Study and Data Acquisition Plan
Induced Seismicity in Groningen
for the update of the
Winningsplan 2016

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1. Introduction

Since 1986 relatively small earth tremors occur in the vicinity of producing gas fields in the North Netherlands provinces Groningen, Drenthe and Noord-Holland. In general, these events only caused feelings of unease amongst residents, but in excess of a certain magnitude and intensity these earthquakes can also cause damage to buildings.

In the early 90’s a multidisciplinary study, EZ-initiated and guided by a Supervisory Committee, analyzed the relationship between gas production and earth tremors, concluding that in view of the seismic pattern, the hypocenters location, difference with historical seismicity and the frequency-magnitude distribution, the earth tremors were of non-tectonic origin and were most likely induced by reservoir depletion (i.e. gas production). Following an agreement with Royal Dutch Meteorological Institute, KNMI, a borehole seismometer network was installed since 1995 in Groningen to detect tremors, pinpoint their location and quantify their magnitude. Accelerometers were also installed in areas where tremors frequently occurred.

The earthquake near Huizinge (16/8/2012) with magnitude $M_w=3.6$ was experienced as more intense and with a longer duration than previous earthquakes in the same area. An order of magnitude more building damage incidents were reported than for previous earthquakes. Also the public observation that seismicity in the Groningen area seems to be increasing over the last years has triggered a renewed focus and attention for the issue of gas production induced seismicity in Groningen.

To better define the relationship between magnitude, duration, frequency, peak ground velocity and peak ground acceleration of earthquakes and potential damage to buildings, an extensive study program was initiated and more monitoring planned. A Study and Data Acquisition Plan was issued October 2012 and has since then been regularly updated during 2013. In November 2012, the Study and Data Acquisition Plan was shared with SodM and the Ministry of Economic Affairs (Ref. 1.). It was made public early 2013. Regular updates of the study progress were provided to the advisory committee of the Minister of Economic Affairs (TBO) the regulator (SodM) and her advisors (TNO-AGE and KNMI).

Results of these studies carried out in 2013 were shared with the technical advisory committee of the Ministry of Economic Affairs (TBO) at three large workshops held in May, July and August and several technical meetings focusing on a particular issue. The study results were reported to the Minister of Economic Affairs and SodM in November 2013 in the “Technical Addendum to the Winningsplan - Groningen 2013” (Ref. 3, 4 and 5). Additional to the winningsplan 2013 and supporting technical documentation, a Borgingsprotocol has been submitted by NAM. This will ensure regular updates on progress of studies and the hazard and risk assessment by NAM to the regulator and her advisors.

Although the work done during 2013 gained new insights and received generally positive comments from peer reviewers and the TBO, it is by no means concluded. Despite the progress made, some technical questions remain unresolved (Ref. 7 and 8), while uncertainties in the geomechanical parameters and in the estimated seismic hazard are large. Some of the remaining uncertainty stems from lack of knowledge (epistemic uncertainty) and is therefore liable to be further constrained with
increasing data acquisition and analysis. The study and data acquisition plan therefore continued in 2014 and will be continued in the following years.

Figure 1.1  RTVNoord footage published on www.Youtube.com on 27 August 2012. Bottles knocked of shelves in the supermarket in Middelstum, due to the earthquake of 16 August 2012.

In January 2014, the minister shared his intention to approve the winningsplan Groningen 2013 for a three year period, requiring an update of the winningsplan in 2016 (Ref. 10). This plan describes the different studies and data acquisition activities supporting the hazard and risk assessment for the update of the Groningen winningsplan 2016.
2. Study and Data Gathering Project Management

2.1 Research Objectives

The prime objective of the study and data acquisition plan is to identify and define the research activities in support of the preparation of the hazard and risk assessment for induced seismicity resulting from gas production from the Groningen field, which can serve as a basis of the Groningen Winningsplan 2016. This is part of NAM’s responsibility to demonstrate it acts as a prudent operator.

This hazard and risk assessment should be based on sound scientific principles and have support from the regulator (and her advisors), the earth sciences community and the trust of the general community. The hazard and risk assessment needs to be implemented as a single exercise to ensure consistency in approach.

Objectives of the research on induced seismicity in the Groningen Field are:

- Assessment of Hazard and Risk and Reduction the uncertainty in the Hazard and Risk Assessment for the update of the Winningsplan 2016,
- Understand the impact of this hazard on buildings and the safety of the community,
- Identify measures to reduce the hazard and risk and evaluate their effectiveness and provide insights to steer the development and deployment of mitigation measures. These measures can be different production policies or the strengthening of buildings,
- Address areas of different scientific views and with additional studies or measurements try to resolve these,
- Monitor subsidence and seismicity as part of the borgingsprotocol,
- Increase our understanding of the mechanism leading to induced seismicity and the resulting hazard and reduce the uncertainty in the hazard and risk assessment.

The figure below shows the different elements of the Hazard and Risk assessment.
To achieve this objective, the “Study and Data Acquisition Plan for Induced Seismicity in Groningen” has been prepared based on the following principles and priorities:

- **Reduce the uncertainty in the Hazard and Risk Assessment.** The current Hazard and Risk assessment, which forms the basis for the Winningsplan 2013, was prepared in 2013. Due to the limited timeframe for this study work, not all factors impacting the hazard and risk could be fully assessed. As a result, at several stages of the assessment, conservative assumptions needed to be made. This has potentially resulted in a high assessment of the hazard and risk at low exceedance levels. With further data acquisition and research the assessment of the hazard and risk can potentially be reduced (section 2.2, reducing uncertainty).

- **Identify measures to reduce the hazard and risk and evaluate their effectiveness.** These measures can be different production policies (depletion or pressure maintenance) to reduce the hazard or the strengthening of buildings (structural upgrading) to reduce risk (section 2.3, measures to reduce hazard and risk).

- **Address areas of different scientific views between NAM and SodM, KNMI and TNO-AGE.** During the technical discussions between NAM and SodM leading up to the update of the Winningsplan 2013, a number of issues could not be resolved (section 2.4, address areas of different scientific views). In the report by TNO-AGE reviewing the technical support for the winningsplan 2013 (Ref. 7) and in SodM’s advice to the minister (Ref. 8) a number of criticisms and area of different technical views were raised and discussed.
Monitor subsidence and seismicity as part of the borgings protocol. Both subsidence and seismicity also need to be monitored closely to be able to identify deviations from the predictions by the models used to assess the hazard and risk.

Increase scientific understanding of the processes leading to seismicity in Groningen.

Provide early insights into the hazard to steer the development and deployment of mitigation measures, like the structural upgrading program.

In the following sections the study plan will be analyzed and tested with these priorities in mind. The results of the studies and data acquisition will be compiled in a hazard and risk assessment for the seismicity induced by gas production from the field.

