KEM sub-panel advice to SodM on the "Development of seismicity during pressure equilibration in the Groningen gas field"

[redacted]

February 6, 2025

1. Preamble

In late 2020, a sub-panel of KEM (Knowledge Programme on Effects of Mining) was established by what was named at the time as the Ministry of Economic Affairs and Climate (EZK) and now Ministry of Climate and Green Growth (KGG) of the Netherlands to follow the development of the public seismic hazard and risk assessment (called pSHRA or SHRA) model for Groningen, accompanying the transition of the responsibility for a SHRA from NAM to TNO. In this advice, the public SHRA of TNO will be referred to as the SHRA as not al functionality is in the official versions and public yet. The SHRA of NAM will be referred to as the NAM-SHRA. The purpose of the sub-panel is to advise State Supervision of Mines (SodM) and the Ministry of Economic Affairs and Climate (since 2024 named the Ministry of Climate and Green Growth) on the scientific aspects of both the SHRA model versions and its development. The specific goals of the sub-panel are: (i) to review the studies having for their potential to be part of the SHRA development, (ii) to advise on the proposed TNO internal and public SHRA versions and developments of TNO on a yearly basis; (iii) to report to the KEM panel about the SHRA progress and development.

The KEM sub-panel is composed of independent researchers with specific expertise on probabilistic hazard and risk assessment overall and on three macro-modules of risk analysis, namely: the seismological source model (SSM), the ground motion model (GMM, and the fragility and consequence model (FCM).

Although all KEM sub-panel members are experts on SHRA in general and interact on all aspects of the official and developments versions of the SHRA of TNO, their primary expertise's are:

- SSM – [redacted] (Delft University of Technology, NL) and [redacted] (ETHZ, Switzerland).
- GMM – [redacted] (Univ. Grenoble, France) and [redacted] (GFZ, Germany).
- FCM – [redacted] (Univ. Naples Federico II, Italy and IUSS, Pavia, Italy).
- [redacted] is the secretary of the sub-panel.

In late September 2024, the sub-panel received a written request for advice from SodM (via [redacted], related to the development of seismicity during pressure equilibration in the Groningen gas field. This advice request, summarized in section 2, addresses deviations in the seismicity rate and potential SHRA model shortcoming or extension. The questions also address issues related to quality assurance and quality control (QA/QC). The KEM sub-panel, after discussion with the Ministry of Climate Policy and Green Growth (i.e., [redacted] confirmed that it can address the questions raised and provide the requested advice. This note contains our advice, all sub-panel members have contributed to the present advice and endorse the document and its conclusions.

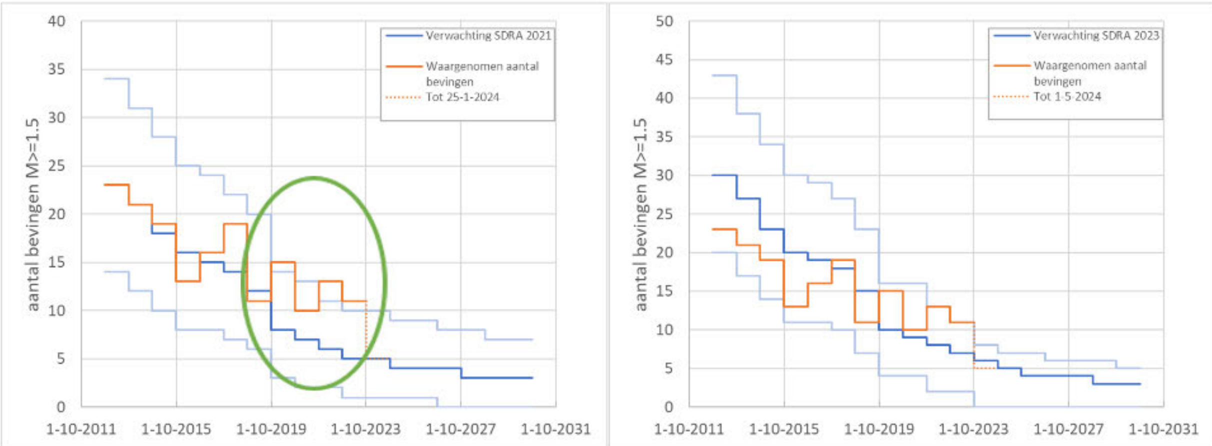
2. Content of the request and response approach

2.1. Request for advice

The request for advice from SodM is repeated here for clarity:

In 2021, SodM identified a developing deviating trend between the observed and modelled seismicity rates of the Groningen gas field (using the official SHRA version of TNO, see illustration in the request for advice). At the request of SodM, TNO as well as the operator NAM studied the cause of this deviation. Intermediate results were presented at various occasions and reported in the TNO status report of October 2023 (Ref. [1]) and in various other publications (Ref. [2] and [3]). On July 12, 2024, NAM reported a synthesis of all their studies with their interpretation of the possible processes explaining the observed deviation (Ref. [4]).

