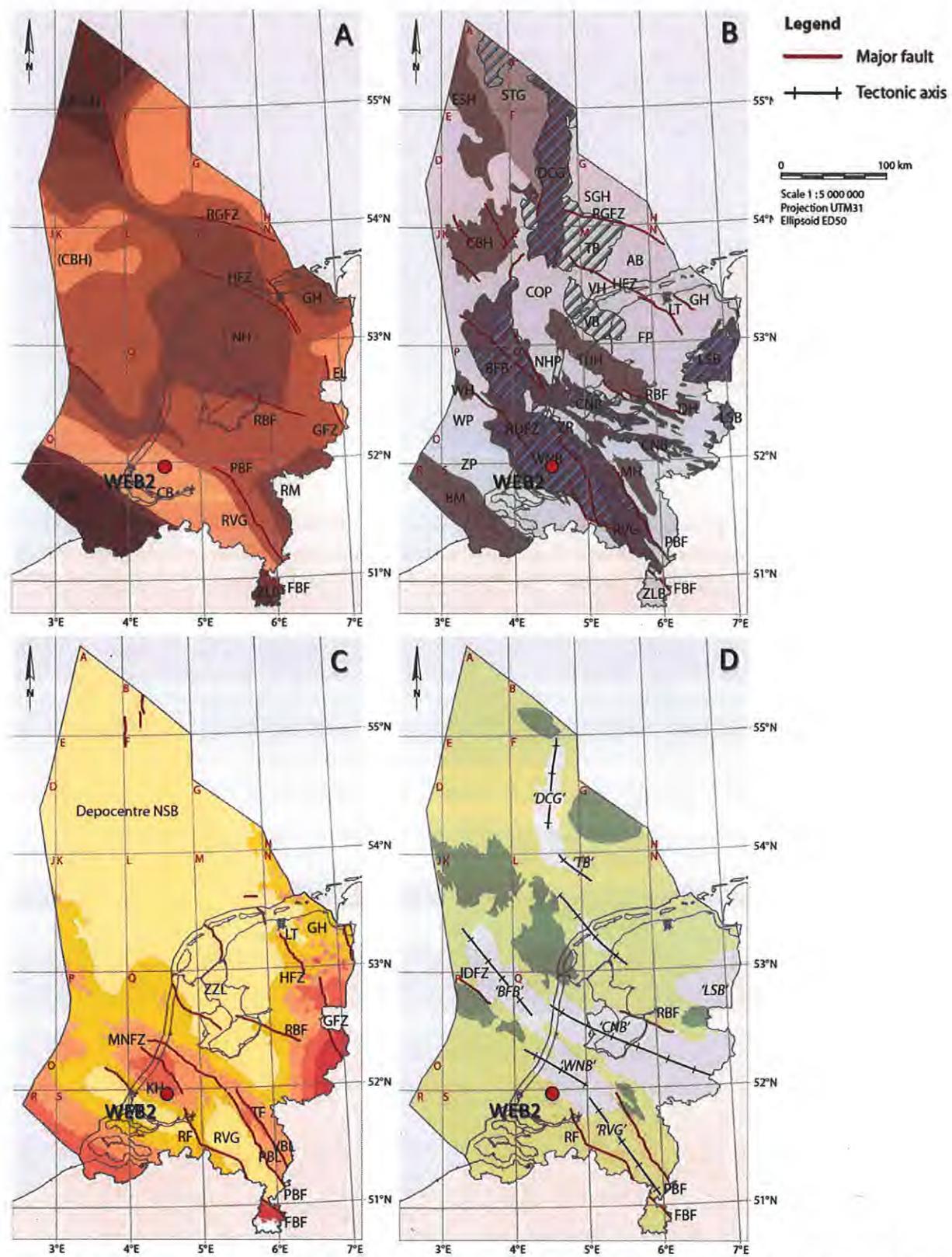


Figure 3-3. Structural elements and major fault zones as present during the Variscan (A), Late Jurassic-Early Cretaceous (B), Late Cretaceous-Early Tertiary (C) and Cenozoic (D) (Duin, 2006).

3.2 Guidelines for gas production (SodM)

The guidelines are focussed on the risks involved with gas production (SodM, 2016). As such, the methodology proposed involves the effects of (future) gas production on the reservoir. Since no free gas is expected in the target reservoirs of WEB2, these guidelines have limited applicability and will therefore not be discussed extensively in this report.

Figure 3-4 shows a decision tree based on the document made by SodM. This report only describes the considerations included in step 1 (Level 1), when the outcome warrants progression to step 2 (Level 2) this will be described in a separate report.

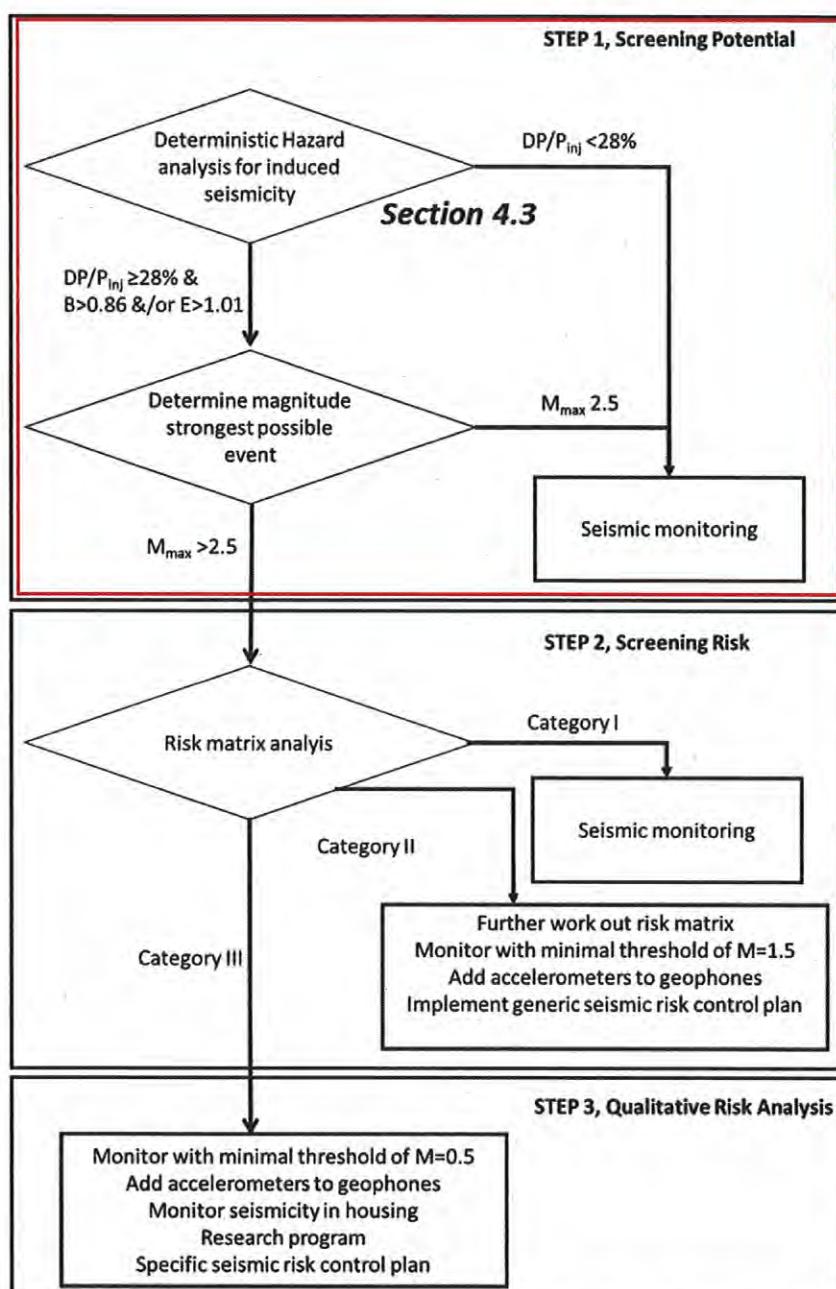


Figure 3-4. Adapted decision tree (SodM, 2013). In this report only Level 1 (red outline) is covered. The sections in which each of the elements are discussed are added in the figure. The definitions of the parameters are discussed in section 4.2.