The study and data acquisition plan is robust against the main criteria. There is sufficient flexibility to adjust the program to incorporate the insights from new findings. The process tracking and reporting ensure a process to identify opportunities to adjust the program.

2.2 Reducing Uncertainty

An integrated probabilistic Hazard and Risk Assessment will be carried out using a Monte Carlo approach.

<table>
<thead>
<tr>
<th>Reservoir Model</th>
<th>Deformation Model</th>
<th>Seismicity Model</th>
<th>GMPE</th>
<th>Exposure Model</th>
<th>Fragility Curves</th>
<th>Injury Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number, magnitude, mechanism and location of earthquakes</td>
<td>Log normal distribution of PGA and PGV values for a given earthquake</td>
<td>Location and classification of buildings in and around the gas field</td>
<td>Probability, for each building class, reaching a damage state DSi as a function of PGA</td>
<td>Probability, for each person, reaching an injury level SLi as a function of DSi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.2 Schematic showing the elements of the integrated probabilistic hazard and risk assessment.

2.2.1 Seismic Hazard

During the period from 2014 to 2016, NAM will continue the research program to gain further insights in the processes leading to earthquakes and the size of the resulting hazard. The analysis of the contributions to the epistemic uncertainty in the hazard using the logic tree approach, showed four factors to be important: the strain partitioning factor describing the coupling between compaction strain and seismicity, the ground motion prediction equation, the compaction and to a lesser extent the b-value.
Figure 2.3 Variation in the maximum PGA found within the Groningen Field with a 2% chance of exceedance over the period 2013 to 2023, due to epistemic uncertainties represented in the logic tree.

The partitioning factor has the largest impact on the uncertainty in the seismic hazard. Both attempts to gain insights from analogy with tectonic earthquakes and further geomechanical investigations are elements of the study program to improve the understanding of the processes inducing earthquakes and the partitioning factor. Sections 7 to 10 show the main activities in the research program into induced earthquakes in the Groningen field for 2014.

2.2.2 Building and Injury Risk

Uncertainties in the risk assessment, focus on the exposure model and the description of the fragility of buildings. In the update of the Winningsplan 2013, the uncertainty description is based on fragility descriptions from literature (Ref. 6).

Fragility of unreinforced masonry buildings constructed using the building practices and designs used locally in Groningen need to be further investigated. Especially, the impact of the shorter duration of the induced earthquakes, compared to tectonic earthquakes, for unreinforced masonry buildings is currently poorly understood. The longer duration tectonic earthquakes form the basis of many of the currently in literature available fragility curves. It is therefore possible that fragility of the buildings is overestimated in the current assessment.

Although the number of concrete buildings is relatively low, these often have higher day-time occupancy rates. More attention will be given to concrete buildings in the risk assessment in 2016. One of the challenges will be to incorporate the impact of the house strengthening program in the risk assessment.

2.3 Measures to reduce Hazard and Risk

Measures to reduce the hazard, focus on other production philosophies for depletion and on pressure maintenance.

2.3.1 Depletion

Currently, the focus is on the assessments of the impact of the production caps, imposed by the ministerial decision following the update of the winningsplan 2013, on seismicity in the field (Ref. 10).
A limitation of the current hazard and risk assessment method is that is has difficulty to assess local effects. Several methodological refinements will be evaluated to improve this.

The Hazard and Risk Assessment will be based on the production plan within the production caps, imposed by the ministerial decision following the update of the winningsplan 2013. For the period past 2016, a number of depletion scenarios will be evaluated. These will be based on potential production restriction imposed by the minister based on the update of the winningsplan 2016.

2.3.2 Pressure Maintenance

In the 2013 winningsplan, pressure maintenance based on nitrogen injection was presented as a potential mitigation measure for induced earthquakes. The feasibility and efficiency of this process could at that time not be confirmed. The contours of such a project were given in the Addendum report, demonstrating the substantial electrical power requirement for the project and the high impact on the surroundings.

Injection can lead to earthquakes by processes other than compaction. Therefore, nitrogen injection can potentially also increase the seismic hazard. The current seismic workflow is only calibrated to the depletion induced earthquake catalogue. It has not been tested nor validated for injection induced seismicity and is not applicable to assess seismic hazard from injection.

The current workflow is applicable only in the theoretical injection scenario where no positive pressure gradients are introduced. This scenario could be regarded as a molecule for molecule replacement process and is basically similar to the stop of production from a pressure point of view. There are currently no other workflows identified that quantify the seismic hazard as a result of injection for the Groningen field. Analogues are not available as most of them are based on the injection of (waste) water in different geological settings.

Currently no workflows are identified that could quantify the seismic hazard in the GPM scenario. The current workflow can be used to assess the hazard in the “ideal” injection case, i.e. a scenario comparable to reservoir depletion where nowhere in the reservoir the pressure will (temporarily) increase. A study will be initiated to review the global experience with seismicity resulting from gas injection.

2.3.3 Structural Upgrading Program.

The house strengthening program will commence before clear recommendation from the current studies in to risk have been completed. Therefore this program will initially have to rely on practical guidelines for house strengthening.

As soon as the first insights of the risk assessment become available, through sensitivity analysis steer will be provided to optimise this activity. In the Risk Assessment different scenarios for the house strengthening program will be evaluated.
2.4 Address areas of different scientific views

During the discussions with SodM and her advisors, KNMI and TNO-AGE, a number of technical and scientific differences were identified. These have been described in “TNO 2013 R11953 | Eindrapport - Toetsing van de bodemdalingssprognoses en seismische hazard ten gevolge van gaswinning van het Groningen veld” (Ref. 7) and “Staatstoezicht op de Mijnen – Advies Winningsplan 2013 / Meet- en Monitoringsplan NAM Groningen gasveld” (Ref. 8).

These were primarily in the following areas:

<table>
<thead>
<tr>
<th>Area</th>
<th>Discussion</th>
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</thead>
<tbody>
<tr>
<td><strong>Static Model</strong></td>
<td>The porosity model near the Loppersum Area and Delfzijl seems to have deficiencies resulting from data extrapolation effects, due to low data density. Improved guidance based on facies modeling and acoustic impedance inversion could be tried to improve the porosity model. Subsidence data suggests an area currently evaluated to have relatively high porosity could have a lower porosity and therefore compressibility. Additionally, an uncertainty analysis needs to be provided for porosity.</td>
</tr>
<tr>
<td><strong>Dynamic Model</strong></td>
<td>The history matching process has focused mainly on matching the reservoir pressure. Both water encroachment and subsidence data were used, but were less influential. A best compaction model should also be prepared using a dedicated process. A model additionally fitting measured subsidence data should be prepared using a novel history matching process. Extend the model to cover the full aquifer, to avoid the use of analytical aquifer.</td>
</tr>
<tr>
<td><strong>Subsidence Monitoring</strong></td>
<td>Carboniferous is not part of the Groningen dynamic reservoir model. Impact on production is expected to be very marginal. However a sensitivity analysis needs to be carried out to confirm effect on total compaction is also not significant.</td>
</tr>
<tr>
<td><strong>Compaction</strong></td>
<td>The choice of the compaction models is being debated. SodM and TNO have proposed several alternative models; RTCM and isotachen. The merit of these different models needs to be better understood. Primary concern with respect to the compaction models is the time delay with which the compaction responds to a pressure drop in the reservoir. Delayed depletion of the underlying aquifer needs to be investigated and potentially incorporated.</td>
</tr>
<tr>
<td><strong>Geomechanical</strong></td>
<td>TNO-AGE believes more support by dynamic modeling and analysis of rupture processes is required. Research in to time-dependent and non–elastic processes like salt creep and compaction and diffusion of pore pressure. This includes modeling based on experimental measurements on core of fault friction</td>
</tr>
</tbody>
</table>
after rupture.

