Bijlage - Quickscan for potential of inducing Seismicity

Nederlandse samenvatting

HET POTENTIEEL VOOR HET OPWEKKEN VAN SEISMICITEIT

QUICK SCAN RESULTATEN

De score van het geothermieproject Hoogweg in de Quick Scan ligt dicht bij de grens van een laag potentieel voor geïnduceerde seismiciteit. Voor een laag potentieel geldt een andere vervolgaanpak dan bij een gemiddeld potentieel. Daarom is het cruciaal om het potentieel voor geïnduceerde seismiciteit zo nauwkeurig en zeker mogelijk te definiëren.
De meeste parameters kunnen niet verder worden gekwantificeerd. De bepaling van de kans op afschuiving van de dichtstbijzijnde breuken zou echter verder kunnen worden gekwantificeerd. Om de onzekerheden verder te verkleinen, kunnen aanvullende reservoirberekeningen worden uitgevoerd met een zone met verminderde permeabiliteit om de drukverandering rond de discontinuïteiten te berekenen.

PUT TRAJECT RESULTATEN

De projectie van de voorgestelde puttrajecten op de dichtstbijzijnde seismische lijnen vertoont geen verstoringen die samenvallen met de puttrajecten. Daarom worden er geen breuken verwacht langs de boortrajecten. Er moet wel rekening mee worden gehouden dat er een beperkt aantal 2D-seismische lijnen is. Daarom kan de mogelijkheid dat er zich toch breuken langs het boortraject bevinden niet worden uitgesloten. We zien echter geen indicatie van breuken langs de puttrajecten op de hierboven getoonde seismische lijnen.

Quickscan for Potential of Inducing Seismicity

Hoogweg Paprikakwekerijen

IF Technology **Creating energy**

Datum	6 december 2017
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Betreft	Potential for inducing seismicity
Behandeld door	[redacted]
Gecontroleerd door	[redacted]
Versienummer	Versie 0.2

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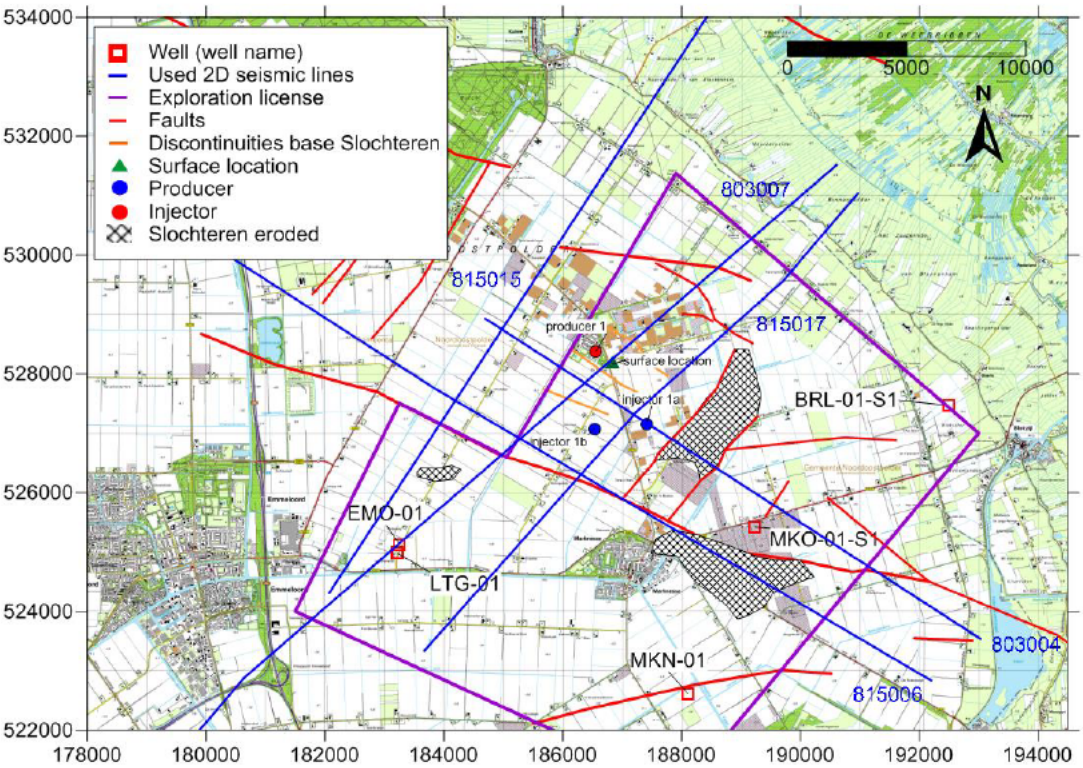
INHOUDSOPGAVE

1 Introduction

Hoogweg Paprikakwekerijen has requested IF Technology to determine the potential for inducing seismicity for a geothermal system. For this determination the quickscan method described in "Defining the framework for a seismic hazard assessment in geothermal projects" was used (Qcon en IF Technology 2016). This is the next step into the realization of the geothermal system.