Given the extent of the possible explanations for the deviation in observed versus modelled seismicity rates by TNO and NAM (from recalibration (e.g. figure 1b) to incorporation of new processes/insights previously deemed secondary, e.g. rate type compaction behaviour, rate-and-state seismicity behaviour, aftershock analysis, etc.) and alternative models published in the scientific literature, SodM has requested the advice of the KEM-sub-panel for the further model development of the seismicity rate part of the seismological model in the SHRA.



Figuur 1 a (left): SDRA2021 model prediction versus observed seismicity; b (right): SDRA2023 model prediction versus observed seismicity. The difference in seismological model between SDRA2021 and SDRA2023 is the adaptation of the TNO calibration procedure in the SDRA2023 and the incorporation of all data up to January 1st 2023 versus all data up to January 2021 in the SDRA2021.

Specifically, we request the advice on the following questions (but please do not feel limited by these questions):

1. *In previous advices (Ref. [0]), the KEM-sub-panel (further panel) has explicitly expressed the importance of utilizing a systematic, extensive QA/QC procedure, including external reviews or structured expert elicitation, for all SDRA model development and implementation of model components in the SDRA. Can the panel elaborate on the extent of the QA/QC of the different studies reported by both TNO and contracted by NAM.*
2. *Which processes/insights have been identified in either the studies by TNO or contacted by NAM that could provide an explanation of the discrepancy between observed and modelled seismicity rates.*
3. *What would be required to incorporate the various identified processes and/or new insights for the deviation in the SHRA model train?*
4. *What would be required to incorporate alternative, published models/processes in the SHRA?*
5. *If the panel cannot easily answer these two questions, would the panel recommend a KEM study to investigate and advise on this?*
6. *What is the overall recommendation(s) of the panel on how to proceed with the implementation and/or adaptation of all studies for the purpose of incorporation in the SHRA?*

Given the fact that the SHRA of TNO is using the alternative calibration method of TNO, we specifically ask the KEM-sub-panel to take note of the recalibration studies of NAM and comment on possible important lessons which could also be relevant for the TNO calibration.

2.2. Response approach

In the production phase of the Groningen gas field the KEM sub-panel advised on a yearly basis. This request for advice is the first advice in the post-production phase of the Groningen gas field (as of 1-10-2023) and focusses very much on the SSM development. Nevertheless, the KEM sub-panel consider it important to also consider the status and QA/QC of complete SHRA for Groningen from a technical and organisational perspective, because many of the ongoing issues are rooted there, and because for some of the questions, the sub-panel considers itself not the relevant stakeholder. Consequently, the response is structured as follows.

Chapters 3-4 address the QA/QC aspects of the SHRA of TNO, from the scientific, technical (including software engineering), and organizational perspectives.

Chapters 5-7 address potential and recommended model developments for the seismic source model components, the ground motion model components, and the fragility and consequence model components respectively.

In chapters 8 and 9 the recommendations are summarized for further development, maintenance, and use of the SDRA for Groningen, and the specific questions raised by SodM are answered.

3. TECHNICAL ACHIEVEMENTS AND STATUS

3.1. Phases of the Groningen SHRA developments

To place the recent development of the public SHRA modelling chain for the public seismic hazard and risk analysis for the Groningen gas field into a broader perspective, the KEM-sub-panel would first suggest the following framing and naming of the Groningen SHRA developments.

- The **Initiation Phase** of NAM-SHRA development was started shortly after the 2012 Huizinge earthquake and lasted broadly until 2021. This phase was characterised by a rapid model developments and improvements, driven by an extensive seismic and subsurface data gathering and modelling effort. The effort was coordinated by NAM but involved many leading international experts. TNO started in 2018 with the development of TNO-SHRA (SHRA). This effort, cofinanced by KEM, resulted in a first version and comparative test with the NAM-SHRA in 2019 (Ref. [5]).
- The **Transition Phase,** started around 2021, when the ministry appointed TNO as responsible for the operation and regular updates of the SHRA for Groningen. During this transition phase, TNO was able to yearly implement and reproduce subsequent SHRA versions and results of the SHRA fully inhered from NAM-SHRA versions with its by now, open-source software framework (Ref. [5]). The official versions approved by EZK and SodM were used to assess the seismic effect of the gas production in this period and gave input to the strengthening program. The latest approved version contains developments up to 2023 and was made public (Ref. [6]). The SHRA was also extended in select aspects based on ongoing research efforts and anticipating post-production needs. SHRA development versions (Ref. [1]), including the latest developments, have only been used for TNO research and EZK policy studies and have not been made public yet.
- In the opinion of the KEM sub-panel, the **Consolidation Phase** has now started. Given the decision to end the gas production and the steady, and expected, decrease in seismicity, it is now even more timely to devote effort to bringing together the existing model components in a systematic way that considers all best available science in a balanced and structured way, to produce an updated development and official SHRA version to be used in practice for the next decade and to make it public as open source. It is also timely to adjust the governance, stakeholder roles, as well as QA/QC procedures, and to consider knowledge transfer and synergies with other Dutch underground mining activities.
- The KEM sub-panel suggests that, from about 2027 onwards, the SHRA should enter into a **Surveillance Phase**, where seismicity and model performance are continuously monitored so that (statistically) significant deviations from the expected behaviours can be identified, triggering re-analysis with the SHRA. There is probably no need for regular Groningen-specific model developments for regulatory purposes related to a production license, unless unexpected seismicity occurs. Instead, the available SHRA framework may be used to show the effect of the building strengthening program in Groningen and to illustrate to the public the continued decrease in seismicity, as anticipated by the models. The state-of-the-art related to Groningen SHRA models should, however, be periodically (e.g., every three years) scanned to see if substantial new developments have emerged that warrant an update.