| **Seismicity** | The dependency of the magnitude and frequency of earthquakes on the rate of depletion / production. Areal differentiation of the hazard model is questioned; areal differentiation of partitioning coefficient and dependency of earthquake magnitude on local compaction are suggested. Additionally, the uncertainty in the partitioning coefficient needs further attention. |
| **Seismic Risk Assessment** | Definitions of personal and group risk should be clarified and be brought in line with best practice in other risk assessment areas. |
| | A probabilistic hazard and risk assessment needs to be carried out in a fully integrated manner. |
3 Data Acquisition Activities

3.1 Introduction

In this section the main data acquisition and seismic monitoring activities are described. These will impact on multiple studies. Data acquisition activities aiming at individual components of the hazard and risk model will be described in their respective sections.

High resolution mapping of seismicity and lowering the current detection and location magnitude threshold is expected to be essential for a better geomechanical understanding of the earthquake hazard. The improved determination of the locations of the hypocenters of the earthquakes will allow better tie-in with the structural model of the Groningen Field.

Three major activities have been initiated to improve monitoring of the seismic activity in the field:

1. Installation of 10 GPS stations on NAM locations in the Groningen field to continuously monitor the vertical and horizontal component of subsidence.

2. To improve the resolution over the whole Groningen field, an extension of the (existing) passive seismic monitoring network will be implemented with installation of 59 additional shallow geophone wells and accelerometers.

3. Installation of two vertical geophone arrays over the reservoir section in deep wells located in the Loppersum area, will improve the determination of earthquake hypocenters. In 2013, temporary geophone arrays have been placed near the reservoir (at 3 km depth) in two deep observation wells (Zeerijp-1 and Stedum-1). These will be replaced later in 2014 and early 2015 by two permanent seismic monitoring wells (Zeerijp-2 and Zeerijp-3).

4. In over 200 buildings accelerometers have been placed in the basement near the foundation. This includes public buildings and provide homes.

3.2 GPS (Global Positioning System) Stations

To monitor both the vertical and horizontal displacement component of the subsidence continuously, Global Positioning System (GPS) stations have been placed at 10 additional locations in the field on locations; Eemskanaal; Froombosch, ’t Zandt, Overschild, Tjuchem, Tankerpark Delfzijl, Zuiderveen, Stedum, Usquert en Zeerijp. This is in addition to the GPS station already placed on the Ten Post location in Q1 2013. Installation of the 10 additional stations was completed with all stations recording by 26th March 2014. If possible the GPS was placed on an existing building. On the locations Stedum, Usquert and Zeerijp, without an existing building, a three legged reinforced concrete construction was placed to anchor the GPS. At these locations a 3/4G modem has been placed for the data transfer.
Figure 3.1 Location of the GPS station in the Groningen field.

Figure 3.2 Location of the GPS station attached to buildings in the Groningen field.
Figure 3.3  Location of the GPS station anchored on a tripod construction in the Groningen field.

3.3  Extension passive seismic network

The current configuration of the Groningen monitoring network has provided field-wide coverage since 1995 for the detection and location of all events with a magnitude larger or equal to 1.5 ($M \geq 1.5$ events). The North Netherlands network consist of 14 borehole stations, 8 installed in 1995 and extended in 2010 with an additional 6 stations, plus 12 accelerometers. This network recorded a catalogue of 233 $M \geq 1.5$ events between 1995 and August 2014 and is the primary basis for current earthquake hazard assessment within the field. The uncertainties in the lateral location are typically about 0.5 km and the events are assumed to be at a depth of 3km.

Extension of the monitoring network would have two key advantages over the existing network; improved sensitivity and improved accuracy.

- More sensitive as more reliable detection and locate more of the $M < 1.5$ events within the field to allow more robust statistical analysis of the relationship between the number of earthquakes and gas production.
- More accurate as measure earthquake locations with sufficient accuracy to reveal their relationship with mapped faults and their depth distribution relative to the reservoir to understand what causes these earthquakes.

To deliver the earthquake data necessary to realize these objectives, the performance criteria for the network are considered to be:
- Detect 10 events for every \( M \geq 1.5 \) event. Given the existing earthquake population has a \( b \)-value of 1, this means reducing the magnitude of completeness from the current \( M = 1.5 \) to \( M = 0.5 \).
- Locate all detected events with a standard horizontal error of less than 200 m and a standard vertical error of less than 500 m (the depth determination is expected to be very dependent on local geology; this criteria might therefore not be met everywhere in the field).

To improve the resolution over the whole Groningen field an extension of the (existing) passive seismic monitoring network is currently being implemented with installation of additional seismometers and accelerometers spread in 6x6km grid with centre point, covering the whole Groningen Field. The network (Phase I) will consist of 59 passive geophone stations including surface accelerometers. Each 200m deep borehole will be equipped with 4 levels of geophones at 50, 100, 150 and 200 meters, one accelerometer at surface including required electronics for data-transmission, pre-amplifiers and communication means.

Figure 3.4 Extension of the shallow borehole geophone network with 59 locations. The locations indicated by a red star are outside the field boundary, but cover the aquifer connected to the Groningen field.

The deepest geophone is placed 200 m deep to reduce noise from activities at surface. The locations have been chosen in collaboration with KNMI and Land-and-lease (NAM). Locations have been
chosen away from noise sources like pipelines and railroads. Proximity to electricity and data cables and landownership have also played a role in the choice of the final locations.

Extension of the current shallow borehole geophone network commenced May 2014, with start of monitoring by the first new borehole stations in June. On 31 December 2014, drilling of 42 geophone wells including the installation of the geophones was completed. At 28 locations the accelerometer and communication equipment had been installed at surface. Of these 23 have been connected to the electricity grid of Enexis. In January the remaining surface equipment was installed.

Phase I of the network extension is expected to be completed in quarter 1 of 2014.
The data will be shared online with KNMI. Ownership of the network will be handed over to KNMI upon completion.