4 Results

4.1 SHA scoring schema (IF/QCON)

4.1.1 Basement connection

Since the basement (crystalline crust) is indicated as being in a critical stress state by various authors, a hydraulic connection between the geothermal reservoir and the basement could be hazardous. The largest magnitude seismic events in Europe are connected to geothermal activity in basement rock (IF-Technology & Q-con, 2016).

In the Netherlands until this date, no geothermal project has been drilled to, or is connected to basement rock. The depth of the basement is poorly constrained. An estimate of the depth of the basement is derived from a map of the top of the pre-Silesian presented by Geluk et al. in 2007 (Figure 4-1). At WEB2, the basement is present at a depth of approximately 7 km, more than 5 km below the target reservoir which is present at around 1650 mTVDss (Figure 4-2). A hydraulic connection between the basement and target reservoir is theoretically possible through faults. Pressure communication between the reservoirs and the basement is highly unlikely given the > 5000 m separation between the reservoir and the basement and the inactivity of faults in the area. WEB2 scores "0" on basement connection (see Table 5-1).

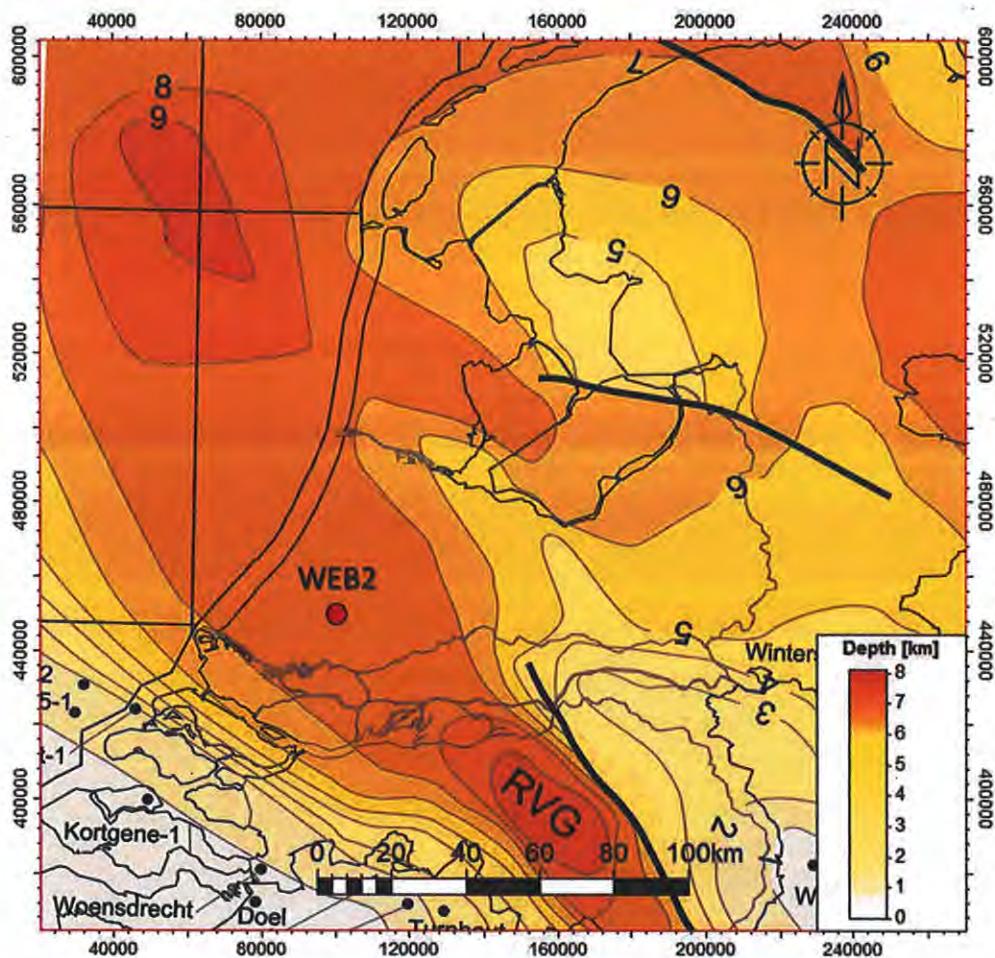


Figure 4-1. Top of the pre-Silesian (Geluk, 2007). The contours represent kilometres of depth.

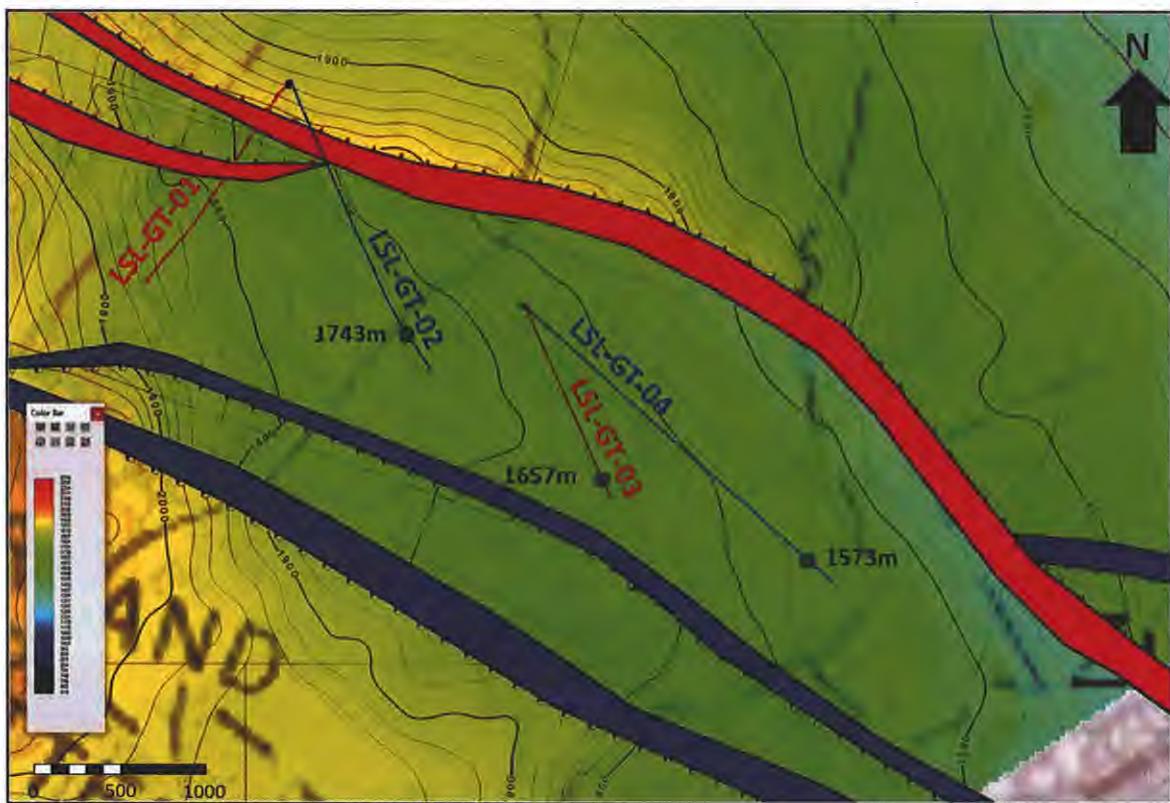


Figure 4-2. Delft mid-reservoir depth map. Fault polygons are displayed in red and blue (PanTerra, Geological Evaluation for project WEB2, 2020).