Adopting such a phasing would allow stakeholders to plan the upcoming work in the short- and mid-term horizons.

3.2. Current status of the Groningen SHRA efforts

The KEM sub-panel would like to highlight the remarkable achievements of the Initiation and Transition Phases. The current Groningen SHRA of TNO is unique globally as the most sophisticated hazard and risk model for induced seismicity applied in practice. The model has set a new standard such that the numerous people and organisations that have contributed to the model development in the past decade should be proud of these achievements, even if they have not enabled the continued operation of the field.

There will always be new and open questions and issues to improve a probabilistic seismic hazard and risk model, i.e., science and development never stops. However, the current model chain is well-tested, generally accepted in its fundamental features, and fit for purpose. A special mention is deserved by the seismicity rate forecasting, which is also the focus of most of the questions posed by SodM to the sub-panel. Figure 1 suggests some deviations in the observed seismicity rate outside the confidence bounds, leading to extensive review activities. The KEM sub-panel also appreciates the efforts by TNO to formally test the model performance, establishing a quantitative way to assess the new SSM component. In summary, the satisfactorily captures the overall trend of seismicity after the stop of the gas production.

There is also consensus on the expected continued decrease in the rate and on the primary physical mechanism at work, even if second-order details in the re-calibration procedure and the relevance of rate-type compaction behaviour are being discussed that would also broaden the uncertainty range (see figure 2, more in Chapter 5). It should be noted that the official version of the SHRA, which can be downloaded on the TNO website (Ref. [6]) is used in yearly applied SHRA studies is and that this version is, except for recalibration, not updated as of 2022.

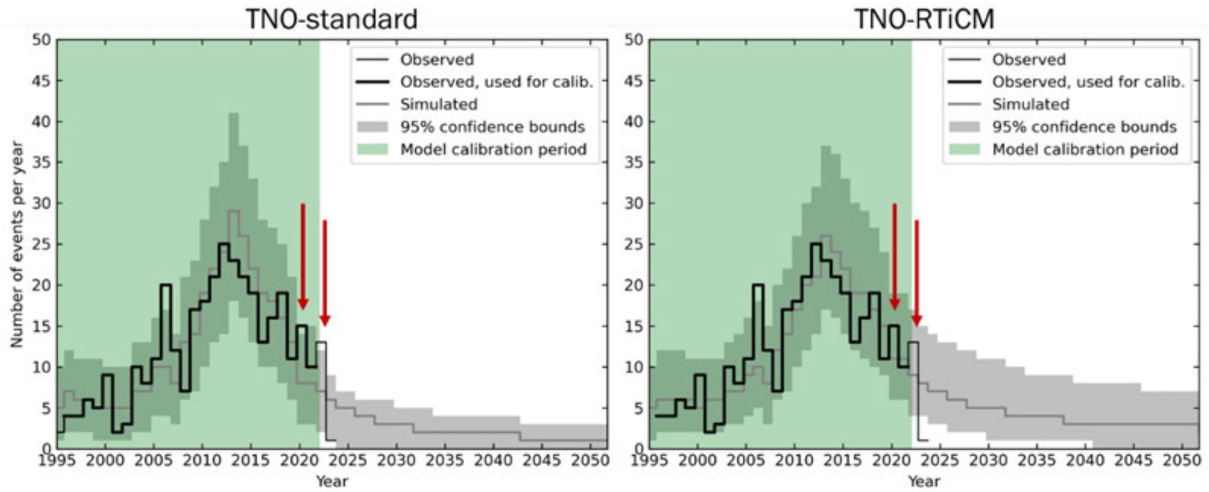


Figure 2 shows the observed and simulated event counts with their 95% confidence bounds of the TNO-standard-2022 model version and including the RTiCM implementation (Ref [2], TNO, 2023).

It is also a fact that induced seismicity in a well-understood context, such as Groningen seismicity, is substantially more predictable than natural seismicity. The KEM sub-panel would, therefore, suggest that there is limited urgency for model adjustments in the SSM and that all stakeholders will recognize and appreciate that the SSM model is serving its purpose of estimating seismic sources. The same can be said for other model components, such as GMMV6&7, where there is a general consensus that this is a sophisticated model, representing the state of the art in a seismic hazard assessment and, even if for some specific parts, for example the fragility and consequence modelling component, some possible improvements could be foreseen; notwithstanding its fitness for purpose.