Based on the results of the monitoring of the full field using the phase I extension of the network, a further phase II extension will be planned and potentially temporary deep geophone arrays might also be installed in observation wells located in other areas of the field.

**Array with SM-64 three component unit**

3.3 **Subsurface vertical seismic arrays**

Downhole seismic monitoring allows monitoring at substantially reduced noise conditions thereby improving signal-to-noise ratio, magnitude detection threshold and precision of the hypocenter determination. From the current surface installed seismic network the vertical location of earthquakes are assumed to be at a depth of 3 km. Implementation of a subsurface seismic array would potentially lead to increased accuracy in horizontal and vertical location of events.

Challenges in borehole seismology are a secure deployment of sensors, safe data transmission to surface, formation temperature and pressure and reservoir fluids. Moreover, drilling is expensive, risky and logistically difficult and requires preparation time. As downhole instruments need to operate at elevated pressure and temperature conditions, proper engineering is essential.

Objective is to have two subsurface installed vertical arrays in the Loppersum area with sensors covering Zechstein down to Carboniferous. The sensors should be designed for a target event
magnitude range of $M=-2.5$ to $M=+1$ over the distance range 500m to 10 km, and a system minimum sampling frequency 2KHz (0.5ms data) or higher.

### 3.3.1 Temporary vertical seismic arrays

With the objective to implement subsurface measurements as soon as feasible, two existing observations wells in the Loppersum area (Stedum-1 and Zeerijp-1) were selected to be modified into seismic observation wells. As these wells have been drilled more than 35 years ago, and were not initially designed as seismic observation wells, it was proposed to temporarily install vertical seismic arrays without performing a workover. Advantage of this solution was deployment at short notice. However, disadvantage is that the vertical coverage is limited to the reservoir section only (below tubing installed in the well).

Based on the experience gained over the last 3 years in Bergermeer (Taqa), a system was designed and installed in October 2013. Two arrays with respectively 8 and 11 levels, with 30m station spacing were installed. The installation required well killing, installation of additional pressure control equipment, and communication and data collection equipment. Objective is to have the equipment operational until the permanent monitoring wells are in place. Continuous monitoring started immediately after installation; and data was made available via a GSM connection to KNMI and the expertise company Magnitude for further analyze.

![Deep Geophone well Stedum-1.](image)
The temporary geophone strings installed in the Stedum observation well started to record data in November and in the Zeerijp well in December 2013. The Stedum geophone string failed late December 2013 and was repaired in March 2014. Also the Zeerijp-1 geophone string has suffered from failures. Despite these failures very valuable data on the depth of the earthquakes in the Loppersum Area has been collected. An initial interpretation of this data can be found on the website www.namplatform.nl.
3.3.2 Permanent vertical seismic arrays

For the permanent vertical seismic arrays newly drilled dedicated observation wells were selected. There are a number of reasons for drilling a new well rather than continue the current situation:

a. The current arrangement of temporary geophones in existing observation wells is not acceptable as a long term solution. Because these wells are perforated, we need the wellhead to be an effective barrier; with the data cable this is difficult possible to achieve.

b. The existing monitoring wells have a completion design that only allows installation of a geophone array with a limited aperture. The difficulties with the interpretation of the acquired data demonstrates the importance of a larger aperture of the geophone string in these new wells.

c. The geophones of Sercel currently in use suffered from recurring failures. Using new wells allows us to use different geophones not supported by a service company, such as the high quality Avalon’s geophones. Also safety risks are much smaller when replacing geophone strings in the new (not perforated) wells.

d. Drilling a new well will allow acquiring data from three wells for a limited period (subject to (a) with an extension of the exemption for the Stedum observation well). At a peer review workshop by international experts, the use of two observation wells was questioned. This would give us an opportunity to test seismic monitoring using three wells.

e. The two observation wells have important monitoring duties. The Stedum well is completed with radio-active markers for compaction monitoring (one of three wells monitored for compaction at reservoir level), while the Zeerijp-1 well is an important well for monitoring the aquifer influx from the Oldorp aquifer (pressure and TDT). These wells will be reinstated for their original purpose.

In a Request for Information contractors have been invited by NAM to propose their solution for permanent seismic monitoring systems. It is the objective to have an operational permanent seismic recording system in the fourth quarter of 2015. Drilling activities for two seismic observation boreholes are scheduled for Q4 2014 on the light land rig and Q2 2015 on the heavy land rig. This
latter well will also drill into the Carboniferous to allow a large aperture of the geophones and coring of intervals in the Rotliegend reservoir section and the deeper Carboniferous formation.

Figure 3.9 Locations for the two permanent geophone wells in the Loppersum Area.

Additional data acquisition is planned in the Geophone wells;

- **Both Wells:**
  - Density logging of the full well length (for calibration of the velocity model and determination of vertical stress),
  - Sonic logging of both shear and compressional waves over full well length (Shear and compressional data will be taken at 360deg phase to determine main stress directions and stress anisotropy),
  - Image logging over reservoir section for stress field direction (to be confirmed),
  - MDT pressure measurements will be performed (depending on hole conditions at the time)
  - Rock strength tests might not be feasible, because we do not want to perforate the casing and leave it in tact.

- **Additional for the HLR Well:**
  - Core over the Rotliegend for compaction measurements (P&T Rijswijk) and ruptures characterization (Univ. Utrecht, NISP) and core over Carboniferous reservoir also for ruptures characterization,
  - Formation evaluation logs like resistivity,
  - Formation water sample.
The following studies in this “Study and Data Acquisition Plan” rely on data acquisition in a well to be drilled in the Loppersum Area:

- Strain Partitioning: Improve 3D velocity field using measurement of the rock density and P- and S-wave velocities in the overburden well sections future wells
- Strain Partitioning: Data QC and possible further processing of the (micro)seismic data from the Stedum and Zeerijp arrays.

![Image of well trajectory](Image)

Figure 3.10 Well trajectory of the two permanent geophone wells in the Loppersum Area.

The following studies rely on the acquisition of a fresh core over the Rotliegend and Carboniferous in a well drilled in the Loppersum Area:

- Compaction: Laboratory Experiments into the compaction behavior of Reservoir Rock
- Strain Partitioning: Experimental testing on core material of dynamic fault friction behaviour, failure and unloading characteristics of reservoir rock.
- Strain Partitioning: Modelling studies to evaluate the physics of dynamic fault rupture and the impact of various geomechanical modelling options

These studies, planned to be carried out by Shell P&T (Rijswijk) and University of Utrecht (potentially as part of NISP), need address both the Rotliegend and Carboniferous formations. Data collected in these wells will also be useful for appraisal of the Rotliegend aquifer and Carboniferous formation for development (also mentioned as a condition in letter of the Minister of EZ).
Figure 3.11  Locations for the two permanent geophone wells in the Loppersum Area relative to the structural model.