4.1.2 Inter-well Pressure Communication

The interpreted faults as shown in Figure 4-2 do not cross or cut-off any of the doublet well pairs. The dominant fault orientation is parallel to the direction of circulation. Possible subseismic faults are unlikely to be sealing since the reservoir thickness is greater than the seismic resolution.

The target reservoirs are permeable (approximately 600 mD) with a net to gross of 70 to 90%. Well connectivity is therefore expected to be excellent. This is confirmed by the successful interference test and production of doublet WEB1 (LSL-GT-01 and -02) (Lingen, 2018).

Pressure communication is vital for the planned doublet. In case that there is no pressure communication between the wells, the project would not be viable. According to the scoring guidelines, the inter-well pressure communication is scored as “yes” (0, see Table 5-1).

4.1.3 Re-injection Pressure

The expected injection pressure at WEB2 is calculated with DoubletCalc v1.4.3. During winter, the flow rate will be approximately 500 m³/hr, resulting in 31.0 bar (3.10 MPa) pressure difference in the reservoir at the injector (Figure 4-3). This corresponds to an injection gradient of approximately 0.123 bar/m. During summer the flow rate will be approximately 250 m³/hr, resulting in 12.2 bar (1.22 MPa) pressure difference (Figure 4-4) and an injection gradient of approximately 0.110 bar/m. These injection

gradients are within SodM protocol (SodM, 2013). Based on the calculated pressure difference at the injector, WEB2 scores a 3 on the re-injection category (1-4 MPa, Table 5-1).

Geotechnics (Input)

Property	min	median	max
aquifer permeability (mD)	211.0	521.0	780.0
aquifer net to gross (-)	0.22	0.3	0.39
aquifer gross thickness (m)	235.0	264.0	295.0
aquifer top at producer (m TVD)	1350.0	1500.0	1650.0
aquifer top at injector (m TVD)	1292.0	1436.0	1580.0
aquifer water salinity (ppm)	90000.0	100000.0	120000.0

Geotechnics (Output)

Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer kH net (Dm)	26.6	41.0	54.71
mass flow (kg/s)	108.76	147.71	174.92
pump volume flow (m³/h)	370.1	502.2	595.0
required pump power (kW)	998.7	1355.2	1605.6
geothermal power (MW)	14.05	19.13	23.16
COP (kW/kW)	13.3	14.2	15.2

Property	value
number of simulation runs (-)	2000.0
aquifer kh/kv ratio (-)	2.0
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.029
mid aquifer temperature producer (°C)	0.0
initial aquifer pressure at producer (bar)	0.0
[Initial aquifer pressure at injector (bar)]	0.0
exit temperature heat exchanger (°C)	22.0
distance wells at aquifer level (m)	1120.0
pump system efficiency (-)	0.7
production pump depth (m)	700.0
pump pressure difference (bar)	68.0
outer diameter producer (inch)	10.63
skin producer (-)	0.0
skin due to penetration angle p (-)	-3.15
pipe segment sections p (m AH)	600.0,1004.0,1234.0,1614.0,1851.0
pipe segment depth p (m TVD)	600.0,1000.0,1200.0,1400.0,1500.0
pipe inner diameter p (inch)	7.92,11.15,9.06,7.02,8.1
pipe roughness p (milli-inch)	0.0,0.0,0.0,0.0,0.0
outer diameter injector (inch)	10.63
skin injector (-)	0.0
skin due to penetration angle i (-)	-4.04
pipe segment sections i (m AH)	100.0,775.0,2050.0,2622.0
pipe segment depth i (m TVD)	100.0,750.0,1250.0,1436.0
pipe inner diameter i (inch)	7.92,15.37,11.15,8.1
pipe roughness i (milli-inch)	1.8,1.8,1.8,1.8

aquifer pressure at producer (bar)	144.05	153.03	162.17
aquifer pressure at injector (bar)	138.05	148.51	154.59
pressure difference at producer (bar)	20.62	23.16	26.12
pressure difference at injector (bar)	27.55	31.02	34.91
aquifer temperature at producer * (°C)	54.92	57.34	59.76
temperature at heat exchanger (°C)	54.62	56.98	59.39

base case (median value inputs)	value
aquifer kH net (Dm)	41.26
mass flow (kg/s)	148.37
pump volume flow (m³/h)	504.5
required pump power (kW)	1361.4
geothermal power (MW)	19.37
COP (kW/kW)	14.2

aquifer pressure at producer (bar)	152.89
aquifer pressure at injector (bar)	146.44
pressure difference at producer (bar)	23.08
pressure difference at injector (bar)	30.87
aquifer temperature at producer * (°C)	57.33
temperature at heat exchanger (°C)	57.01
pressure at heat exchanger (bar)	32.51

* @ mid aquifer depth

Figure 4-3: DoubletCalc 1.4.3 results for production during winter.

Geotechnics (Input)

Property	min	median	max
aquifer permeability (mD)	211.0	521.0	780.0
aquifer net to gross (-)	0.22	0.3	0.39
aquifer gross thickness (m)	235.0	264.0	295.0
aquifer top at producer (m TVD)	1350.0	1500.0	1650.0
aquifer top at injector (m TVD)	1292.0	1436.0	1580.0
aquifer water salinity (ppm)	90000.0	100000.0	120000.0

Geotechnics (Output)

Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer kH net (Dm)	26.55	40.72	55.22
mass flow (kg/s)	52.24	73.43	91.36
pump volume flow (m³/h)	177.4	250.0	310.4
required pump power (kW)	190.1	287.8	332.6
geothermal power (MW)	3.52	5.05	6.62
COP (kW/kW)	16.7	19.0	21.5