In April 2012 a Masterplan Geothermal energy has been written for the Luttelgeest area (Panterra 2012). In 2017 a report was written by IF technology for a SDE+ application for Hoogweg (IF Technology 2017a). The SDE+ was granted in the spring of 2017. After the SDE+ was granted additional questions by SodM about the possibility and consequences of compartmentalization have been asked. These questions were answered in the memo "Breukanalyse Hoogweg Luttelgeest" (IF Technology 2017b).

Figure 1.1 | The location of the proposed geothermal system for Hoogweg Paprikakwekerijen. The well's surface location and sub-surface locations at top reservoir are indicated. In orange the observed discontinuities at base reservoir level.



The proposed geothermal system for Hoogweg Paprikakwekerijen is located within the exploration license of Luttelgeest II. The geothermal system targets the Slochteren Formation as the reservoir formation. The geothermal system consists of one triplet as proposed in the SDE+ application by IF Technology, 2017 and (Figure 1.1).

The current report consists of a quickscan of the potential for inducing seismicity for the triplet system proposed in the SDE+ report. The potential for inducing seismicity is assessed for both the reservoir part of the triplet configuration and for the drilling of the well trajectories.

The quick scan is executed for the locations of the orange discontinuities at the base of the Slochteren Fm.

2 Quickscan

2.1 METHODOLOGY

The methodology used in the quickscan for the potential for inducing seismicity follows the guidelines as specified in the technical report "Defining the Framework for seismic hazard Assessment in geothermal Projects" as published by Qcon and IF technology in 2016. The decision tree for the three-level hazard and risk assessment procedure is shown in Figure 2.1.

Based on the decision tree a quickscan approach can be followed, because the answer to the first three questions is no:

- No major fault zones are present within 100 meters of the project location.
- The project location is not situated in the tectonically active Roer Valley rift system.
- The project location is not influenced by the Groningen gasfield.

Therefore, the next step is to work out the quickscan scoring table. This is done in the current report.

The first step is a quickscan for induced seismicity potential. In the quickscan the potential for inducing seismicity is evaluated, by assigning scores for the project using several key parameters (Figure 2.2).

The scores of the different parameters are summed up, divided by the maximum possible score and subsequently compared to the categories in Figure 2.3. This result gives the potential for inducing seismicity category of the geothermal project and dictates which steps are needed next.

Figure 2.1 | Decision tree for the three-level hazard and risk assessment procedure.

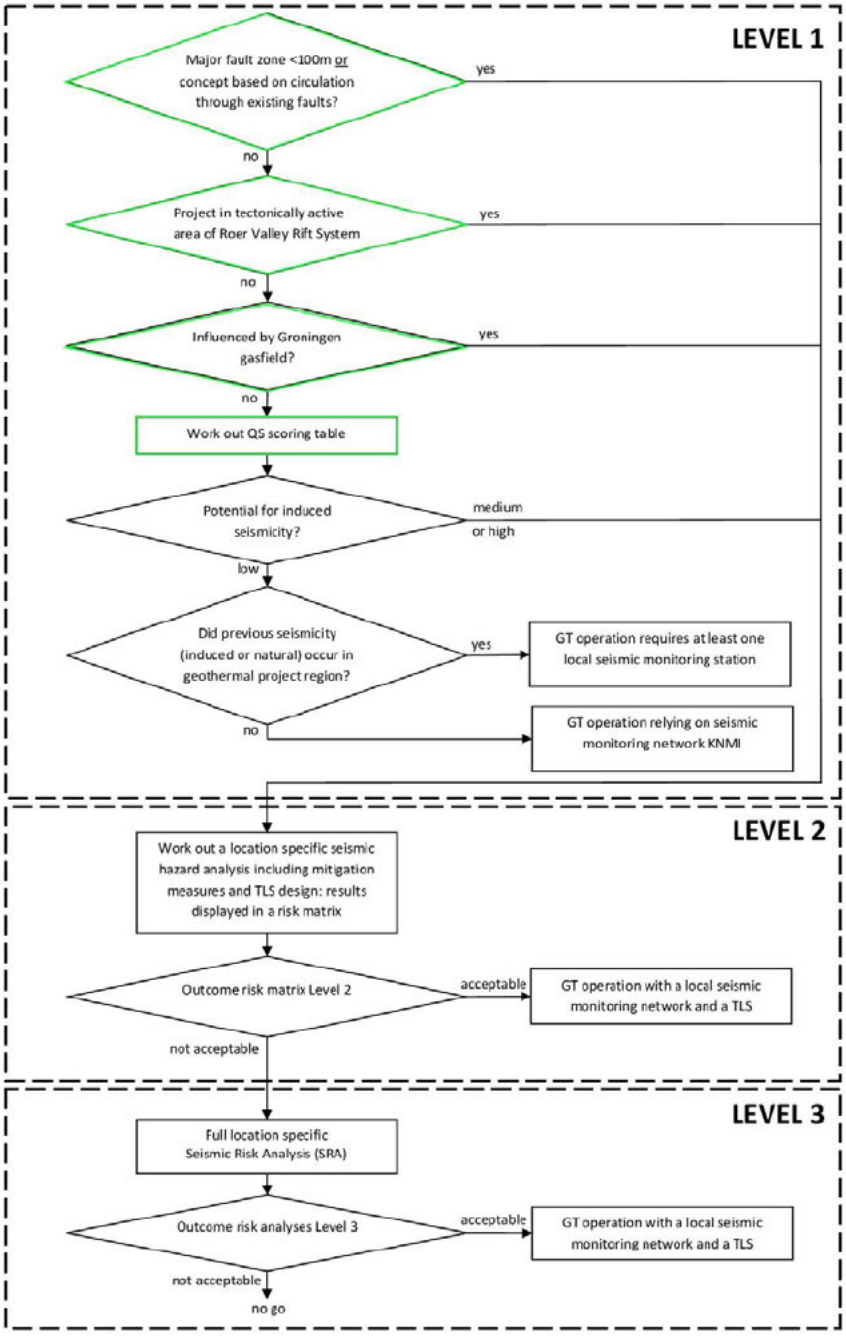
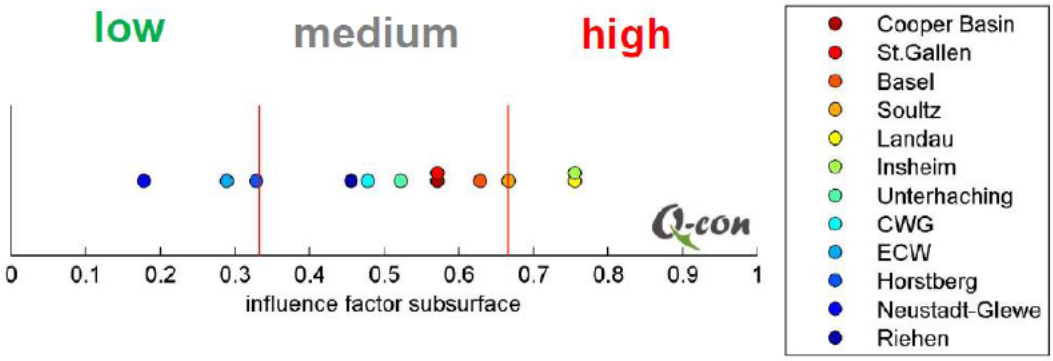