Figure 3.12  Well design for the two permanent geophone wells in the Loppersum Area
3.4 Sensors in buildings

Accelerometers have been placed at the foundations of buildings in the area. Some 20 accelerometers have been placed in public buildings (mainly town halls) and over 180 accelerometers have been placed in private homes. The selection of these buildings was done to cover different building typologies and soil conditions. The geographic spread (seismic hazard) and distance to geophone stations also was taken into account.

These sensors meet the following strict specifications to ensure the collected data can be used in the study program:

- Accelerometers placed at foundation
- Acceleration is measured in three directions (x-, y- and z axis)
- Measurement range 200 mm/s
- Measurement frequency 250 Hz
- Time registration accurate within a second
- Follow-up action threshold of 1 mm/s

Figure 3.13 Installation of the building sensors.

Figure 3.14 Velocity measured by the sensor in the Bedum town hall. Clearly the movement of the building during the day and evening can be seen.
Figure 3.15  Velocity measured by the sensor in the Bedum town hall during the Boer (Thesinge) earthquake at 30 September 2014. The three graphs show the movement in the horizontal X (purple), horizontal Y (green) and vertical (blue) directions.

The data recorded by the sensors is shared via a web-portal. There the measurements from the public building can be seen, while the data from the private homes is grouped for privacy reasons.

Figure 3.16  The data measured by the building sensors is collected in a data center and shared with home owners and the public.
4. **Overview of studies.**

4.1 **Hazard and Risk Assessment**

Preparations have been made to develop a methodology for a fully probabilistic risk assessment based on the current fully probabilistic hazard assessment model. Uncertainties at each level will be consistently carried through the calculation chain. A Monte-Carlo based proto-type is being developed for this.

![Schematic showing the elements of the probabilistic risk assessment.](image)

Figure 4.1 Schematic showing the elements of the probabilistic risk assessment. This bridge spans from cause (gas production) to effect (impact on individual safety). The left section of this bridge required mainly geological expertise, while the right section of the bridge required mostly civil engineering expertise.

The assessment start with the cause, gas production, to the effect, impact on the safety of people. The research studies are grouped into:

- Subsidence and Compaction,
- Seismicity and Partitioning Factor,
- Ground Motion Prediction,
- Building Stock and Response and
- Consequence Assessment.

A detailed description of the studies can be found in the [appendix](#) of the report.
4.2 Subsidence and Compaction

The subsidence for the update of the Groningen Winningsplan 2013 relied to a large extent on the compaction models and subsidence prediction methods developed in the Waddenzee and used in the Winningsplannen for Waddenzee, Ameland and Anjum. It therefore contained the work program for the measurements on the core acquired in the Moddergat well, but few additional fundamental studies.

When in November 2013, a report prepared by TNO-AGE on the isotach model was made available this model was incorporated in the subsidence prediction models and added to the subsidence analysis for the Groningen Winningsplan 2013. There was no time available to review the validity and applicability of the isotach model to compaction in the Rotliegend reservoir of the Groningen field. It was therefore used alongside the preferred time decay-model.

In this new research plan more emphasis will be placed on new data acquisition, research and development of new methods for the prediction of subsidence and compaction. The following studies
have been initiated to obtain a better understanding of compaction and to reduce the uncertainty in the compaction prediction:

1. Geodetic analysis of the measured subsidence data, using spatio-temporal analyses (derive subsidence from all available geodetic measurements in an integrated manner over time and space) to obtain a best estimate of the full subsidence field. This will lead to a design of a consistent workflow for processing geodetic data from different geodetic observation techniques for contributing to geomechanical modelling and providing measurement-based deformation maps.

2. Insar Data descending and resending / lateral movement (use of high resolution InSAR (ascending/descending track): to monitor vertical and lateral compaction displacement (and investigate options for monitor of building settlement).

3. Investigate the option to use gravity studies to determine subsurface mass redistribution and aquifer movements at the Groningen gas field.

4. Better use the existing geodetic data to better constrain the different compaction models and to use modern statistical tests to decide on the relative likelihood of each model being the true model given the available data. These relative likelihoods will then inform the choice of which compaction models to include in the logic tree for future seismic hazard and risk assessments.

5. Update of the porosity model for the Groningen field in view of new measured subsidence data. Deliverable is a static and dynamic model realisation of the Rotliegend reservoir of the Groningen field that provides a good match with (1) reservoir pressure measurements (2) water encroachment observations and (3) subsidence measurements. This Petrel and MoReS model will be used to improve subsidence modelling and the hazard analysis. Focus will be on trends based on depositional environment, differences in porosity in gas and water filled reservoir and use of seismic inversion techniques.

6. Review of proposed compaction models based on time-dependent and non-elastic processes by external experts.

7. Core measurements of compaction behavior a rupture behavior on the core planned to be recovered from the Zeerijp-C well. These experiments will be carried out at the University of Utrecht (Chris Spiers), Laboratorium of Shell in Rijswijk and the Upstream Research Centre of Exxonmobil in Houston.

8. Investigation of the physical mechanisms and fundamental mechanics that govern compaction of the Slochteren sandstone. Develop an understanding and derive constitutive laws that are based on these fundamental micro-mechanical processes observed in experiments and in microstructural studies of cored sections of depleted and un-depleted reservoirs. A secondary but still crucial aim is to determine the balance between elastically stored energy and energy expended in inelastic processes. This project will make use of existing core material and the core planned to be recovered from the Zeerijp-C well and be executed in cooperation with the University of Utrecht.

9. Research into upscaling of compaction models from laboratory scale to field scale.
In appendix A of this report detailed descriptions of the various studies can be found. The main areas of attention are:

- The temporal response behavior of compaction is a point of discussion with SodM and TNO-AGE (Studies 4, 6, 7, 8 and 9).
- Improvement of the porosity model and aquifer behavior is expected to result in a better compaction match and prediction (Studies 3 and 5).
- Additional acquisition (core in the Loppersum Area) and improved analysis of measured subsidence (Studies 1 and 2).
4.3 **Seismological Model (Partitioning Factor)**

For the winingsplan 2013 a seismological model was developed based on compaction and a partitioning factor. The following studies into the seismological model, partitioning factor and improved geomechanical understanding of the rupture process have been initiated:

1. The pre- and post-failure behavior of faults and adjacent formations determines the energy storage and release prior to and during seismic events. The following activities are foreseen:
   a. Experimental testing into the dynamic fault friction behavior, failure and unloading characteristics of reservoir rock, to better understand the physics of fault re-activation and rupture and the conditions which determine whether fault slip is seismic or a-seismic. Also the effect of pore fluid needs to be investigated.
   b. Modeling studies to evaluate experimental results and the impact of various geomechanical modeling options on the physics of fault re-activation and rupture (geometrical aspects (reservoir thickness, fault dip angle and dip azimuth angle), fault slip softening and stiffness and stress contrast).
   c. Detailed geomechanical modeling to investigate whether a rupture initiated in of below the Rotliegend reservoir section will propagate into the Zechstein salt or whether the Zechstein salt will limit rupture growth in the case of Groningen.
2. Currently, the association of the earthquakes with identified faults in the structural model is hampered by the large uncertainty in the hypo-centre location of the earthquakes and uncertainty in the characterization of the structural model. Two data acquisition initiatives have been initiated to address this issue by improving hypocentre location of the earthquake and characterization of the source radiation parameters (see section 5):
   a. Extension of the field wide geophone network consisting of some 59 borehole stations each with a string of geophones with 50 meter spacing and a surface accelerometer.
   b. Placement of geophones at reservoir level in deep wells located in the Loppersum area. Over the limited region covered by these deep arrays the accuracy of measured event depths will be greatly enhanced.

