Reservoir Pressure and Subsidence Groningen Field update for Production Profile GTS - raming 2021

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Contents

Executive Summary

The main conclusions from this report are listed below for each Chapter.

Introduction

- On instruction of the Minister of Economic Affairs and Climate Policy NAM has prepared 10 Hazard and Risk Assessments (HRAs) since 2012. This year is the first time the HRA is prepared by TNO.
- NAM delivers the reservoir pressure and subsidence forecasts. Reservoir pressure forecasts were delivered to TNO on February 15th as input for the HRA.

Reservoir and Pressure Modelling

- The minister has requested assessments based on a single Operational Strategy (OS) and for two temperature scenarios: an average and a cold gas year 2021/2022. For these scenarios demand profiles have been provided to NAM (GTS-raming 2021).
- The Operational Strategy is in line with OS2 as proposed by NAM last year in the HRA2020. The OS2 start-up sequence applies until April 1st 2022. Thereafter, production volumes are equally distributed over regions South-East and South-West.
- Forecasted reservoir pressures at the start of gas-year 2021/2022 are slightly higher than forecasted for the HRA2020 (based on GTS-raming 2020). This is due to higher than average ambient temperatures in 2020 and additional measures to reduce Groningen production volume.
- Forecasted pressures in the active production regions based on the new estimate (GTS-raming 2021) are slightly lower in the period 2025-2027 than forecasted in 2020 (based on GTS-raming 2020). This is the result of the small additional production volumes associated with the minimum flow requirement to ensure availability of gas production capacity. The pressure differences are negligible after 2032.

Subsidence

- The compaction/subsidence model was calibrated using results from 16 levelling campaigns spanning from 1964 to 2018.
- Subsidence forecasts were made for 2025, 2031 and 2050 based on GTS-raming 2021.
- In 2031 around 42 cm of surface subsidence (since start of production) is expected in the deepest point of the subsidence bowl, with a P95 uncertainty range up to 3 cm.

1 Introduction

1.1 Previous Hazard and Risk Assessment Reports

Since 2012 NAM has prepared Hazard and Risk Assessments (HRA) for different production scenarios. Table 1.1 provides an overview of these HRA reports. Currently, the hazard and risk assessment for induced earthquakes in Groningen is updated annually. The update is initiated each year with an expectation letter from the Minister of Economic Affairs and Climate Policy sent on the 1st February. Six weeks later a hazard and risk assessment based on the instructions and production scenarios presented in this expectation letter would be submitted to SodM and the ministry. In the gas production profile, the actual production until the previous 1st January is used and for the remainder of the gas-year of publication of the report (from 1st January to 1st October) the production is based on the latest ministerial decision.

In figure 1.1 the annual production rates for the previous production profiles; (1) Coalition Agreement, (2) Basispad Kabinet March 2018 Letter, (3) Basispad Kabinet Expectation May 2018 Letter, (4) Expectation Letter February 2019, (5) Expectation Letter February 2020 and (6) Expectation Letter February 2021 are compared. The comparison is shown in this figure for cold, average and warm year gas demand.

1.2 Expectation Letter (verwachtingenbrief) 2021

In accordance with article 52c of the Mining Law, NAM proposed in previous HRA reports two operational strategies based on the premises for these strategies contained in the expectation letter. Due to the very low remaining production, differences in the operational strategy will only have a very minor impact on hazard and risk. The assessment of risk and building damage will in the coming years be dominated by the equilibration of reservoir pressure between the North-Western area and the South-Eastern area of the field. In this report the development of reservoir pressure and subsidence will be presented. The expectation letter received by NAM on 1st February 2021 has been attached to this report as Appendix A.

The expectation letter also describes the maps, graphs and tables to be included in this report. In order to present a clear analysis additional maps, graphs and tables have been included in this report when required for clarity. The forecast for reservoir pressure has been requested to be presented based on gas-years. Gas-years are the 12-month period starting at 1st October. The gas-year 2021/2022 is the period from 1st October 2021 up to and including 30st September 2022. Gas-years are used to avoid the high gas demand winter period to be split over two reporting periods. The assessment of subsidence included in this report uses calendar years to be in line with other subsidence reports.

1.3 TNO SDRA – Seismische Deigings- en Risicoanalyse

As part of the wider program to remove NAM from the Groningen earthquake dossier, TNO has taken over the assessment of hazard and risk from NAM. TNO has built their own modelling tool for the assessment of hazard and risk in Groningen (de TNO "Modellentrein") and will use this for the preparation of the Hazard and Risk Assessment 2021.

NAM has delivered the forecasts for reservoir pressure to TNO for their Hazard and Risk Assessment on 15th February 2021 and confirmed on 19th February that the assurance had been completed successfully. Reservoir pressure predictions have been prepared for input into the Hazard and Risk Assessment based on two production scenarios; a scenario for gas production during a cold ambient temperature year and for an average ambient temperature year. Additionally, an operability check has been done for a warm ambient temperature year.

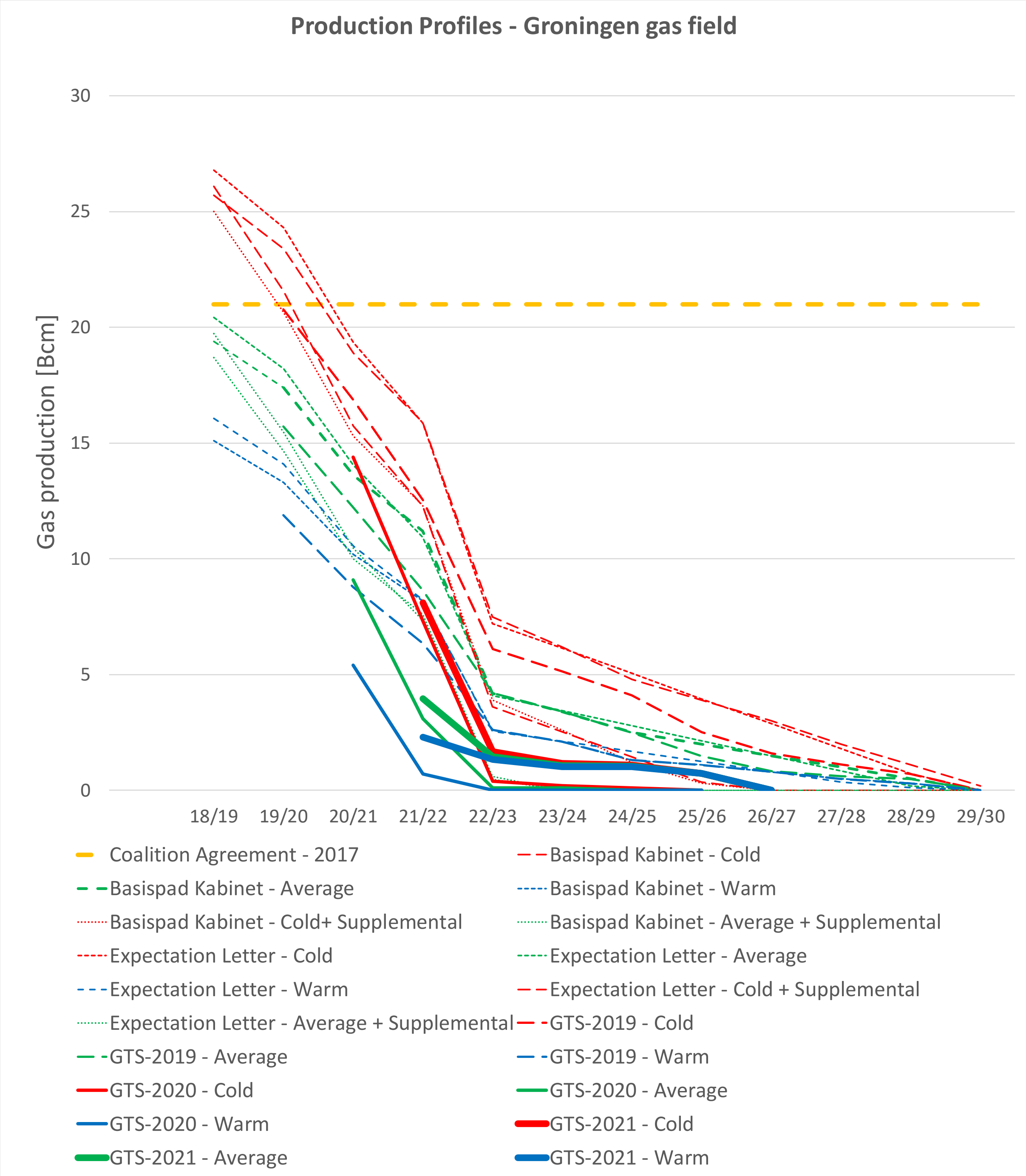

Figure 1.1 *Comparison of the production profiles:*

1. *Coalition Agreement (Regeerakkoord) (10/10/2017),*
2. *"Basispad Kabinet" from Kamerbrief (29/3/2018) in blue (Ref. 24),*
3. *"Basispad Kabinet" from the Expectation Letter (verwachtingenbrief) (2/5/2018) in red (Ref. 26)*
4. *Production profile GTS-raming 2019 in green (Ref. 27)*
5. *Production profile GTS-raming 2020 (Ref. 28) and*
6. *Production profile GTS-raming 2021.*
   For GTS-raming 2020 and GTS-raming 2021, th eproduction profiles for a warm gas-year are shown in blue. Those for average and cold temperature gas-year in green and red respectively.

Hazard and Risk Assessment	Ref	Submitted to EZK & SodM	Production profile	Ref	Comment
Winningsplan 2013 and Technical Addendum to Winningsplan 2013	1, 2	November 2013	In the Technical Addendum to the Winningsplan hazard for several production scenarios were assessed.		Probabilistic hazard assessment combined with a scenario based risk assessment.
Supplementary Information to Technical Addendum to Winningsplan 2013	2	December 2013	Letter to NAM: Mijnbouwwet instemmingsbesluit winningsplan Groningenveld; aanvullingsverzoek, 20-12-2013.	21	Two production scenarios were requested: (1) 'market demand' scenario and (2) 'market demand' scenario with closing in five clusters around Loppersum (LRM, OVS, PAU, POS and ZND).
Hazard Assessment Eemskanaal Region and Addendum to: Hazard Assessment for the Eemskanaal area of the Groningen field	3, 4	May 2014	Requested by SodM.		Additional hazard assessment for production from the cluster located close to the city of Groningen.
Dreigings- en risicoanalyse voor geïnduceerde seismiciteit Groningen - Onderzoek 1 dreigingsanalyse and Onderzoek 2 risicoanalyse	5, 6	May 2015	Requested by Scientific Advisory Committee and SodM.		Uncalibrated probabilistic hazard and risk assessment.
Hazard and Risk Assessment for Induced Seismicity in Groningen	7	November 2015	Requested by Scientific Advisory Committee and SodM.		First calibrated probabilistic hazard and risk assessment. This was also the first HRA where LPR results could be compared to the Meijdam-norm (Ref. 29 to Ref. 31).
Winningsplan 2016, Technical Addendum to Winningsplan Groningen 2016	8 – 14	April 2016	Verwachtingen brief	22	
HRA 2017 - Addendum to WP 2016	15	November 2017	Requested in Instemmingsbesluit Wijzigingsbesluit of 24th May 2017.	23	Production scenario with 24 Bcm/year plateau was prudently used.
HRA for a selection of production profiles	16	March 2018	Assessments were prepared for a wide range of production profiles.		Report was prepared to inform decision on the future production from the Groningen gas field.
HRA Basispad Kabinet	17, 18	August 2018	Letter to parliament 29 March 2018 en 6 Juni 2018 Verwachtingenbrief of 2nd May 2018	24, 25 and 26	
HRA GTS-raming 2019	19	March 2019	Verwachtingenbrief of 12th February 2019	27	
HRA GTS-raming 2020	20	March 2020	Verwachtingenbrief of 1st February 2020	28	
HRA GTS-raming 2021		March 2021	Verwachtingenbrief of 1st February 2021		In appendix A of this report.

Table 1.1 Overview of the Hazard and Risk Assessments prepared by NAM.

2 Reservoir and Pressure Modelling

Modelling the pressure in the Groningen gas reservoir forms the starting point for both the seismic hazard and risk assessment as well as the subsidence forecast. The future pressure distribution in the reservoir depends on the amount of gas produced and on how this production is regionally distributed.

2.1 Production: Demand profiles GTS-raming 2021

The Ministry of Economic Affairs and Climate Policy provided demand profiles for Groningen gas with the Expectation Letter (Verwachtingenbrief - Appendix A) sent to NAM on the 31st of January 2021. The future demand for Groningen-quality gas has been determined by GTS, incorporating the latest knowledge around nitrogen blending capacity, conversion in the L-gas market, export requirements etc. Accounting for the contributions of UGS Norg and PGI Alkmaar results in the net Groningen production profiles. For gas-year 2021/2022 daily demand profiles have been provided based on temperature profiles of the last 30 gas-years. Three reference years were chosen, for which longer term daily as well as monthly demand profiles have been supplied. These reference years correspond to the temperature profiles of gas-years 1996 (cold year), 2012 (average year), and 2007 (warm year).

The seismic hazard and risk assessment is performed for two scenarios, based on (i) gas demand in the average temperature scenario, and (ii) gas demand for a cold gas year 2021/2022 followed by average years. These two demand profiles are used to simulate subsurface pressures and are plotted in Figure 2-1.

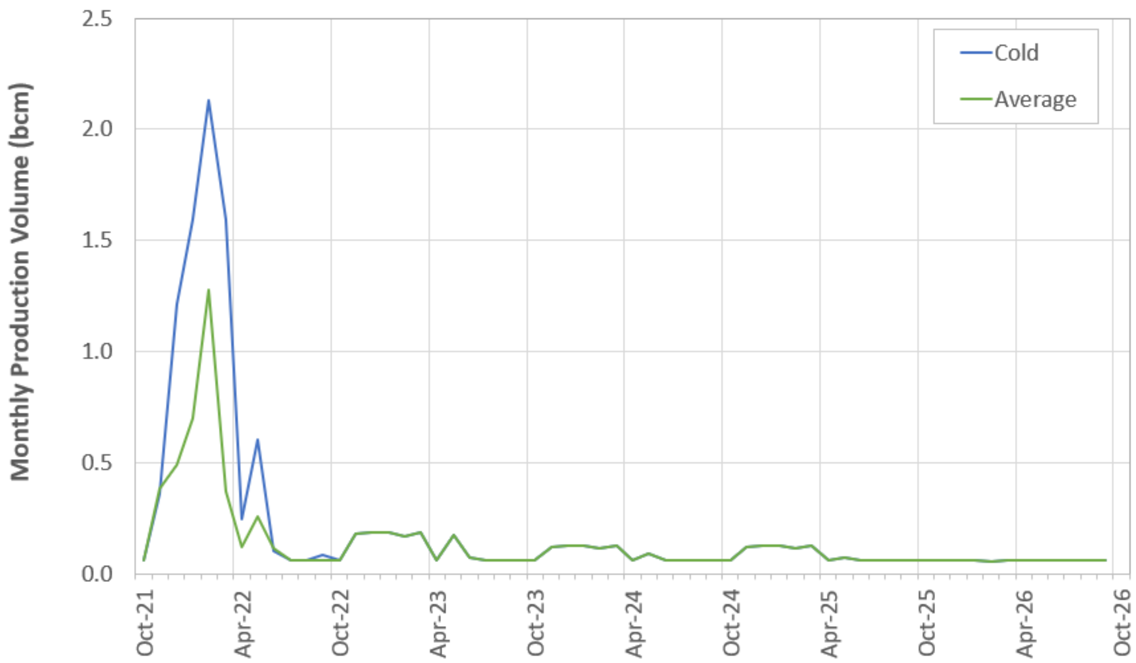

Figure 2-1: Groningen field monthly gas production according to GTS-raming 2021. The cold temperature scenario applies to gas-year 2021/2022 only.