Property	value
number of simulation runs (-)	2000.0
aquifer kh/kv ratio (-)	2.0
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.029
[mid aquifer temperature producer (°C)]	0.0
initial aquifer pressure at producer (bar)	0.0
[Initial aquifer pressure at injector (bar)]	0.0
exit temperature heat exchanger (°C)	38.0
distance wells at aquifer level (m)	1120.0
pump system efficiency (-)	0.7
production pump depth (m)	700.0
pump pressure difference (bar)	27.0
outer diameter producer (inch)	10.63
skin producer (-)	0.0
skin due to penetration angle p (-)	-3.15
pipe segment sections p (m AH)	600.0,1004.0,1234.0,1614.0,1851.0
pipe segment depth p (m TVD)	600.0,1000.0,1200.0,1400.0,1500.0
pipe inner diameter p (inch)	7.92,11.15,9.06,7.02,8.1
pipe roughness p (milli-inch)	0.0,0.0,0.0,0.0,0.0
outer diameter injector (inch)	10.63
skin injector (-)	0.0
skin due to penetration angle i (-)	-4.04
pipe segment sections i (m AH)	100.0,775.0,2050.0,2622.0
pipe segment depth i (m TVD)	100.0,750.0,1250.0,1436.0
pipe inner diameter i (inch)	7.92,15.37,11.15,8.1
pipe roughness i (milli-inch)	1.8,1.8,1.8,1.8

aquifer pressure at producer (bar)	144.02	153.04	162.06
aquifer pressure at injector (bar)	138.07	146.52	154.59
pressure difference at producer (bar)	10.61	11.65	12.62
pressure difference at injector (bar)	11.14	12.2	13.28
aquifer temperature at producer * (°C)	54.9	57.3	59.76
temperature at heat exchanger (°C)	54.28	56.62	59.0

base case (median value inputs)	value
aquifer kh net (Dm)	41.26
mass flow (kg/s)	74.49
pump volume flow (m³/h)	253.3
required pump power (kW)	271.4
geothermal power (MW)	5.19
COP (kW/kW)	19.1

aquifer pressure at producer (bar)	152.89
aquifer pressure at injector (bar)	146.44
pressure difference at producer (bar)	11.59
pressure difference at injector (bar)	12.16
aquifer temperature at producer * (°C)	57.33
temperature at heat exchanger (°C)	56.69
pressure at heat exchanger (bar)	9.78

* @ mid aquifer depth

Figure 4-4: DoubletCalc 1.4.3 results for production during summer.

4.1.4 Circulation Rate

The expected flow rate is approximately 500 m³/hr during winter (6 months) and 250 m³/hr during summer. The average, year-round flow rate is 375 m³/hr. According to the SHA guidelines, these flow rates result in the maximum score of 10. When critically reviewing the document, this seems to be quite pessimistic. Figure 4-5 shows the plot presented in the document. It needs to be noted that the majority of the projects with doublet flow in sedimentary reservoirs plot on the 'none' level. Also, the trend presented plots higher than all but one of the sediment flow points and the trend presented is mentioned to be a trend for the basement points. Moreover, the figure shows that all of the sediment flow points plot below the 2.5 magnitude threshold set by SodM in their guidelines (Figure 3-4) and that for the flow rates at WEB2, none of the points plots above 'none'. Though it may not be truly representative, the rating given for the flow rate is score "10" (>360 m³/h, see Table 5-1).

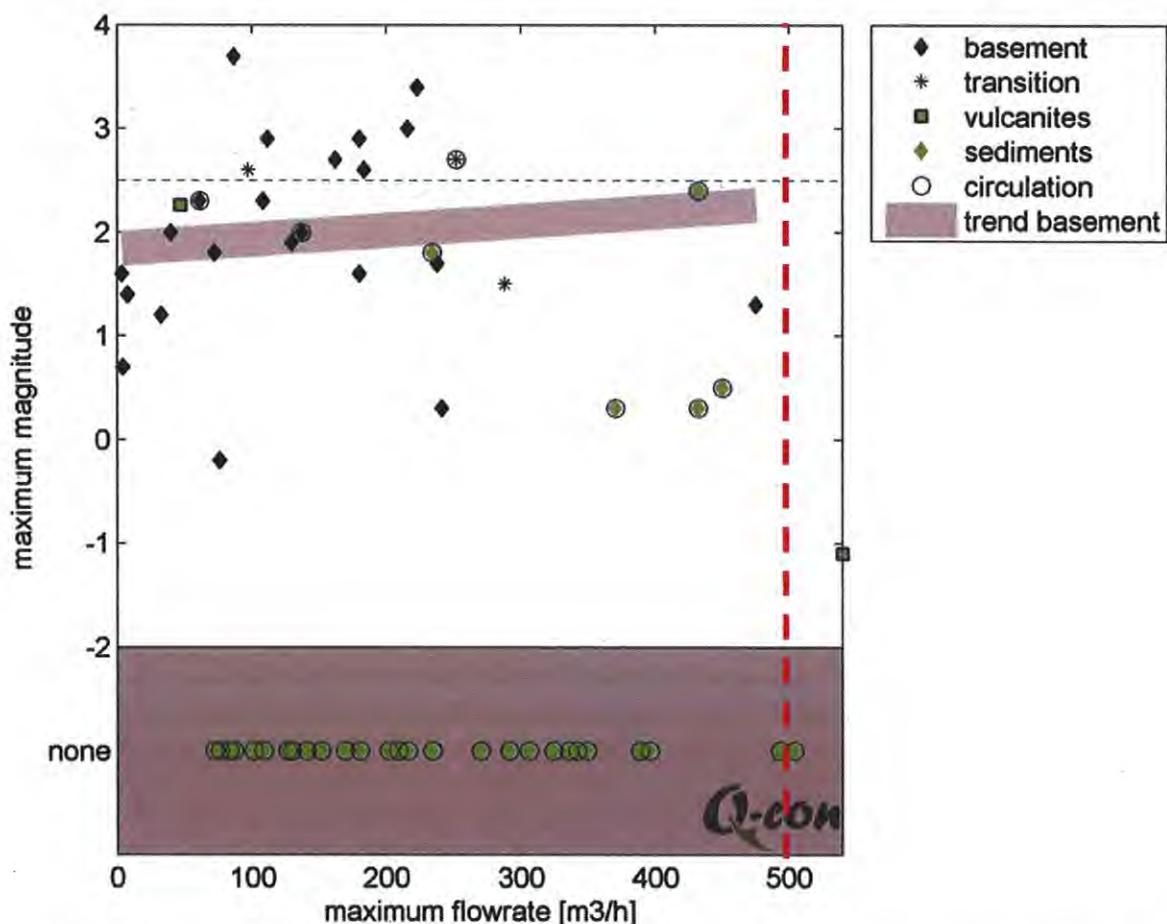


Figure 4-5. Maximum magnitude of induced events as a function of the (re-)injection rate for geothermal projects. Rock type of the target formation is indicated according to the legend. Symbols in circles denote circulation operations, open symbols denote fluid injection. The trend line (bold grey) was fitted to basement data points (IF-Technology & Q-con, 2016). Data points with no seismicity were discarded for fitting the trend line. The blue dashed line highlights the M 2.5 threshold from SodM and the red dashed line represents the nominal flowrate range expected for WEB2. See text for discussion.

4.1.5 Seismicity in the area

Seismicity in the region can either be induced or natural. The map shown in Figure 4-6 covers the entire seismicity dataset (natural and induced) of the Netherlands. No induced or natural earthquakes have been recorded near WEB2.

The nearest producing hydrocarbon fields are the Gaag, Pernis and Rotterdam fields, some 20 km to the southwest of WEB2, yet no seismicity has been recorded in this area. TNO classifies these fields unlikely to cause induced events (TNO, 2018) (Figure 4-8). The hydrocarbon fields that have elevated risk of induced seismicity are far away in the northeast of the Netherlands (Figure 4-7 and Figure 4-8).

Based on the IF/QCON scoring scheme, the distances to induced and natural seismicity fall into the > 10 km category which is the lowest category with a score of 0 (see Table 5-1).