Figure 2.2 | From IF Technology and Qcon, 2016. Scoring scheme for the Quick/Scan. 'Basement connected' refers to a hydraulic connection between injection well and the crystalline basement (or rock mass with comparable properties). 'Inter-well pressure communication' refers to the hydraulic connection between the injection and production wells. 'Distance to fault' refers to the distance between the injection well and the nearest mapped fault. 'Orientation of fault in current stress field' refers to the orientation of the nearest mapped fault. 'Net injected volume' refers to the difference between injected and produced fluid volume (e.g. hydraulic fracturing or injection test).

score	basement connected	inter-well pressure communication	re-injection pressure [MPa]	circulation 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]
10	yes	no	> 7	> 360	< 1	< 1	< 0.1	favorable	> 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

Figure 2.3 | Translation of score to potential for inducing seismicity



2.2 PARAMETERS

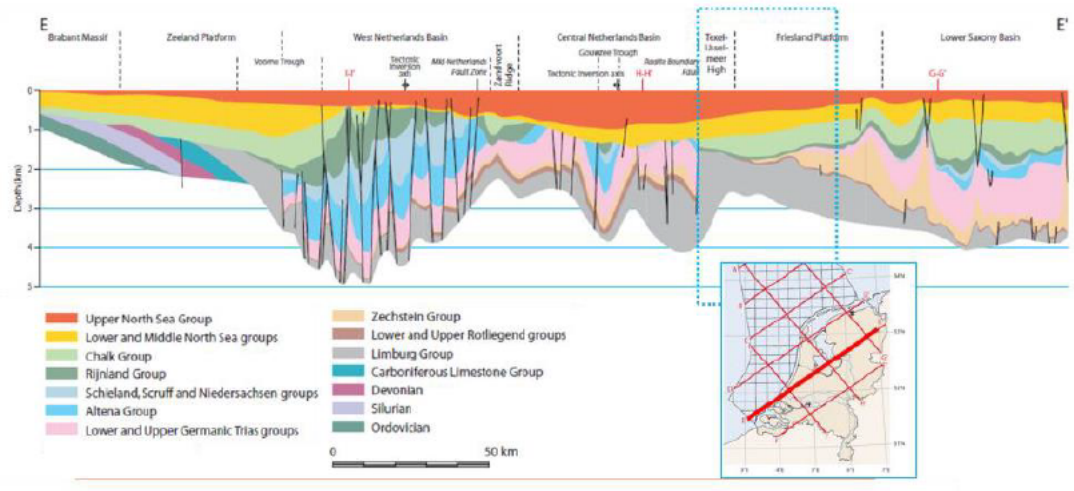
2.2.1 Basement connected

A key parameter is the hydraulic connection to the basement. With the term basement a crystalline rock or a rock mass with comparable hydraulic and mechanical properties is described. If a hydraulic connection between the open part (screens) of the wells and the basement is present, the potential for inducing seismicity is increased. This parameter was incorporated in the Quick-Scan because fluid injection into crystalline rock typically produces seismicity and the largest magnitude seismic events associated with geothermal activities in Europe consistently occurred in basement rock. Well LTG-01 is located about 10 kilometres to the southwest from the geothermal

project and has drilled to 5115 m TVD and ended in the top of the Devonian. The well didn't encounter basement rock. The vertical distance from the geothermal reservoir to the basement is therefore more than 3 km. (Figure 2.3).