2.2 Spatial distribution of production

2.2.1 Production regions

In Article 1.3a.1 of the Mining Regulations ("Mijnbouwregeling"), the Groningen production regions ("clusters") are defined as follows:

a) Bierum: production location Bierum
b) Eemskanaal: production location Eemskanaal
c) East-Central ("Centraal-Oost"): production locations Amsweer, Schaapbulten, Oudeweg, Siddeburen, and Tjuchem
d) South-East ("Zuidoost"): production locations De Eeker, Scheemderzwaag, and Zuiderpolder
e) South-West ("Zuidwest"): production locations Kooipolder, Slochteren including Froombosch, Spitsbergen, Tusschenklappen including Sappemeer, and Zuiderveen
f) Loppersum: production locations De Paauwen, Leermens, Overschild, 't Zandt, and Ten Post

Production regions

Figure 2-2: Production locations and regions.

The production locations are shown in a different color for each region in Figure 2-2. Production from the Loppersum clusters stopped in February 2018, following the instruction from the Minister of Economic Affairs and Climate Policy. As decided in the 2020 Vaststellingsbesluit (Article 3), clusters Bierum, Eemskanaal, and production location Siddeburen are no longer part of the operational strategy and remain closed in.

2.2.2 Start-up sequence

In 2020 the minister instructed NAM to follow Operational Strategy 2. In this Operational Strategy gas is produced preferentially from the South-East. If more production is required production locations in the South-West are first added, followed by the Central-East region when required. The operational strategy is practically implemented by the use of a start-up sequence; the order in which the production locations are taken into production, when more production from the field is required. The start-up sequence for this Operational Strategy is given in Table 2-1.

From April 2022 onwards, when the Zuidbroek nitrogen installation will be operational, the role of the Groningen field changes and the start-up sequence from Table 2-1 no longer applies. Groningen will then operate on minimum flow in order to maintain on stand-by such that it can perform its back-up function for extreme circumstances. This is further discussed in the Operational Strategy document.

Start-up group	OS2
EKR/SZW/ZPD	1
SPI/ZVN	2
SAP/TUS	3
FRB/KPD/SLO	4
SCB/OWG	5
AMR/TJM	6

Table 2-1: Production start-up list for the current Operational Strategy (OS2).

For pressure forecasting it is assumed that from April 2022 onwards equal volumes are produced from regions South-East (EKR/SZW/ZPD) and South-West. In South-West, production locations SPI, ZVN, and TUS/SAP will be operational. Start-up groups 4, 5, and 6 from Table 2-1 are no longer needed.

2.3 Modelling setup

An Integrated Production System Model is used for forecasting. In this set-up, the dynamic reservoir model in MoReS is coupled to the surface network model in Genrem. As last year, dynamic reservoir model V6 is used (Ref. 32). The average deviation in pressure between the V6 model and measured data at locations within the Groningen field is within ±2 bar for all pressure data up to 1-1-2021.

The history-match period was run in (stand-alone) MoReS until the end of calendar year 2020. Genrem-MoReS forecasting starts from 1-1-2021 onwards, where the Latest Estimate (LE) is used to constrain production up to 1-10-2021. This LE is in accordance with the graaddagen formula of the Vaststellingsbesluit for gas-year 2020/2021. The various pressure forecast scenarios therefore have a common starting point at the start of gas-year 2021/2022.

2.4 Forecast Scenarios

As requested in the Expectation Letter (Appendix A), seismic hazard and risk calculations are performed for 2 temperature scenarios. The distribution of production volume over the regions and the forecasted pressure distributions are discussed below.

2.4.1 Regional distribution of volumes

Figure 2-3 compares the distribution of production volume over the regions for the two temperature scenarios, which only differ for gas year 2021/2022. Figure 2-4 shows these distributions over each of the next 5 gas-years. The regional distribution is in line with the outcome of the operational strategy based on daily demand profiles. After April 2022, volumes are equally distributed over the two regions South-East and South-West.

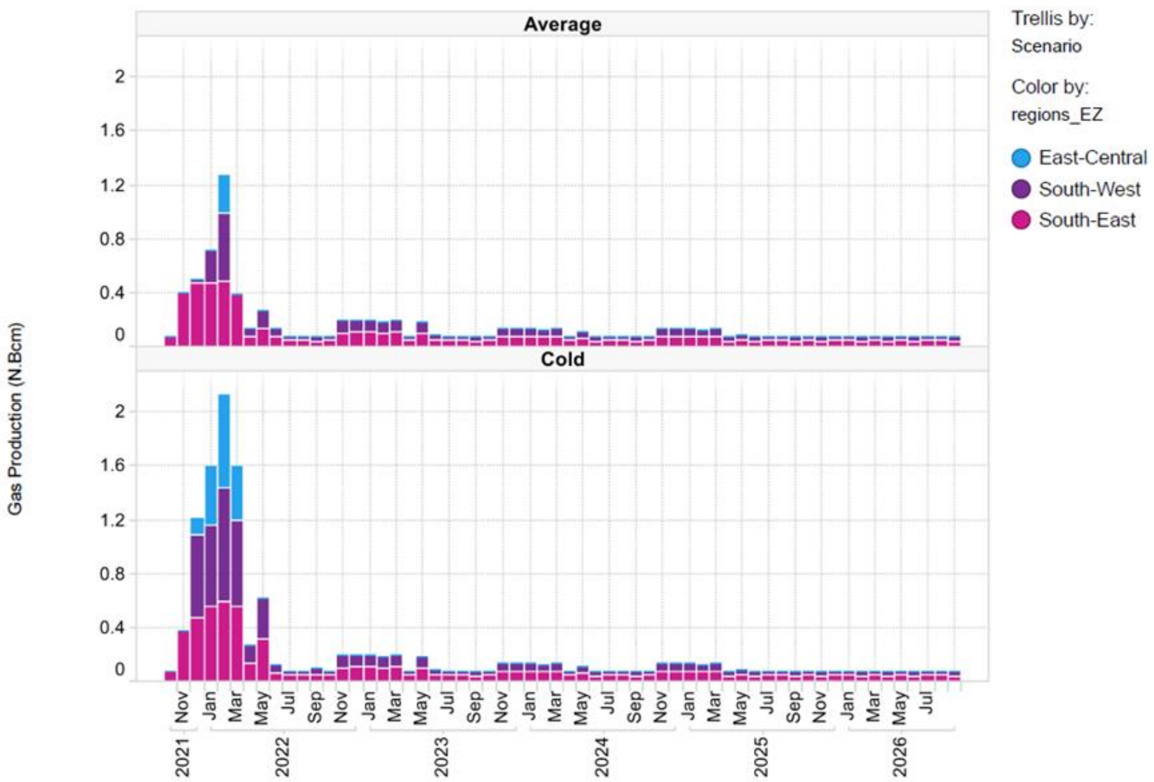

Figure 2-3: *Monthly production volume per region for the next 5 gas-years for the average temperature (top) and cold (bottom) scenario. Cold temperature only applies to gas year 2021/2022.*

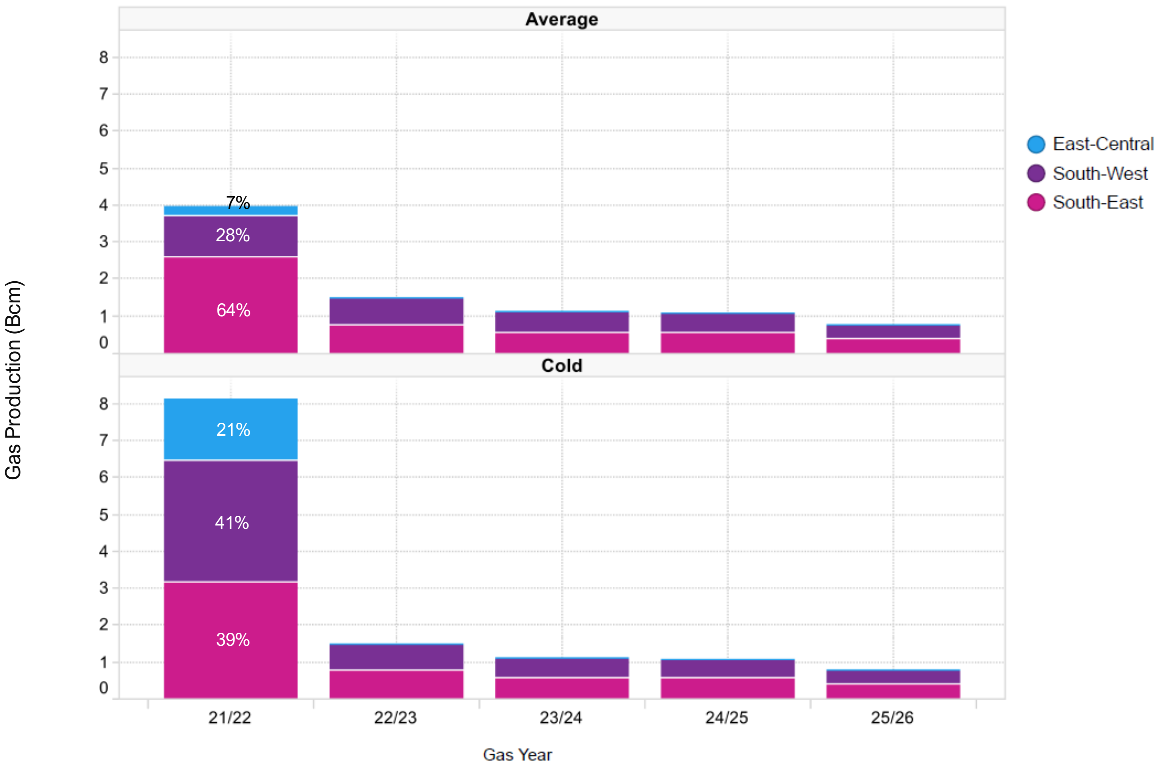

Figure 2-4: *Regional distribution of production volume per gas-year for the average temperature (top) and cold (bottom) scenario. Cold temperature only applies to gas year 2021/2022.*

2.4.2 Pressure Maps

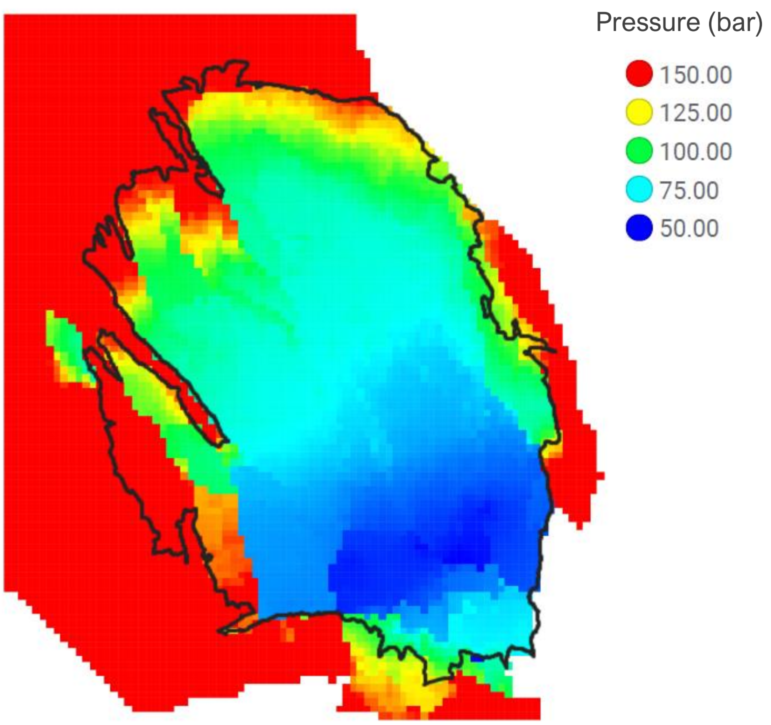

Figure 2-5 Modelled reservoir pressure on 01-10-2021: start of gas-year 2021/2022

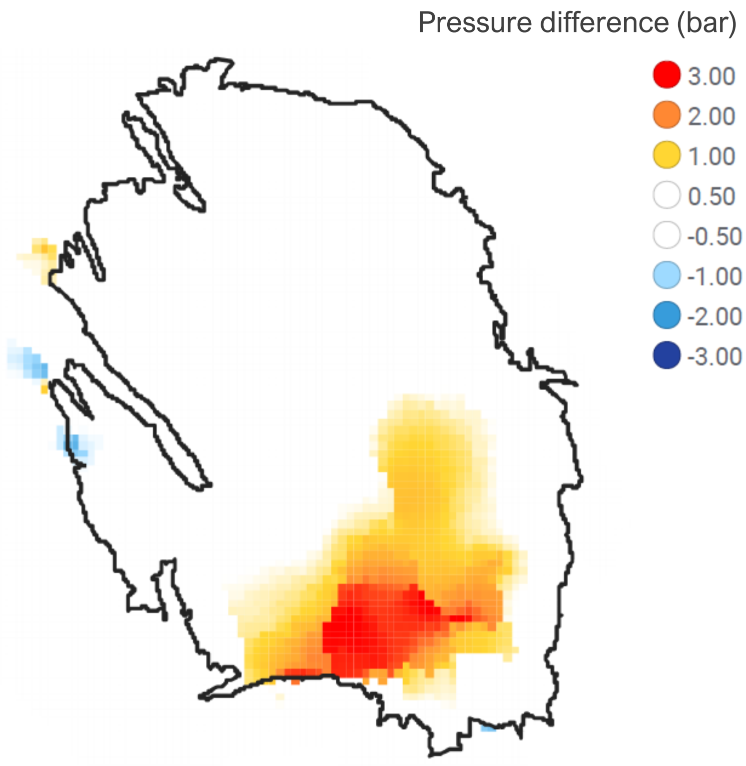

Figure 2-6 Pressure difference at 01-10-2021 compared to last year's forecast for average temperature and OS2 (pressure HRA21 – pressure HRA20).

Figure 2-5 shows the modelled reservoir pressure distribution on 1-10-2021, which is the start of gas-year 2021/2022. This pressure distribution is the common starting point in the two temperature scenarios.