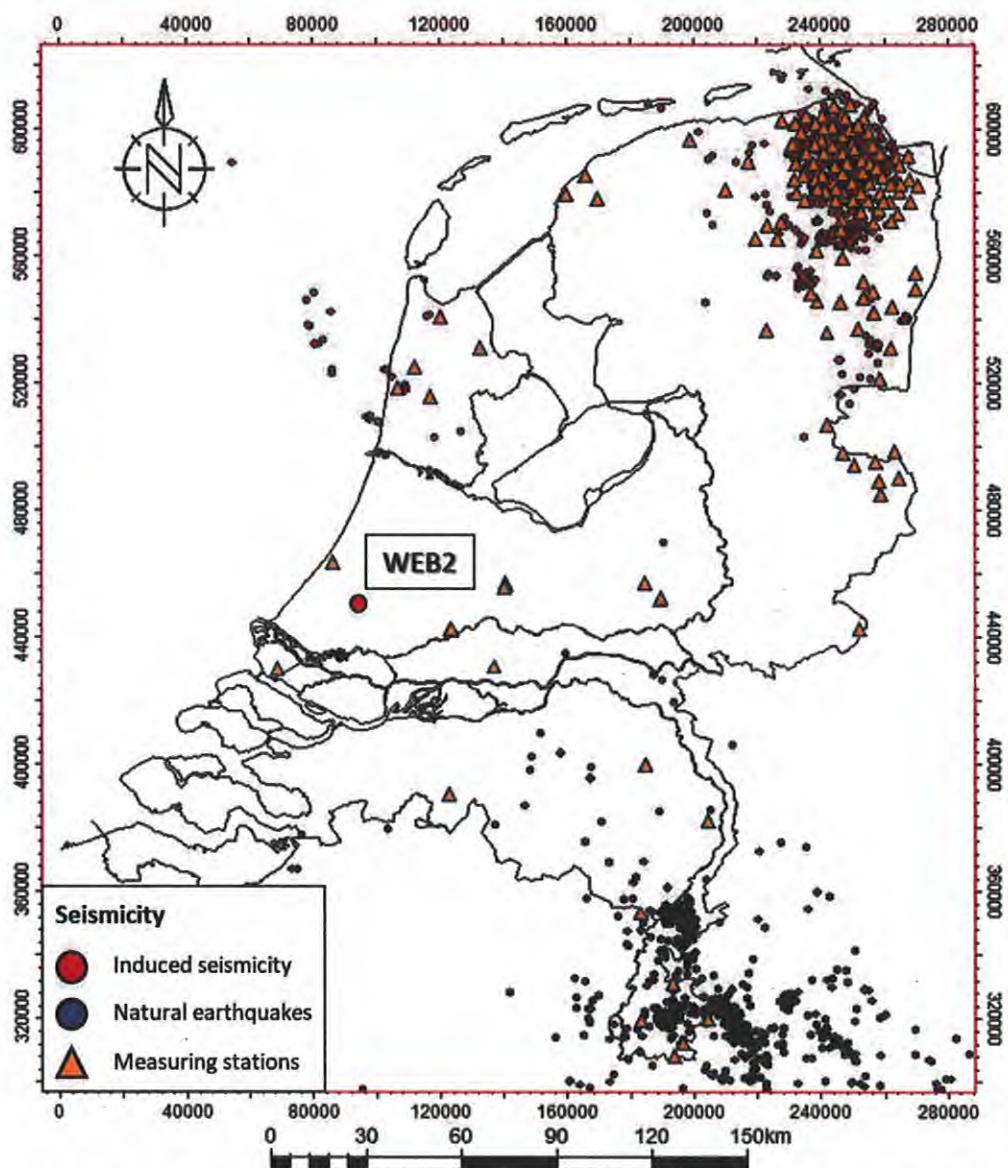


Figure 4-6. Map showing the epicentres of the seismicity in the Netherlands (red circles, induced seismicity) and the measuring stations (orange triangles). Hotspots for induced seismicity are far away near Groningen (NNE) and Schoonebeek (NE). Natural earthquakes (blue circles) are only common in the south-eastern part of the Netherlands.

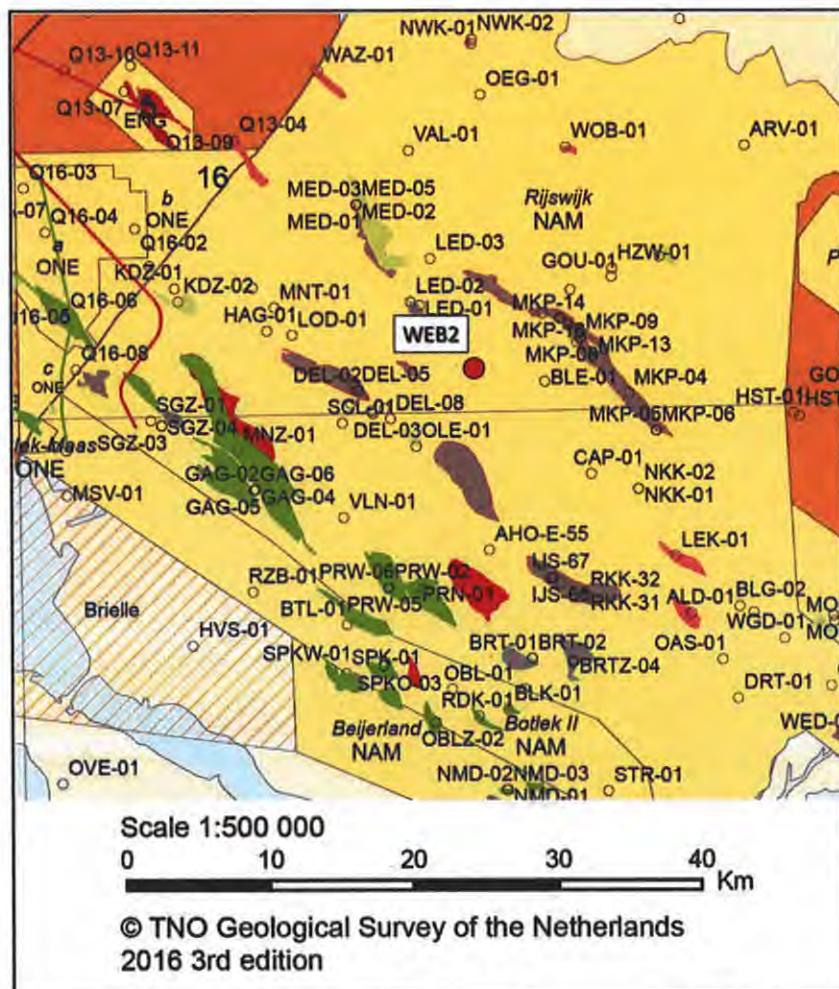


Figure 4-7 Oil and Gas field map made by TNO (January 2016). WEB2 is situated in the oil- and gas production license Rijswijk (yellow) owned by NAM. Nearby oil- and gas fields are indicated green (gas), red (oil) and grey (abandoned).