The KEM-sub-panel, therefore, suggests that the current SHRA has reached a Consolidation Phase in which the current model chain has matured substantially with time, is of high quality and gives defensible probabilistic forecast of earthquake occurrences or ground motion and direct consequences (i.e., the risk).

The ultimate goal of a probabilistic seismic hazard analysis is to ***capture the centre, body, and range of technically defensible interpretations*** (Ref. [7]). Much of the Groningen SRHA was constructed following this concept, initially introduced for PSHA of nuclear facilities, yet now accepted and applied to many standard civil engineering applications. The KEM sub-panel considers it timely to finalise the development of the SDRA Groningen in a short and focused consolidation phase, so that viable alternative approaches are adequately considered in all model components and included in the SHRA official version and published as open source. Achieving such a consolidation is not so much a scientific endeavour, nor does it require extensive coding, since most components are already available (see Section 3.3). It requires primarily a structured and transparent process with clearly defined roles for different stakeholders. In our assessment, this process has been partially lacking in the transition phase, particularly in the SSM part, ultimately leading to many of the questions posed by SodM. How the KEM-sub-panel envisions the consolidation and subsequent surveillance phase is addressed in section 4.2 and 8.

3.3. Model implementation status and open issues

Several specific items have been identified in the transition phase as potential improvements of the model chain (see table 3.2 in Ref. [1]), and all of these have been technically implemented by TNO. In 2023, the developments of the SHRA focused on describing the current post-production seismic behaviour in the Seismological Source Model (SSM) to address the observed underprediction of the mean event rate of earthquakes in the Groningen region. In particular, a *rate-type isotach compaction model* (RTiCM) has been included as an option in the SSM. In addition to the linear elastic compaction of the previous SSM, the current model includes an inelastic time-dependent reservoir compaction.

Several versions of the rate-and-state friction model have been implemented to improve the timing of the seismic events, but tests pointed out that these are not viable alternatives to the original implementation of the extreme threshold failure model [Ref. 11] and its variations. The estimation of the *b-value* (the value that relates the base-ten logarithm of the number of earthquake occurrences to the magnitude of the earthquakes) in the model for the seismic magnitude appears to be most accurate with a combination of a step model conditioned on thickness and a linear model conditioned on stress. Table 1 presents the realized model developments.

In parallel to the activities at TNO, NAM has been extending their model development and with the help of a team at Caltech (Jean-Philippe Avouac and colleagues) established an alternative modelling approach for the forecasting of earthquake occurrences. Progress in this development has been shared with EZK, SodM, TNO and the KEM sub-panel in a meeting in October 2023. Caltech is developing an independent method for estimating earthquake probabilities for any future scenario of gas extraction at Groningen, that can be transferred to other applications. The KEM sub-panel greatly appreciates and welcomes these contributions to understanding seismicity. Although this work has led to several important research findings (published or about to be published in papers by Acosta, Kaveh, Heimisson, Smith, Meyer and others), the data and software of this research are not yet directly accessible to the TNO development team, and implementation of the methodologies in the SHRA and their future maintenance may not be straightforward.

With the in-house proposed adaptations of the 2023 model components (Table 1 of Ref. [1]) the development version of the SHRA provides statistically non-rejectable seismic rate matching post-production monitoring data. This progress in this development has also been shared with EZK, SodM, TNO and the KEM sub-panel in a meeting in October 2023. Therefore, the in 2023 by TNO proposed constellation of model components should be the base for the consolidation that the KEM sub-panel proposes, and only minor improvements should be considered in some of the (sub)models to reach a final consolidated version in a couple of years. Various suggested developments in SSM, GMM and FCM towards consolidation are described in Chapter 6-8. With the start of the surveillance phase, the KEM sub-panel considers changes to the consolidated versions only justified when data proven inconsistent with the models occur, or new scientifically underpinned insights and model implementations become available, which also result in improved prediction power with respect to monitoring data. Suggestions for this observation phase of Groningen and beyond are described in Chapter 9.

Table 1 Overview of recent model developments, after table 3.2 in Ref. [1].

model version	documentation	TNO software implementation	HRA		Official SHRA			TNO proposal	TNO realised
			2019	2020	2021	2022	2023	2023	2025
SSM									
NAM-V6	Bourne et al., 2019	TNO, 2020c		x	x	x			
TNO-2020	Bourne et al., 2019; TNO, 2022a	TNO, 2020c					x		
TNO-2023	Bourne et al., 2019; TNO, 2022a & 2023x	TNO, 2023x						x	x
SSM sub models									
TNO-Model calibration		TNO, 2020a					x	x	x
NAM-Model calibration provided as input		not part of HRA	x	x	x	x			
Single Coulomb stress conditioned to activity rate		TNO, 2020a	x						
Coulomb stress predictor for activity rate		TNO, 2020c		x	x	x			
Coulomb stress predictor for magnitude distribution									
Coulomb stress distribution predictor for activity rate		TNO, 2020a					x	x	x