Figure 2-6 plots the difference in pressure on 1-10-2021 compared to last year’s forecast (HRA 2020) for average temperature and operational strategy 2. This strategy is comparable to the current operational strategy. Compared to last year’s demand estimate, actual production up to 1-1-2021 and estimated production for the remainder of the gas year result in less cumulative production at the start of next gas year on 1-10-2021. This is due to a warmer than average 2020 and additional measures to reduce Groningen production volume. As a result, a positive pressure difference is seen (i.e. higher pressure based on the new estimate including actual production up to 1-1-2021), with a maximum local difference of around 3 bar.

Figure 2-9 shows difference maps for a selection of later years. In the period 2025-2027 the forecast based on the new estimate has a slightly lower pressure in the active production regions as a result of the small additional production volume due to the minimum flow requirement. A small difference (of around 1 bar) can be seen in Borgsweer, due to an update of the water injection forecast. Outside the boundary of the Groningen field some higher pressures are seen in the Warffum and Kielwindeweer fields, since production stops earlier in the updated forecast for these fields. From 2032 onwards the difference in pressure in the Groningen field between the current year and previous year forecast is negligible.

Figure 2-7 shows the pressure distribution on 01-10-2022 for the average temperature scenario, and Figure 2-8 for the cold gas year scenario. Figure 2-10 shows the difference in pressure between the two scenarios at the end of gas year 2021/2022 (top left), and 1, 3, 5, 10, and 20 years later. At the end of gas year 2021/2022 the local pressure difference between the average and cold scenario has a maximum of 3.8 bar. Over time this difference dissipates. Twenty years later a maximum local pressure difference of 0.6 bar remains in the South-East corner of the field.

Pressure maps for subsequent gas years in the average temperature scenario are given in Figure 2-11 (2023-2028), Figure 2-12 (2029-2034), and Figure 2-13 (2035-2050, every 3 years).

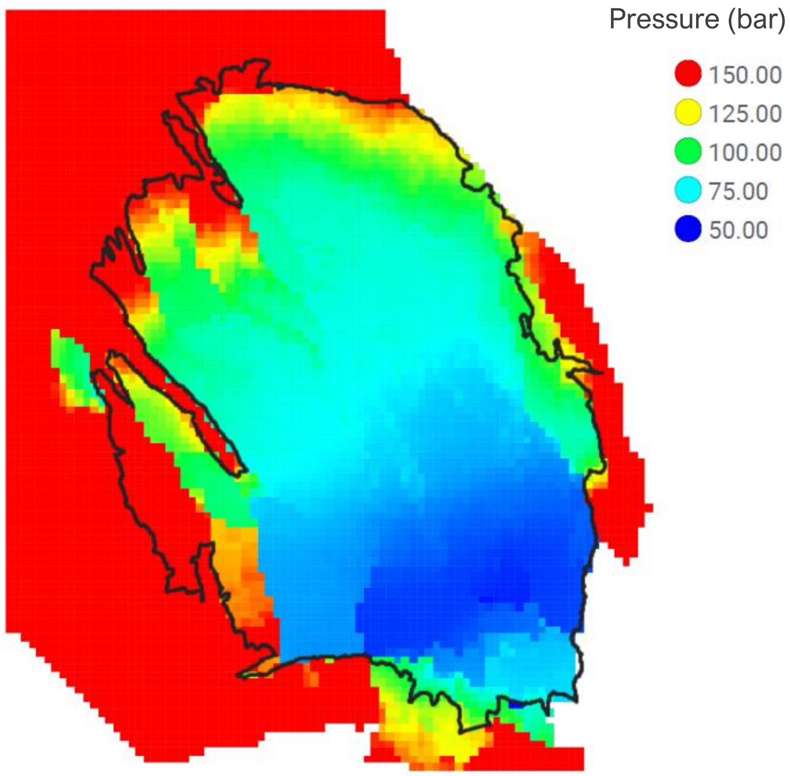

Figure 2-7: Reservoir pressure on 01-10-2022 (end of gas year 2021/2022) for average temperature scenario

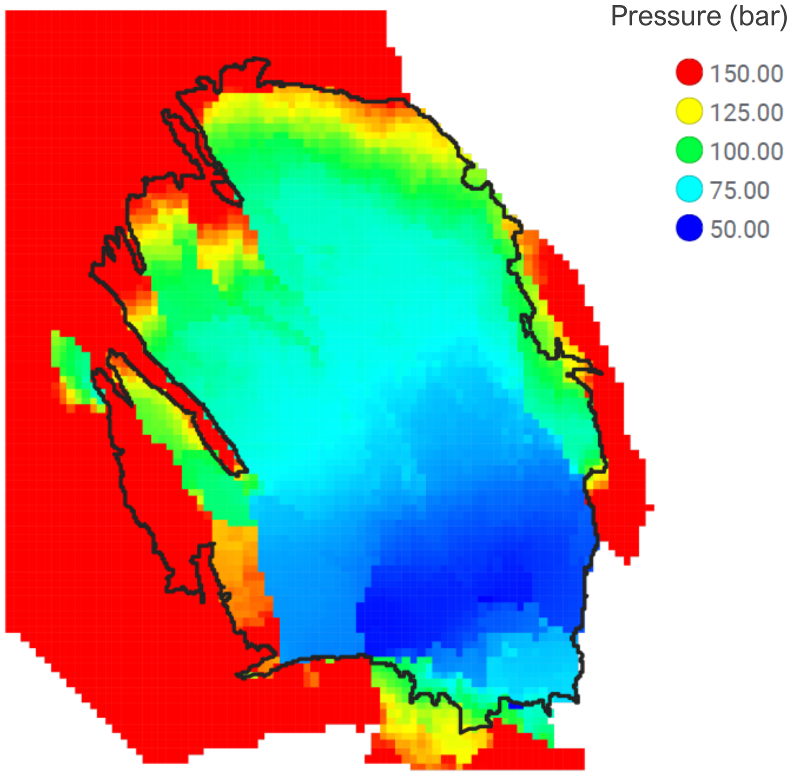

Figure 2-8: Reservoir pressure on 01-10-2022 (end of gas year 2021/2022) for cold temperature scenario

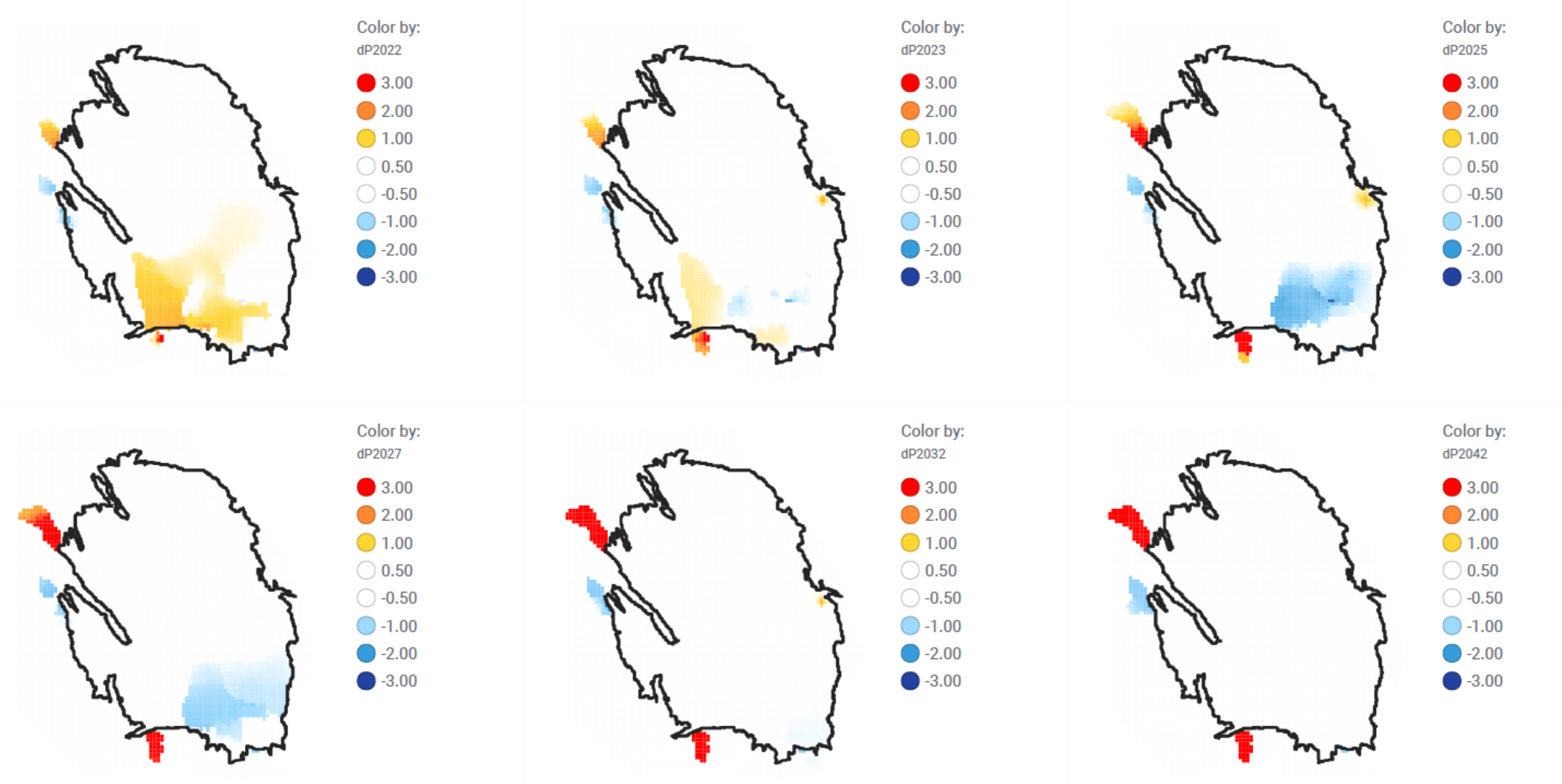

Figure 2-9: Pressure difference maps for average temperature scenario: pressure HRA 2021 – pressure HRA 2020 (OS2). At end of gas year 2021/2022 (top left) and after 1, 3, 5, 10, and 20 years (bottom right).

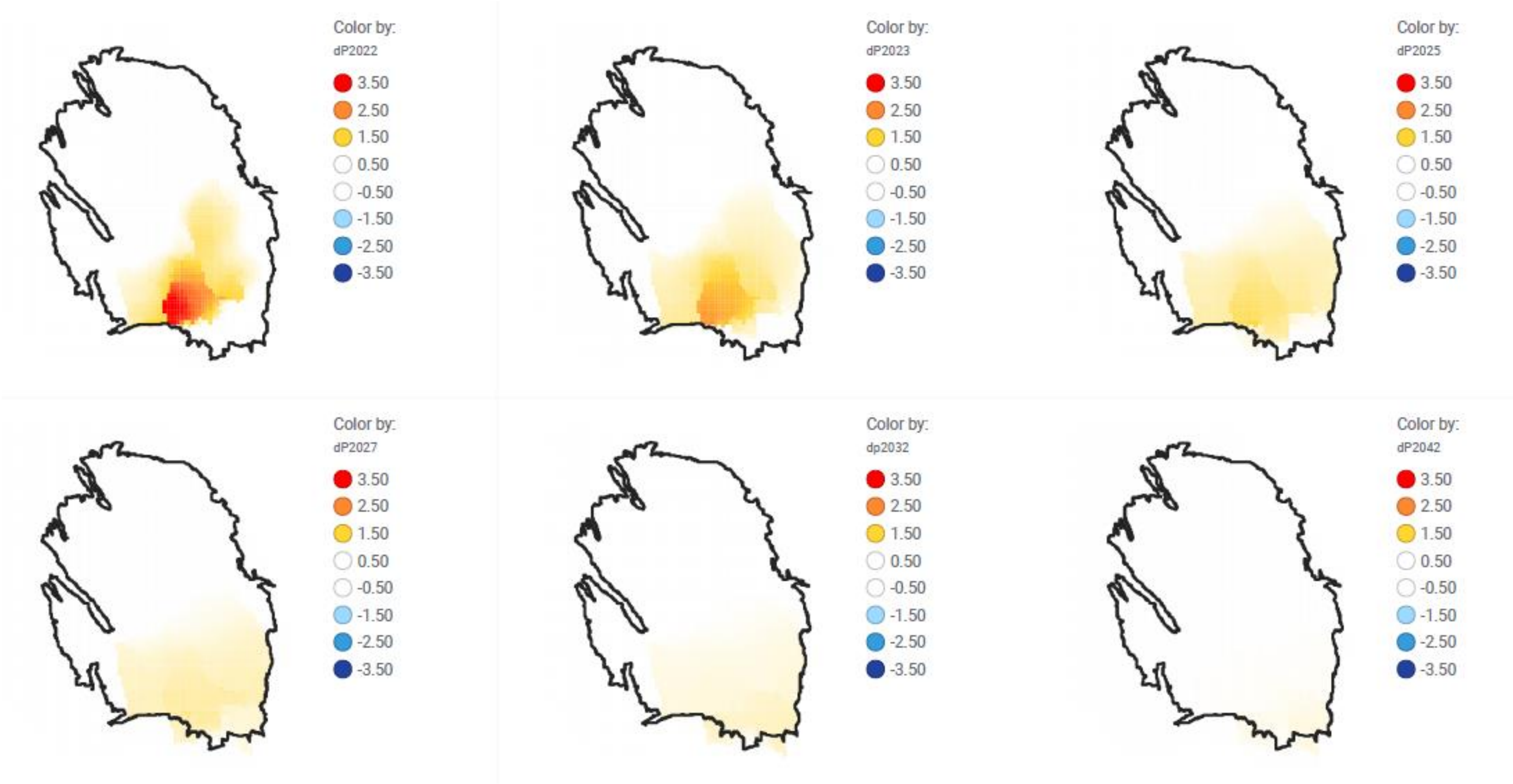

Figure 2-10: *Pressure difference maps: pressure average scenario – pressure cold scenario. At end of gas year 2021/2022 (top left) and after 1, 3, 5, 10, and 20 years (bottom right).*