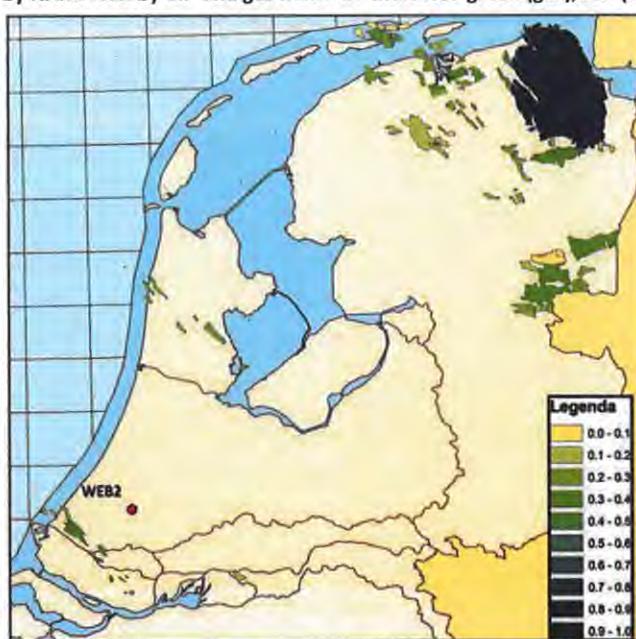


Figure 4-8. Probability of induced seismicity for gas fields on Dutch territory (TNO, 2018). Some gas fields exist near (20km) WEB2. However, these fields are expected to have a low risk of induced seismicity (see text for discussion).

4.1.6 Regional Fault properties

WEB2 is covered by 3D seismic data. The most recent seismic interpretation was performed on reprocessed depth cube R-2824 (PanTerra, Geological Study Oostland, 2020). The quality of the seismic data is average to good. The base reservoir map with mapped faults is displayed in Figure 4-2. Cross sections are displayed in Figure 4-9 and Figure 4-10. Several faults are present in the subsurface near WEB2, the general direction is WNW – ESE. The distance between the wells and faults at reservoir level is approximately 400 to 500 m for LSL-GT-03 and 600 to 700 m for LSL-GT-04. As a result, the score is a 7 (distance between 0.1 and 0.5 km, see Table 5-1).

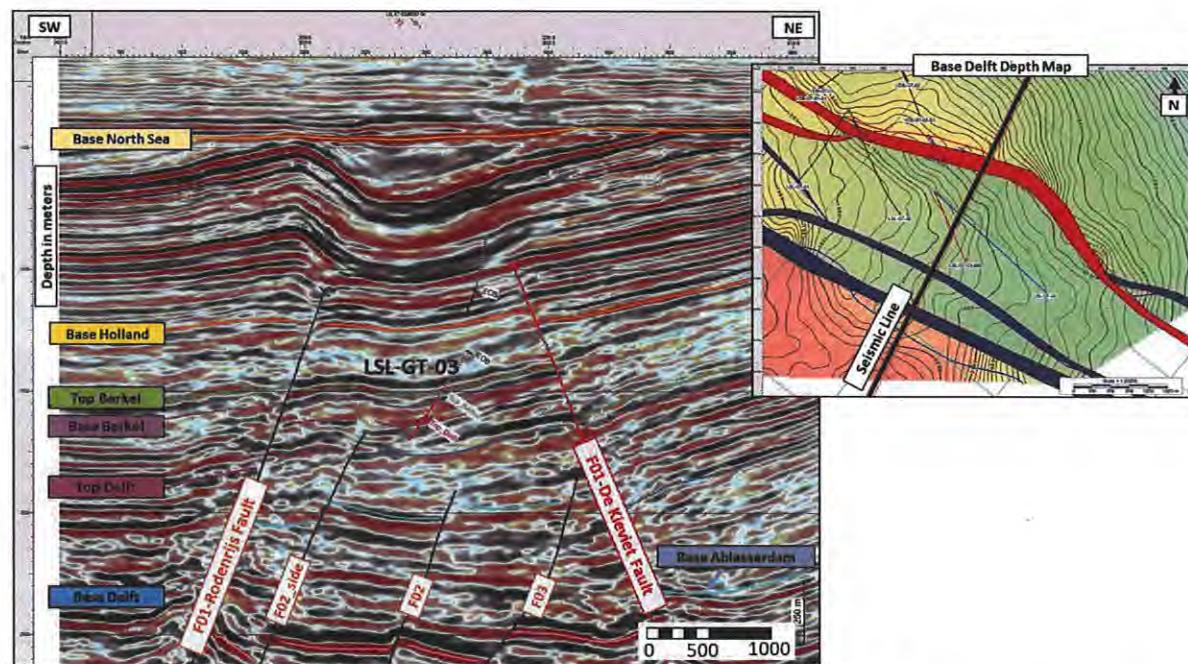


Figure 4-9: Seismic cross section perpendicular to faults, through the target of well LSL-GT-03.

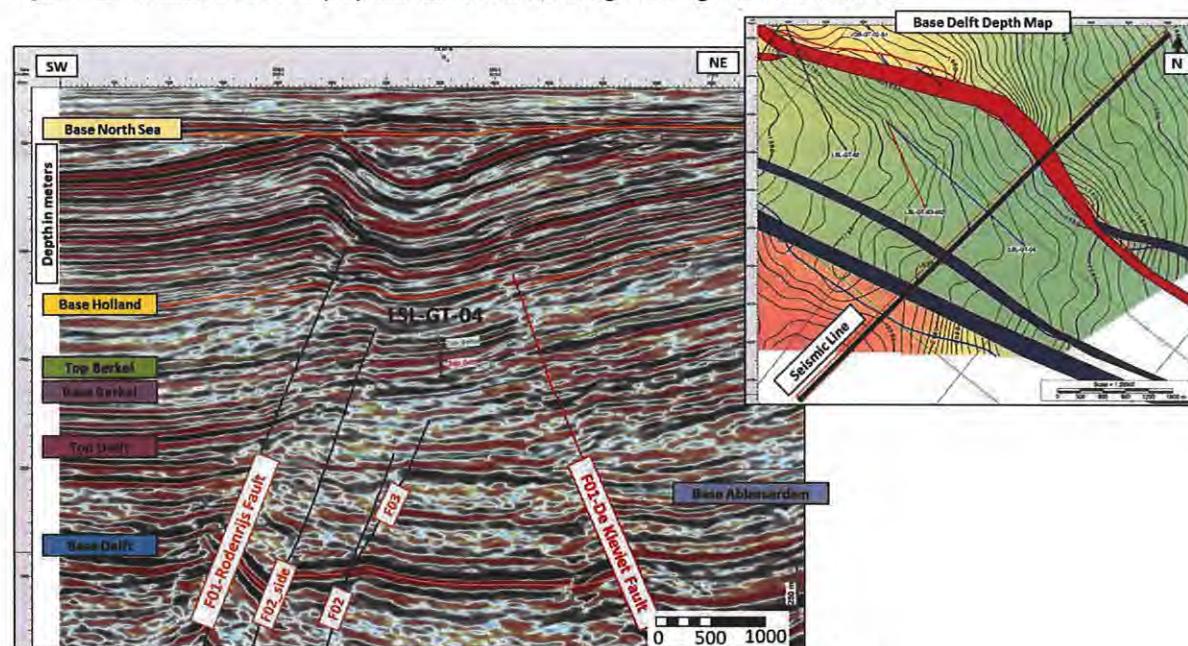


Figure 4-10: Seismic cross section perpendicular to faults, through the target of well LSL-GT-04.

4.1.7 Current stress field

The map in Figure 4-11 shows the location of WEB2 with respect to the nearest in-situ stress measurements interpreted in the Netherlands. These measurements represent the orientation of the maximum horizontal stress, S_H , interpreted from well data in a number of formations.