There is the possibility of hydraulic connection between the Rotliegend reservoir and the basement through open permeable faults. This possibility cannot be fully excluded. However, the presence of faults that enable pressure communication between the injection well and the basement over a vertical distance of more than 3 kilometres is considered very unlikely. Especially since the carboniferous strata mainly consist of shales that exhibit ductile behaviour: faults would probably be sealed. Therefore, a connection to the basement is deemed very unlikely and a score of 0 is assigned.

Figure 2.4 | Geological cross-section through the Netherlands with the Luttelgeest area indicated by the blue dotted box. The regional mapping has stopped at the Limburg group in the Luttelgeest area. The Carboniferous strata are situated below these strata, as is indicated by LTG-01. Source IF Technology, 2017.



2.2.2 Inter-well pressure communication

The pressure differences created at the injection or production well propagate through the reservoir. Inter-well pressure communication can be blocked or hindered, when the injection and production wells are separated by a hydraulic barrier. This barrier can be a low permeability layer in the reservoir itself (when production and injection occur in different strata within the reservoir and a confining layer is present in between) or a (partly) sealing fault that separates the producer from the injection wells.

The geothermal system at Hoogweg is designed such that the production and injection wells target the same strata with a horizontal distance of 1.400 m at reservoir level. The risk of compartmentalization was investigated by IF Technology, 2017 (IF Technology 2017b). The seismic data interpretation shows discontinuities with a limited spatial extent. The discontinuities/ disturbances are visible at the base of the reservoir. However, they are not observed at the top of the reservoir. The analyses of these discontinuities show that it is unlikely that they form hydraulic barriers. Therefore, inter-well pressure communication is deemed likely and a score of 3 is assigned to this parameter.

2.2.3 Re-Injection Pressure

The re-injection pressure as used in the DoubletCalc software calculation for the SDE+ application (P50) are used in this quickscan (IF Technology 2017a). The P50 is used to be on the safe side since the P90 has a lower re-injection pressure, and thus a lower risk. The DoubletCalc software is designed for a doublet configuration. Therefore, the parameters have been adjusted to suit a triplet configuration (IF Technology, 2017 a). The injection pressure is 32.6 bar per injection well (3.26 MPa) which coincides with a score of 3.

2.2.4 Circulation rate

The circulation rate for the entire system is 500 m^3/h. The critical point is at the re-injection well, where pressure is increased by the injection. Since the geothermal system has two re-injection wells, the circulation per re-injection well is 250 m^3/h. This is the circulation rate used in the quickscan scheme. This results in a score of 7.

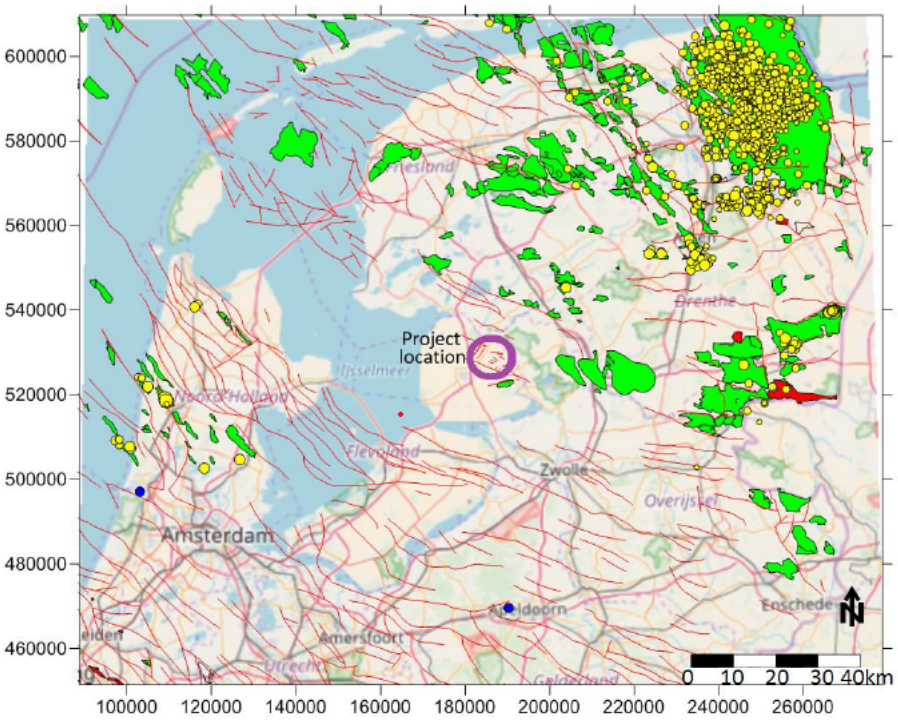
2.2.5 Epicentral distance to natural earthquakes

The shortest distance between the screens of the re-injection wells to the nearest natural earthquake was determined using the most recent earthquake catalogue by KNMI. The distance to the nearest event in Apeldoorn is far more than 10 kilometres (see Figure 2.5). This results in a score of 0.