Activity rate		TNO, 2020a	x	x	x		x	x	x
Activity rate RTiCM		TNO, 2023						x	x
ETAS		TNO, 2020a	x	x	x	x	x	x	x
MD: constant b-value & Mmax distribution		TNO, 2020a							
MD: inverse power law b-value & Mmax distribution		TNO, 2020a	x						
MD: hyperbolic tangent b-value & Mmax distribution		TNO, 2020c		x	x	x	x		
MD: single b-value & exponential taper & Mmax distribution		TNO, 2020c		x	x	x			
MD: linear stress b-value & Mmax distribution		TNO, 2022						x	x
MD: step thickness b-value & Mmax distribution		TNO, 2022						x	x
GMM									
NAM-V7	Bommer et al., 2022	TNO, 2022b						x	x
NAM-V6	Bommer et al., 2019	TNO, 2020c		x			x		
NAM-V6-2021	Bommer et al., 2019	TNO, 2020c			x	x			
FCM									
TNO-2020	TNO, 2022a	TNO, 2020a						x	x
NAM-V7	Crowley and Pinho, 2020	TNO, 2020a		x	x	x	x		

4. QA/QC ACHIEVEMENT AND STATUS

4.1. Status of QA/QC procedures

Questions 1-6 posed by SodM to the KEM-sub-panel are closely related to quality assurance and quality control (QA/QC), and the sub-panel shares the view that QA/QC procedures are essential for ensuring sound technical decisions and a widely acceptable official and open SHRA. The sub-panel previous recommendations (KEM sub-panel advice on the SHRA Groningen development plan for 2021 and 2023) have, in fact, discussed in detail the criteria, guiding principles and QA/QC procedures associated with developing a risk model for decision-making purposes, but not all of these recommendations have so far been fully implemented. Some of these recommendations are – therefore – reiterated below, and the purpose of the next paragraph is to review the practical implementation of these principles in the past development processes of the models developed by TNO and NAM and to suggest improvements for future TNO developments.

Guiding principles for the development of seismic risk models as part of a decision-making process
Risk analysis entails associating probabilities with future scenarios. Models will always be conditional on available knowledge, for example: representation and understanding limitations, computational available capacity, access to calibration data, assumptions, and uncertainty. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Because of this use for decision-making, several committees, scientific papers and reports have discussed the key principles which should guide the development and use of models associated to decision-making. Criteria are indeed useful to decide whether and when a model is suitable to aid decision-making since models evolve, reflecting new scientific findings, acquisition of additional data, and improved algorithms. This process is not a strict validation or verification procedure but is one that builds confidence in model applications and increases the understanding of model capabilities and limitations. From the references cited above, some guidelines developed by the European Facilities for Earthquake Hazard and Risk, and the professional experience of the KEM sub-panel members, some principles are set to guide the advice on the development of the public Groningen hazard and risk assessment model and to contribute to increasing the confidence in the use of the model. The KEM sub-panel uses these guiding principles in judging the state of the SHRA developments and the official SHRA models versions to be applied for yearly assessments.

Guiding development principles and present implementation in TNO and NAM models
The public seismic hazard and risk model, or model components (and associated datasets or outputs) developed for the Groningen gas field should abide by the following main principles.

Principles	Present implementation at TNO and NAM
Calibration against past observations and testability against future observations.	This principle has been followed.
Robustness. The models show limited variations when part of the data is removed, or new data are added.	This point could be examined in greater detail in the near future.
Component coherence. The model components are supported by basic/state-of-the-art theories and parameterizations, initial and boundary conditions by phenomenological theories and empirical assumptions.	This principle has been followed.
Parsimony (Occam's razor principle). The simplest possible theoretical explanation/models for explaining existing are adopted.	Developments in recent years have led to increasingly complex models, and it remains unclear whether simpler models could still explain the data satisfactorily.
Objective evaluation of available methods, models and data. There has been an objective evaluation of all available data, models, and methods developed by the technical informed community that could be relevant to the characterization of the hazard and risk at the site.	This principle has been followed.
Uncertainty evaluation. There has been an integration of the outcome of the available knowledge into models that reflect both the best estimate of each element of the hazard /risk input with the current state of knowledge and the associated uncertainty of technically defensible interpretations	This component is essential, and efforts must continue to evaluate and compare epistemic uncertainties.
Reproducibility, Transparency and FAIR principles. Reproducibility of the model – is one basic and unavoidable principle of modern science [6]. Transparency ensures that all aspects of scientific methods and results are understood, available for critique, compliment or reuse. The data and models used or produced by the KEM project should be Findable, Accessible, Interoperable and Reusable. Such FAIR-principles [7] and an open circulation of models and corresponding results increase their acceptability [8].	Some model components (in particular those of NAM) will remain difficult to reproduce. As discussed in the previous recommendations of the KEM-sub-panel, a public model such as that of the TNO must perform on this principle and TNO must continue its efforts in this direction.
Peer review. An independent peer review process (internal and external) has been developed to confirm that the evaluation did consider relevant data, models, and methods, and that the evaluation was conducted objectively and without bias.	All the teams make significant and necessary efforts to publish their results in peer-reviewed journals. NAM has also established a very high-level internal review using external authorities process (based on the nuclear industry model).
Respect of the intellectual property and clear scientific ownership. A clear scientific ownership and proper credit of technical or scientific efforts foster faster and more efficient research progress and provide the means to share data with future researchers.	The scientific ownership (names of the experts in charge of the model component developments or internal technical review) is easy to identify for models developed by NAM. The independent and participatory review approach used by NAM to develop GMM models can be worth to be considered to design the peer-review process in TNO.