3. Accurate imaging of the earthquake hypocenter requires knowledge of the 3D velocity field. Measurement of the rock density and P- and S- wave velocities in the overburden well sections of Borgsweer-5 well and future wells aim to improve our knowledge of the 3D velocity field (see also GMPE).

4. Advanced multi-scale mechanical modeling combined with a geomechanics-seismicity relationship might provide a suitable framework to better understand seismic fault slip behavior and assess future seismicity via a physically-constrained strain partitioning (i.e., partition factor). This will be the subject of future study work, which will aim to establish a workflow leading to a robust integration between 3D explicit fault modeling and the existing Seismological Modeling to reduce seismic uncertainty.

5. Improvement of the current full field geo-mechanical modeling, to investigate the possibility of sub-surface stress management. Results of the aforementioned model selection studies are to be incorporated. Further calibration is supported by additional field measurements of:
   a. The minimum horizontal stress across the field, in particular in and around the depleting formations.
   b. The pore pressure field over time in the underlying aquifer and the overlying Ten Boer clay stone.

The partitioning factor is the largest uncertainty contribution to the hazard. How much this uncertainty can be reduced by studies and data acquisition is a matter of further debate, as it consists of both aleatory and epistemic uncertainty. Experience in tectonic earthquakes and induced earthquakes by other human activities (like water disposal or geothermal projects) might be able to shed further light on this.

Main focus are:
- Additional acquisition and improved analysis (Studies 1, 2 and 3). The Zeerijp geophone wells potentially offer an opportunity to collect data in the earthquake prone region. This includes obtaining a core in de Loppersum Area.
- Geomechanical studies into fault rupture and post-failure behavior (Studies 1, 4 and 5)
Geomechanical modelling is key to bring the role of faults into the seismological model supporting the hazard assessment.
4.4 Ground Motion Prediction

In the 2013 study plan, the ground motion prediction methodology was based on an empirical GMPE based on larger (M≥4) tectonic earthquakes calibrated with the limited Groningen acceleration data at low magnitudes. For the hazard and risk assessment supporting the update of the Groningen winningsplan 2016, an extensive study program has been set up to derive improved GMPE. This equation should capture the uncertainty, be calibrated to the geological layers above the gas field from reservoir to the soils and predict those ground motion parameters required for fragility estimation for buildings typical for this area. Currently, fragility curves are currently based on PGA only, inherently assuming the longer tectonic response. Correction of fragility curves for shorter duration was implemented, but needs to be further substantiated.

To improve the prediction of ground motion and to reduce the potential conservatism and uncertainty in the current approach, the following studies have been initiated:

1. Detailed description of the soil and shallow subsurface geology (up to 300 m) for the Groningen Area. Aim is to determine local amplification and investigation of the potential for soil liquefaction. Deltares has been approached to build the geological model. Data on local shallow geology has been acquired from a large number of existing sources (mainly acquired over the last decades as part of building foundation and other civil engineering assessments). Additionally, during the drilling of the shallow wells for the extension of the geophone network valuable geological and soil data was collected.
2. Conduct site response analyses (based on field measurements of Vs30 and borehole geophone data) to give spatially varying site corrections and a field-specific rather than generic site amplification model. The impact of soil response could potentially have a substantial impact on the risk assessment.

3. Calibration of GMPE for the prediction of PGA, PGV, response spectral ordinates and duration for a wide range of earthquake magnitudes, and vector predictions of amplitude and duration.

4. Surface ground motion data for further calibration of the GMPE on a much denser grid than currently possible will be obtained by the accelerometers placed in some 59 additional geophone wells of the extension of the network. Data from the geophones in the 59 shallow wells will also be valuable for characterizing site response.

5. Waveform modeling and full waveform inversion (FWI) to understand the impact of spatial heterogeneity of rock properties and the role of the Zechstein interval in attenuating amplitudes from source to surface and also to give insight into possible alternative forms of GMPE.

6. To improve the modeling of propagation of the seismic wave field through the subsurface, the velocity field in the rock overlying the reservoir section needs to be known in greater detail. If well design allows, measurement of the rock density and P- and S- wave velocities in the overburden will be acquired in future wells (i.e. Zeerijp-2 and Zeerijp-3).

7. Estimation of stochastic source, path and site parameters from seismic recordings in the Groningen field.

8. Analogue study into meaningful characteristics of smaller earthquakes (literature study into damage and fatalities) for building of consequence models.

Focus of the studies is:

- Improved description of the soil layer (Study 1 and 2) will allow improved prediction of ground motion at specific sites.
- Improved data acquisition of ground motions will allow better calibration (Study 4 and 6)
- More detailed description of the ground motion (than only by PGA) (Study 3, 7 and 8) and full waveform modeling (Study 5) could provide a better description of the ground motion for use in fragility curves.
4.5 Pressure Maintenance

The study on pressure maintenance options for Groningen field provides an outline for a nitrogen injection development of the Groningen field. Feasibility and effectiveness of this have yet to be demonstrated and implementation of such a development has a relatively long timeline.

A follow-up feasibility study into pressure maintenance is planned to be started early 2014. This will address the main technical feasibility of the sub-surface gas recovery process and the required facility infrastructure aspects of such a pressure maintenance development. The assessment of the large impact of such major development on the Groningen community, integration and identification of potential synergies with other industrial activities will also be part of this study.

Three studies have been initiated:

1. **Maturation of a pressure maintenance development based on Nitrogen Injection**

2. **Groningen 2.0 - Investigate pressure maintenance alternatives ‘conventional’ Nitrogen production, distribution, and injection,**

3. **Effects of injection of nitrogen on seismicity.**

Workstream 1 of Groningen 2.0 has focus on “Alternatives for Nitrogen production & rejection”. Coordination between NAM, PTU and Groningen 2.0 is crucial and a focus of the framing discussions.
4.6 Building Stock and Response

To be able to assess the impact of an earthquake on buildings, information of all buildings located in the vicinity of the gas field is required. Additionally, the response of these buildings to the ground motion needs to be investigated. The research into building fragility have been divided into two studies; those of buildings constructed using URM (unreinforced masonry) and the other buildings. As this is required a large effort, NAM has set up a study program with four partners, to inventories the building stock and assess the fragility of the building in Groningen:

- Eucentre in Pavia,
- ARUP,
- Technical University Delft and
- Mosayk.

