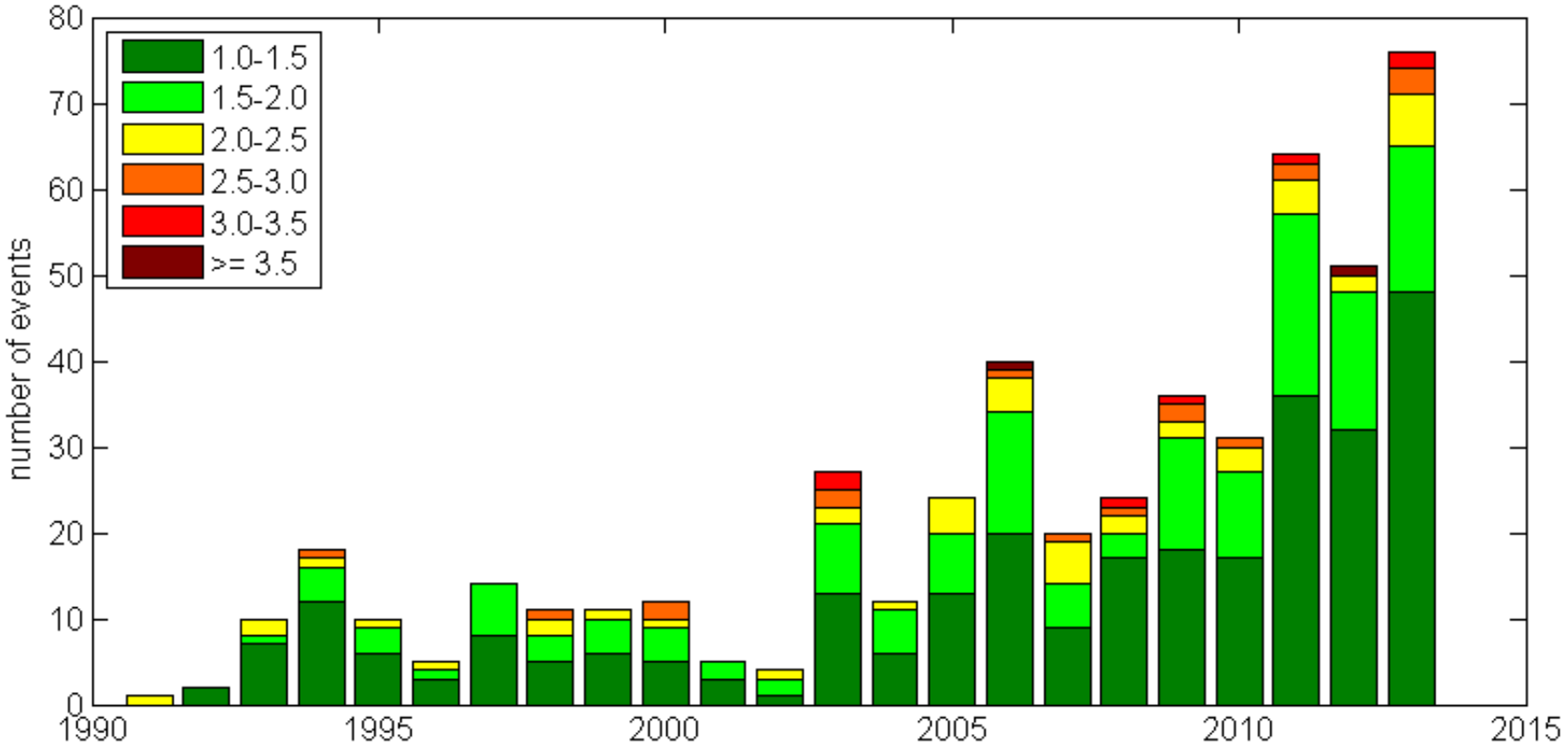
State Supervision of Mines
Ministry of Economic Affairs and Climate