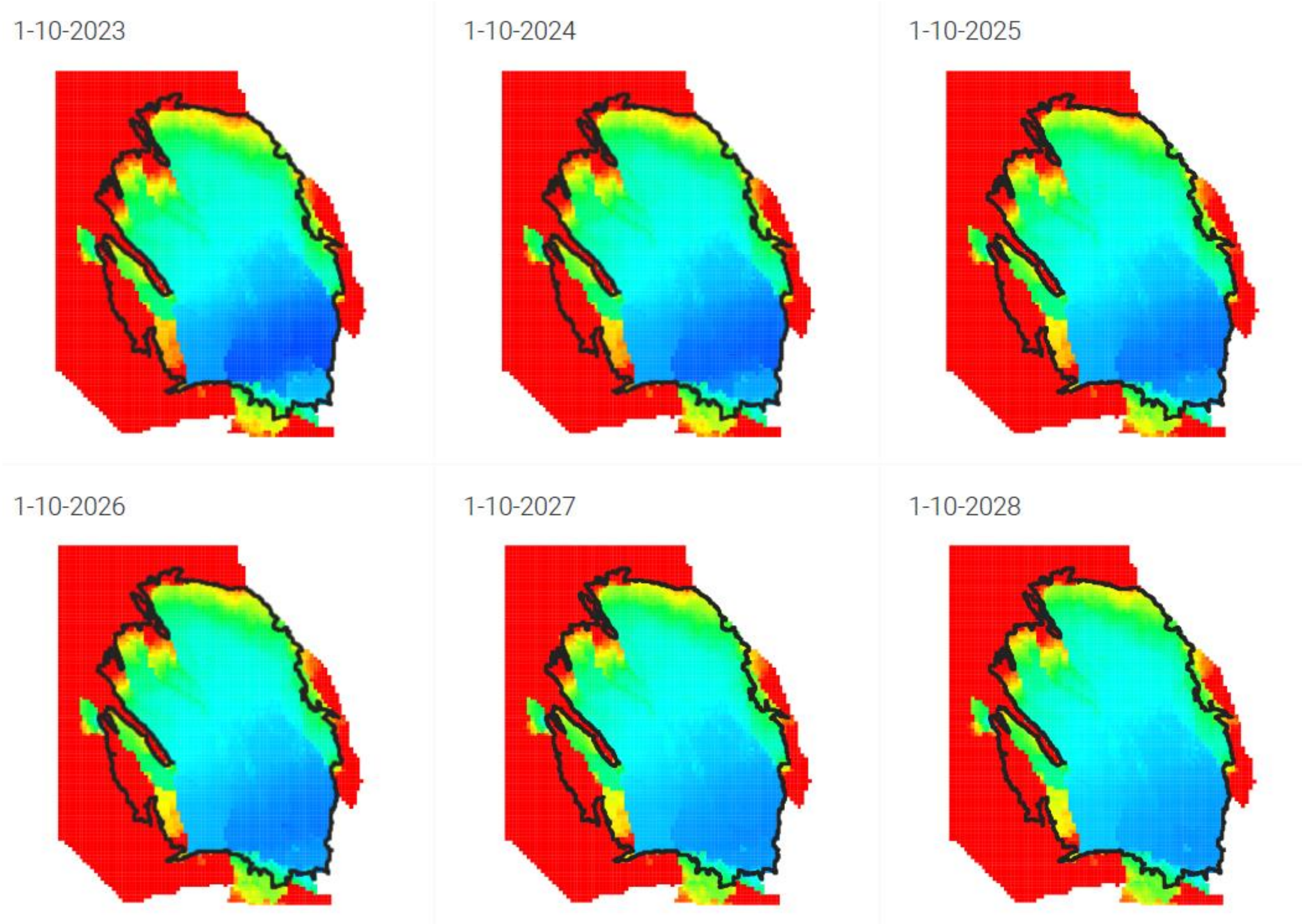

Figure 2-11: Pressure distribution at 1st of October 2023-2028 for average temperature scenario. See for colour scale Figure 2-5.

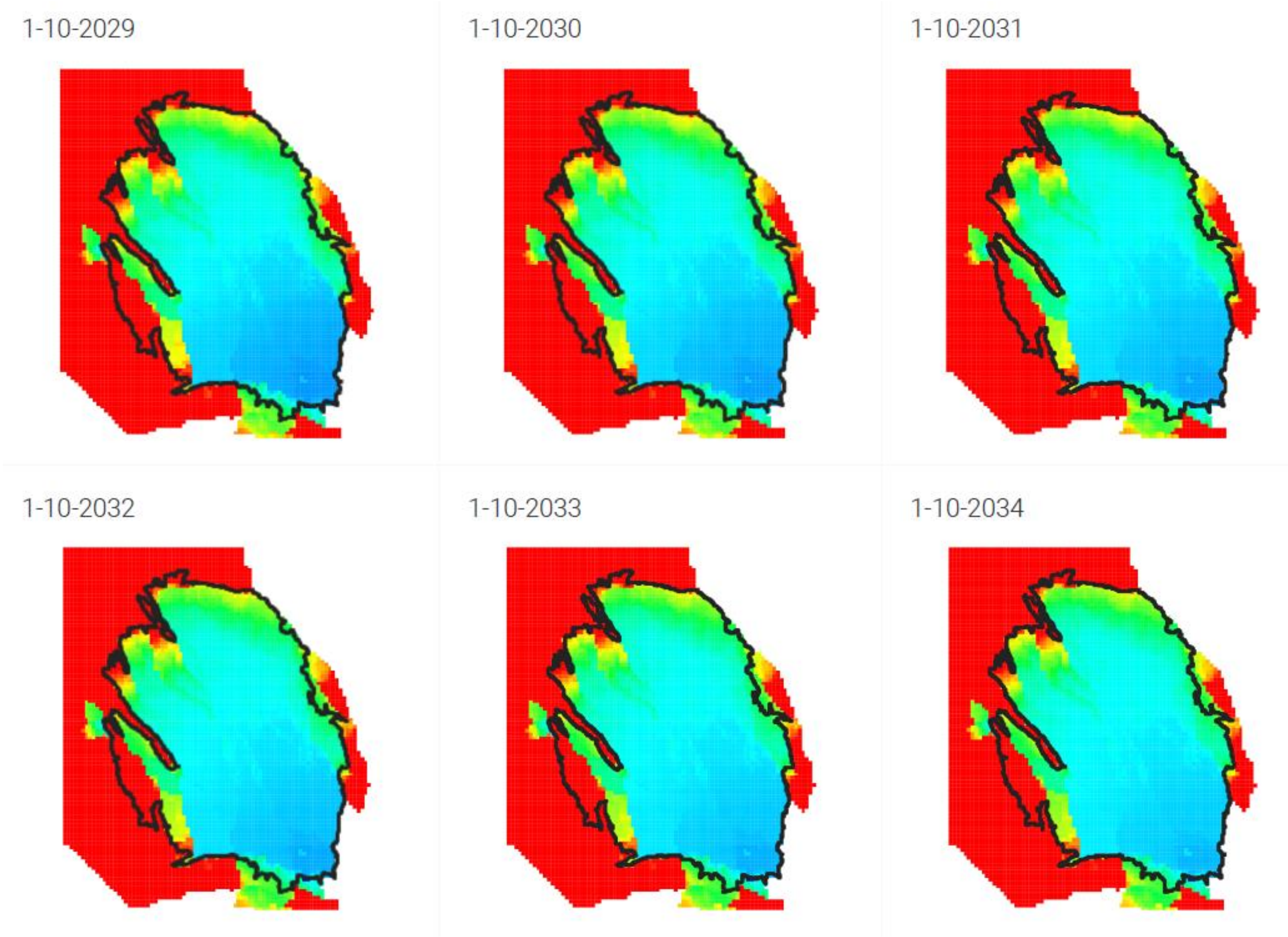

Figure 2-12: Pressure distribution at 1st of October 2029-2034 for average temperature scenario. See for colour scale Figure 2-5.

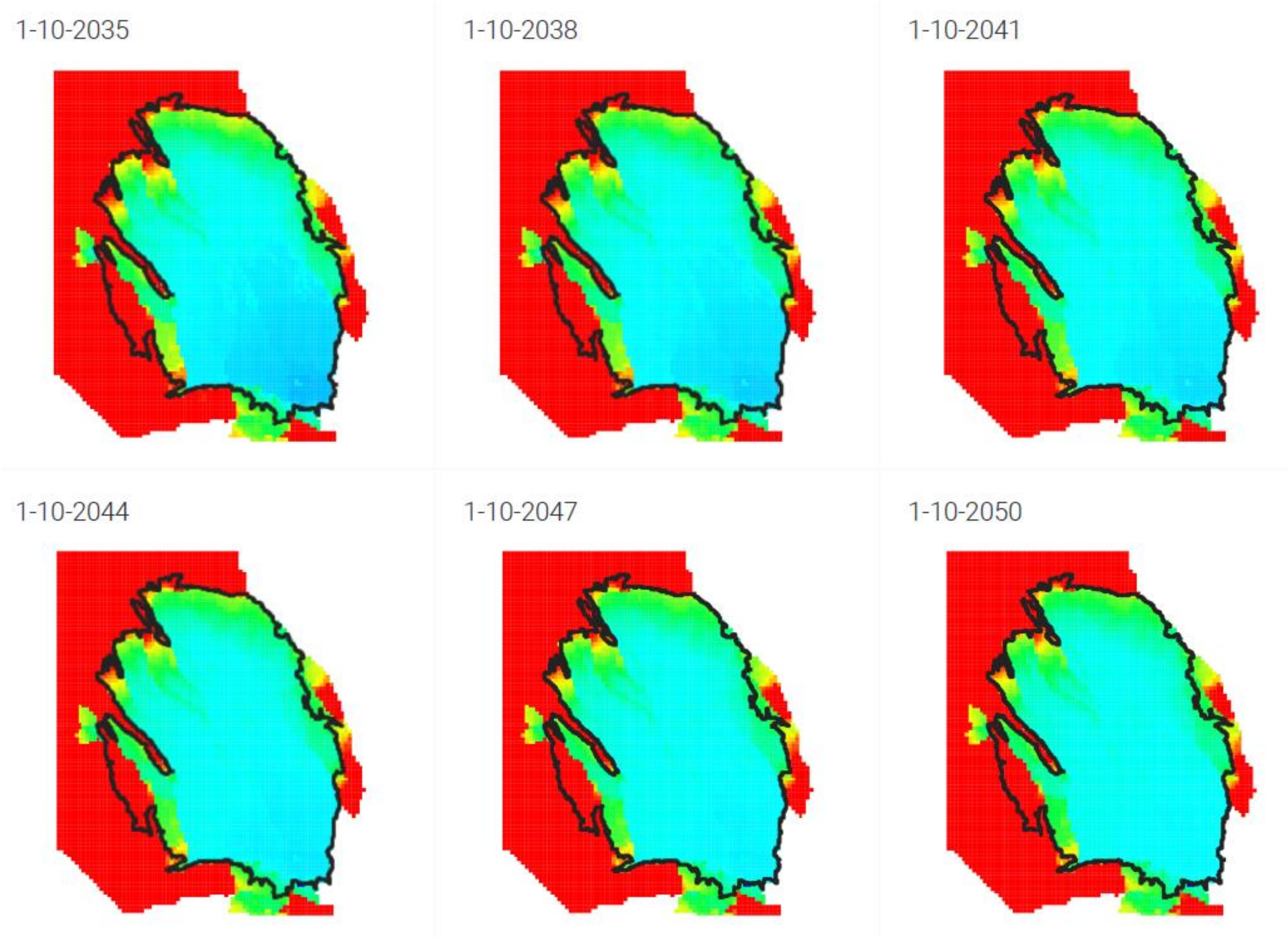

Figure 2-13: Pressure distribution at 1st of October 2035-2050 (every 3 years) for average temperature scenario. See for colour scale Figure 2-5.

3 Subsidence

In this HRA report for Groningen, subsidence is assessed for the period 2021-2031 for both the gas field and connected aquifers. Ongoing pressure depletion in the subsurface of the areas is driving the subsidence. This chapter presents the forecast of surface subsidence based on “GTS-raming 2021”, average temperature and the Operational Strategy as described in Chapter 2 of this report. In a series of updates of the Winningsplan Groningen 2016 (Ref. 8 to Ref. 14), this chapter is an updated version of relevant paragraphs on subsidence.

The study area is defined by the Groningen gas field and the most important connected aquifers surrounding the field (Figure 3-1). These aquifers are:

- The “Southern Lauwerszee Trough (Zuidelijke Lauwerszee Trog)” aquifer located between the Groningen field and the smaller fields of Vries and Roden.
- In the north, the “Mowensteert” aquifer is connected to the Groningen gas field causing possible subsidence in the Waddenzee.
- The Rysum aquifer is connected to the eastern part of the field.
- In the south, an aquifer between Annerveen and Groningen is connected to the Groningen field.

The white coloured aquifers in Figure 3-1, e.g. the Goldhoorn aquifer to the east of the Groningen, have no connection to the gas field due to large offset faults blocking lateral fluid flow and hence preventing pressure communication. The “Noordelijke Lauwerszee trog” is mainly connected to the Bedum and Warffum fields.

Possible depletion in the connected aquifers to the Groningen gas field was the main driver for conducting the Groningen long term subsidence forecast study (Ref. 35) in 2020. The study describes a statistical workflow that defines the most likely subsidence scenario including the quantification of the model uncertainty. Results from this study were also used in Ref. 36.

This chapter in the current HRA report uses the calibrated subsidence scenario and uncertainties from these studies but based on the latest (GTS-raming 2021) pressure forecast. Short summaries per block in the modelling chain will be provided.

The compaction is described in section 3.1 The influence model translates the compaction in the subsurface to the earth’s surface and is described in section 3.2.

The calibrated model, the uncertainty estimation and the resulting subsidence forecast are presented in section 3.3 and 3.4.

Figure 3-1 *Overview of the most important lateral aquifers attached to the Groningen field. In red the field names that are mentioned in the text.*

3.1 Compaction model

The RTCiM model (Ref. 38) was used For the subsidence forecast, as it gives the best match to core deformation experiments when compared to any of the other compaction models. Another advantage of the RTCiM model is that it spans a wide range of temporal behaviours to reflect the possible visco-plastic behaviour of the sandstone. The RTCiM model can behave more linear with depletion or exhibit time decay and temporal characteristics by changing parameter values. None of the other models is as versatile. This choice concurs as well with the findings of the LTS-II research (Ref. 39).

3.1.1 Input to compaction model

Reservoir compaction is mainly dependent on pressure depletion, reservoir thickness and rock compressibility. These parameters will be described in the following sections.

3.1.1.1 Pressure scenario for the reservoir and laterally connected aquifers

The basis for the pressure scenario is the V6 reservoir model which includes a depleting Carboniferous as a separate layer (Chapter 3). Following the results from the Groningen long term subsidence study (Ref. 35), the V6 model also delivers the pressure forecast for the aquifer areas Rysum, Möwensteert, and South (aquifer between Groningen and Annerveen). The aquifer pressures in the Southern Lauwerszee Trough are described by a set of 5 box models. Each box model provides 5 possible pressure realisations. The geodetic measurements above these box models were used to select the most likely combination of these possible realisations. Pressures from this box-model combination was stitched to the V6 model. More information on the workflow and selection procedure for the aquifer realisations can be found in Ref. 35Ref. 15.

3.1.1.2 Reservoir Thickness

A reservoir thickness map from the V6 reservoir model reflecting the net thickness was used as input for the compaction model in the HRA 2020 update (Figure 3-2). The same information is used as well in the HRA 2021 update. Net thickness is specified for both the ROSL and DC.