QA/QC procedure and present implementation in TNO models

In its advice in 2023 SHRA of TNO, the KEM sub-panel made two main recommendations in relation to QA/QC procedures.

- The introduction of clear milestones for the results of the QA/QC process that can be tracked, documentation of the decision-making processes used or access to internal review reports.

- The implementation of planning for external reviews regularly or closely linked to model changes that would improve QA/QC.

In order to implement these two main recommendations, the following improvements were suggested to improve QA/QC in the future. They are listed in the table below and their current implementation is discussed.

2023 KEM sub-panel recommendation to enhance QA/QC	Implementation
R1.1: in the first half of 2023, TNO would report in a meeting to the sub-panel, SodM and KGG on their existing QA/QC procedures, also giving the opportunity to suggest improvements.	This recommendation has been implemented
R1.2: in future documents, TNO specifically comments on the QA/QC procedures and steps applied. It is suggested that any substantial change of the model should be accompanied by a decision-making process with clear decision gates (for example, Identify, Assess, Select, Define, Execute, Operate). Each decision gate should be accompanied by a review with relevant experts outside of the project team (typically internal experts, occasionally external)	This recommendation has been partially implemented. To the KEM-sub-panel knowledge, TNO's decision's gates have not been accompanied yet by reviews with relevant experts outside of the project team or TNO (not mentioned in the QA/QC procedure document, see ref [8]). Only certain audits are mentioned.
R1.3: TNO should allocate sufficient resources to QA/QC procedures, also allowing to involve external experts or expert panels where appropriate (and as part of the decision-making procedure). The independent review approach used by NAM can be worth to be considered to design the peer-review process	The way in which this recommendation has been integrated must be specified.
R1.4: Any documentation of information important for external review is written in English.	This recommendation has been implemented.
R1.5: Innovations developed for public SHRA are published in international scientific peer-reviewed as much as possible and the public SHRA software is provided with manuals and made publicly available for reproducibility and what-if analysis from others	This recommendation has been implemented.

KEM sub-panel QC/AC recommendations

In conclusion, it is to be highlighted and encouraged that the development efforts and results by the TNO teams are published in reputed peer-reviewed scientific journals. These efforts must be continued and must be accompanied by complementary actions to follow the principles set out above.

Scientific publications alone cannot guarantee (although they should) the reproducibility of results (an essential element if the public and the scientific community are to have confidence in prediction models). A continued effort must be made to make the codes developed and their documentation available, not only of the TNO-standard version of 2022, only updated by recalibration. TNO is committed to implementing robust tests to assess whether the models correctly predict new seismicity data (CSEP-type tests). These efforts must be continued. New possibilities exist to facilitate these tests and make them sustainable at lower cost (pyCSEP) and TNO could benefit from these recent developments.

In our view, an additional effort should be made by TNO to improve the ownership of model development (see also 4.2) and internal review (independently of the review that takes place during the scientific publication process).

Task	KGG	TNO	SodM	NAM	Mining Council	Regional govern-ments	BZK	NCG	NEN	KEM panel
Adoption decision										
Determine which model versions will be used for the HRA in the following year	A/R	I	C							
Drafting letter of expectations to NAM	A/R	I	C	I						
Proposal for one or more operational strategies	I	I	I	A/R	I	I				
Conducting threat and risk analysis	A	R		I						
Submit threat and risk analysis to OS.	I	I	I	A/R	I	I	I	I		
Drafting determination decision	A/R	C	C	I	C	C	I			
Semi-annual seismicity report	I	I	I	A/R						
Reinforcement										
Linking HRA outcomes to addresses.	I					I	A	R		

Review and update of local plans of action	I		C			A	I	R		
Generate threat map wrt NPR	A	R	I				I	I	I	
Develop NPR	I	C	I				A		R	
Changing risk perception										
Reporting after signal parameters are exceeded	I		I	A/R						
Possibly implementing (part of) the HRA	A	R	C							
Further development										
Preparation of an annual HRA development plan.	A	R	C							C
Implementation SDAP	I	I	I	A/R						I
Model developing information from studies KEM, DeepNL, SDAP	A	I	A	I						R
Review development models in KEM	A	C	C							R
Development of models TNO	A	R	C							C
Development of models in KEM program	A	I to R	A							C
Development of models by NAM in SDAP	I	I	I	A/R						I
Implementation model and testing on Groningen	A	I to R	I							C
Building in models	A	R	C							C

Notes on the letters
R (Responsible, EN: Accountable): the person responsible for execution. Accountability is given to the person who is accountable.
A (Accountable, EN: ultimately responsible): the one who is (ultimately) responsible, authorized and approves the result. When it matters, he/she must be able to make the final judgment, have veto power. Only one person is accountable.
C (Consulted, EN: Consulted): this person (co)directs the outcome, he/she is (obligatorily) consulted prior to decisions or actions. This is two-way communication.
I (Informed, NL: Informed): someone who is informed about the decisions, progress, results achieved, etc. This is one-way communication.