The continuing challenge of managing Groningen induced seismicity

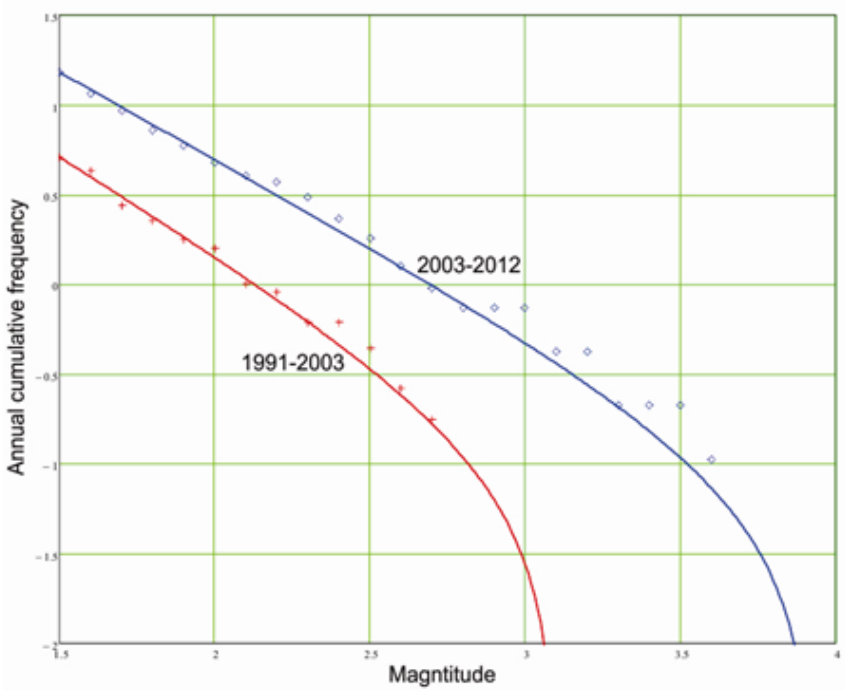
Annemarie G. Muntendam-Bos

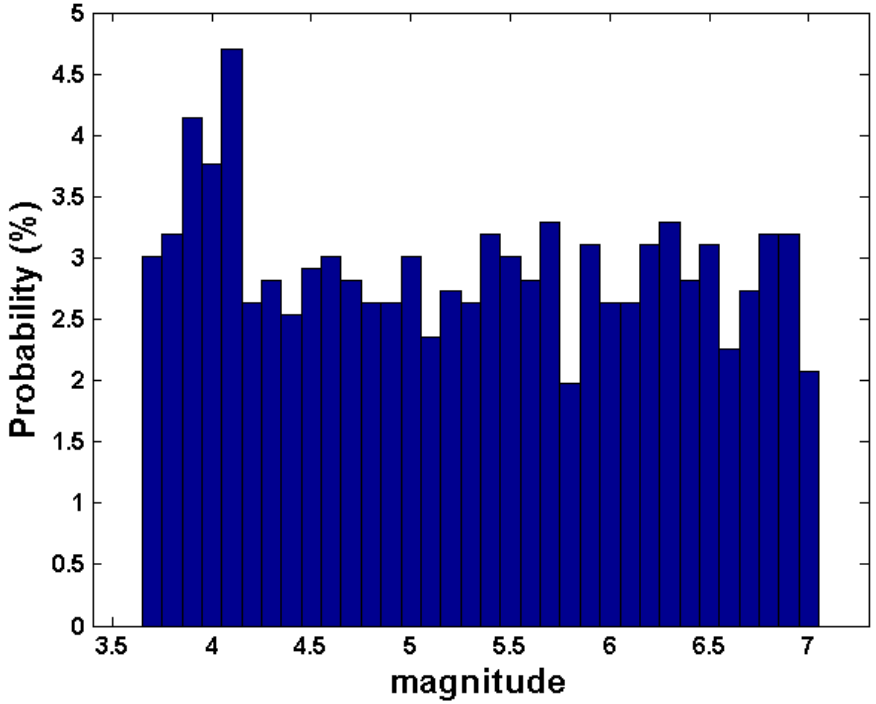
Development of Groningen seismicity
1991-2013



Year	Mmax
1993	3.3
1997	3.7
2003	3.9

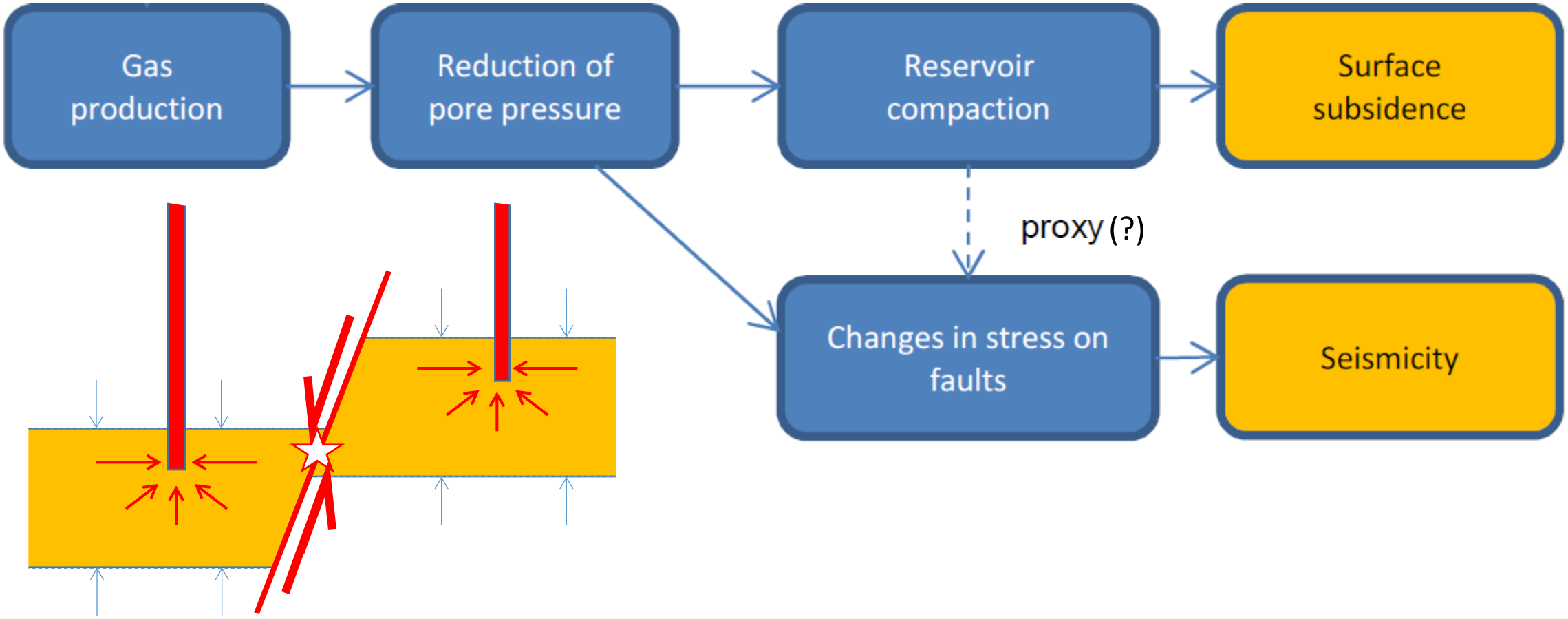
Development of Groningen seismicity
1991-2013