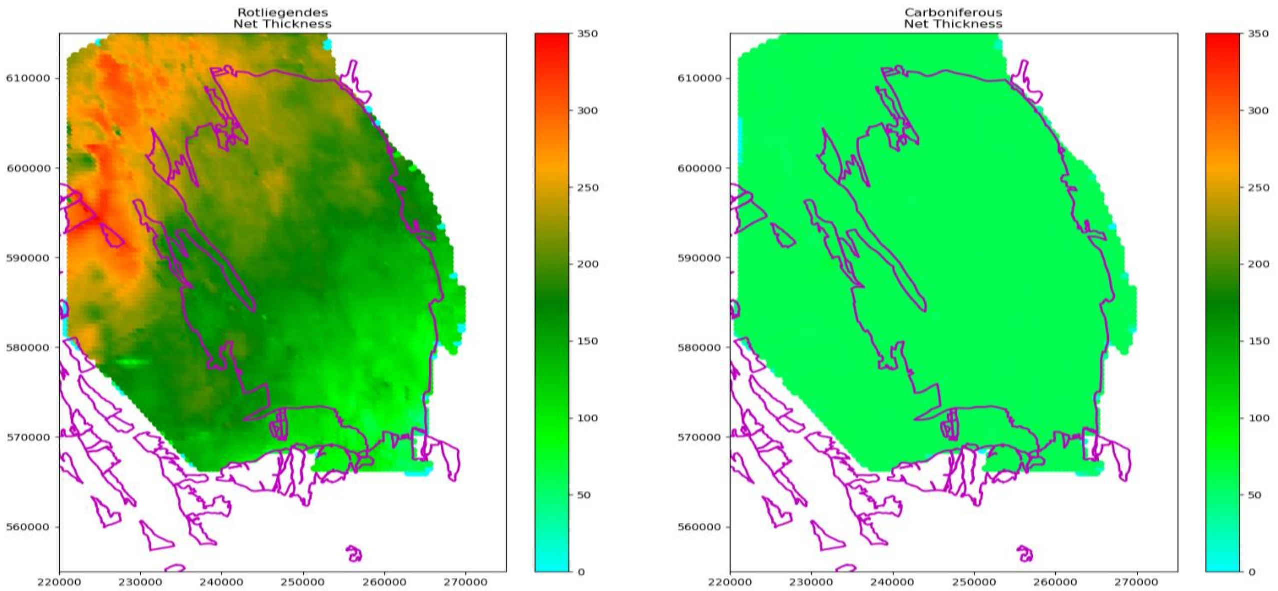

Figure 3-2 Net reservoir thickness [m] of the V6 reservoir model. Left: Net thickness for ROSL. Right: Net thickness for DC.

3.1.1.3 Rock compressibility

Rock compressibility is described by the RTCiM compaction model and the parameter values used for the HRA 2021 forecasts result from the workflow that is described by Ref. 35 and listed in Table 3-1.

Table 3-1, parameter values of the RTCiM Ref. 35

Posterior RTCiM parameters	Value
A [-]	0.85
d [-]	0.40
b [-]	0.021

Ref. 35 also investigates the likelihood of possible spatial correlations between the compressibility (C_m) and other subsurface parameters like velocity and porosity. The updated posterior correlation to the porosity showed the highest probability in the workflow and was therefore selected. A map of the prior porosity map and the posterior map (after an inversion step in the workflow) are visualised in Figure 3-3. The value for the DC Cm value was deduced from recent core experiments. These experiments show a range of Cm values from 0.1 to 0.6 $10^{-5}bar^{-1}$. As no clear relation between compressibility and e.g. the porosity of the samples was observed, we assumed a constant (average) value of 0.3 $10^{-5}bar^{-1}$ for the DC. (Ref. 37).

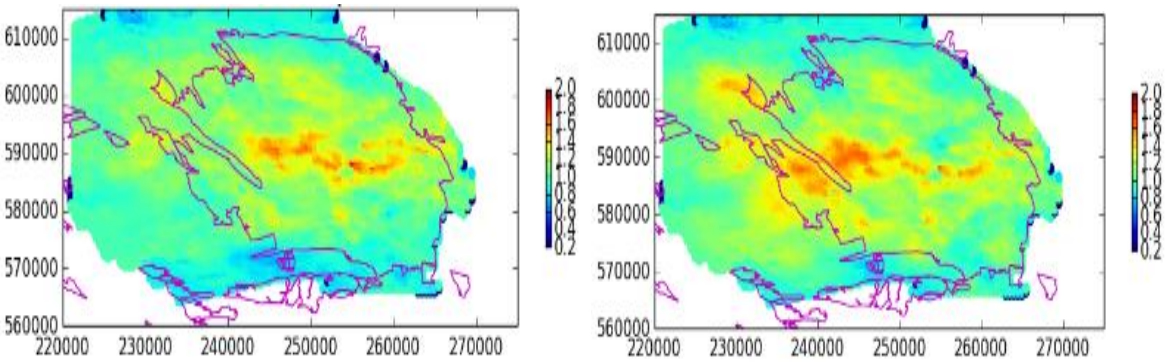

Figure 3-3 Left: prior Cm-porosity map. Right: Posterior Cm-porosity map.

3.2 Influence model

The influence model translates the compaction of the reservoir into surface subsidence. In Ref. 39, it was concluded that a thick salt layer above the Ameland reservoir significantly impacts the temporal behaviour of the subsidence. Compared to the Groningen field, the Ameland field is relatively small, where compaction leads to stress arching in the overburden, changing the shear stress above the reservoir. These shear stresses cause creep deformation in the salt resulting in a narrower and more profound subsidence bowl. Due to its large size, stress arching is nearly absent above the Groningen field and therefore it is assumed in this study to neglect salt creep. Still the salt can result in a steeper edge of the subsidence bowl, a phenomenon that already was recognised and described earlier (**Error! Reference source not found.**). We adopted therefore the influence model as described in Ref. 35, that combines a half-space model with a rigid basement (Ref. 40) using a value of 7 km for the rigid basement and a Poisson's ratio of 0.2. The effect of this model results in a change of the bowl shape that is time independent.

3.3 Uncertainty estimation

The uncertainty estimation for the modelled subsidence is described in Ref. 35. The Monte Carlo-Markov Chain procedure calculates for each subsidence scenario the model uncertainty Σ_{emp} that is largely dependent on the modelled subsidence.

The covariance matrix Σ_{emp} is calculated with only having non-zero values on the diagonal of the matrix and uses the following equation to describe the error at a given location:

$$\Sigma_{emp} = \sigma_0 + \alpha\mu_i$$

where μ_i is the modelled displacement (double difference) for location i. For the most likely scenario, the value for σ_0 of 0.53 and a value of 0.029 for α was calculated in Ref. 35.

3.4 Subsidence forecast

In this section the current status and expected development of subsidence (and uncertainty) up to 1-1-2032 is presented. Subsidence caused by gas production and aquifer depletion from the Groningen field is combined with the effects from ongoing gas production from neighbouring fields as published in Ref. 36.

Figure 3-4 shows the results of the subsidence model in comparison with the measured subsidence in benchmark locations across the gas field for the period 1972-2018.

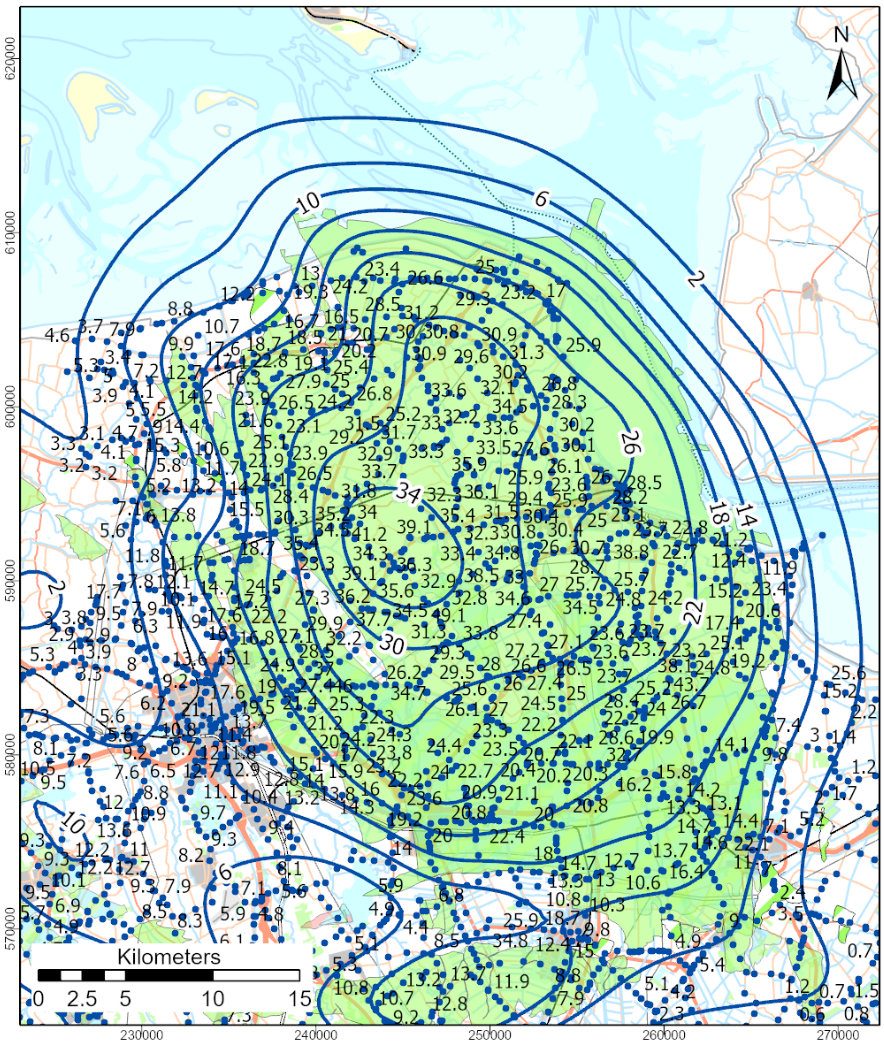

Figure 3-4 Contours (solid blue lines) of the modelled subsidence between 1972 and 2018 compared to the measurements (green dots with value label) spanning the same period. All values are in cm.

Subsidence forecasts for the end of year 2025, 2031 and 2050 are presented in respectively Figure 3-5, Figure 3-6 and Figure 3-7. The base case is presented by the contour lines while the P95 uncertainty is visualized by the coloured overlay. Note that the uncertainty presented is only based on the subsidence caused by the Groningen field and connected aquifers.

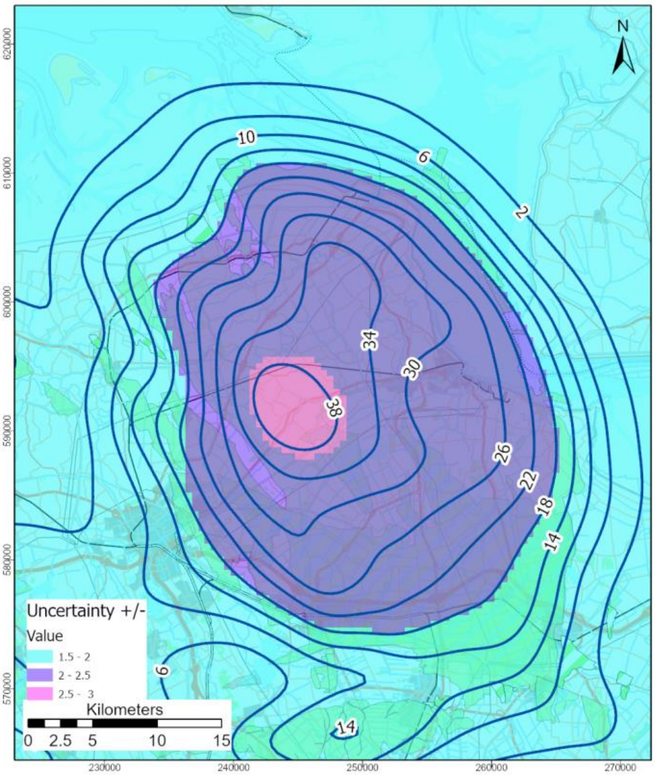

Figure 3-5 *Subsidence forecast in cm for the end of 2025 (contours). The colours indicate the P95 uncertainty in the subsidence.*

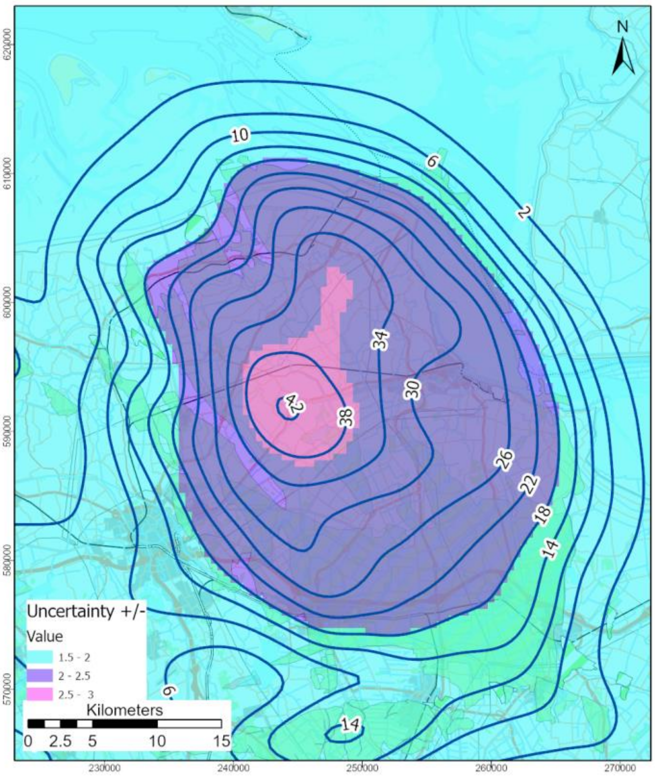

Figure 3-6 *Subsidence in cm for the end of 2031 (contours). The colours indicate the P95 uncertainty in the subsidence.*

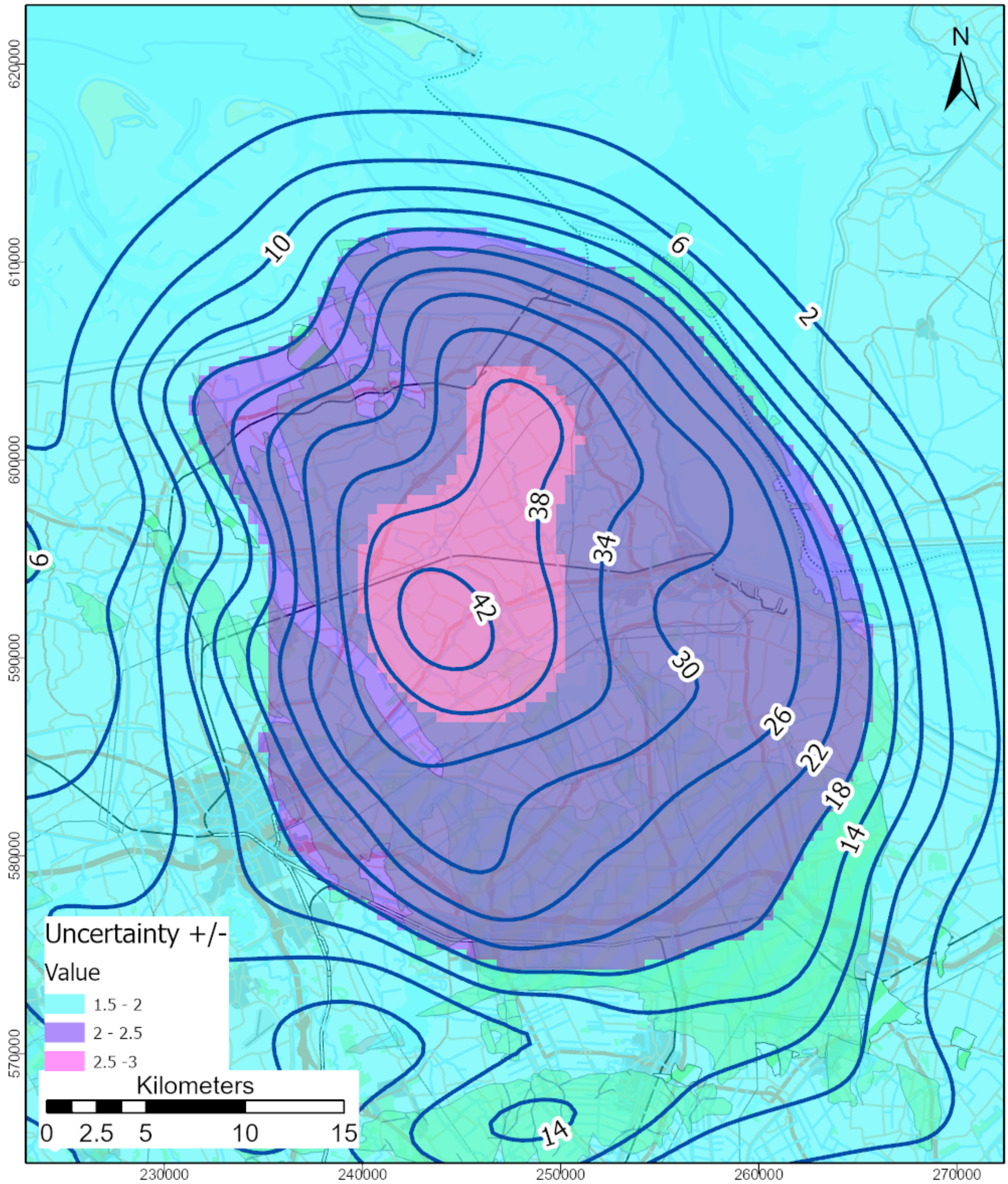

Figure 3-7 Subsidence in cm for the end of 2050 (contours). The colours indicate the P95 uncertainty in the subsidence.

To visualise the match between modelled and measured subsidence over time since the first levelling surveys, a number of plots are presented in Figure 3-8, showing modelled and measured subsidence at various benchmark locations over the Groningen field.

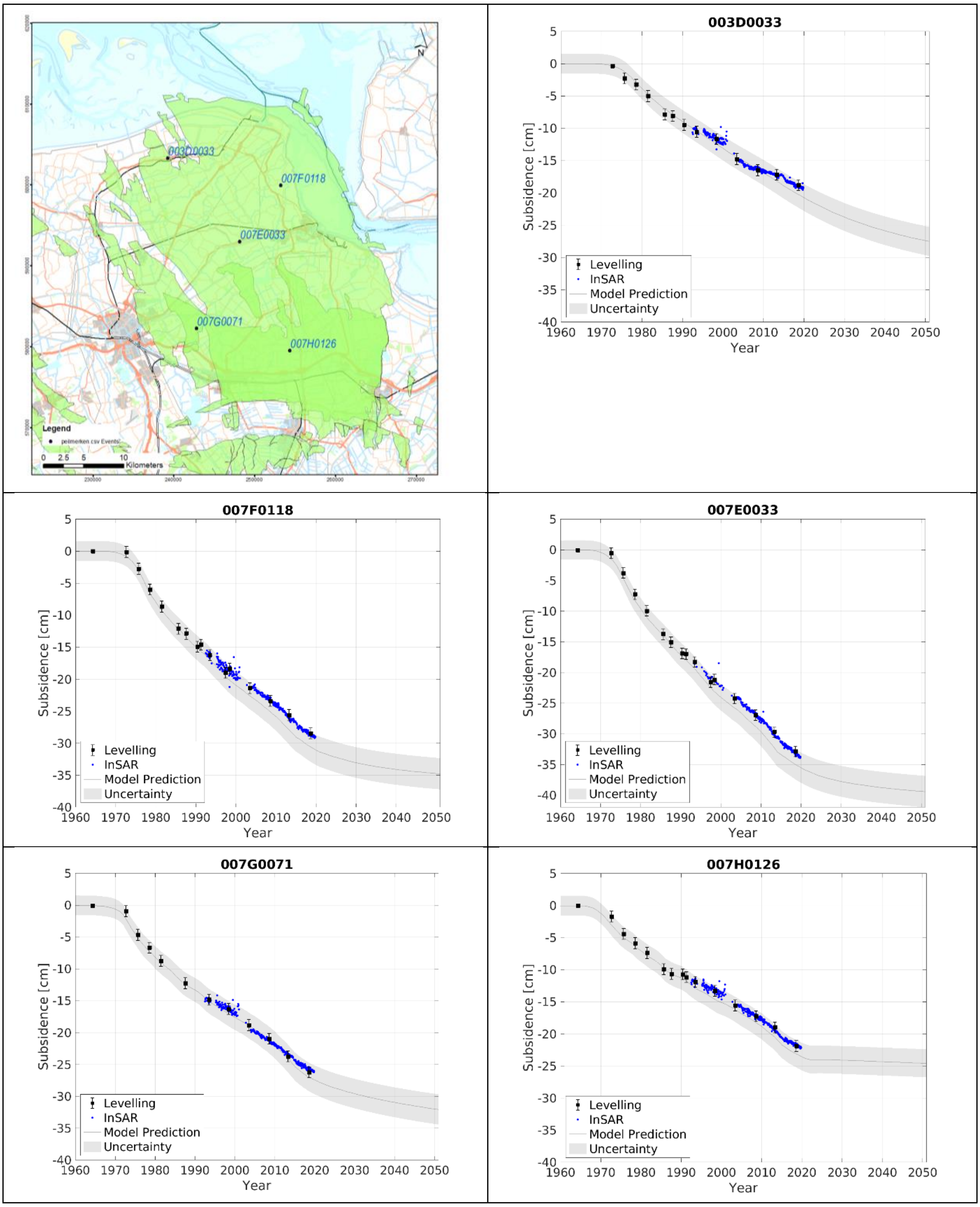

Figure 3-8 *Subsidence at benchmark locations: dark grey line is the predicted subsidence, grey is the P95 uncertainty interval, black dots are levelling measurements plus uncertainty, the blue dots are the InSAR measurements.*

4 References

All reports referenced in this section prepared by NAM can be downloaded from the webpage “onderzoeksrapporten” on www.nam.nl.

Ref. 1 *Het Winningsplan Groningen 2013, NAM, Dec 2013.*

Ref. 2 *Technical Addendum to the Winningsplan Groningen 2013 - Subsidence, Induced Earthquakes and Seismic Hazard Analysis in the Groningen Field and Supplementary Information, Jan van Elk, Dirk Doornhof, Stephen Bourne, Steve Oates, Julian Bommer, Clemens Visser, Rob van Eijs and Peter van den Bogert, NAM, Shell and Imperial College, Dec 2013.*

Ref. 3 *Hazard Assessment for the Eemskanaal area of the Groningen field, Jan van Elk and Dirk Doornhof, NAM, Nov 2014.*

Ref. 4 *Addendum to: Hazard Assessment for the Eemskanaal area of the Groningen field, Jan van Elk and Dirk Doornhof, NAM, Nov 2014.*

Ref. 5 *Dreigings- en risicoanalyse voor geïnduceerde seismiciteit Groningen - Onderzoek 1 dreigingsanalyse, Jan van Elk and Dirk Doornhof, NAM, May 2015.*

Ref. 6 *Dreigings- en risicoanalyse voor geïnduceerde seismiciteit Groningen - Onderzoek 2 risicoanalyse, Jan van Elk and Dirk Doornhof, NAM, May 2015.*

Ref. 7 *Hazard and Risk Assessment for Induced Seismicity in Groningen, Jan van Elk and Dirk Doornhof, NAM, Nov 2015.*

Ref. 8 *Winningsplan Groningen gasveld - 2016, NAM, April 2016. EP201604259068*

Ref. 9 *Technical Addendum to the Winningsplan Groningen 2016 (chapter 1-5), Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 10 *Technical Addendum to the Winningsplan Groningen 2016 (chapter 6), Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 11 *Technical Addendum to the Winningsplan Groningen 2016 (chapter 7), Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 12 *Technical Addendum to the Winningsplan Groningen 2016 (chapter 8), Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 13 *Technical Addendum to the Winningsplan Groningen 2016 (chapter 9), Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 14 *Supplement to the Winningsplan Groningen 2016, Jan van Elk and Dirk Doornhof, NAM, Apr 2016.*

Ref. 15 *Assessment of Hazard Building Damage and Risk for Induced Seismicity in Groningen - 2017, Jan van Elk, Dirk Doornhof, NAM, Nov 2017.*

Ref. 16 *Seismic risk assessment for a selection of seismic risk production scenarios for the Groningen field, Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Per Valvatne, Eddy Kuperus and Dirk Doornhof, NAM, Apr 2018.*

Ref. 17 *Assessment of Hazard, Building Damage and Risk based on Production Scenario Basispad Kabinet for the Groningen field, Jeroen Uilenreef, Jan van Elk and Assaf Mar-Or, NAM, July 2018.*

Ref. 18 *Assessment of Subsidence based on Production Scenario “Basispad Kabinet”, Dirk Doornhof and Onno van der Wal, NAM, July 2018. EP201806209337*

Ref. 19 *Hazard and Risk Assessment - GTS raming 2019, Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Jeroen Uilenreef and Dirk Doornhof, NAM, Mar 2019.*

Ref. 20 *Hazard and Risk Assessment Groningen Field – update for Production Profile GTS-raming 2020, Jan van Elk, Anke Jannie Landman, Jeroen Uilenreef and Dirk Doornhof, NAM, Mar 2020.*

Ref. 21 *Letter to NAM: Mijnbouwwet instemmingsbesluit winningsplan Groningenveld; aanvullingsverzoek, Directeur Energy Markt Ministry of Economic Affairs, 20 December 2013.*

Ref. 22 *Verwachtingenbrief – Winningsplan 2016*

Ref. 23 *Wijzigingsbesluit 24th May 2017*

Ref. 24 *Letter to Parliament “Gaswinning Groningen”, 29th March 2018, Minister of Economic Affairs and Climate Policy.*

Ref. 25 *Letter to Parliament “Betreft Voortgang maatregelen gaswinningsbrief”, 6 juni 2018, Minister of Economic Affairs and Climate Policy.*

Ref. 26 *Letter “Verwachtingenbrief aanvulling winningsplan Groningenveld 2016” to NAM, 2nd May 2018, Minister of Economic Affairs and Climate Policy.*

Ref. 27 *Verwachtingenbrief “verzoek tot voorspellen van twee operationele strategieen voor het gas jaar 2019-2020”, Ministerie van Economische Zaken en Klimaat met 13 Februari 2019 met bijlage “raming benodigd Groningenvolume en capaciteit gasjaar 2019/2020 en verder”, Gasunie Transport Services, Februari 2019.*

Ref. 28 *Verwachtingenbrief – GTS Raming 2020*

Ref. 29 *Eerste advies Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ 23rd June 2015*

Ref. 30 *Tweede advies Omgaan met hazard- en risicoberekeningen in het belang van handelingsperspectief voor Groningen Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ 29th October 2015*

Ref. 31 *Eindadvies Handelingsperspectief voor Groningen Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ (Commissie-Meijdam), 14th December 2015*

Ref. 32 *Groningen Dynamic Model Update 2018 – V6, Quint de Zeeuw and Leendert Geurtsen, NAM, Oct 2018. EP201809202872.*

Ref. 33 *Investigation of gas presence in the aquifer of the Groningen field, Gulfiia Ishmukhametova, NAM, Sept 2018.*

Ref. 34 *Groningen Basin Model 2018, Hemmo Boscher, NAM, June 2018.*

Ref. 35 *Groningen long term subsidence forecast, NAM, 2020 EP202008201822, version 2*

Ref. 36 *Bodemdaling door gaswinning - Bodemdaling door aardgaswinning in Groningen, Friesland en het noorden van Drenthe, NAM, 2020, EP202011201629 https://nam-onderzoeksrapporten.data-app.nl/reports/download/bodemdaling/nl/aa0e05c7-704a-4f9f-a02c-ea7ece904905*

Ref. 37 *van der Linden, A.J., Marcelis, F.H.M., Hol, S. & El Azouzi, K. (2020) Mechanical compression testing Carboniferous underburden material from the Zeerijp-3A well, Groningen Field, The Netherlands. Shell report SR.20.00670*

Ref. 38 *Pruiksma, J.P. & Breunese, J.N. & Thienen-Visser, Karin & De Waal, Hans. (2015). Isotach formulation of the rate type compaction model for sandstone. International Journal of Rock Mechanics and Mining Sciences. 78. 127-132. 10.1016/j.ijrmms.2015.06.002.*

Ref. 39 *NAM (2017) Ensemble Based Subsidence application to the Ameland gas field – long term subsidence study part two (LTS-II) continued study.*

Ref. 40 *Geertsma, J. and van Opstal, G. (1973). A Numerical Technique for Predicting Subsidence Above Compacting Reservoirs, Based on the Nucleus of Strain Concept. Verh. Kon. Ned. Geol. Mijnbouwk. Gen., 28, pp. 63-78.*

Appendix A – Relevant Correspondence

Expectation Letter (Verwachtingenbrief) – 1st February 2021

Ministerie van Economische Zaken
en Klimaat

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Nederlandse Aardolie Maatschappij
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Afschrift aan TNO

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Projectdirectie Groningen

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Uw kenmerk

Bijlage(n)
3

Datum
Betreft verzoek tot voorstellen operationele strategie voor het gasjaar 2021-2022

Geachte heer Atema,

Hierbij verzoek ik u conform artikel 52c van de Mijnbouwwet een operationele strategie voor het gasjaar 2021-2022 voor te stellen op basis van de bijgevoegde GTS-raming voor hetzelfde gasjaar. In deze brief (inclusief bijlagen) geef ik de uitgangspunten voor de in te dienen operationele strategie, die uiterlijk 19 maart 2021 in mijn bezit dient te zijn.

