Defining the Framework for Seismic Hazard Assessment in Geothermal Projects V0.1

Technical Report

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Overview

1. What is the cause of induced seismicity?
2. Experience from other geothermal systems
3. Procedure to assess the seismic hazard
   - Level 1: Quick Scan
   - Level 2: Seismic Hazard Assessment
   - Level 3: Seismic Risk Assessment
4. Recommendations for seismic monitoring
5. Show cases in The Netherlands

What can cause an earthquake?

- Geothermal activities cause stress changes in the subsurface, e.g. fluid injection/production and cooling.

- Under specific conditions, subsurface stress changes can cause seismicity.

→ natural faults play an important role

→ specific combination of subsurface & operational parameters can lead to seismicity

Experience

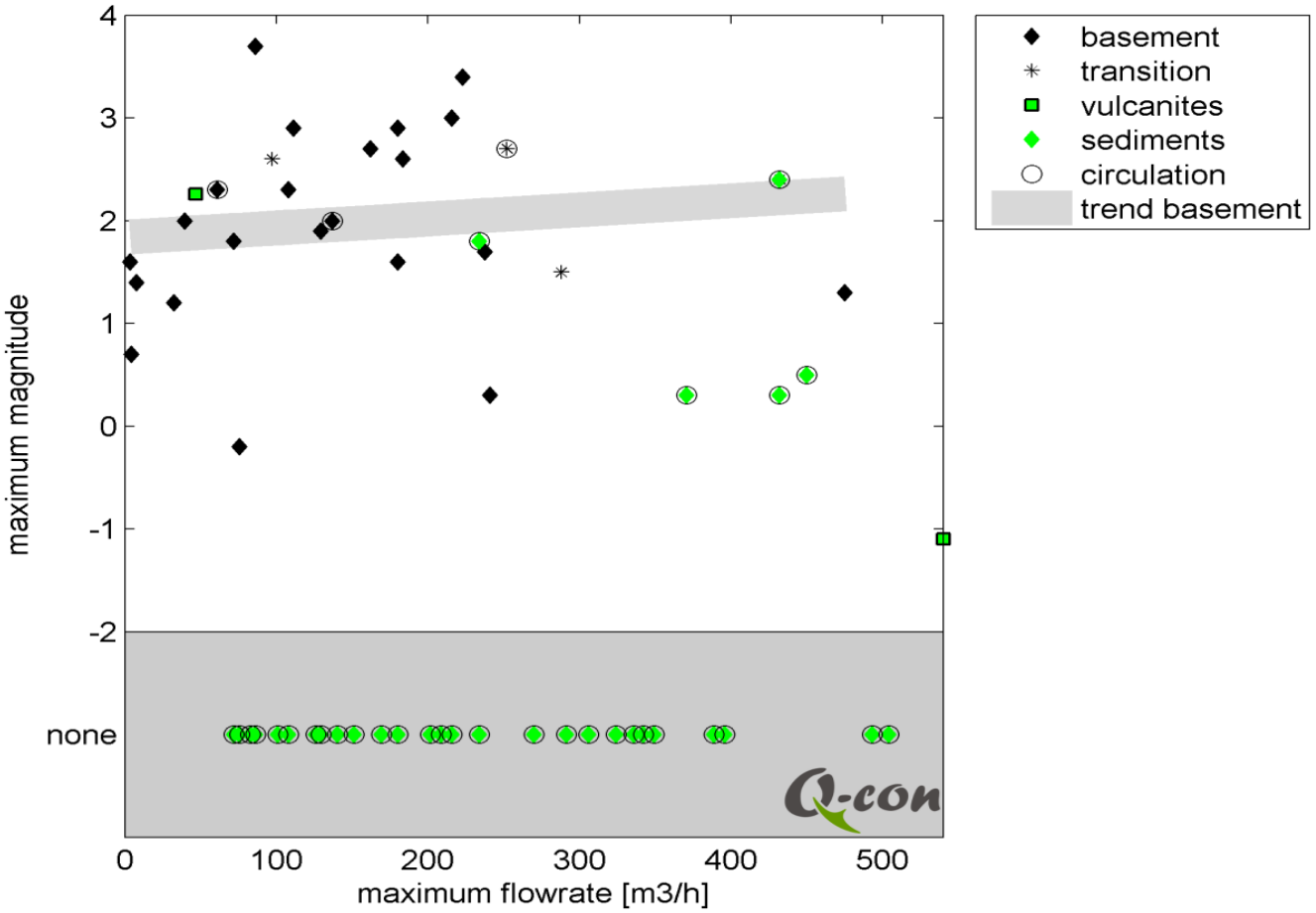
We compiled a (global) geothermal project data base to identify parameters that are relevant for the occurrence of induced seismicity:

→ most geothermal systems are operated without seismicity

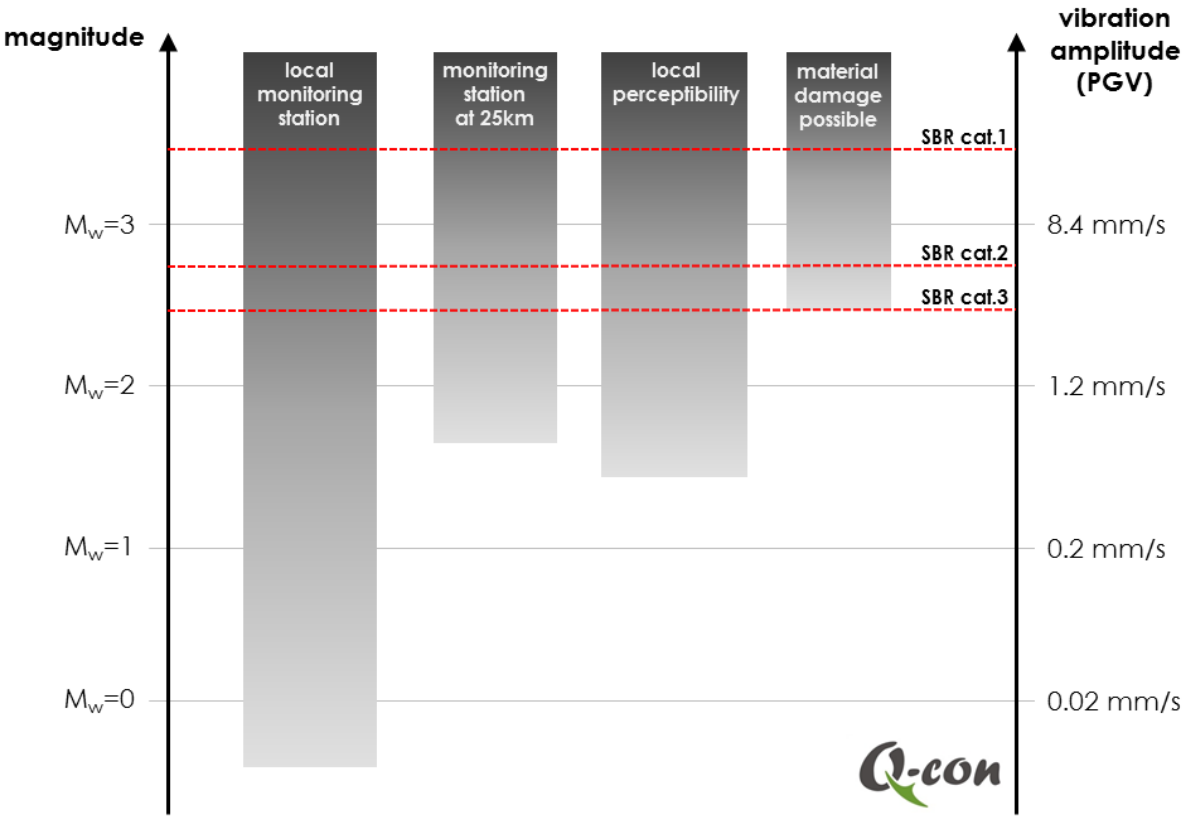
→ most seismicity occurs in basement rock

→ seismicity is not controlled by a single parameter but by a combination of specific parameters

Experience


basement
transition
vulcanites
sediments
circulation
trend basement
maximum magnitude
4
3
2
1
0
-1
-2
none
0
100
200
300
400
500
maximum flowrate [m3/h]
Q-con

Experience



- in rare cases, geothermal seismicity has caused (non-structural) material damage
- largest damage: EGS Basel → 7 Mio SFR compensated

Three-Level Procedure: Quick Scan

- The Quick Scan is a simple measure to assess the potential for inducing seismicity by geothermal operations.
- It is based on physical concepts and experience.
- It can be applied already in the planning phase of a future project.