Only one stress measurement is available from the Schieland Group; 340 ± 20 degrees (Figure 4-11). The average S_H from all measurements available surrounding the target area is about 320 ± 20 degrees. Major faults in the WEB2 area as displayed in Figure 4-2 strike 310 ± 20 degrees (NW). The angle between fault lineaments and maximum horizontal stresses in the WEB2 area is thus 10 ± 40 degrees and hereby covers the range in which stress orientation on faults is suitable for reactivation (10 to 30 degrees; (Nieuwland, 2012)). As a result, the stress field versus fault orientation criteria is given a 'shearing possible' qualification with a score of 7 (see Table 5-1). A local approximation of the stress field could be made through analysis of e.g. borehole breakouts or drilling induced tensile fractures.

4.1.8 Net Injected Volume

Since the WEB2 doublet is based on mass-balanced fluid circulation, the net injected volume is zero. Also note that the pressure communication between the wells in doublets is good. The volumes involved with degassing and the addition of inhibitor are negligible. Therefore, the net injected volume criterion is given a <0.1 rating with a score of 0 (see Table 5-1).

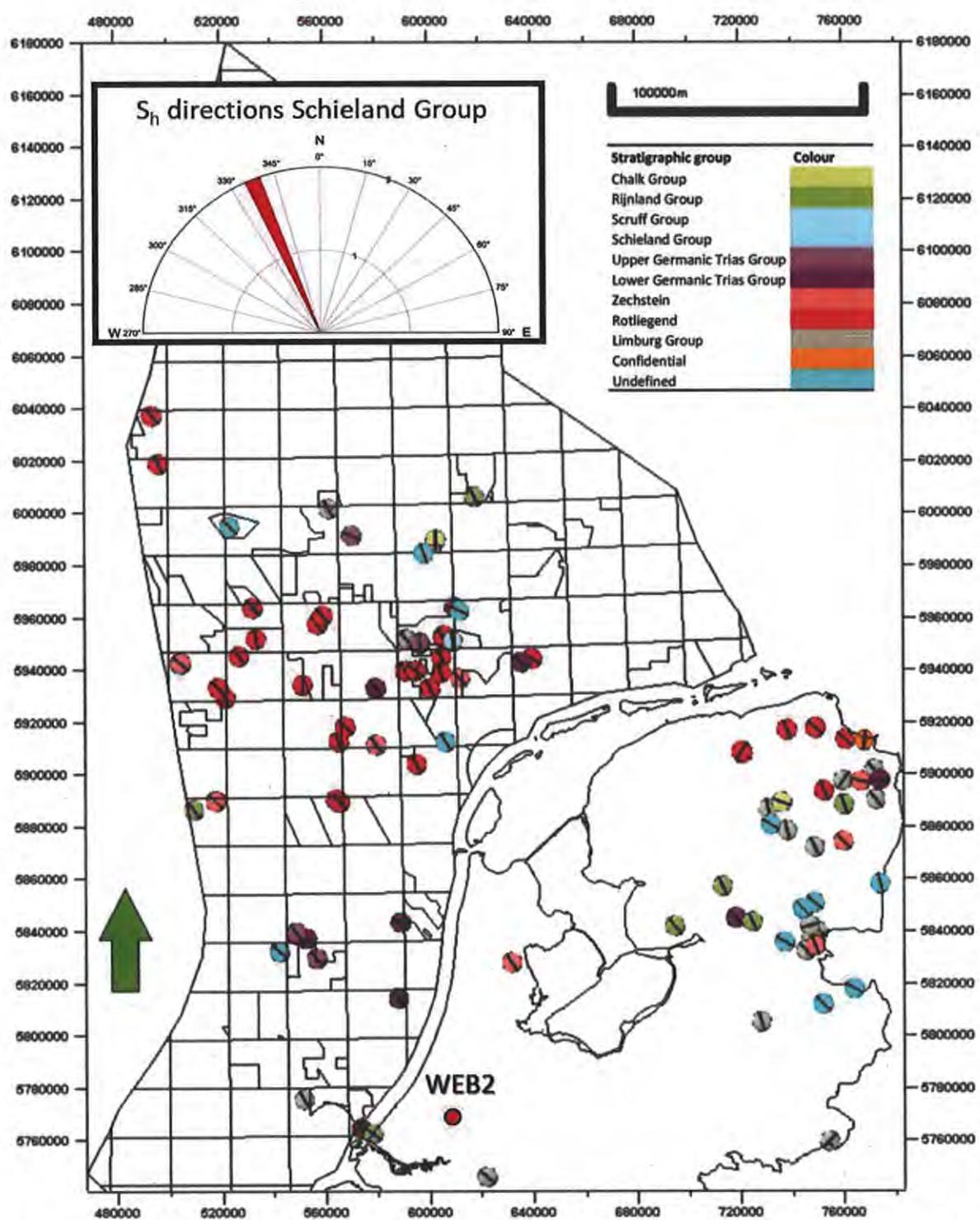


Figure 4-11. Dutch Stress Map data (DSM) presented by Mechelse (2017). The coloured circles show the orientation of average S_h per stratigraphic Group. The inlay shows the rose diagram of all the Dutch Schieland measurements.

4.2 Deterministic risk analysis for induced seismicity (SodM)

The SodM guidelines for risk analysis of induced seismicity have been written specifically for gas exploration (SodM, 2016) and is focussed on depletion and compaction. Therefore, the application for geothermal projects is limited. However, the cooling of the reservoir due to geothermal activity also results in compaction and could give rise to a scenario similar to depletion (Brouwer, Lokhorst, & Orlic, 2005); (Fokker & Van Wees, 2014) which is not further discussed in this report.

The SodM guidelines apply the probability class system defined by TNO (TNO, 2016), see Table 4-1. In this table the parameters mentioned are:

- DP/Pini: The ratio of the pressure difference (DP) and initial pressure (Pini) in the reservoir at a given moment in time;
- E: The ratio between the Young's moduli of the overburden and the reservoir rock;
- B: A measure of the reservoir fault intensity.

B is defined as follows:

$$B = \frac{\text{fault surface area}^{3/2}}{\text{gross rock volume}} = \frac{l_b^{3/2} h^{1/2}}{A}$$

Where h is the maximal thickness of the gas column, l_b is the total length of the intra-reservoir faults and bounding faults and A is the surface area of the accumulation.

Table 4-1. Risks of seismicity in the presence of oil or gas (TNO, Seismiciteit onshore gasvelden Nederland, 2016).

Seismicity has already occurred	
DP/P _{ini} ≥ 28%	B > 0,86 en E ≥ 1,34: P _h = 0,42 ± 0,08
	B > 0,86 en 1,01 ≤ E ≤ 1,33: P _h = 0,19 ± 0,05
	B < 0,86 en/of E < 1,01 Risk Negligible
DP/P _{ini} < 28%	Risk Negligible

The reservoir pressure difference which occurs during geothermal production at WEB2 is expected to be very small. This is due mainly to the fact that the produced and injected volumes are equivalent. Also, as paragraph 4.1.2 discusses, no significant flow boundaries are expected. The expected pressure difference for geothermal doublets (more than 100m away from the well bores) is generally somewhere around 2 Bar (Brouwer, Lokhorst, & Orlic, 2005), which makes DP/Pini about 1% (Pini = 146 bar), significantly lower than the <28% threshold. Therefore, for WEB2, the assumed risk based on the SodM guidelines is negligible.

5 Conclusions

This Seismic Risk Analysis is primarily focussed on the IF/QCON framework for geothermal projects and the SodM (2016) guidelines for gas exploration. Based on these, **the risk for the WEB2 doublet is assessed as low (see Figure 5-1)**. The weighted score for the IF/QCON quickscan is 0.30, below the 1/3 threshold for medium risk (see Figure 5-2). Similarly, the SodM criteria do not warrant further investigation since the deterministic risk analysis gives a negligible risk (see Figure 5-3).