In de Mijnbouwregeling is in artikel 1.3a.2, eerste lid, vastgelegd dat een operationele strategie omvat:

a. een beschrijving van de volgorde van de inzet van de clusters en de verdeling van het volume over de clusters per kalendermaand uitgaande van het referentiejaar voor een gemiddeld gasjaar;
b. de wijze waarop de inzet over de clusters en de verdeling van het volume over de clusters wordt verlaagd dan wel verhoogd, afhankelijk van de ontwikkeling van de actuele temperatuur gedurende het gasjaar, waarbij in ieder geval een beschrijving wordt gegeven van de volgorde van de inzet van de clusters en de verdeling van het volume over de clusters uitgaande van het referentiejaar voor een koud en voor een warm gasjaar.

Daarnaast zijn in het tweede en derde lid van artikel 1.3a.2 van de Mijnbouwregeling ter onderbouwing van de operationele strategie nadere eisen opgenomen, bijvoorbeeld over de rol van gasopslag Norg, de invloed van geplande onderhoudswerkzaamheden en dreigings- en risicoanalyse behorende bij een operationele strategie.

Bij het voorstellen van de operationele strategie verzoek ik u de beschrijvingen te volgen zoals vastgelegd in artikel 52c van de Mijnbouwwet en artikel 1.3a.2 van de Mijnbouwregeling.

Met betrekking tot de dreigings- en risicoanalyse is u bekend dat ik mijn verdere besluitvorming zal baseren op de analyse die de Nederlandse organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO) in mijn opdracht uitvoert. U kunt van deze analyse gebruik maken bij de invulling van de eisen die aan de

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onderbouwing van de operationele strategie zijn gesteld en ik verwacht dat u dat ook zult doen. Ik verzoek u zo snel mogelijk doch uiterlijk 19 februari 2021 aan TNO de daartoe benodigde gegevens te verstrekken. In bijlage C van deze brief geef ik een gedetailleerde omschrijving van de uitgangspunten van de dreigings- en risicoanalyse. Een afschrift van deze brief en de betreffende bijlage stuur ik naar TNO. U zult uiterlijk 12 maart 2021 de dreigings- en risicoanalyse van TNO ontvangen.

Voor de volledigheid merk ik op dat uit de GTS-raming blijkt dat het Groningenveld vanaf 2022-2023 alleen nog als reservemiddel nodig is. De raming bevat de bijbehorende benodigde capaciteit om het veld als reservemiddel te kunnen gebruiken. Ik verzoek u bij het opstellen van de operationele strategie het in stand houden van deze capaciteit in acht te nemen. In bijlage A van deze brief geef ik u daartoe meer specifiek de uitgangspunten.

De Minister van Economische Zaken en Klimaat,
namens deze:

Marc Hoenders
Directeur projectdirectie Groningen

Bijlagen:
A: Uitgangspunten voor de operationele strategie 2021-2022
B: Advies leveringszekerheid voor benodigde Groningenvolumes en -capaciteiten
C: Uitgangspunten voor de dreigings- en risicoanalyse

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Bijlage A

Uitgangspunten voor de operationele strategie 2021-2022
De operationele strategie is een voortzetting van de door MEZK vastgestelde operationele strategie voor het huidige gasjaar 2020-2021 en aangepast aan de uit de GTS-raming volgende graaddagenformule voor het gasjaar 2021-2022. Deze voldoet derhalve aan de benodigde productiehoeveelheid van gas uit het Groningenveld om te kunnen voldoen aan het niveau van leveringszekerheid in het gasjaar 2021-2022. Deze staat, evenals de graaddagenformule die voor het gasjaar 2021-2022 van toepassing zal zijn, beschreven in de GTS-raming "Advies leveringszekerheid voor benodigde Groningenvolumes en -capaciteiten" van 31 januari 2021, met de aanvullende bijlagen "raming benodigde Groningenvolumes en -capaciteiten" en "uitgangspunten volumeberekeningen". De GTS-raming is als bijlage bij deze brief gevoegd. Uw voorstel voor de operationele strategie houdt rekening met operationele omstandigheden.

De uitgangspunten als bedoeld hierboven zijn als volgt (in volgorde van prioriteit):

1. Produceer die hoeveelheid Groningenveldgas die jaarlijks nodig is voor de leveringszekerheid binnen de graaddagenformule 2021-2022;
2. Zorg voor voldoende werkvolume in de underground gas storage (hierna: UGS) Norg gedurende de hele winter ten behoeve van de leveringszekerheid;
3. Houd de door GTS geraamde benodigde capaciteit voor het gasjaar 2021-2022 en daaropvolgende gasjaren in stand, met inachtneming van:
    - Alle benodigde productielocaties worden operationeel gehouden;
    - In de periode november tot en met maart is gemiddeld, buiten vorstperiodes, de helft van de benodigde productielocaties direct opregelbaar;
    - Bij vorst zijn alle voor de capaciteit benodigde productielocaties direct opregelbaar.

   Voor het gasjaar 2021-2022 is het benodigde volume voor het in stand houden van de capaciteit reeds in de graaddagenformule verwerkt.
4. Produceer het volledige werkvolume uit Norg, onder de randvoorwaarde dat de stikstofinstallaties maximaal worden gebruikt;
5. Streef binnen de graaddagenformule en de voorwaarden van het instemmingsbesluit gasopslag Norg naar het maximaal vullen van UGS Norg gedurende het injectieseizoen.

U heeft door de uitgangspunten die ik vastleg geen mogelijkheid meer om actief overschrijdingen van regionale productiefluctuaties te voorkomen. Wel vraag ik u bij uw voorstel voor de operationele strategie het verwachte aantal overschrijdingen op te nemen. Daarbij vindt een overschrijding plaats als het verschil in maandelijkse productie groter is 50% voor een cluster, zoals bedoeld in de Mijnbouwregeling onder artikel 1.3a.1 onder 1, die voor productie in gebruik is.

De uitgangspunten voor de dreigings- en risicoanalyse vindt u in bijlage C.

Wij vragen u bij de rapportage van de operationele strategie in elk geval de volgende elementen op te nemen, waar relevant separaat voor een warm, gemiddeld en koud gasjaar:

- Een tabel of figuur waarmee de inzet van de clusters als functie van de dagvraag eenduidig wordt vastgelegd.
- Een beschrijving van de wijze waarop u in de operationele strategie invulling geeft aan het uitgangspunt 3 ten aanzien van het in stand houden van capaciteit zoals hierboven beschreven.
- Een doorkijk van de voorgestelde clusterafbouw (inclusief de productielocaties) bij de geraamde afbouw van de productie in de jaren na het komende gasjaar, uitgaande van een gemiddeld temperatuurverloop in de gasjaren na 2021-2022.
- Voor zover relevant, het verwachte aantal overschrijdingen van regionale productiefluctuaties.

Voor de rapportage over de dreigings- en risicoanalyse verwijs ik naar bijlage C.

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Bijlage C

Uitgangspunten voor de dreigings- en risicoanalyse
De dreigings- en risicoanalyse dient de elementen te bevatten die in artikel 1.3a.2, derde lid, van de Mijnbouwregeling zijn opgenomen. Hierbij merk ik op dat bij uitwerking voor het gasjaar 2021-2022 van een koud en gemiddeld uitgegaan dient te worden, voor de jaren hierna kan een gemiddeld temperatuurprofiel worden gehanteerd.

U berekent de elementen die ingevoerd moeten worden in de publieke SDRA en levert deze aan TNO. Conform het advies van Staatstoezicht op de Mijnen (SodM) wordt u verzocht om nog één keer de kalibratie van het seismologisch model uit te voeren op basis van alle beschikbare data tot 1 januari 2021 en de resulterende inputfiles voor het seismologisch model voor 5 februari 2021 bij TNO aan te leveren voor implementatie in de publieke SDRA modeltrein voor het gasjaar 2021/2022.

Als onderdeel van de verwachte bodembeweging dient een verwachting te worden gegeven van de bodemdaling voor de komende 30 jaar, waarbij de modellen gekalibreerd zijn aan de meest recente data. De analyse betreffende bodemdaling dient door u te worden verstrekt.

Bij uitwerking van onderdeel b artikel 1.3a.2, derde lid, van de Mijnbouwregeling dient een schadeprognose te worden gemaakt – als gevolg van geïnduceerde bevingen – voor de schadegrenstoestanden DS1, DS2 en DS3 uit het EMS-98, European Seismological Commission, 1998. U dient hieraan een analyse van de kans op DS1-schades toe te voegen. U kunt daarbij verwijzen naar de studies van vorig jaar, mits vergezeld van een beschrijving van de redenen waarom dit geoorloofd is. De DS2 en DS3 klassen worden door TNO verstrekt als uitkomst van de publieke SDRA Groningen.

Voor het uitvoeren van de publieke SDRA Groningen dient u de volgende informatie aan TNO te verstrekken:

- Kalibratie files van het seismologisch model
- Resultaten van het compactiemodel
- Drukken uit het reservoirmodel per tijdstap
- Extractie van de gebouwendatabase

De onderdelen c, d en e van artikel 1.3a.2, derde lid, van de Mijnbouwregeling, worden door TNO met de publieke SDRA Groningen berekend en verstrekt. De onderdelen f en g van artikel 1.3a.2, derde lid, van de Mijnbouwregeling, dienen door u te worden versterkt. Hierbij dient u voor het gasjaar 2021-2022 uit te gaan van een koud en gemiddeld scenario, voor de jaren hierna kan een gemiddeld temperatuurprofiel worden gehanteerd.

Modelversies
Om te komen tot een keuze voor de te hanteren versies en keuzes van de modelcomponenten voor de dreigings- en risicoanalyse is een zorgvuldig proces ingericht en gevolgd. Op 9 oktober 2020 heeft TNO een technisch status rapport

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opgeleverd waarin een voorstel is opgenomen voor de te gebruiken modelversies en modelparameters voor de publieke SDRA Groningen 2021. Ik heb SodM gevraagd om te beoordelen welke versies van de verschillende modelcomponenten geschikt zijn om te gebruiken voor de uit te voeren dreigings- en risicoanalyse voor gasjaar 2021-2022. Daarvoor zijn leden van het wetenschappelijk panel van het Kennisprogramma Effecten Mijnbouw geconsulteerd. Mede op basis van het advies van SodM stel ik vast dat de dreigings- en risicoanalyse dient te worden uitgevoerd met grotendeels dezelfde keuzes voor modelcomponenten als bij de risicoanalyse van 2020, meer specifiek:

- Seismologisch bronmodel versie 6 in dezelfde vorm en met dezelfde weging van de takken in de beslisboom als gebruikt in de HRA voor het gasjaar 2020/2021.
- Grondbewegingsmodel versie 6, waarbij voor de 'period-to-period-correlatie' de formulering zoals in de documentatie van NAM wordt aangehouden.
- Schade/risicomodel versie 7 in dezelfde vorm, met dezelfde coëfficiënten en met dezelfde weging van de takken in de beslisboom als gebruikt in de HRA voor het gasjaar 2020/2021.
- De NAM Exposure Database (gebouwendatabase) versie 7 met de door NAM voorgestelde actualisaties.

Rapportage TNO
De rapportage voor de resultaten van de publieke seismische dreigings- en risicoanalyse wordt door TNO opgesteld en aan u verstrekt. In deze rapportage wordt in ieder geval het volgende opgenomen:

- Een overzicht van de kans op zwaardere bevingen (M>3,5; 4,0; 4,5) per gasjaar, voor het gasjaar 2021-2022 en de 10 volgende gasjaren.
- Berekeningen van het Plaatsgebonden Persoonlijk Risico (LPR) (hazardkaarten en LPR-curves) voor het gasjaar 2021-2022 en een overzicht in een tabel van het aantal gebouwen dat niet voldoet aan de veiligheidsnorm (berekend met de verwachtingswaarde van het risico per gebouw, en met P90 in een bijlage) per gasjaar, voor het gasjaar 2021-2022 en de 10 volgende gasjaren.
- Daarnaast een zelfde overzicht met het aantal gebouwen berekend met zowel de verwachtingswaarde als P90 voor de kalenderjaren 2021 tot en met 2031.
- Ontwikkeling van de seismische activiteit tot 10 jaar na het gasjaar 2021-2022, weergegeven in gasjaren.
- Verschilkaarten van de seismische dreiging, aardbevingsdichtheid en seismische risico tussen een gemiddeld en koud gasjaar.
- Ontwikkeling van de seismische activiteit van de operationele strategie tot 30 jaar na het gasjaar 2021-2022, weergegeven in stappen van 5 jaar.
- Overzicht van de overschrijding van de schadecategorieën DS2 en DS3 per gasjaar, voor het gasjaar 2021-2022 en de 10 volgende gasjaren

Rapportage NAM
Zoals hierboven beschreven kunt u voor de onderbouwing van de operationele strategie op bovenstaande punten gebruik maken van de risicoanalyse die door

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TNO wordt versterkt. Aanvullend vraag ik u in elk geval het volgende te rapporteren:

- Een analyse van de kans op DS1-schades.
- De verwachte bodemdaling voor de komende 30 jaar, waarbij de modellen gekalibreerd zijn aan de meest recente data.
- Kaarten van de drukontwikkeling tot 30 jaar na het gasjaar 2020-2021.

Ten slotte
In aanvulling op de overzichten van de gebouwen in de rapportage, zal ik TNO vragen de BAG-ID's van de betreffende gebouwen aan te leveren zodat voor de Nationaal Coördinator Groningen (NCG), conform de afspraken omtrent de uitwisseling van persoonsgegevens, gebouwen op adresniveau herleidbaar zijn.