This program will address the fragility of buildings typical for the Groningen Area (rather than use data from other earthquake regions) and is also closely linked to the House Strengthening program.
To improve the understanding of the response of the buildings in the Groningen area to an earthquake, the following studies have been initiated:

1. Preparation of an exposure and occupancy database covering the full impact region of the earthquakes (this work is carried out by ARUP).
2. Determine the building typologies characterizing the Groningen building stock.
3. Characterize geometrical, material and dynamic properties of Groningen buildings using structural drawings, in-situ testing and monitoring.
4. Reproduce mechanical properties of typical Groningen masonry in the laboratory.
5. Prepare fragility models for the main URM building typologies and the main non-URM building typologies.
6. Calibration of numerical models for masonry buildings and non-masonry buildings (including retrofitting schemes)
7. Full-scale shaking-table testing of four representative masonry buildings (i.e. one full-scale test a year, from 2015 to 2018) to establish the actual seismic response of 4 most common Groningen building typologies when subjected to representative ground motion records will be planned.

Focus of the studies is:

- Establishing which buildings are located in the Groningen Area (Study 1) and
- Predict their response to an earthquake (Studies 2 to 7).
4.7 Consequence Model

![Diagram of Consequence Model]

Additional research and data acquisition on fragility (Studies 2, 3, 4, 5, 6) and vulnerability (Study 7) is required to generate input into the risk analysis.

1. Analogue study into meaningful characteristics of smaller earthquakes (literature study into damage and fatalities) for building of consequence models.

2. Derivation of vulnerability models for casualty estimation.
5. Study Governance and Quality Assurance

5.1 Quality Assurance

In order to ensure technical quality and alignment with key experts and stakeholders, the Groningen earthquake studies and data acquisition projects have both an internal and external governance structure. Given the importance of the earthquake issue in some instances research is duplicated by different studies.

This will give us certainly benefits:

1. It might provide insights and results additional to our internal studies (simply because they are done from a different perspective: “fresh pair of eyes”.)
2. Independent assurance by external parties (MIT, NORSAR etc. and other reputable parties).
3. It will help us to convince external experts involved in the earthquake discussion and SodM/TNO/KNMI.
4. It will help us in discussions with skeptical local stakeholders as it will clearly show we are doing everything possible to understand the earthquake issue and not only depend on our own knowledge.

Figure 5.1  Assurance model used for the studies in support of the update of the Winningsplan Groningen - 2016

For those area where expertise is available in NAM/Shell, the existing assurance processes and assigned subject matter experts will be used. For areas of expertise where within NAM/Shell expertise is not available, assurance by external experts will be done.
The Internal Assurance is supplemented by Independent (external) Assurance. For the petroleum engineering work SGS Horizon has been contracted to perform an independent review of the subsurface work (Geology and Reservoir Engineering).

### 5.1.1 Experts and Institutes

NAM has contacted external institutes with relevant expertise and knowledge to perform targeted studies and provide assurance for internally executed studies. The most significant experts that have been approached are:

- **Ian Main** is Professor of Seismology and Rock Physics at the University of Edinburgh. Professor Main’s areas of expertise are: processes that lead up to catastrophic failure events, from earthquakes, rock fracture, and volcanic eruptions to failure of building materials and bridges, and in quantifying the resulting hazard.

- **Julian Bommer**, Civil Engineer and formerly Professor at Imperial College London, specialising in the characterisation and prediction of earthquake ground motions; he has published more than 100 journal papers on seismic hazard and risk that have more than 3,500 citations on Web of Science. As a consultant in the field of seismic hazard and risk assessment, his engagements have included the Seismic Advisory Board for the Panama Canal Authority, review roles hazard studies for nuclear sites in Abu Dhabi, California, Romania and the UK (the latter for the Office for Nuclear Regulation), and leading site-specific studies for nuclear power plants in Brazil and South Africa, as well as at the DOE Hanford site in Washington state.

- **Rui Pinho**, Civil Engineer with a specialisation on seismic analysis, assessment and retrofitting of structures in earthquake-prone areas, a field in which he has authored close to 250 publications. In addition to having held academic positions at Imperial College London and at the University of Pavia, he was also co-founder of Seismosoft, the leading developer and provider of earthquake engineering software solutions, and served as Secretary-General of the Global Earthquake Model, a public-private non-profit Foundation charged with the task of developing tools, methods and standards for estimating seismic risk at global, regional and local scales.

- **Helen Crowley**, Civil Engineer with MSc and PhD degrees in Earthquake Engineering. She has 10+ years’ experience in research and consulting in seismic fragility, risk and loss assessment and is an author of over 120 publications. Over a period of 5 years, she served as the Risk Coordinator for the Global Earthquake Model, and has been the recipient of a number of awards including the 2012 EERI Shah Prize for Innovation in Earthquake Engineering and the 2009 European Geosciences Union Plinius Medal for “outstanding contributions in the fields of earthquake risk assessment and seismic risk mitigation”.

- **Ellen Rathje**; Warren S. Bellows Centennial Professor in the Department of Civil, Architectural, and Environmental Engineering at the University of Texas at Austin, USA. Her research interest include seismic site response analysis, seismic slope stability, field reconnaissance after earthquakes, and remote sensing of geotechnical phenomena. She has published over 100 papers on these topics and has supervised the research of over 30 graduate students.
research has been funded by the U.S. Geological Survey, the U.S. Nuclear Regulatory Commission, the U.S. National Science Foundation, and the United Nations Development Programme.

- **Florian Lehner** Florian Lehner is Scientific Advisor and Research Collaborator at the Department for Geodynamics and Sedimentology of the University of Vienna. He held for some 30 years positions is Shell research laboratory studying Reservoir Engineering, Structural Geology and Geomechanics. In the 1980’s he was asst. Prof. Engineering at Brown University in the USA. He is lecturer and Honorary Professor of Geology at the University of Salzburg, Austria and holds Visiting Professorships at University of Bonn (1996/97), École Polytechnique Palaiseau (1997/98), École Normale Supérieure, Paris (2001), Kyoto University Graduate School (2002). His research interests are Mechanics and chemomechanics of porous media, Stress-induced seismic time-lapse phenomena around depleting reservoirs, Formation of bending joints in multi-layer sequences and Modelling of structures caused by (salt) substratum mobility.