2.2.6 Epicentral distance to Induced seismicity

The shortest distance between the screens of the open part of either of the re-injection wells to the nearest induced seismicity event is determined using the most recent earthquake catalogue by KNMI. The nearest induced event is more than 23 kilometres to the northeast (Figure 2.5). Since this is more than 10 kilometres, a score of 0 is applicable.

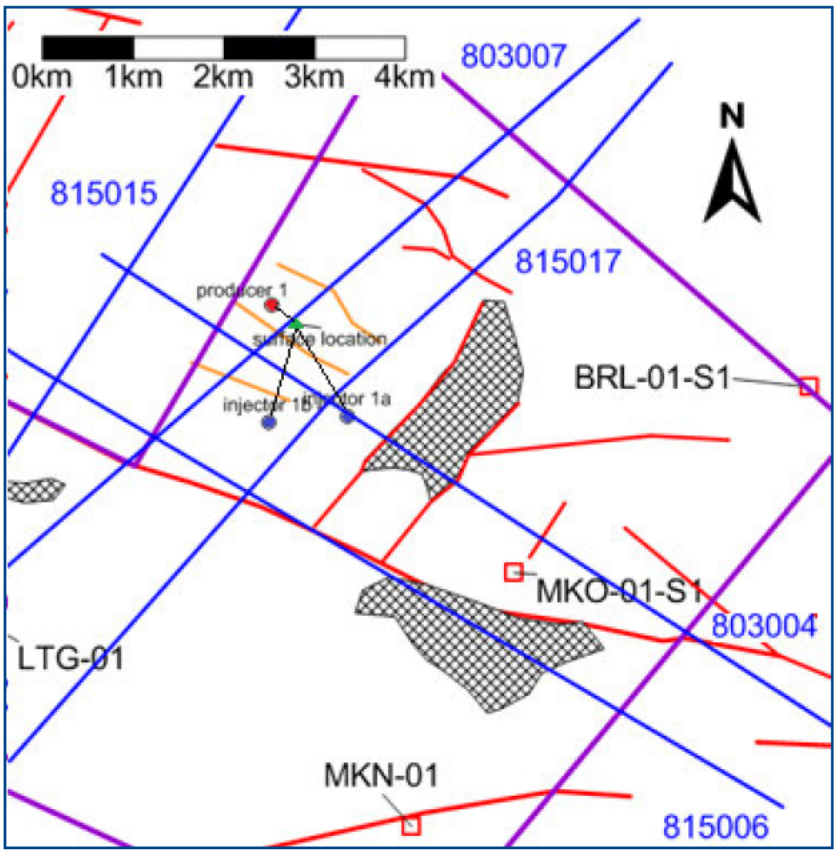
Figure 2.5 | the most recent earthquake catalogue by KNMI (yellow dots are induced seismic events and blue dots tectonic).



2.2.7 Distance to faults

The distance of the screens of the re-injection well(s) to faults is another key parameter to deduce the potential for inducing seismicity. The shorter the distance the larger the effect of the injection well at the concerning fault and the larger the potential for inducing seismicity. Injector 1b is situated closest to a possible fault: the shortest distance is 280 meters from a discontinuity. Injector 1A is situated 470 meters from a fault (Figure 2.6). Both translates to a score of 7.

Figure 2.6 | Overview of the 2D seismic lines (blue), planned/proposed well locations (surface location green triangle, location at top reservoir in red for the producer and in red fort he re-injection wells, with a black line the well trajectory is indicated), interpreted faults (red) and discontinuities at the base of the Slochteren Fm. (orange). In the hatched areas, the Slochteren Formation has been eroded completely.



2.2.8 Orientation of fault in current stress field

The quick scan score for the orientation of a nearby fault in the stress field is expressed as the likeliness of shearing of that fault based on the orientation of the fault in comparison to the stress field. Here the fault with the highest score is leading, for example: when the orientation of the nearest fault in the stress field is unfavourable for failure, it may be required to use another nearby fault with a more critical orientation (higher total score for “distance to fault” and “orientation of fault in current stress field”).

The orientation of the stress field (Sv, SHmax, and Shmin) is determined using the world stress map (www.world-stress-map.org). This map indicates a direction of approximately 130° (between 120 and 140°) for SHmax. Shmin is oriented perpendicular to SHmax and Sv oriented in vertical

direction. Most faults in the direct vicinity of the project location have a strike orientation of approximately 120 degrees. This orientation makes shearing possible. However, the faults have a steep inclination; a dip of 75 to 90 degrees. A quick scan calculation of the slip and dilation tendencies shows that a pressure increase of at least 18 bar is needed at the faults within the reservoir to create critically stressed faults. The calculated pressure change in the reservoir at the fault location is approximately 2-3 bar. This means that shearing is unlikely and a score of 3 is applicable.

2.2.9 Net Injected Volume

The geothermal system is configured to have a mass balanced fluid circulation. Therefore, the net injected volume is zero, which results in a score of 0.

2.3 SCORING RESULTS

The geothermal project scores are summarized in Table 2.1, resulting in a normalized score of 0.26. This is below the boundary of low to medium potential for inducing seismicity. Following the guidelines, the project classifies as a low potential for inducing seismicity.