Appendix B – Glossary of Terms

This appendix contains a glossary of terms used in this report and the documents references in this report. More extensive glossaries for terms used in earthquake studies have been compiled by the USGS:

https://earthquake.usgs.gov/learn/glossary/?alpha=ALL

and at the web-site www.earthquake-report.com.

https://earthquake-report.com/2011/02/15/glossary-of-earthquake-terms-2/

Term	Explanation
Acceleration	The rate of change of velocity of a reference point. Commonly expressed as a fraction or percentage of the acceleration due to gravity (g) where g = 980 cm/s2. - (USGS)
Accelerogram	The recording of the acceleration of the ground during an earthquake.
Building Code	A building code, or building control, is a set of rules that specify the minimum acceptable level of safety for constructed objects such as buildings and non-building structures. The main purpose of building codes are to protect public health, safety and general welfare as they relate to the construction and occupancy of buildings and structures. A seismic code, refers to a building code which uses earthquake-resistant design principles. (USGS - CEDIM)
Cold temperature year	The demand for gas is dependent on the weather and especially on whether the winter will be cold. This is also reflected in the production required from the Groningen gas field to ensure security of supply. Therefore a sensitivity is performed in this hazard and risk assessment where the target year (gas-year 2020/2021) has a cold winter.
Earthquake	The expected (or probable) life loss, injury, or building damage that will happen, given the probability that some earthquake hazard occurs. Earthquake risk and earthquake hazard are occasionally used interchangeably. (USGS)
Epicenter	The point on the Earth's surface vertically above the point (focus or hypocenter) in the crust where a seismic rupture nucleates. (EQCanada)
Eurocode 8	The Eurocodes are the current technical standards for structural design in Europe, and it is now compulsory for the 28 countries in the Eurocode zone to adopt these. Eurocode 8 specifically deals with earthquake-resistant design of structures (CEN, 2006). Each country adopting Eurocode 8 must develop a National Annex to indicate how the code is implemented; the National Annex for the Netherlands is being developed. Eurocode 8 uses a standard practice to represent seismic hazard via PGA maps associated with ground motions having a 10% probability of exceedance during 50 years, equivalent to 0.2%/year for a stationary process, or a return period of 475-years.
Disaggregation	Disaggregation of a Monte-Carlo simulation result is a technique to determine the range of the factors with the largest impact on the simulation result.
Fault	A fracture along which there has been significant displacement of the two sides relative to each other parallel to the fracture. (USGS)
Fault Plane	The surface on which the earthquake movement takes place. (CEDIM)

Gas-year	Gas-years are the 12-month period starting at 1st October. The gas-year 2020/2021 is the period from 1st October 2020 up to and including 30st September 2021. Gas-years are used to avoid the high gas demand winter period to be split over two reporting periods.
Geophone	A device that converts ground movement (velocity) into voltage, which may be recorded at a recording station. The deviation of this measured voltage from the base line is called the seismic response and is analysed for structure of the earth.
Ground Motion (Shaking)	General term referring to the qualitative or quantitative aspects of movement of the Earth's surface from earthquakes or explosions. Ground motion is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the Earth and along its surface. (USGS)
GTS-raming	The hazard and risk assessment is based on a production profile for the Groningen field. This is based on a prognosis of demand for Groningen gas prepared by GTS. GTS raming 2020 as made in January 2020.
Gutenberg-Richter	Earthquakes appear to follow a pattern through time in terms of no. of earthquakes vs. magnitude. This is called the Gutenberg-Richter criterion. (CEDIM)
Hazard	Any physical phenomenon associated with an earthquake that may produce adverse effects on human activities. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunami, and seiche and their effects on land use, manmade structures, and socioeconomic systems. A commonly used restricted definition of earthquake hazard is the probability of occurrence of a specified level of ground shaking in a specified period of time. (USGS)
Hypocenter	The point within the Earth where an earthquake rupture initiates. Also commonly termed the focus. (USGS)
Individual Earthquake Risk	The individual earthquake risk is the annual risk that an individual is exposed to in the various structures in or near which this individual is present (See also table 7.1).
Inside Local Personal Risk (ILPR)	The probability of death of a fictional unprotected person who is permanently present in a building (See also table 7.1).
Liquefaction	seismology, it refers to the loss of soil strength as a result of an increase in pore pressure due to ground motion. This effect can be caused by earthquake shaking. (IASPEI)The transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore water pressures and reduced effective stress. In engineering
Local Personal Risk (LPR)	The probability of death of a fictional unprotected person who is permanently present in or near a building. This person is thought to be inside the building 99% of the time and outside near the building 1 % of the time (See also table 7.1).
Local site conditions	A qualitative or quantitative description of the topography, geology, and soil profile at a site that affect ground motions during an earthquake. (IASPEI).
Nationale Praktijk Richtlijn: NPR 9998	This document describes the structural safety of a building in case of earthquake loads. Constructors can use this guideline to calculate how strong a building must be in order to comply with the seismic safety standard for buildings used in the Netherlands.
Magnitude	A number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded

	by a seismograph(sometimes for earthquake waves of a particular frequency), corrected for attenuation to a standardized distance. Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as Richter magnitude, (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). ML, Ms and Mb have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types. In principal, all magnitude scales could be cross calibrated to yield the same value for any given earthquake, but this expectation has proven to be only approximately true, thus the need to specify the magnitude type as well as its value. An increase of one unit of magnitude (for example, from 4.6 to 5.6) represents a 10-fold increase in wave amplitude on a seismogram or approximately a 30-fold increase in the energy released. In other words, a magnitude 6.7 earthquake releases over 900 times (30 times 30) the energy of a 4.7 earthquake - or it takes about 900 magnitude 4.7 earthquakes to equal the energy released in a single 6.7 earthquake! There is no beginning nor end to this scale. However, rock mechanics seem to preclude earthquakes smaller than about -1 or larger than about 9.5. A magnitude -1.0 event releases about 900 times less energy than a magnitude 1.0 quake. Except in special circumstances, earthquakes below magnitude 2.5 are not generally not felt by humans. (USGS-IASPEI)
Mijnraad 1500 Lijst	These are the ca 1,500 buildings that in the advice of the Mijnraad of mid-2018 had a mean LPR > 10^{-5}/year.
Monte-Carlo Simulation	The Monte Carlo simulation is a simulation technique whereby a physical process is simulated not once but many times, each time with different starting conditions. The result of this collection of simulations is a distribution function that displays the entire area of possible outcomes.
Object-related Individual Risk	The Objectgebonden individual earthquake risk is the risk that an individual dies in a year due to collapse or falling objects (as a result of an earthquake) of a building in which or in the direct vicinity of which this person is present. The residence time in/around that building is therefore taken into consideration (See also table 7.1).
Outside Local Personal Risk	The probability of death of a fictional unprotected person who is permanently present near a building (See also table 7.1).
P Wave	A seismic body wave that involves particle motion (alternating compression and extension) in the direction of propagation. (USGS)
P wave	A P wave, or compressional wave, is a seismic body wave that shakes the ground back and forth in the same direction and the opposite direction as the direction the wave is moving.
Peak Acceleration	The highest acceleration in terms of value. (USGS)
PGA	The maximum acceleration amplitude measured or expected in a strong-motion accelerogram of an earthquake. (IASPEI)
Primary Wave	See P Wave (CEDIM)
Risk	The probabilistic determination of the damages a certain hazard can cause given the existing vulnerability, location and time. (UN)
Risk Assessment	Definition: A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people,

	property, services, livelihoods and the environment on which they depend.Comment: Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process. (UN/ISDR)
Rupture	The instantaneous boundary between the slipping and locked parts of a fault during an earthquake. Rupture in one direction on the fault is referred to as unilateral. Rupture may radiate outward in a circular manner or it may radiate toward the two ends of the fault from an interior point, referred to as bilateral. (USGS)
S-wave	An S wave, or shear wave, is a seismic body wave that shakes the ground back and forth perpendicular to the direction the wave is moving.
S Wave Velocity	The velocity of a secondary or S wave. Generally measured in m/s. (CEDIM)
Secondary Wave	A seismic body wave that involves a shearing motion in a direction perpendicular to the direction of propagation. When it is resolved into two orthogonal components in the plane perpendicular to the direction of propagation, SH denotes the horizontal component and SV denotes the orthogonal component. Also known as S waves and shear waves. (PDC)
Seismic hazard	Risk of a certain ground motion occurring at a location (this can be defined by scenario modeling via stochastic catalogues, DSHA, PSHA or other such methods, and can include different types of earthquake effects) (CEDIM)
Seismic Risk	See earthquake risk, also the probabilistic risk is the odds of an earthquake occurring and causing damage within a given time interval and region. (EQCanada)
Seismic Station	A ground position at which a geophysical instrument is located for an observation. (U-Milwaukee)
Seismic Waves	An elastic wave generated by an impulse such as an earthquake or an explosion. Seismic waves may propagate either along or near the Earth's surface (for example, Rayleigh and Love waves) or through the Earth's interior (P and S waves). (USGS)
Seismicity	1) The geographic and historical distribution of earthquakes. 2) A term introduced by Gutenberg and Richter to describe quantitatively the space, time, and magnitude distribution of earthquake occurrences. Seismicity within a specific source zone or region is usually quantified in terms of a Gutenberg-Richter relationship. (ICWGroup/IASPEI)
Seismogram	A record written by a seismograph in response to ground motions produced by an earthquake, explosion, or other ground-motion sources. (ICW Group)
Seismometer	A seismometer is a damped oscillating mass, such as a damped mass-spring system, used to detect seismic-wave energy. The motion of the mass is commonly transformed into an electrical voltage. The electrical voltage is recorded on paper, magnetic tape, or another recording medium. This record is proportional to the motion of the seismometer mass relative to the Earth, but it can be mathematically converted to a

	record of the absolute motion of the ground. Seismograph is a term that refers to the seismometer and its recording device as a single unit. (NASA)
Velocity	In reference to earthquake shaking, velocity is the time rate of change of ground displacement of a reference point during the passage of earthquake seismic waves commonly expressed in centimeters per second. (USGS)

Appendix C – List of Abbreviations

AHN	Actueel Hoogtebestand Nederland
ALLEA	All European Academies
AGE	TNO - adviesgroep economische zaken
ALARP	As Low As Reasonably Practicable
ARUP	Engineering Company named after founder: Ove Arup
ACVG	Adviescollege Veiligheid Groningen
BAG	Basisregistratie Adressen en Gebouwen
Bcm	N.Bcm refers to a volume of a billion normal cubic meters. Normal means the volume is measured at a standard temperature (0 degree C) and pressure (1 bar)
BGS	British Geological Survey
BOA	Begeleidingscommissie Onderzoek Aardbevingen
BZK	Ministry of Internal Affairs (Ministerie van Binnenlandse Zaken)
CBS	Centraal Bureau Statistiek
CEA	China Earthquake Administration
CEDIM	Center for Disaster Management and Risk Reduction Technology
CMI	Compaction Monitoring Instrument
CMOC	Crack Mouth Opening Displacement
CPT	Cone Penetration Test
CVW	Centrum Veilig Wonen
DAS	Distributed Acoustic Sensing
DEEP.nl	Research program led by NWO
DC	Carboniferous Formation
DIC	Digital Image Correlation
DS	Damage State
DSS	Distributed Strain Sensing
DTS	Distributed Temperature Sensing
DvhN	Dagblad van het Noorden (regional newspaper)
EBN	Energy Beheer Nederland
EDB	Exposure Database
EMS	European Macroseismic Scale
EPOS	European Plate Observatory System
ERIC	European Research Infrastructure Consortium
EVS	Extended Visual Screening
EZ	Ministerie van Economische Zaken (in English MEA)
EZK	Ministerie van Economische Zaken en Klimaat (in English MEAC)
FDSN	Federation of Digital Seismograph Networks
Frl	Friesland
GBB	Groninger Bodembeweging
GEM	Global Earthquake Model
GMPE	Ground Motion Prediction Equations
GMM	Ground Motion Model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GR	Group Risk
GWC	Gas water contact

HRA	Hazard and Risk Assessment
HRBE	High Risk Building Element
ILPR	Inside Local Personal Risk
I&M	Ministerie van Infrastructuur en Milieu
InSAR	Interferometric Synthetic Aperture Radar
IR	Individual Risk
IVO	Instituut versterkingsopgave
IU	Interrogation Unit
KEM	Kenninsprogramma Effecten Mijnbouw (Knowledge program Effects of Mining)
KNAW	Koninklijk Nederlands Academie van Wetenschappen (Royal Netherlands Academy of Arts and Sciences)
KNGMG	Koninklijk Nederlands Geologisch Mijnbouwkundig Genootschap
KNMI	Koninklijk Nederlands Meteorologisch Institute
KU Leuven	Katholieke Universiteit Leuven (Catholic University Leuven)
LE	Latest Estimate
LIDAR	Laser Imaging Detection And Ranging
LPR	Local Personal Risk
LNEC	Laboratorio Nacional de Engenharia Civil (Lisbon)
M	Earthquake Magnitude
MEA	Ministry of Economic Affairs (prior to 2017)
MEAC	Ministry of Economic Affairs and Climate Policy (from 2017 onwards)
MR	Maatschappelijk Risico
MASW	Multichannel Analysis of Surface Waves
MIT	Massachusetts Institute of Technology
NAM	Nederlandse Aardolie Maatschappij B.V.
NARS	Network of Autonomously Recording Seismographs
NCG	Nationaal Coordinator Groningen
NFU	Netherlands Federation of University Medical Centres
NGO	Non-governmental Organisation
NORSAR	Norwegian Seismic Array (Norwegian independent, not-for-profit, research foundation within the field of geo-science)
NPR	Nationale Practijkrichtlijn
NTNU	Norges teknisk-naturvitenskapelige universitet (Norwegian University of Science and Technology in Trondheim)
NWO	Nederlands Organisatie voor Wetenschappelijk Onderzoek (Dutch National Science Foundation)
OECD	Organisation of Economic Cooperation and Development
OGP	Onafhankelijk Geologen Platform
OIA	Objectgebonden Individueel Aardbevingsrisico (Object related individual earthquake risk)
OIR	Object-related individual risk (same as OIA)
OVV	Onderzoeksraad voor Veiligheid (Safety Board)
PGA	Peak Ground Acceleration
PGK	Petroleum Geologie Kring
PGV	Peak Ground Velocity
PNL	Pulsed Neutron log
PRBE	Potential High Risk Building Elements
QRM	Quantitative Reservoir Management
RFT	Repeat Formation Tester

RGD	Rijksgeologische Dienst (later also TNO-NIGT)
RMSE	Roor Mean Square Estimate
RUG	Rijksuniversiteit Groningen
RVS	Rapid Visual Screening
RvS	Raad van State
RWS	Rijkswaterstaat
SAC	Scientific Advisory Committee
SCAL	Special Core Analysis Laboratory
SED	Schweizerischer Erdbebendienst (Swiss Seismological Survey)
SINTEF	Stiftelsen for industriell og teknisk forskning (Foundation for Scientific and Industrial Research)
SMS	Samenwerking Mijnbouw Schade
SodM	Staatstoezicht op de Mijnen (also SSM State Supervision of Mines)
SPE	Society of Petroleum Engineers
SPG	Static Pressure Measurement
SPTG	Static Pressure and Temperature Measurement
SSHAC	Senior Seismic Hazard Analysis Committee
Tcbb	Technische commissie bodembeweging
TCMG	Tijdelijk Commissie Mijnbouwschade Groningen
TIVO	Tijdelijke Instituut versterkingsopgave
TK	Tweede Kamer (Dutch equivalent of House of Commons)
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, Netherlands Organisation for Applied Scientific Research
TNO-AGE	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek – Advies Groep Economische Zaken
TO2	Toegepast Onderzoek Organisaties (Federation of Applied Research Institutes); Deltares, MARIN, NLR, TNO and WR
TPA	Technische Platform Aardbevingen
TU Delft	Technische Universiteit Delft
TU/e	Technische Universiteit Eindhoven
UU	Universiteit Utrecht
UvA	Universiteit van Amsterdam
URM	Un-reinforced Masonry
USGS	United States Geological Survey
USNRC	United States Nuclear Regulatory Commission
VoVo	Voorlopige voorziening
VSNU	Vereniging samenwerkende universiteiten in Nederland (Association of Universities in the Netherlands)
V_{s800}	Shear wave velocity up to a depth of 800 m