Three-level Procedure: Quick Scan

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]
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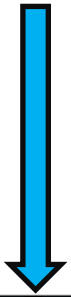
Three-level Procedure: Quick Scan

likelihood that overpressure is applied to the basement



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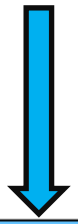
likelihood that subsurface closed loop system is achieved



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4. Three-level Procedure: Quick Scan

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likelihood that subsurface closed loop system is achieved

pumping pressure & rate

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likelihood of critically stressed fault

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hydraulic stimulation

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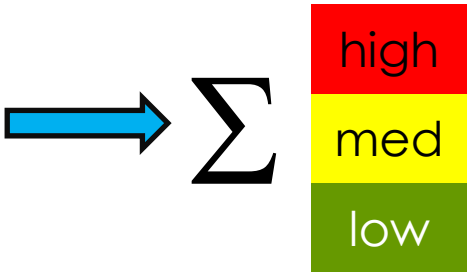


Three-level Procedure

- Quick Scan score defines the required degree of detail

high	Level 3: Seismic Risk Assessement
med	Level 2: Seismic Hazard Assessement
low	Level 1: Quick Scan sufficient

- Exceptions where at least Level 2 is mandatory:

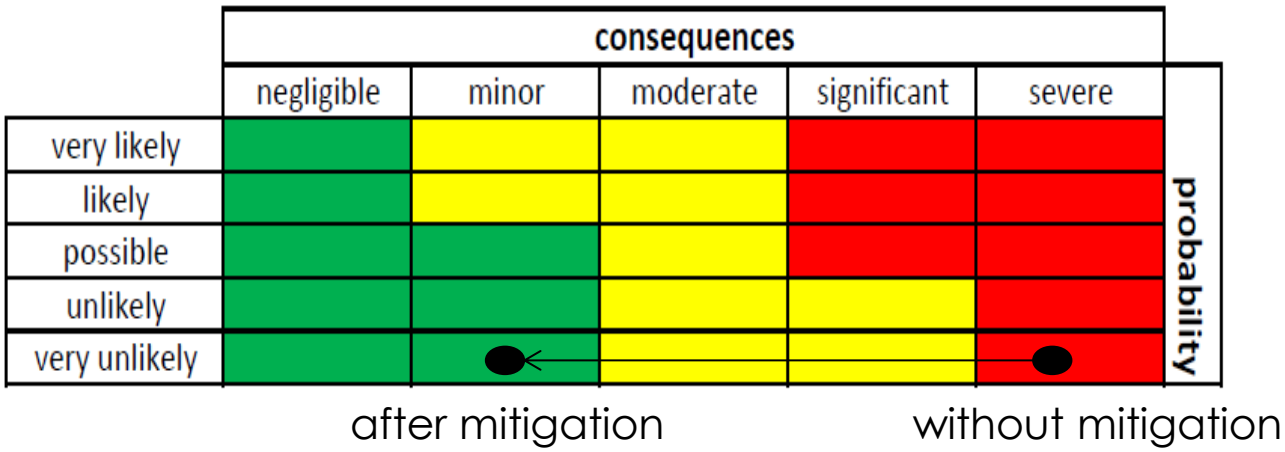
✓ tectonically active area
✓ major fault in immediate vicinity
✓ close to Groningen gas field

Three-level Procedure: Level 2 SHA

- Different methodologies can be used to perform SHA.

- Scientific study, addressing:
  - relevant physical processes
  - geological situation
  - planned subsurface operations
  - SHA for the planned operations
  - identification of mitigation measures
  - estimate of surface impact (consequences)

Three-level Procedure: Level 2 SHA



Three-level Procedure: Level 3 SRA

Seismic Risk Analysis

- Similar to Level 2 but with a detailed analysis of parameter uncertainties and the surface impact.

