# Seismic threat assessment for the potential injection and storage of produced water in the Drenthe Zechstein Carbonate reservoirs

NAM

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## Nederlandse samenvatting

Een analyse van de seismische dreiging ten gevolge van mogelijke injectie van Schoonebeek productiewater in de Drenthe-ZEZ-velden is beschreven in deze notitie. De analyse volgt de methodiek die gebruikt is voor de Twente-injectievelden. In het algemeen is de seismische dreiging voor de Drenthe-velden hoger dan voor de Twente–velden: de Drenthe-velden zijn echter te splitsen in twee groepen. De eerste groep bestaat uit velden waarbij voelbare bevingen zijn waargenomen gedurende de productiefase van het veld. De tweede groep omvat de velden waarbij geen of slechts niet-voelbare bevingen zijn geobserveerd. De aanbeveling is om in eerste instantie de laatstgenoemde groep velden te gebruiken als mogelijk kandidaat voor injectie van productiewater. Daarbij wordt tevens aanbevolen om het geofoon netwerk verder te optimaliseren en het seismisch risicoprotocol zoals ook geldig is voor de Twente-velden in werking te laten treden.

## Introduction

The Zechstein carbonate fields (Figure 1) in the province of Drenthe are considered for the storage of produced water that originates from the Schoonebeek oil field. This note describes the seismic threat that possibly arises from the injection and storage process in those fields, following the methodology that was used for the assessment of the seismic threat in the Twente fields (NAM, 2015).

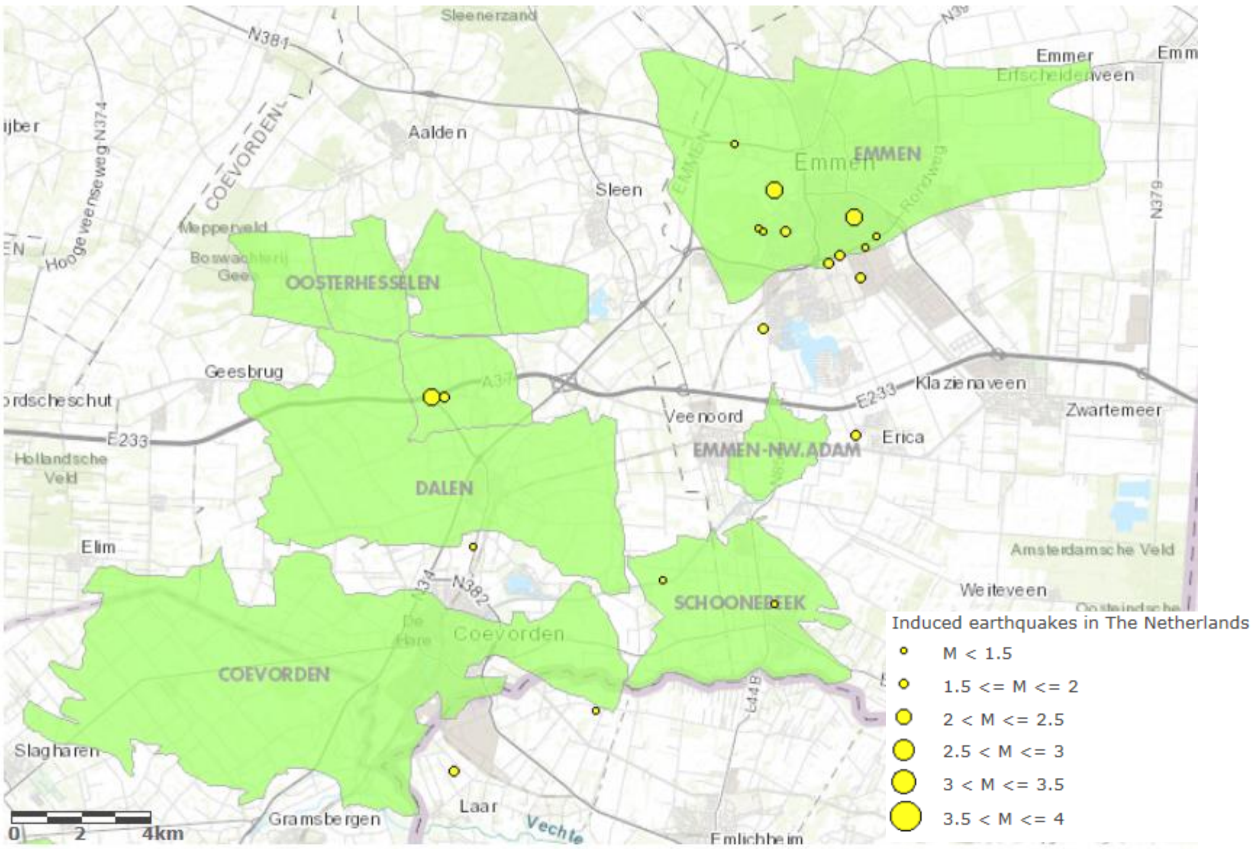


Figure 1 Location of the Drenthe storage candidates and an overview of the recorded earthquakes till 11-11-2016

## Induced seismicity during injection

Injection of water may lead to reactivation of faults and related induced seismicity (e.g. NAM, 2015a, TNO, 2014). In the global literature (e.g. National Research Council, 2012) several cases are described of seismicity related to the injection of fluids and gas. Whilst these seismically active fields only represent a very small fraction of the total number of injection wells (Zoback 2012), no guarantee can be given that injection in the Drenthe Zechstein fields may not lead to induced seismicity.