It is key for WEB2 to maintain mass balance as to not build up or reduce reservoir pressure. In case well trajectories are changed, the distance to faults should be an important parameter to consider. It is recommended to retain a minimum distance of 100 m, preferably 200 m. This is most critical for the injector.

It is recommended to carry out an interference test when the new wells are drilled. An interference test tests the intra-well communication, which is critical for the risk of seismicity (and performance of the doublet). Based on the drilling and well test results of the new doublet, the SHA scoring scheme and weighted SHA score should be adjusted accordingly.

Despite the low seismicity potential, it is recommended to monitor the wells during the entire lifespan of the doublet.

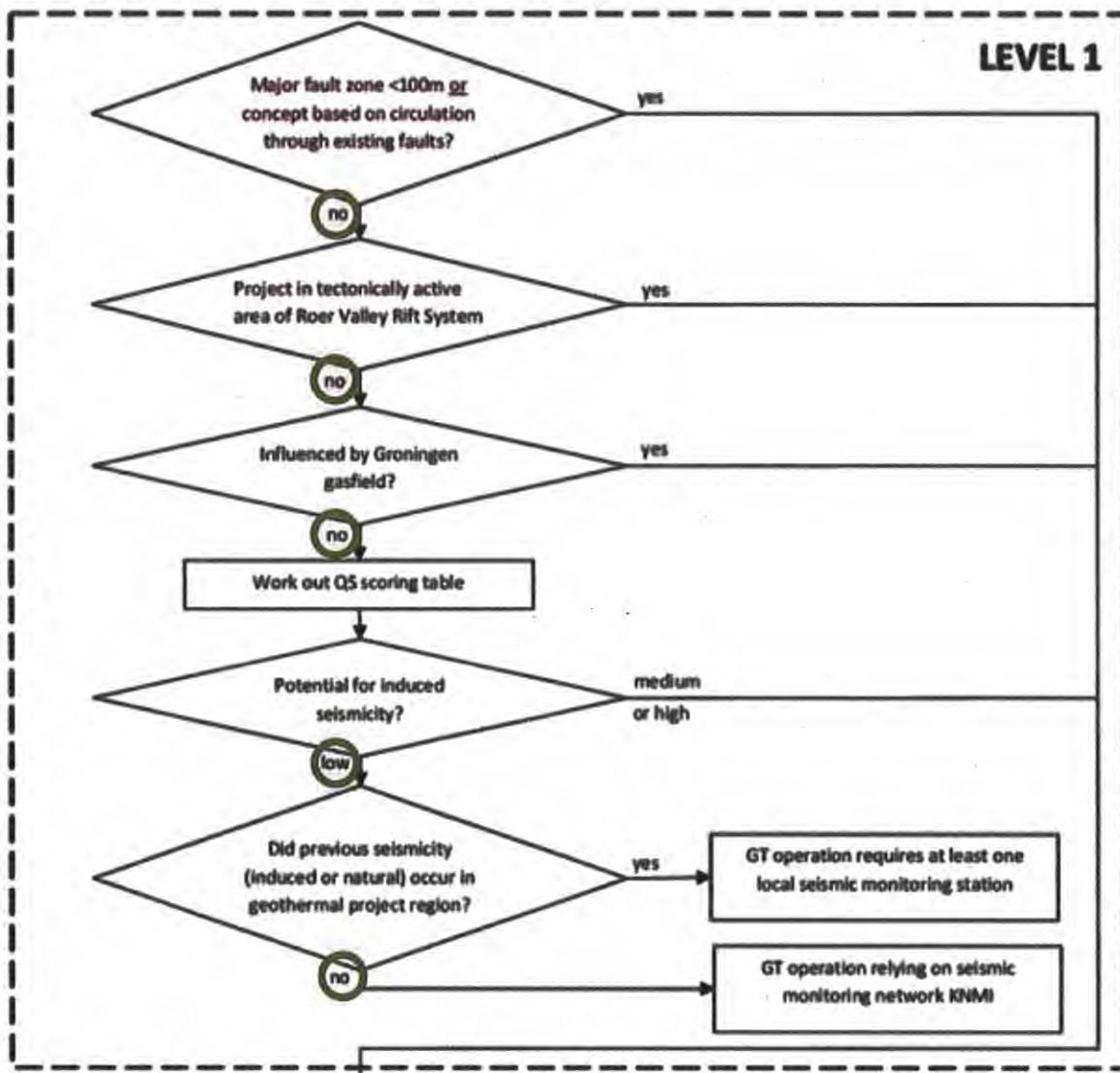


Figure 5-1. Level 1 SRA assessment for WEB2 based on the IF/QCON guidelines.

Table 5-1 SRA scoring scheme for WEB2. The applicable scores are highlighted in red.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Flow 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 [$1000 m^3$]	Sum of column scores	Normalized score
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		
Column Score	0	0	3	10	0	0	7	7	0	27	0.30

Figure 5-2. Result of the SRA quickscan based on the IF/QCON framework.

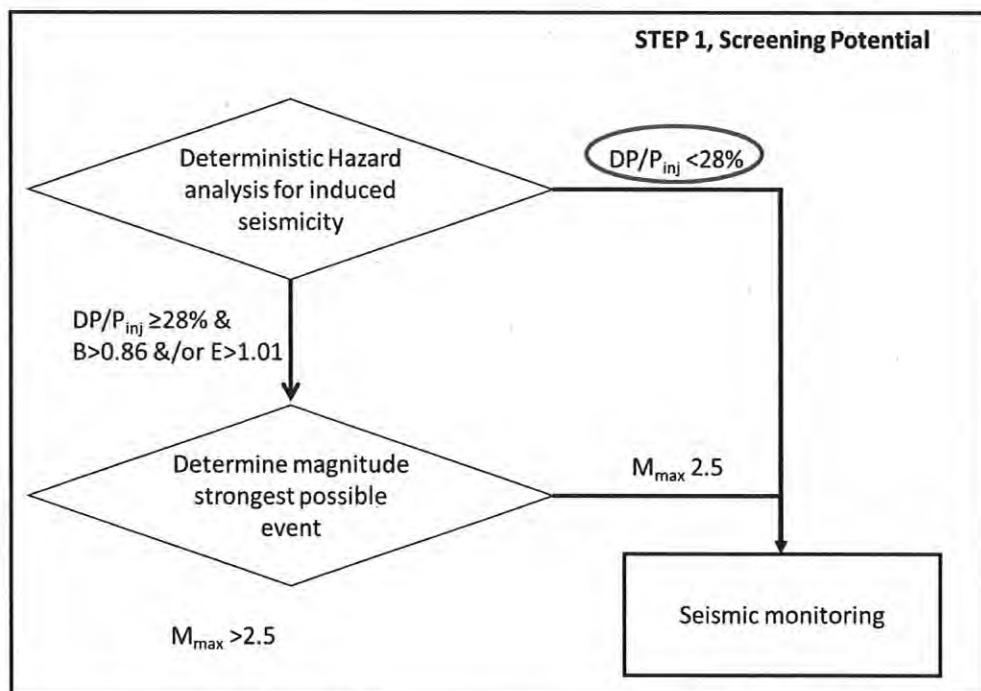


Figure 5-3. Step 1 SRA assessment for WEB2 based on the SodM framework.

6 References

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