Table 2 RACI table for the SHRA of TNO, in operation from 2021, Ref. [9].

4.2. Status of Groningen pSDRA governance

Since 2021, the responsibilities and roles have been defined for the development of SHRA code and the selection of model components versions for the official SHRA to be used in yearly assessments. This is documented in a memo (Ref. [9], KGG) including a RACI table including the organisations or actors involved, which is included as Table 3.

The KEM sub-panel is of the opinion that the organisation and responsibilities are generally well documented and clear, but quite complex, especially with respect to the responsibilities for scientific choices for specific model versions and components implementations. In a number of cases, the yearly proposed upgrades, by TNO, supported by advises of the KEM sub-panel, have not been followed by SodM and KGG. The KEM sub-panel understands that the balance in keeping the outcomes of the official SHRA stable, for example, important for the strengthening program, versus changing to a new version including the best available models, for example, for policy or scenario analysis, is not obvious but requires transparent decision-making communication to professionals and citizens.

Ownership of the SHRA - both in terms of the decisions to select and run the model and to decide on model developments and official version configuration and weights, is too much distributed between KGG or SodM and TNO. The KEM-sub-panel is concerned that it is increasingly used by KGG and SodM as a decision-making body, which should not be its role. The sub-panel role is critically reviewing and questioning scientific model developments and implementations, but not to be model owner, which should be TNO.

The KEM sub-panel also observes that the TNO-team responsible for developments of SHRA are not continuously and equally resourced over the risk model components, with a clear bias towards the SSM, and to a much lesser extent towards the GMM, and almost none towards FCM, at least so far. It is a probabilistic risk analysis principle that all the components implement the maximum knowledge available, that – in turn – requires appropriate dedicated effort. Therefore, a dedicated team including principal investigators assigned and all required disciplines or competencies on board should be present at least to the end of the consolidation phase or easily made available or activated in the surveillance phase (e.g., as emergency response teams in other risk areas).

KEM sub-panel governance recommendations
The KEM sub-panel advises stakeholders to revisit the current organization and RACI table for the ongoing consolidation phase and reflect on how the responsibilities are best assigned during the surveillance phase to come. It might be of interest to stakeholders to get informed about the advice to study the SSHAC guidance in the Updated Implementation Guidelines for SSHAC Hazard Studies (Ref. [7]) and adopt the PSRDA process in that spirit.

Many of the key ingredients of the NUREG SSHAC process are reflected in the Groningen SDRA process. As Table 2 demonstrates, substantial efforts have gone into defining roles and their responsibilities and attributes. However, some of the questions 1-6 were brought to the panel stem from the unclear separation of roles. Section 5 suggests how the consolidation phase may be governed.

5. Status of the SSM Component

5.1. General considerations

As outlined in Section 3.2, the KEM sub-panel considers the SHRA, including the SSM component, mature and fit for purpose. The existing rate model well explains the observed seismicity rate (Figure 2), we are not overly concerned about the small observed discrepancies (Q2) and there is no immediate urgency to adopt the SSM immediately. Nonetheless, the currently implemented SSM is not living up to the standard of capturing the centre, body, and range of technically defensible interpretations. The currently implemented SSM models remains too simple to reproduce the full complexity of the reservoir behaviour and the open access SHRA version does not fully reflect the progress made in studies of the past 5 years. The ongoing discussions on QA/QC, calibration procedures, the role of inelasticity, tapering, the use of higher resolution catalogues, pore pressure stress coupling, alternative b-value assessment with space and time, alternative source modelling approaches etc., and the questions posed by SodM, signal that the current source model does any longer capture the state of the art in a satisfying and defendable fashion. In the opinion of the KEM-sub-panel, the SSM needs a consolidated effort that will bring it to the same standard as the GMM model. This update should consider the QA/QC criteria we outlined in section 4.1, and it should be governed in a way that maximises the independence and quality of the model.

The KEM sub-panel should not suggest which mechanisms are relevant in the next SSM. As already defined in the RACI Table (Figure 3), the sub-panel is consulted on model development and can critically comment or suggest alternative points of view, refraining from becoming too close to steering the model development or weighting but comment on well-developed and well-documented models, for the GMM component. The current status of the SSM is too unstructured, so rather than commenting in detail on Q2, the next section suggests a new process that will address Q1 - Q6 in a comprehensive, community-accepted, sustainable way.