Table 2.1 | Scoring of the geothermal project mean case.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Circulation 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]
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

2.4 DISCUSSION AND RECOMMANDATIONS

The parameters for re-injection pressure, epicentral distances and the net-injected volume are certain. However, the following parameters for the Hoogweg geothermal system have a degree of uncertainty:

- The orientation of faults with respect to the current stress field
- The inter-well pressure communication
- Basement connection

The first two parameters can be assessed further, thus potentially limiting the uncertainty. The uncertainty of the inter-well pressure communication ranges between a likely to a certain connection. The worst case would be that the discontinuities partially prevent the inter well pressure connection. However, a connection is still expected since they are of limited spatial extent and these discontinues are very likely open for fluid flow (IF Technology 2017b). A score of 3

is deemed appropriate even for this worst-case scenario. In the scenario that they are partly closed, the injection pressure is likely to increase. This increased pressure change might make the faults more prone to slip, which results in a higher score (7 instead of 3)

The connection to the basement cannot be assessed any further since it is very hard to quantify the possibility of fluid movement possible in the faults, along the entire depth range, connecting the basement with the reservoir. Considering the vast vertical distance (>3km) between the basement and reservoir combined with clay rich formations in between, a connection is considered unlikely to non-existent. However because a connection can't be excluded fully, the risk on inducing seismicity is also calculated with a score of 3 (instead of 0) for this parameter.

Both topics combined lead to an increase in score of 7 (23 > 30). Normalized the score will increase to 0.33, which is the transition between the low potential case and the mid potential case.

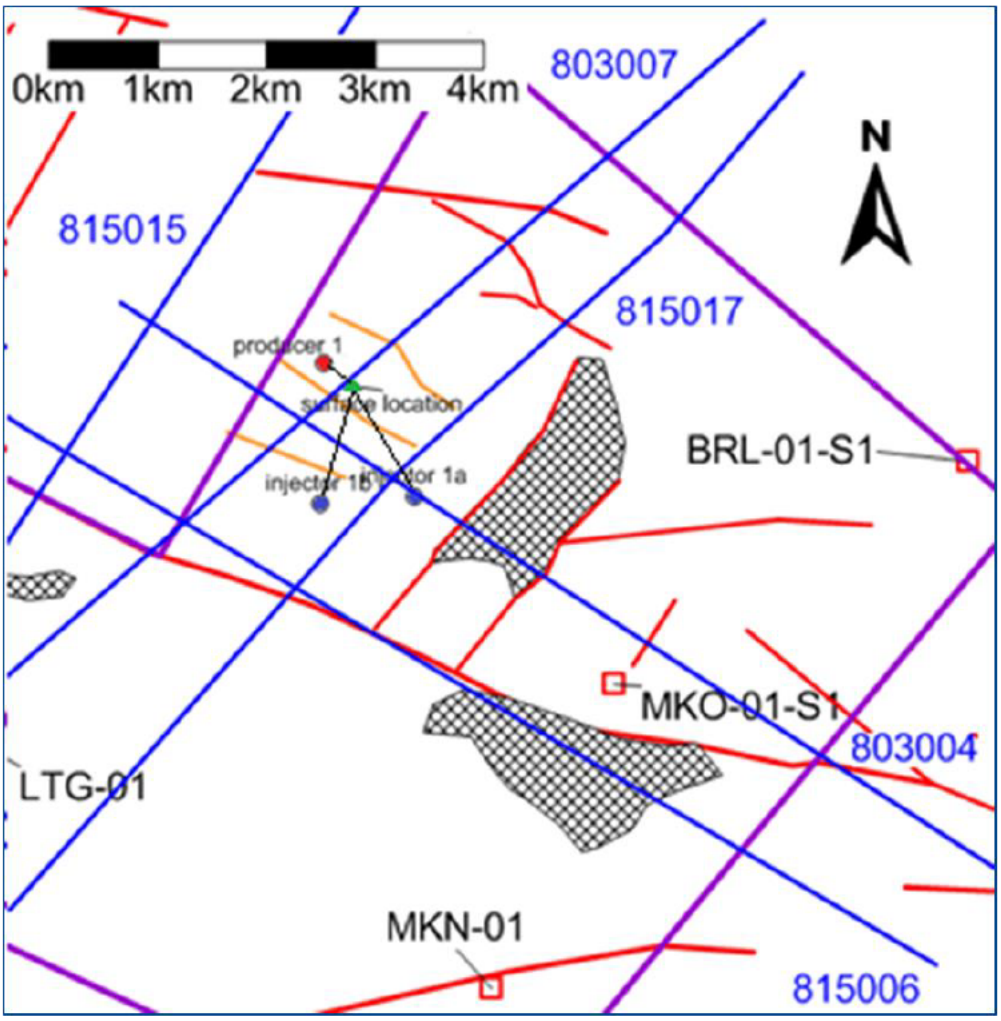
Because a zone with reduced permeabilities increases the potential on inducing seismicity it might be useful to further quantify the effect of the reduced permeability on the pressure change and its effect on the risk on shearing the faults.