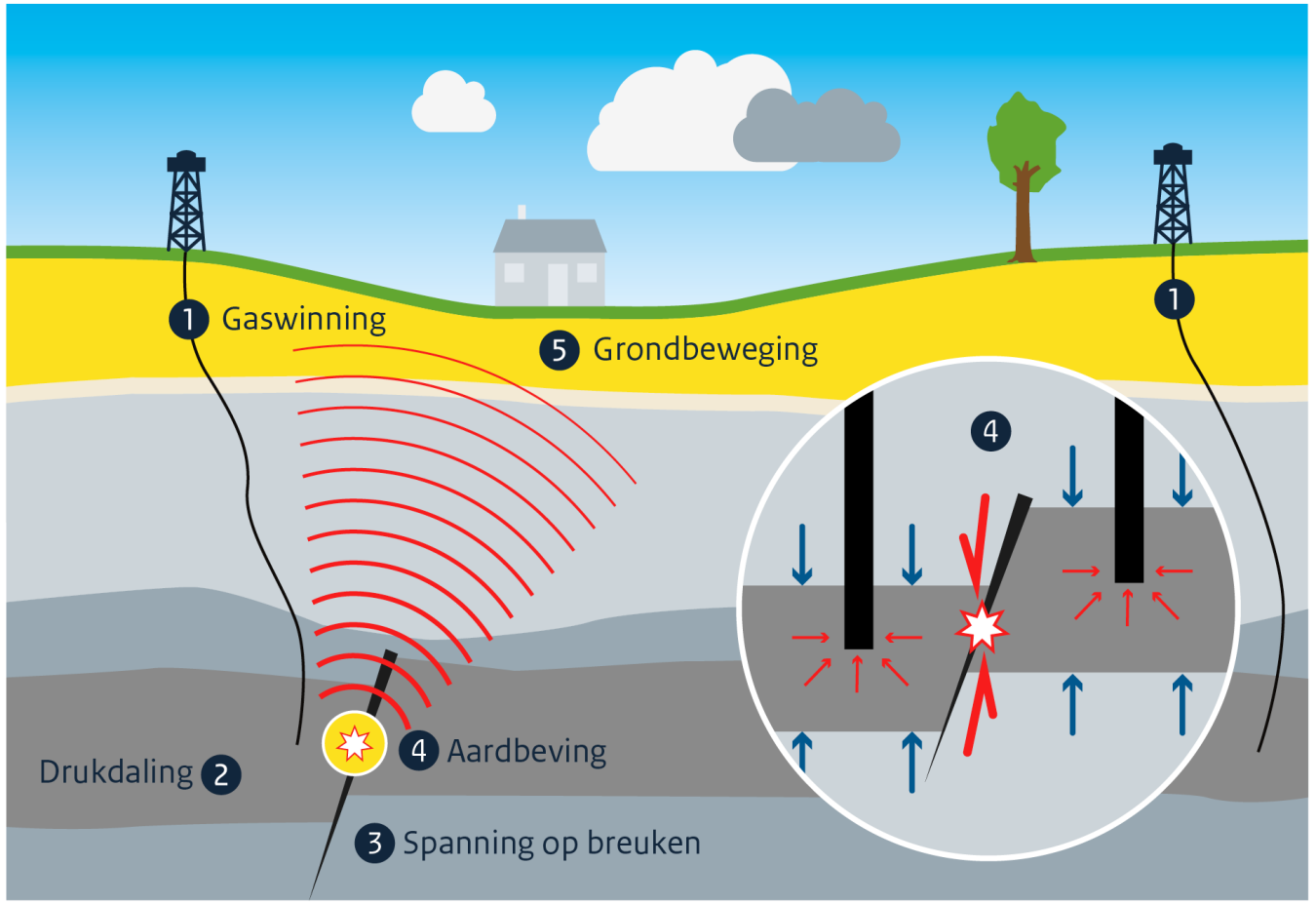


Year	Mmax
1993	3.3
1997	3.7
2003	3.9
2012	??

From gas production to seismicity



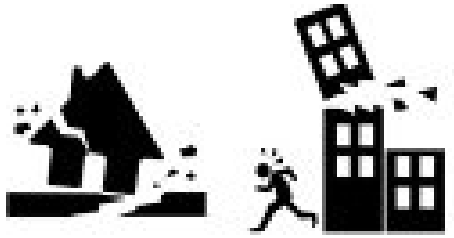
From gas production to risk



Induced seismic risk

- Object related Individual Risk (OIR):

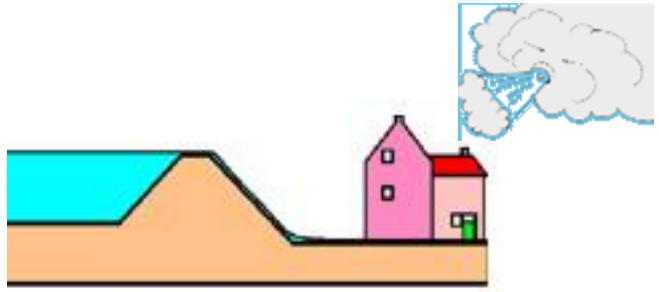
  The risk an individual is exposed to when residing in a building or when exposed to possible falling objects.



- Dutch law stipulates a norm for the OIR:

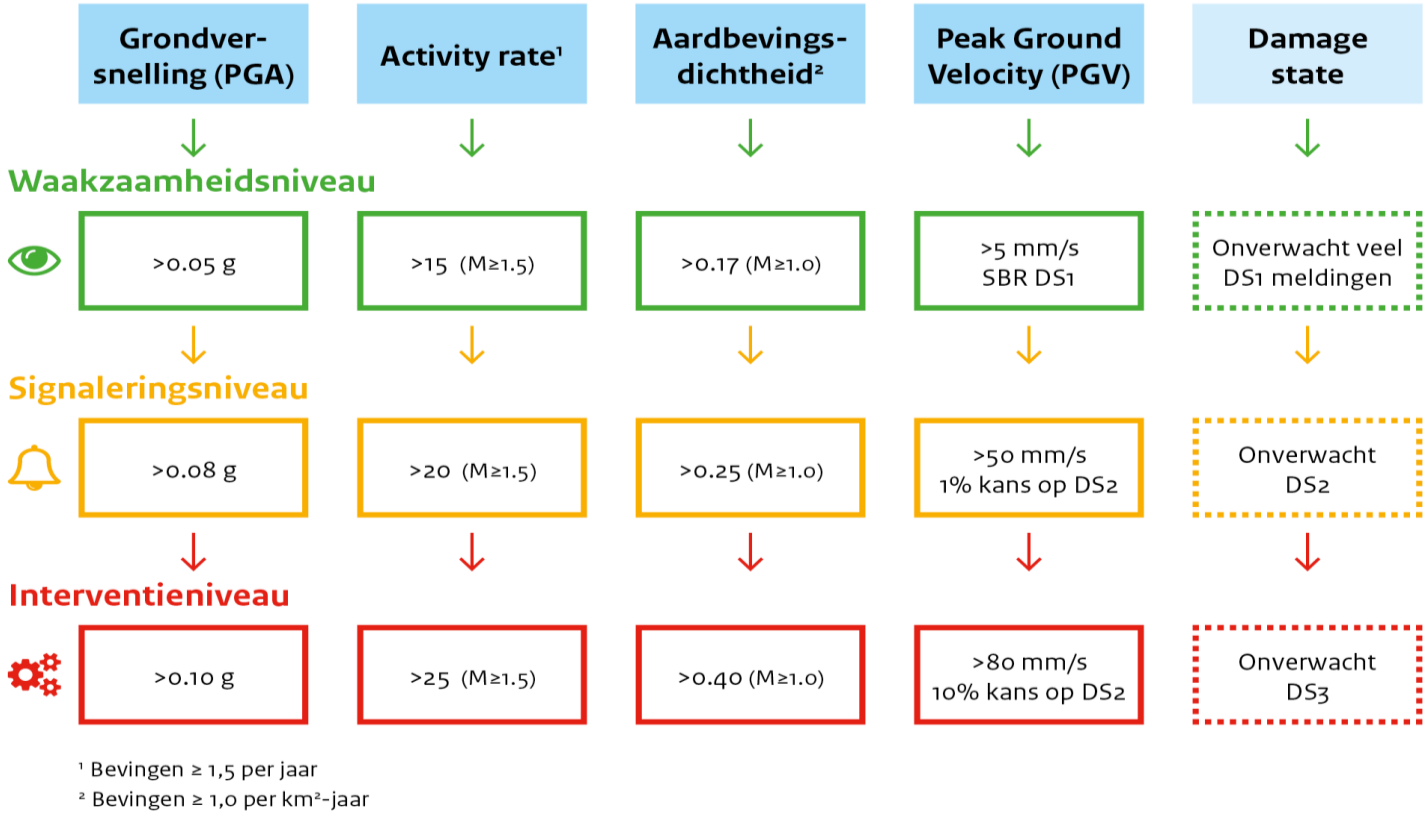
  $OIR < 10^{-5}/yr$

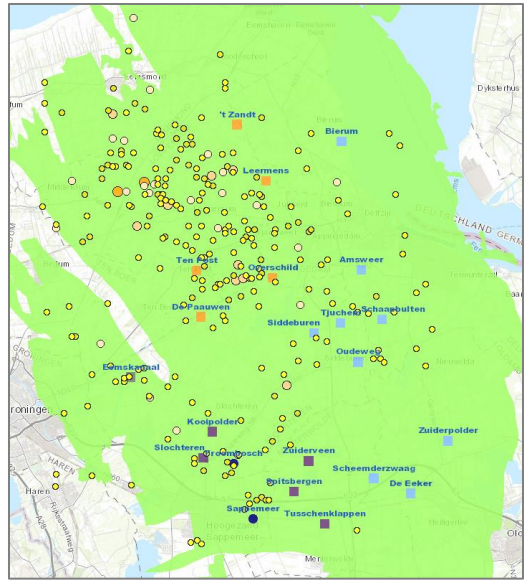
  Consistent to building code norms for storms and flooding



- Damages need to be avoided as much as realistically possible

Groningen risk-management-system: The Measurement and control-protocol



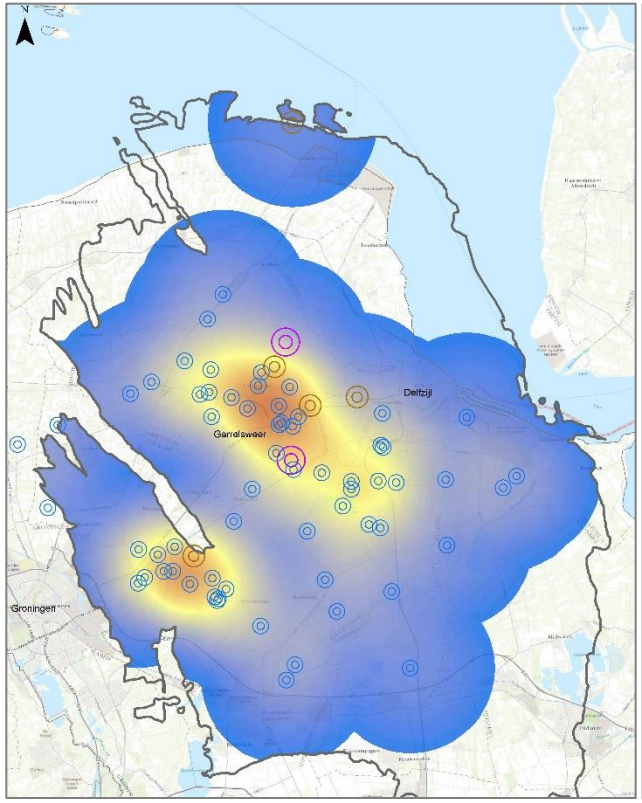


Production measures taken

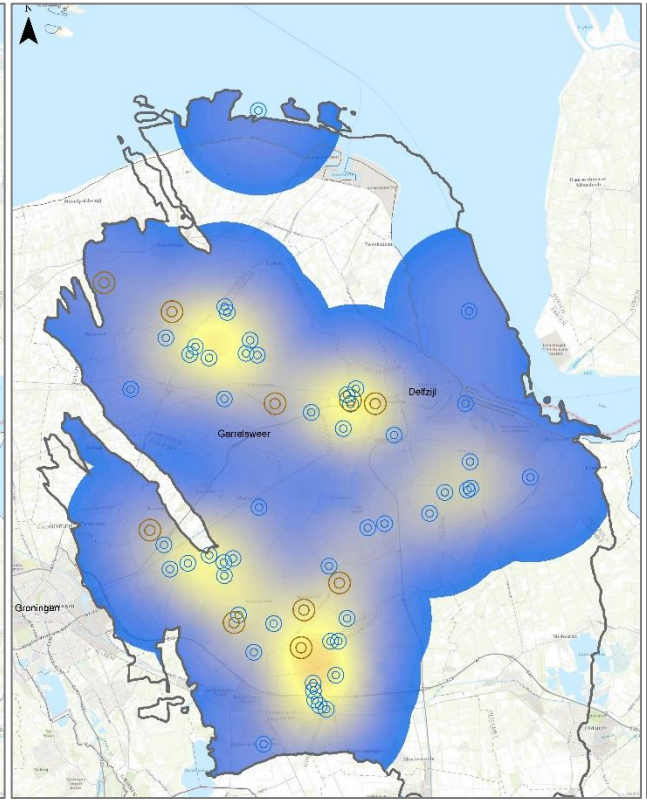
- January 2014: Reduce production center field by 80%
  54 bcm 2013 -> 49,5 bcm/yr 2014
- January 2015: Reduce production SW to level 2012
  -> 37 bcm/yr 2015
- June 2015: Reduce production evenly to 33 bcm/yr; diminish seasonal fluctuations if possible
- November 2015: Counsil of State ruling: 27 bcm/yr; diminish seasonal fluctuations if possible
- Oktober 2016: Reduce production evenly to 24 bcm/yr; minimize fluctuations in production
- April 2017: Reduce production evenly to 21.6 bcm/yr; minimize fluctuations in production

Impact production measures on seismicity

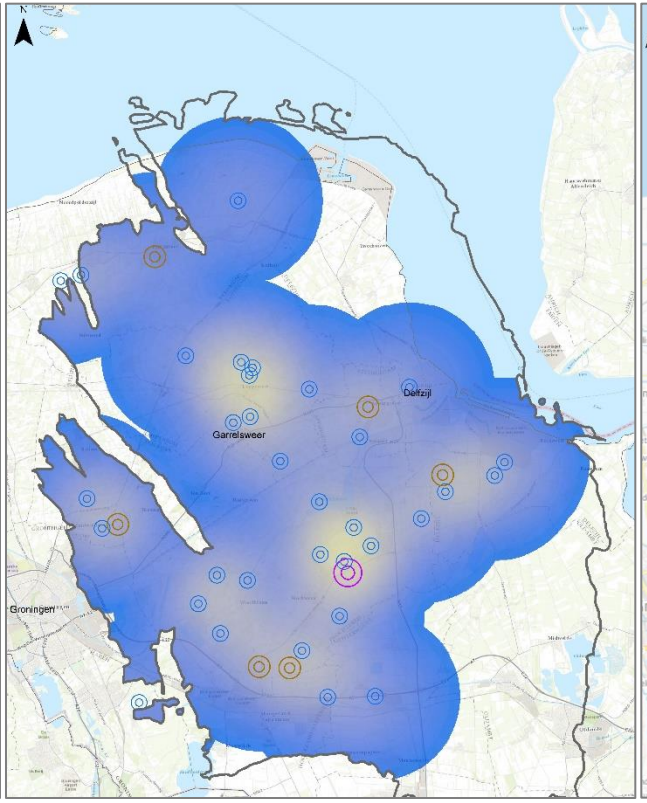
March 2013-March 2014



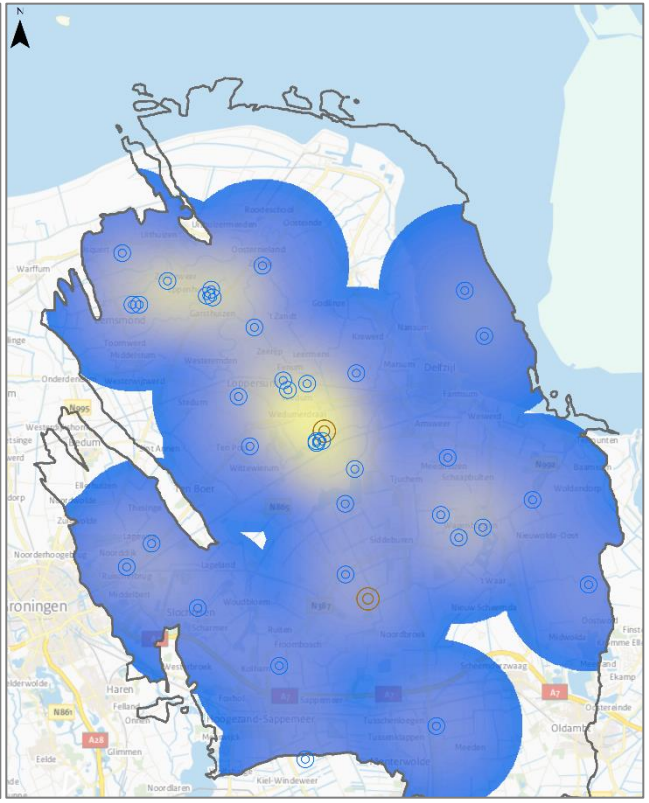
March 2014-March 2015



March 2015-March 2016

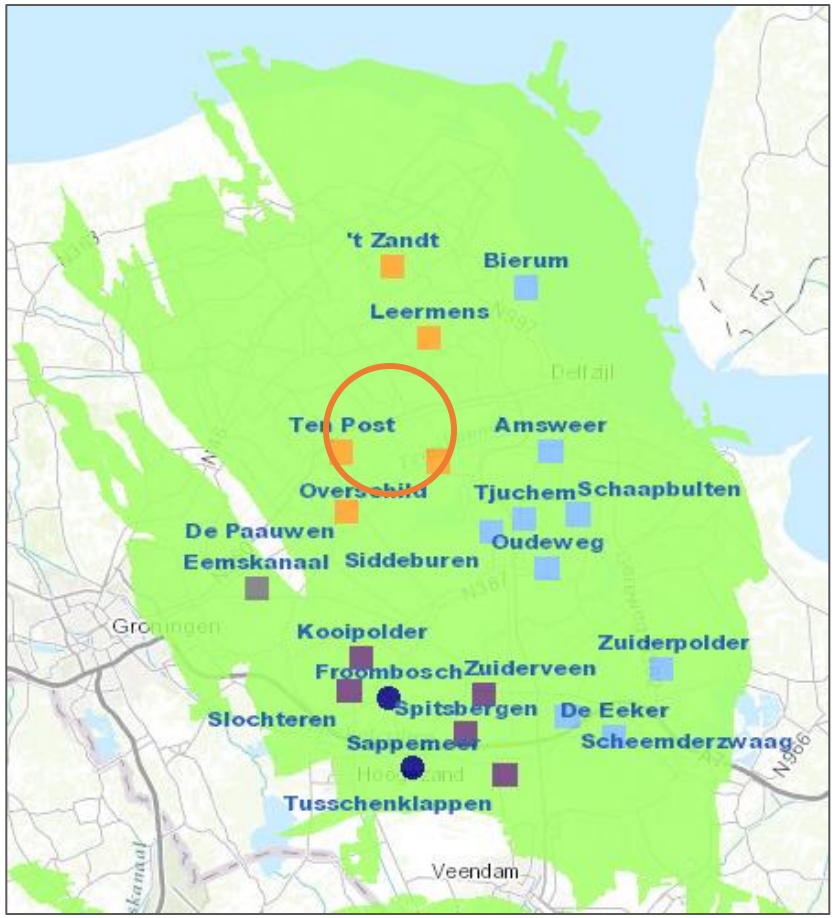


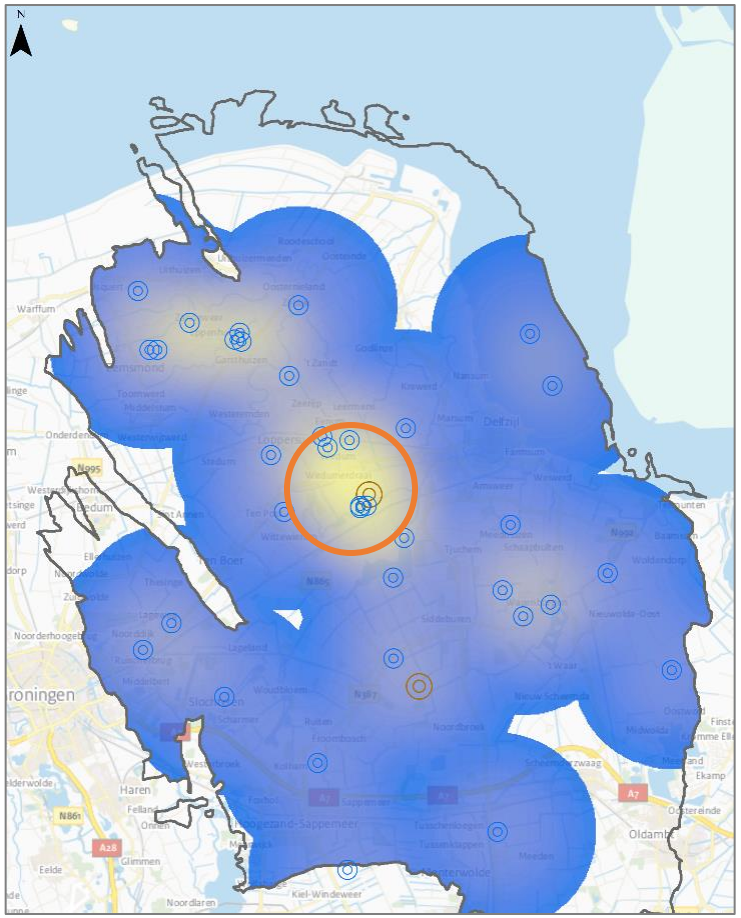
March 2016-March 2017



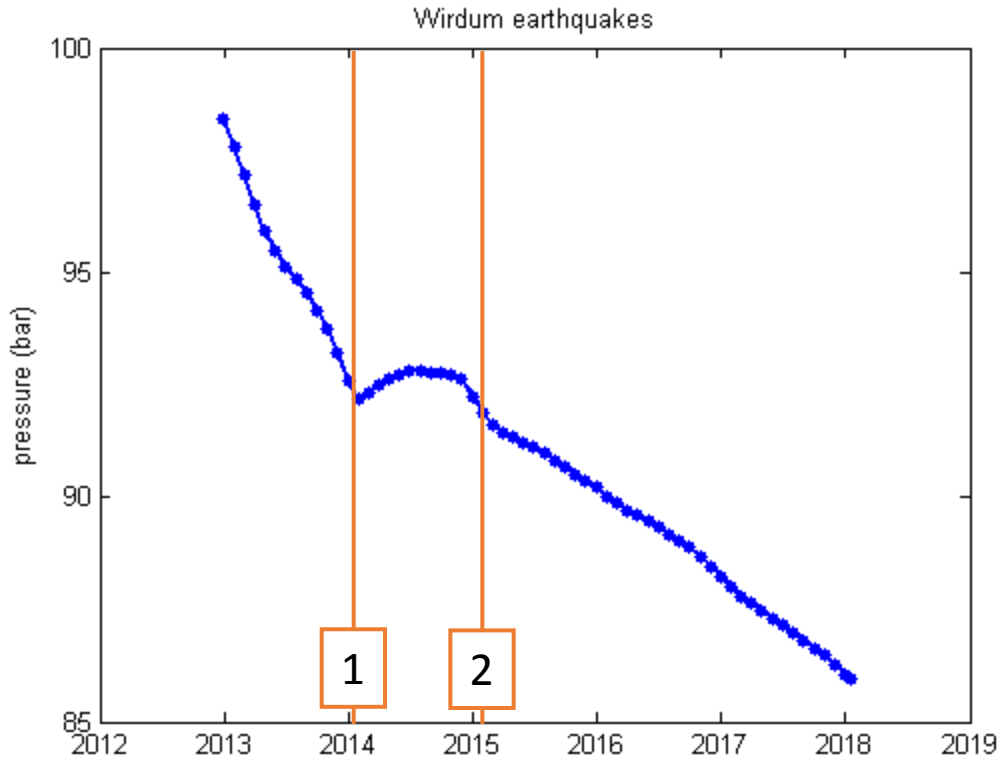
Source: TNO

Increase in event rate at Wirdum in November 2016





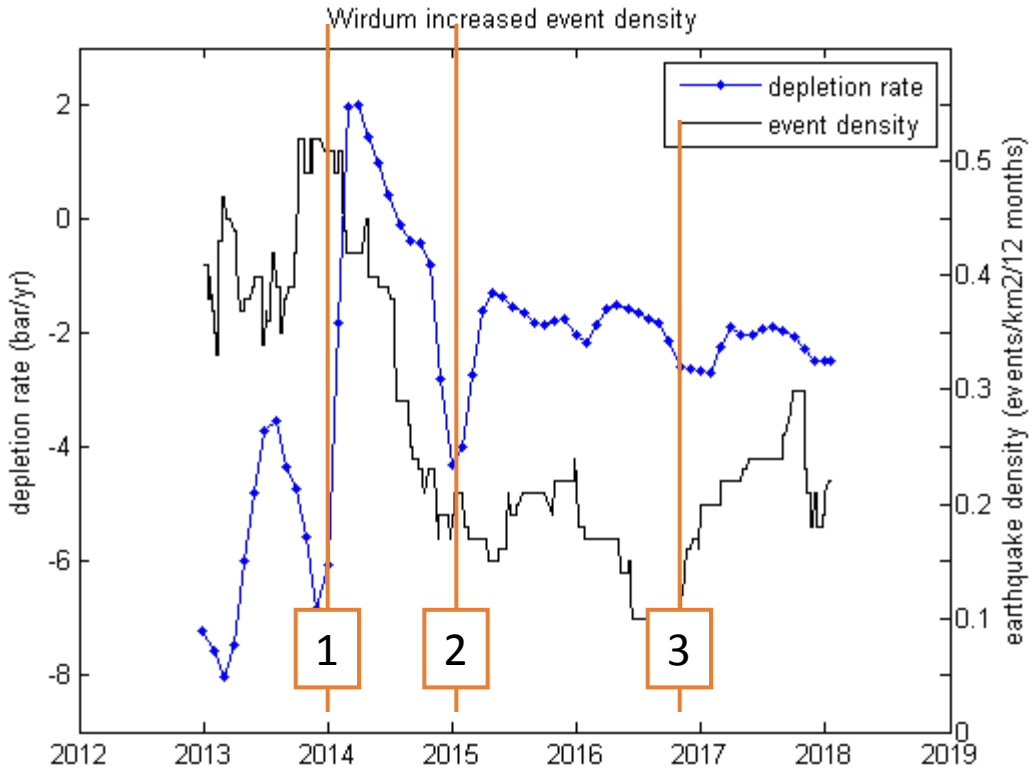
Pressure development and seismicity



- 1 = production reduction Loppersum -> depletion is interrupted, temporary increase in pressure
- 2 = pressure returns to level of prior to measure

- For 1 year depletion was interrupted
- Since 2015 pressure is in decline again and stress on the faults is increasing.
- However, stress is accumulating at a lower rate

Pressure development and seismicity

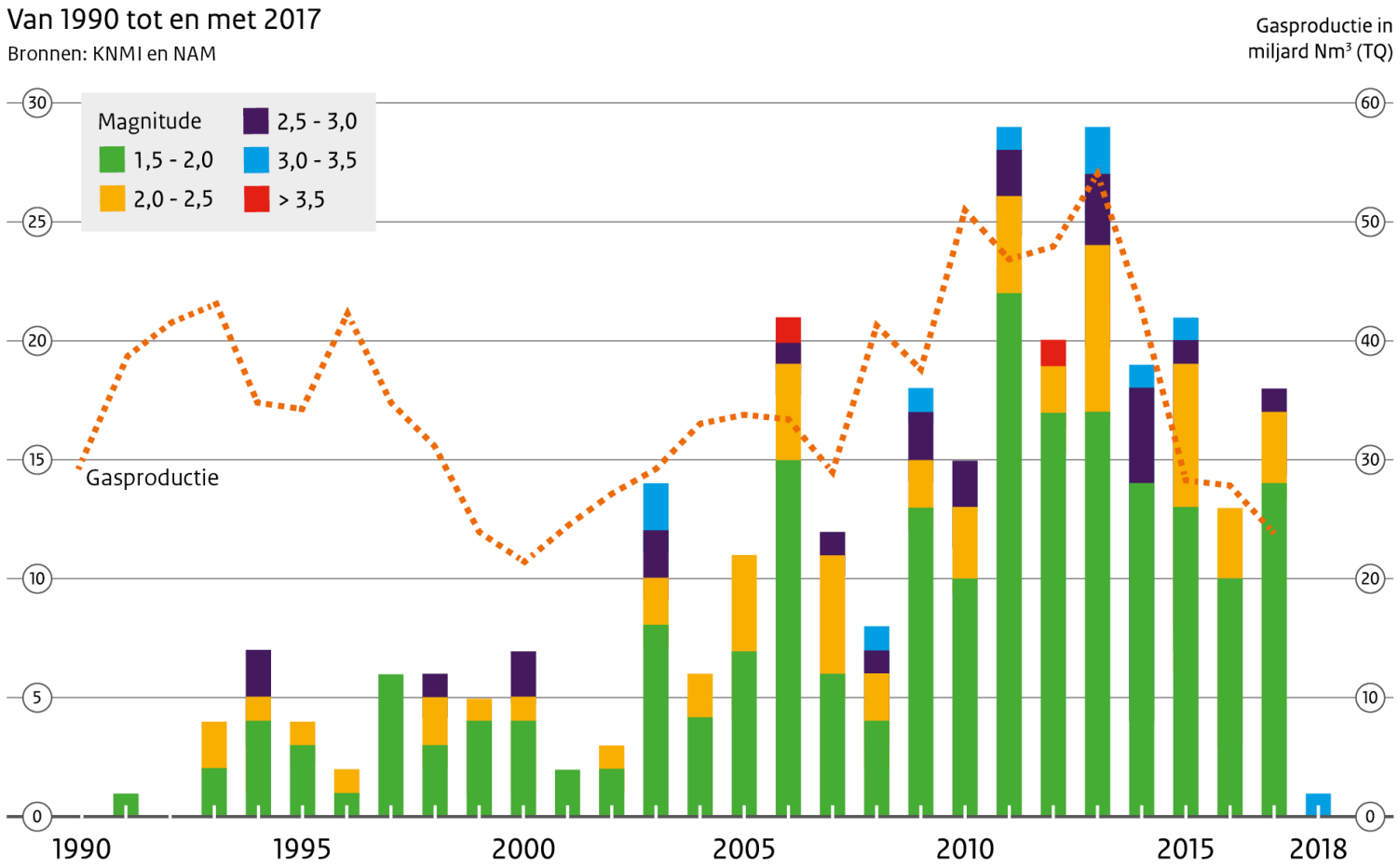


- 1 = production reduction Loppersum
- 2 = short production increase

  Dec 2014 – Jan 2015
  -> M2.7 event on January 8, 2015
- 3 = increase in seismicity Nov 2016

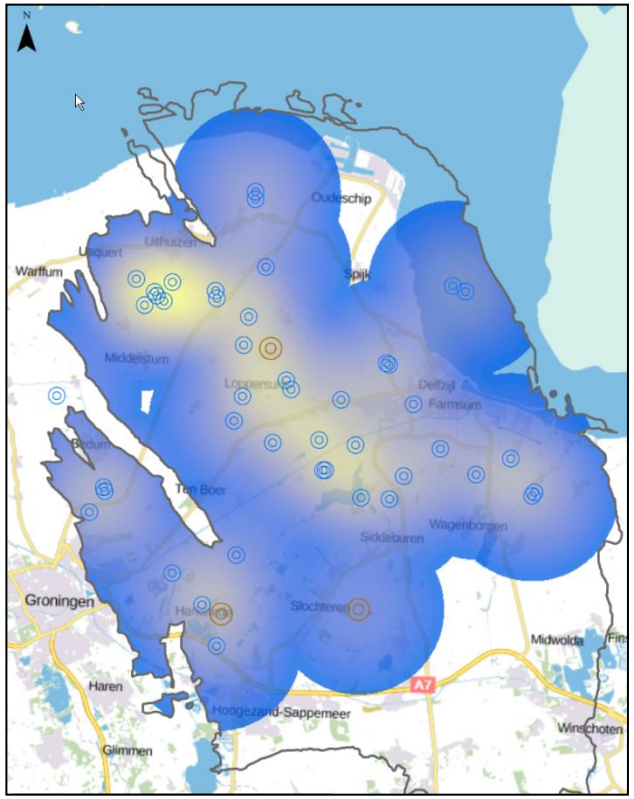
The faults are so critically stressed that small that small accelerations in the depletion can trigger either a cluster of events and/or a larger magnitude event.

Groningen gas production and seismicity

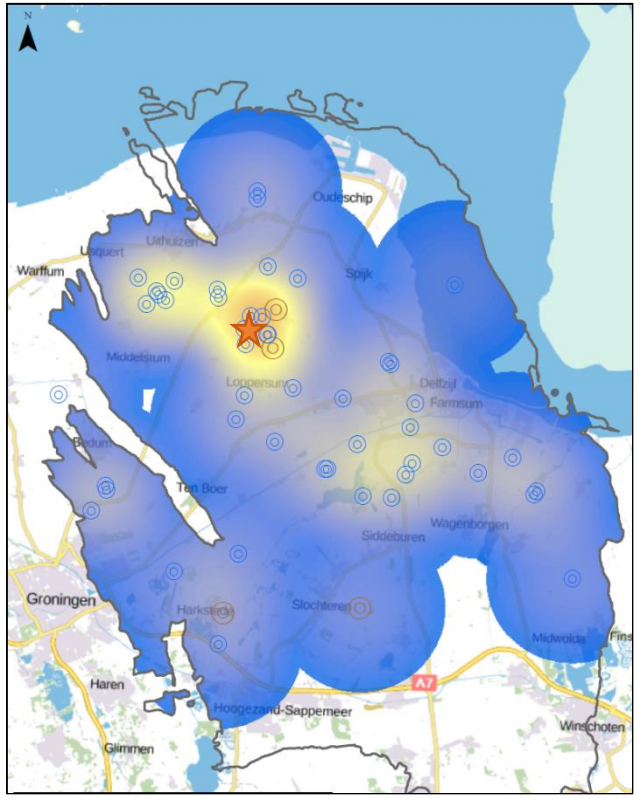


Most recent developments

December 2016-December 2017



4 Januari 2017 – 4 januari 2018



Source: TNO

Conclusions

- Induced seismicity has been increasing exponentially up to 2013
- The decreases in production have been effective in at least temporally interrupting this trend throughout the field.
- Also less larger magnitude events (M>3.0) were observed and none between September 30, 2015 and January 8, 2018.
- Some clustering of small magnitude events is still observed –> very small stress perturbations can already trigger seismic slip.
- In January 2018 a cluster of events resulted in a larger magnitude event
- Towards the future seismicity and gas production will be managed further with the Measurement and Control protocol.

Thank you for your attention