The relevant mechanisms that can cause induced or triggered earthquakes are (TNO, 2014; NAM, 2015a):

1. Poro-elastic stress effects as a result of the production or injection of a substitute in the subsurface
2. Pore pressure increase in a (sub) critically stressed fault
3. Chemical reactions reducing the strength of a fault
4. Thermal changes effecting stresses

These mechanisms were studied for the Twente injection fields (NAM2015a) and are relevant as well for the assessment of the seismic threat for the Drenthe fields. The results of this assessment are listed in Table 1.
Qualitatively, the level for the seismic threat in the Drenthe fields is higher when compared to the threat for the Twente fields. This difference with the Twente fields is founded by the following observations:

- The recording of earthquakes above the Drenthe fields during the production phase (Figure 1). This proves the presence of critically stressed faults in the depleted fields during the injection phase.
- A higher expected temperature difference between the injected fluid and the reservoir rock. More cooling will lead to higher change in rock stress around the injection well.
- A higher value for the estimated maximum magnitude. This is based on the methodologies provided in the guideline by the Dutch mining regulator, SodM (2016).

On the positive side, the Drenthe fields are located deeper below the surface. This implies that for an earthquake with a given magnitude, the ground acceleration and velocity in the Drenthe context will be lower than in Twente. The magnitudes recorded so far above any of the Zechstein carbonate fields in the eastern part of the Netherlands are small and have not exceeded $M_l$=2.3. None of the 23 earthquakes recorded so far has resulted in damage. From the observed seismicity the Drenthe fields can be split in two groups:

1. Fields with maximum seismicity above Ml = 2 like Emmen and Dalen. Especially the southwest part of the Emmen field showed a relative high number of small earthquakes. Following a M2.3 tremor in 2015, damage was claimed but after inspection (Witteveen en Bos, 2016), the conclusion was that none of the claimed damage was a result of earthquakes. Still the observed seismicity points to critically stressed faults that might reactivate during large scale injection of water.

2. Fields with no or little seismic activity like Schoonebeek, Oosterhesselen and Coevorden. These fields show that fault reactivation only led to very small events during production, which makes these fields the preferred injection candidates from a seismic threat point of view. It is though recommended to do a more thorough seismic risk assessment (NAM, 2016).

It should be mentioned that the structural setting is similar for all Zechstein carbonate fields in SE Drenthe and whether potential earthquakes during injection will follow a similar trend as observed during production should be confirmed by additional monitoring combined with a seismic risk management plan comparable to the one that is in place for the Twente injection fields (NAM, 2015b). In the SE Drenthe area the seismic network already has a detection limit of Ml=1.5 and a localisation threshold of Ml=2.0. In addition accelerometers have been installed in selected public buildings in the greater Emmen region.

## References

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Table 1 overview of the qualitative assessment for the proposed Drenthe injection fields (right) in comparison with the assessment for the Twente fields (left, NAM 2015)

| Twente | | | Drenthe | |
|---|---|---|---|---|
| Mechanism or consequence | Qualitative Assessment | Reasoning | Qualitative assessment | Reasoning |
| Poro-elastic stresses | + | + Low ambient shear stress<br>+ Limited pressure increase<br>+ No seismicity during depletion<br>– DC reservoir more prone to fault reactivation | + - | + Low ambient shear stress<br>+ Limited pressure increase<br>– seismicity during depletion |
| Pressure increase in faults | + - | + Low ambient shear stress<br>+ Limited pressure increase<br>– Zechstein carbonate reservoir are known to be fractured reservoirs | + - | + Low ambient shear stress<br>+ Limited pressure increase<br>– Zechstein carbonate reservoir are known to be fractured reservoirs |
| Chemical reactions | + - | + No seismicity observed during four years of injection<br>– One small earthquake occurred in a Dutch Zechstein reservoir at low injection pressures. Chemical changes were proposed as the main driver in that case. | + - | + No seismicity observed during four years of injection in analogue fields<br>– One small earthquake occurred in a Dutch Zechstein reservoir at low injection pressures. Chemical changes were proposed as the main driver in that case. |
| Thermal changes | + | + Temperatures differences are limited | + - | + - Fields are deeper and therefore a higher temperature difference between rock and injected fluid |
| Maximum magnitude | + | + Assessment of possible maximum magnitudes shows values up to a magnitude of 3.2. This a lower maximum than the general reported value of 3.9 by the KNMI | + - | + - Assessment of possible maximum magnitudes shows values up to a magnitude of 3.7. This a lower maximum than the general reported value of 3.9 by the KNMI |
| PGA | - | – Shallow depth of the fields could result in relative high PGA's at the location of the epicenters | + - | + - Earthquakes in deeper fields result in relative lower values for the PGA's at the location of the epicenters |