Seismic Monitoring

Objectives

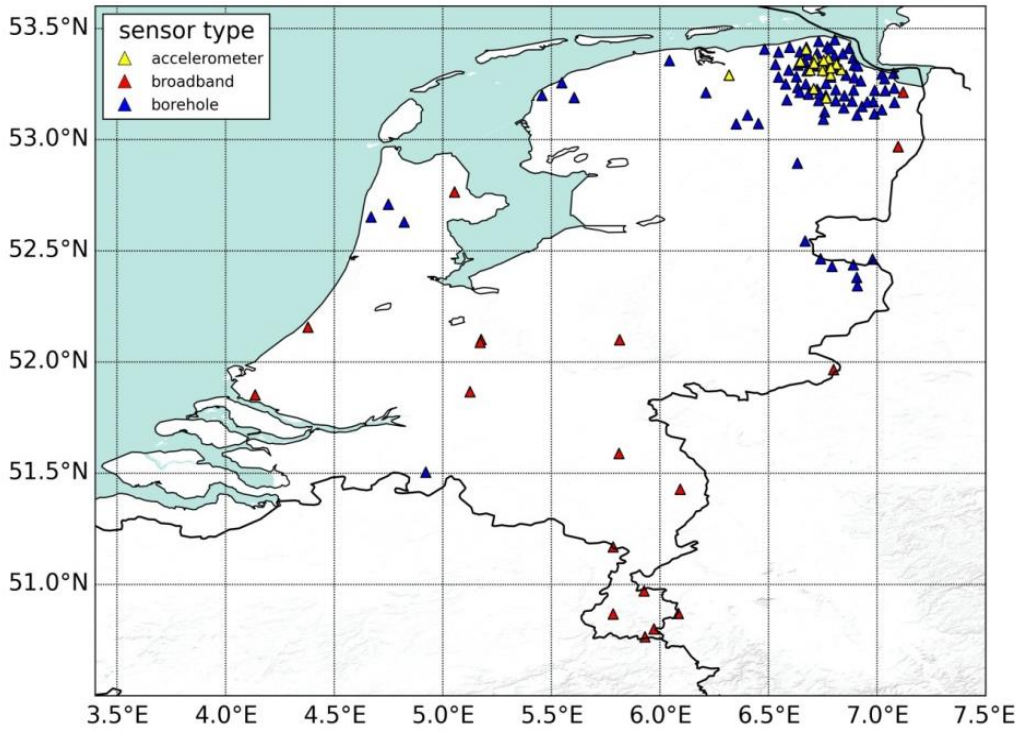
Monitoring the location and strength of seismicity near geothermal sites

→ discrimination (who caused the earthquake?)

→ traffic light system

Minimum requirements are defined for meeting these objectives.

Seismic Monitoring: KNMI Network



monitors magnitude M~2 everywhere in The Netherlands

Seismic Monitoring: Recommendations

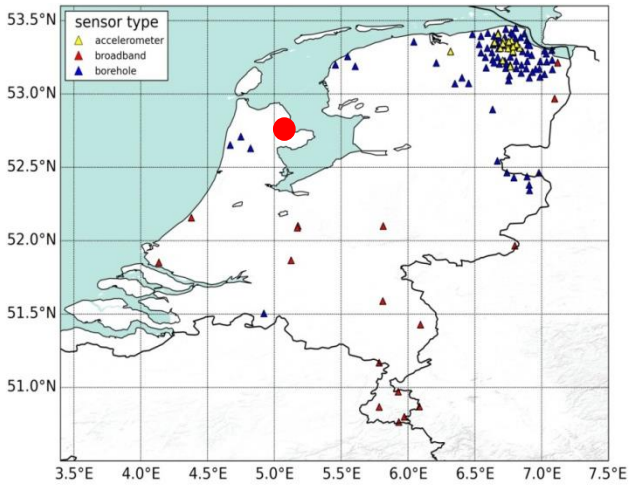
Level 1 Scenario:

- KNMI network coverage is considered sufficient
- If induced seismicity has occurred in neighbouring reservoirs, a single monitoring station near the geothermal site is recommended.

Level 2 and Level 3 Scenario:

- A local seismic monitoring system with 5 stations is recommended (existing KNMI stations can be part of it).

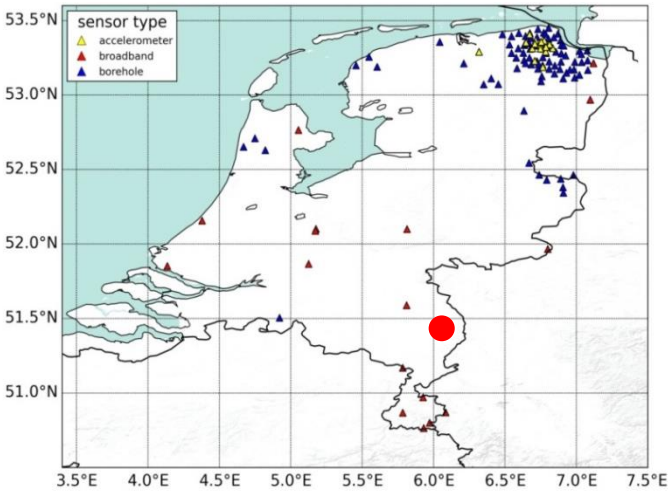
Showcase: ECW



- heat supply for green houses, started in 2013

- Quick Scan → low potential for induced seismicity (Level 1)
- Single detector station operated during initial 30 days, then handed over to KNMI. No induced seismicity detected.

Showcase: Californie



- heat supply for green houses, started in 2013

- Quick Scan → medium potential for induced seismicity (Level 2)
- <u>Level 2 SHA:</u>
  - ✓ based on numerically simulating stress changes associated with geothermal operations
  - ✓ five-station seismic monitoring system is operated with a traffic-light system

Thank you!