- **Teng-fong Wong** 黃庭芳, is Professor & Director, Earth System Science Programme, Faculty of Science, The Chinese University of Hong Kong. The holds a MS in Applied mathematics from Harvard and a PhD (Geophysics) from MIT. Assistant Professor, Department of Geosciences, State University of New York at Stony Brook. His research fields and current research interests include experimental rock deformation, rock physics applied to energy resources, earthquake mechanics and environmental hydrogeology. He has received several honours and awards, Louis Néel Medal of the European Geosciences Union (in the areas of rock magnetism, rock physics and geomaterials) and the SUNY Chancellor’s Award for Excellence in Scholarship and Creative Activities.

- **Peter Stafford** senior lecturer at the Faculty of Engineering, Department of Civil and Environmental Engineering and is a Fellow of the Willis Research Network and is also the RCUK Fellow / Lecturer in Modelling Engineering Risk. He was appointed to the Structures section in late 2007 and is now actively involved in teaching at both undergraduate and postgraduate levels. His research background is primarily in engineering seismology although he also has professional consulting experience as both a structural and geotechnical engineer. Dr Stafford’s current research interests relate to probabilistic methods in engineering seismology and earthquake engineering as well as to more general civil engineering applications. His ongoing work includes research into the development of earthquake loss estimation methodologies, probabilistic seismic hazard and risk analyses, and the development of empirical ground-motion models.

- **Benjamin Edwards** is a Lecturer and Senior Researcher of Seismic Hazard at the Swiss Seismological Service (SED), ETH Zürich. He specialises in earthquake ground-motion modelling and prediction: from seismic sources and wave-propagation to site-specific amplification and attenuation. He has recently worked as resource expert for the swissnuclear PEGASOS Refinement Project, a seismic hazard assessment for nuclear power stations in Switzerland, and is currently part of the SED - Swiss Federal Nuclear Safety Inspectorate's Strong Ground-Motion Expert Group.
Chris Spiers is Professor of Earth Materials - and Head of the High Pressure and Temperature Laboratory - in the Department of Earth Sciences at the Faculty of Geosciences at Utrecht University. He specialises in research on the mechanical and transport properties of rock materials under conditions that characterise the Earth’s crust and upper mantle, and the effects that fluid-rock interactions have on these properties. Prof. Spiers holds a BSc and PhD from Imperial College, London. He worked as a Miller Fellow for a number of years thereafter at the University of California at Berkeley, before moving to The Netherlands and to Utrecht University, where he established the HPT Laboratory. His research interests include topics ranging from the solid state flow and mechanical damage behaviour of crustal and upper mantle rocks (from rocksalt and carbonates to olivine), to the frictional and healing behaviour of faults, natural and induced earthquake nucleation, the compaction behaviour of sands and sandstones, and to the effects of CO2 on the mechanical behaviour of reservoir rocks, caprocks, coals and gas shales - in the context of both geological storage of CO2 and enhanced hydrocarbons production methods.

5.2 External Quality Assurance

5.2.1 Groningen Scientific Advisory Committee (SAC)

The Ministry of Economic Affairs has set-up a Groningen Scientific Advisory Committee (formerly named Klankbord Committee). The Groningen Scientific Advisory Committee (SAC) monitors and reviews the investigations executed out by NAM or its contractors as part of the development of the Groningen Winningsplan (FDP) 2016. The role of the SAC is to ensure the quality, completeness and impartialness of these investigations.

The Groningen Scientific Advisory Committee will consist of working groups for different expertise areas and be headed a steering committee. Groningen Scientific Expertise Groups have been set up for Subsurface/Geomechanics, Seismological Model, Ground Motion Prediction, Seismic Hazard and Fagility/Risk. The Groningen Scientific Advisory Committee will be engaged to monitor study progress and provide early external review of the study activities. Experts from SodM, KNMI, TNO-AGE will participate as observers in the working groups and Groningen Scientific Advisory Committee.

5.2.2 Monitoring Committee of the Dialogue table

To improve the communication and alignment with local community in Groningen, a dialogue table was set up. The dialogue table has set up a monitoring committee to ensure it is informed about the progress with seismic monitoring. Currently the committee has four members:

- Margot Philippart of the Groningen Municipality,
- Alrita Borst of the regional safety board (veiligheidsregio),
- Joop Kruize of the NGO Vereniging Groninger Bodem Beweging (GBB) and
- Derwin Schorren also of the NGO Vereniging Groninger Bodem Beweging (GBB)
NAM will keep the monitoring committee abreast of the progress made with installing the monitoring projects and the results from these projects. At the same time it will from the committee gain insight into the requirement for information on this in the region. The meetings are also attended by representatives of SodM, KNMI and TNO-AGE.
5.3 Additional Studies

5.3.1 Studies in Scoping Phase

A number of studies are carried out externally from NAM, but are supported by NAM. These studies complement the study and data acquisition program executed by NAM.

Research Program MIT (Massachusetts Institute of Technology)

MIT submitted two research proposals, which are supporting by NAM:

- **Project 1:** Seismic Analysis of Historic Data from the Groningen Field (Mike Fehler)
- **Project 2:** Geomechanical and Geodetic Investigation of Groningen Seismic vs Aseismic Deformation
  - Geodetic analysis (Tom Herring)
  - Geomechanical analysis (Brad Hager)

NISP – National Induced Seismicity Program

The science partners KNMI, RUG, TNO, TUD and UU proposed a 5-year National Induced Seismicity Program (shortly NISP) to create the fundamental basis needed for improved hazard estimates of induced seismicity and to develop strategies for risk mitigation based on subsurface technology.

NISP is organized in 6 work packages:

- **WP1:** program management
- **WP2:** physics understanding,
- **WP3:** imaging & model parameterization,
- **WP4:** monitoring & hazard assessment, and
- **WP5:** mitigation options and
- **WP6:** dissemination

Research Program NORSAR

The Norsar-Gassnova project is “assessing the capabilities of induced seismicity monitoring for CO₂ storage”. NAM’s contributes the data from the deep geophone wells. NAM’s participation will be for the induced seismicity activities of the research program only and is not linked to CO₂ storage.

The research supported by NAM with data are:

- **WP1:** Improved detections and locations of seismic events in complex 3D velocity models
- **WP2:** Seismic event characteristics and interpretation
- **WP3:** Seismic network design

The NORSAR project is funded by the Norwegian Government and industry partners. NAM contributes data from the deep geophone wells as an in-kind contribution to the program.
6 Schedule

The winningsplan update for Groningen needs to be submitted before 1st July 2016. This sets the timeline for the research activities. To allow time for stakeholder engagement, a draft update of the winningsplan will be prepared by 1st January 2016.

A high level schedule is shown below.

The high level schedule diagram also shows the main flows of information and study results into the hazard and risk assessment. In particular, the core measurements will impact the geomechanical work stream as will the analysis of the geophone data. Important is the update of the fragility of the build environment with the impact of the house strengthening program. Ultimately, all studies contribute to the bi-annual updates of the hazard and risk assessment.
References:


