MEMO

To:	Inspector General of Mines
Cc:	
From:	
Date:	7th April 2017
Subject:	NAM report: 'Report recent earthquakes Wirdum and Garsthuizen 2016/2017', March 14th 2017

Dear ,

Please find below my comments on the NAM report *Recent earthquakes Wirdum and Garsthuizen 2016/2017*.

Kind regards,

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1. Background

State Supervision of Mines (SODM) asked me to provide an expert opinion on the report 'Recent earthquakes Wirdum and Garsthuizen 2016/2017' dated March 14th 2017. The request was sent by email on March 30th, 2017 and an English translation of the NAM report was sent on March 31st, 2017 (both by).

The specific questions I was asked are

1. Do I find the analyses and conclusions drawn scientifically sound?
2. How do I perceive the further development of the seismicity in the near and intermediate future?
3. Given that from a societal perspective new and further escalation of seismicity is unacceptable, do I deem it wise to further reduce the level of production?

As a member of the Scientific Advisory Committee for the Groningen Winningsplan 2016 I followed the seismic hazard and risk analysis performed by NAM until May 2016. Additionally, I received an update of the CBS studies ( ) during a SODM workshop in November 2016. This defines the 'state of knowledge' on which my expert opinion is based on.

2. Comments to NAM (2017)

The NAM (2017) report is motivated by recent seismicity occurring in the central area of the Groningen field near Wirdum and Garsthuizen. Although seismic activity did not exceed M_L=2.2, a signal parameter based on local earthquake density is close to the 'preliminary warning threshold' as defined in Instemmingsbesluit (2016). The NAM (2017) report aims to investigate the relevance and the cause of this seismicity increase.

As main conclusions, NAM (2017) finds that the current seismicity does neither deviate from historical patterns nor from expectations based on geomechanical models. No correlations of the seismicity with a specific gas production pattern were found and the seismic activity is interpreted to be driven by the general (field wide) pressure decrease.

Although these conclusions appear to be reasonable given my understanding of the Groningen gas field, the underlying analysis is frequently not presented according to scientific standards as outlined below. The ten data elements and the associated questions identified in NAM (2017, Table 2) cover key aspects and provide a good basis for the

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analysis. The analysis itself, however, is frequently not well documented and it is not always clear to me what exactly has been done:

Chapter 4: The main conclusion of this chapter is that earthquakes do not occur on specific faults. This conclusion could only be supported if the uncertainties of the hypocenter locations and the fault trajectories had been considered. To my understanding, this has not been done. Associated confidence ranges (epicentres, trajectories) should be added to Figure 4 and Figure 5 and statistical tests should be performed in order to support (or reject) the conclusion above. From Figure 5 it appears to me that the current seismicity can be much better associated with mapped faults than indicated in previous studies. Is this due to the improved location accuracy of the extended KNMI network?

Chapter 5: The main conclusion of this chapter is that seismicity does not show a consistent correlation with gas production patterns (Figure 6). I cannot assess this conclusion since Figure 6 does neither show the seismic activity nor does it provide a (readable) scale for the production rates. Little details are given regarding the underlying analysis. Was it simply a visual comparison?

Chapter 6: Two main conclusions of this chapter are that (i) the reservoir pressure in the seismically active region is also affected by the more distant production clusters and that (ii) the local pressure decline is relatively insensitive to a production stop of the nearest cluster (POS). For supporting the first conclusion, I consider a flow line plot (Figure 7) inadequate, as it is not possible to infer pressure from flow simply by eye. In order to support the second conclusion, (simulated) reservoir pressure should be mapped for different times. The local pressure evolution could then be investigated for different production scenarios. It would also be interesting to look at the pressure levelling in a scenario of immediate field closure.

In chapter 9 a ‘conceptual’ discussion is presented regarding the return of larger magnitude earthquakes in the central part of the field. It is concluded that observations are consistent with the seismicity being driven by pressure drop and the thickness of the HC column. Although I feel that this may well be the case, the report does not present compelling evidence for this conclusion.

In chapter 8 and chapter 10 it is investigated whether or not the current seismicity near Loppersum is different from previous seismicity patterns. It is noted that the ‘preliminary warning threshold’ was exceeded several times in the past. I consider this an important observation. The observation could become even stronger if the local lower magnitude

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detection threshold of the KNMI network is considered under actual conditions (i.e. taking into account station outages and transient noise contaminations). Due to the large number of additional monitoring stations it has become less likely that an earthquake with $M_L > M_c$ could remain undetected, even if data of one or more local stations is not available.

3. Questions Posed by SODM

1. Do I find the analyses and conclusions drawn scientifically sound?

   The NAM (2017) report frequently does not meet scientific standards (see comments above). Many conclusions are not substantiated by a proper scientific analysis.

2. How do I perceive the further development of the seismicity in the near and intermediate future?

   Our forecasting abilities for the seismicity in the Groningen field are very limited and key aspects are not well understood. These include the dependency of the seismicity to the production rate (more precise: to the rate of pressure decline) as well as the occurrence of post-production seismicity, e.g. driven by pressure levelling or after-deformation. Recent work by CBS (e.g. Pijpers, 2016) and TNO (Nepveu et al., 2016) indicate that the seismicity response to changes of the production pattern might be much faster than previously thought. This is an encouraging result since it suggests that seismicity is, to some extent, controllable by the production pattern. It is, however, not clear how the field wide decline of the reservoir pressure impacts the seismicity. In this respect it is possible that larger magnitude earthquakes return to the Loppersum area even when the Loppersum clusters remain at low/no gas production.

   As far as the observed increase of the event density is concerned, I do not see this as a compelling indicator for an upcoming larger magnitude earthquake in the Loppersum area. As stated in the NAM (2017) report, the signal parameter exceeded the 'preliminary warning threshold' several times in the past. The current models (at least those I am aware of) do not allow forecasting larger magnitude events from these threshold exceedances.

3. Given that from a societal perspective new and further escalation of seismicity is

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unacceptable, do I deem it wise to further reduce the level of production?

From a scientific point of view, further reduction of the production level is the most promising measure to minimize the occurrence of seismicity. Additionally, closing parts of the field can be seen as an experiment for studying the 'controllability' of the induced seismicity.
From a holistic view angle, however, it is clear that a risk-based decision is required, taking into account all sorts of risks including societal risks and economic losses due to a cap on production. Quantifying and balancing these risks should be a focus of the ongoing Groningen studies (e.g. the 'engine' used for the seismic risk analysis in the Winningsplan 2016 is not suited for this type of analysis for two reasons: firstly, material damage cannot be modelled and secondly, the engine is relatively insensitive to changes of the production pattern). The above question can only be answered after all risks have been quantified.

4. References

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