3 Well trajectories

The potential for inducing seismicity by the geothermal system also depends on the seismicity potential during drilling of the wells to the sub-surface target locations. The potential for inducing seismicity during drilling is primarily defined by the location of the well trajectories relative to faults. If the well trajectory intersects faults, the potential for inducing seismicity will increase.

The well trajectories for the producer and the two re-injection wells as defined for the SDE+ application in 2017 are used for the current analyses. The well trajectories have been projected onto the nearest seismic lines (803007, 815017 and 803004) to establish whether any disturbances are visible along the well trajectories. Please note that the trajectories shown are approximate as the trajectories do not plot directly onto the available 2D lines. The surface location of the seismic lines and wells as well as the wells sub-surface location at the top of the reservoir are indicated in figure 3.1.

Figure 3.1 | Project and seismic locations. For the legend see Figure 1.1.



The production well trajectory is projected on to the nearest seismic line 803007 (Figure 3.2). The seismic line shows no visible disturbances along the well trajectory. The well trajectory is oriented parallel to the nearest interpreted structures and perpendicular to the seismic line. This orientation further minimizes the possibility of intersecting unseen faults. The production well is also projected onto seismic line 803004. This line doesn't show any visible disturbances along the well trajectory either.

Figure 3.2 | Projection of the production and injection well 1b on seismic line 803007. The two injection wells will be drilled approximately 1300 and 1550m to the South (IF Technology, 2017). BTU (Base Tertiary Unconformity) in yellow, BCU (Base Cretaceous Unconformity) in green and BPU (Base Permian Unconformity) in pink. The BPU is the base of the reservoir.

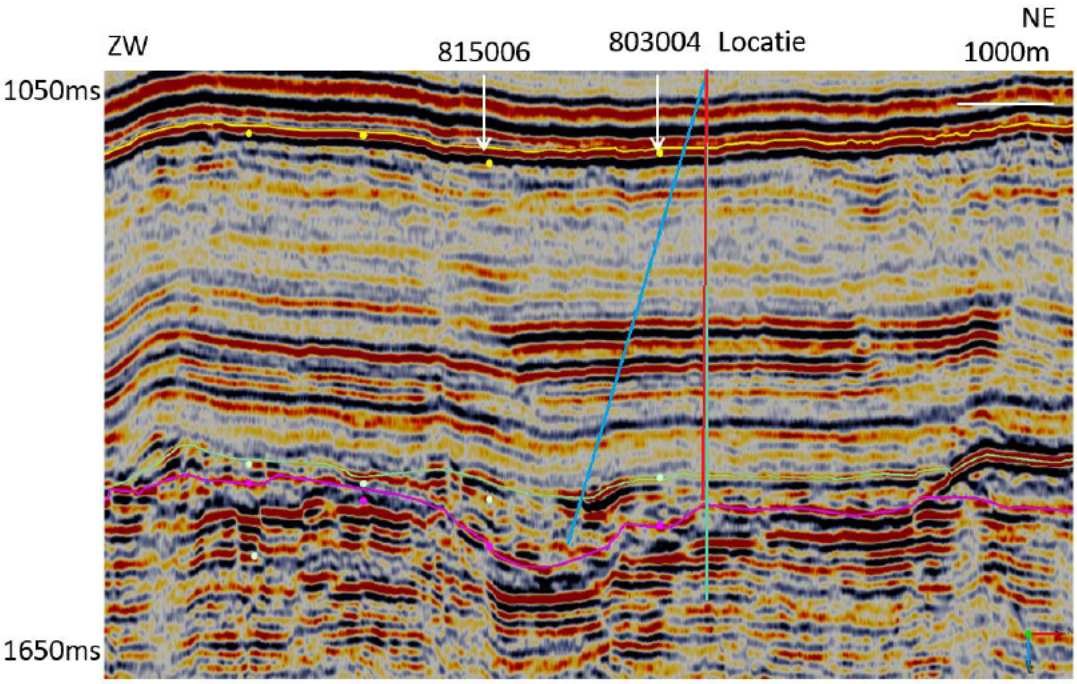
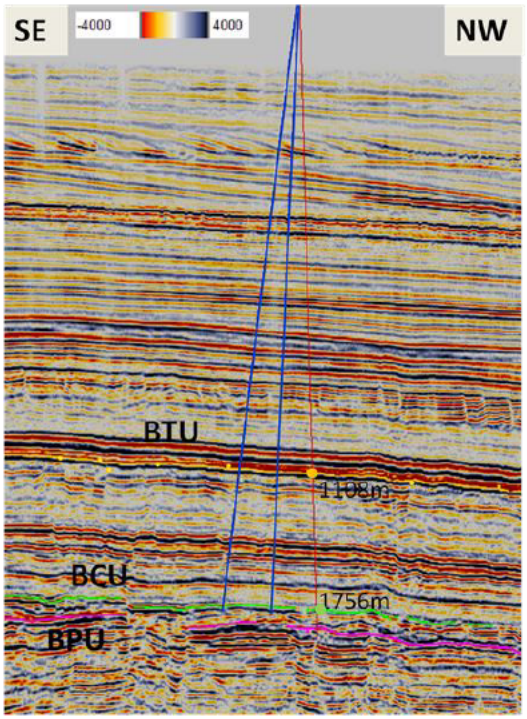


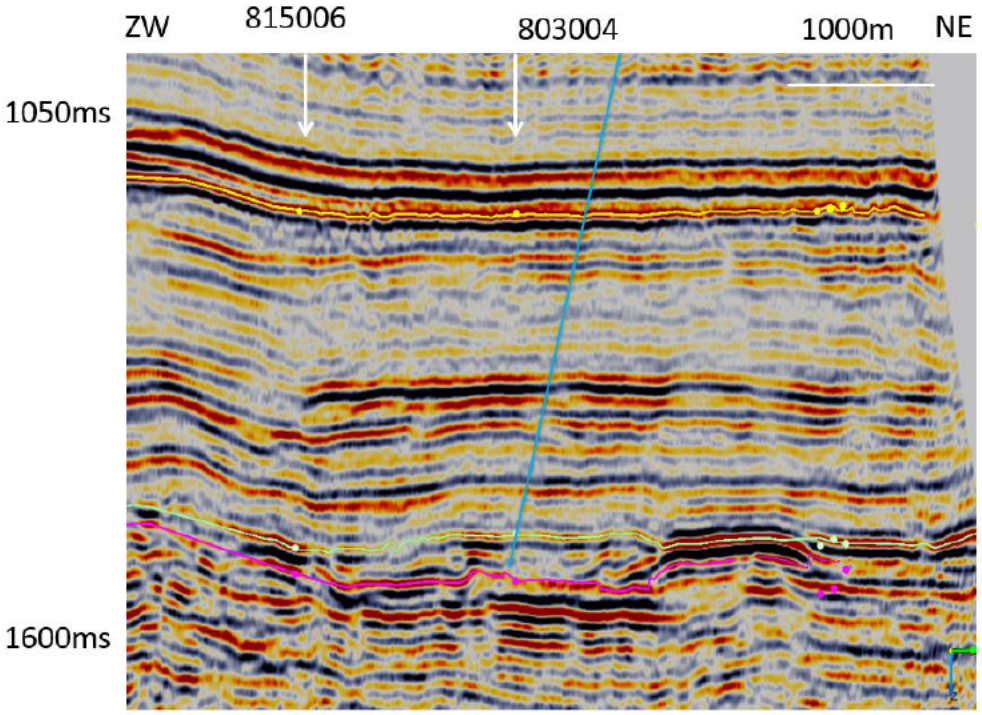
Figure 3.3 | Projection of the proposed well trajectories of the injection and production wells on seismic line 803004(IF Technology, 2017). The injection and producer well trajectories are in blue and red, respectively. See Figure 3.2 for the abbreviations. Injection well 1a is on the SE side, 1b in the middle, and production well on the NW side.



The injection wells are projected onto seismic line 803004 (Figure 3.3). The well trajectories start on one side of this seismic line, cross it and end on the other side. No disturbances along the projected well trajectories are observed on this seismic line.

The top reservoir location of re-injection well 1a is very close to seismic line 815017. Therefore, the projected well trajectory on this seismic line is shown in Figure 3.4. No disturbances are visibly along the projected well trajectory.

Figure 3.4 | Seismic line 815017 with the location of the projected well trajectory of injection well 1a indicated in blue. The red lines visualize interpreted faults. Although the blue line continues further down it only continues down to the base of the Slochteren reservoir. See Figure 3.2 for the colour legend of the lines.



4 The Potential for inducing seismicity

4.1 QUICK SCAN RESULTS

The score of Hoogweg geothermal project in the Quick Scan is close to the boundary of a low to mediate potential for induced seismicity. A low and medium potential for induced seismicity result each in a different follow up approach. Therefore, it is crucial to define the potential as accurately and confidently as possible.

Most parameters can't be further quantified. However, the determination of the chance of shearing of the nearest faults might be further quantified. Additional reservoir calculations with a zone of reduced permeability to calculate the pressure change around the discontinuities can be carried out to further decrease the uncertainties.

4.2 WELL TRAJECTORY RESULTS

The projection of the proposed well trajectories on the nearest seismic lines shows no disturbances that coincide with the well trajectories. Therefore, no faults are expected along the well trajectories. It must be kept in mind that we have a limited amount of 2D seismic lines. Therefore, the possibility of faults along the well trajectory cannot be excluded. However, we see no indication of faults along the well trajectories on the above shown seismic lines.

NL TRANSLATION

HET POTENTIEEL VOOR HET OPWEKKEN VAN SEISMICITEIT

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De projectie van de voorgestelde puttrajecten op de dichtstbijzijnde seismische lijnen vertoont geen verstoringen die samenvallen met de puttrajecten. Daarom worden er geen breuken verwacht langs de boortrajecten. Er moet wel rekening mee worden gehouden dat er een beperkt aantal 2D-seismische lijnen is. Daarom kan de mogelijkheid dat er zich toch breuken langs het boortraject bevinden niet worden uitgesloten. We zien echter geen indicatie van breuken langs de puttrajecten op de hierboven getoonde seismische lijnen.

5 References

IF Technology. 2017a. "SDE+ Application Hoogweg Paprikakwekerijen".
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