5.2. Suggestion for an update of the SSM model component: SSM26

For the consolidation phase, a dedicated effort is made to build a SSM by the end of 2026 (from here on SSM26) that ensures that the available data, models, and methods are evaluated and integrated such that the SSM capture the centre, body, and range of technically defensible interpretations. The SSM26 consolidation phase should not take more than two years and take place in a structured process under clear QA/QC guidelines and with a clear role separation, possibly following these suggestions:

Sponsor: The sub-panel would suggest that KGG and SodM consider themselves in the NUREG terminology ´project sponsors´, the organisation that funds the SDRA and, therefore, also owns the products and uses them. the sponsors define the requirements and also ensure that appropriate QA guidelines are in place and adhered to. The Sponsor will be kept informed but should not intervene in any way other than to communicate any changes in terms of schedule or deliverables; at meetings, the sponsor is generally an observer.

Participatory Peer Review Panel (PPRP): The PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment; that the models developed to capture the centre, body, and range of technically defensible interpretations; and that all technical decisions are adequately justified and documented. KEM sub-panel, or at least some of its members, is envisioned as serving as the PPRP in a potential SSM26, but an independently established panel would also be sensible.

TNO Project Manager: A project manager at TNO should be responsible for the SSM26, including running the project, communicating with the sponsor, adhering to schedule, budget, scope, and compliance with QA procedures.

TNO Project team: TNO must provide a capable team of scientists that can ensure the technical integration and execute within SSM26 as well as document the hazard and risk calculations.

Technical Integrators and evaluators team: The TI Team is to ensure that (i) the available data, models, and methods are evaluated; (ii) the integration of the interpretations into SSM26, that capture the centre, body, and range of technically defensible interpretations; and (iii) documentation of the study. The TI Team evaluates data and diverse models, challenges their technical bases and underlying assumptions, and, where possible, tests the models against observations. The TI team has ownership of the model. The evaluation phase includes interaction among the experts in workshops and being informed by external experts (resource experts or proponents). In the end, the TI team would be responsible for developing a new logical tree for the SSM that can be used in the surveillance phase. It important is that TI team members do not advocate their own opinions but objectively and, as a team, try to build a model that captures the centre, body, and range of technically defensible interpretations.

We can envision a TI team of 3 - 5 renowned experts that are informed by one or several workshops, similar to the ones that already have taken place under the lead of NAM for the evaluation of the maximum possible magnitudes (*Mmax*) evaluation and GMM. Since the SSM has already developed and matured in many parts, the effort to build SSM26 is limited and could be concluded within 12 months. The setup of the SSM phase would inherently address the QA/QC, calibration and model-related concerns raised by SodM in questions 1-6. It is envisioned that the SSM26 efforts are folded into a KEM-related and KEM-funded effort, addressing Q5.

6. Status of the GMM Component

6.1. General considerations

Overall, the KEM sub-panel considers the GMM component, as already outlined in section 3.2, mature, state-of-the-art, and developed in a well-governed process, under clear QA/QC procedures and well-documented. This was our assessment already in our recommendations in December 2022 (Ref. [0]): "*…the new model is thoroughly verified and well documented. It has also been exposed to reviews and evaluations by TNO and by the KEM sub-panel. Therefore, the GMM V7 …can be considered scientifically sound and state-of-the-art. There are few avenues for improvement except a specific analysis of the uncertainty related to the choice of the p2p correlation model, the choice of models for calculating the nonlinearity of soil amplifications, and the assumed geometries for the finite sources in the stochastic simulations*".

The KEM sub-panel was thus recommending the use of the GMMV7 model: "*The KEM sub-panel supports this implementation since several important improvements (Bommer et al., 2022a) have been incorporated with respect to the V6 GMM and earlier models… While some open issues remain, public official SHRA from 2023 onwards should use the GMM V7.*" This recommendation was nevertheless associated with recommendations on further investigations about a few remaining issues.

1. The unexplained underestimation of PGA and high frequencies: although it can be argued that it negligibly affects the "SA_{avg}" parameter used in the fragility consequence model components, and therefore the expected risk levels (when the metric is the average loss), it could be an issue for other applications based only on the PGA value or involving relatively short vibration periods. (e.g., seismic hazard maps or ShakeMaps).
2. Evaluating alternative choices to compute the non-linearity of the amplifications and the effects of damping, since these could also impact PGA values.
3. Developing a Groningen-specific (vibration-) period-to-period (p2p) correlation model based on the data acquired in Groningen and ensuring consistency with the FCM model.

4. Ensuring consistency with the SSM model by investigating whether the geometry of elongated sources for moderate events, with moment magnitude between 3 and 4.5 might significantly impact the surface ground motion predictions using the stochastic simulation approach.

Since these recommendations of late 2022, several decisions have been taken, and several new results have been obtained.

- SodM decided to keep the use of GMMV6 model for the years 2023 and 2024 (partially as a consequence of difficulties in obtaining the "P90" values with GMMV7), but asked TNO to implement the amplification factors on dwelling mounds ("Wierden") in the V6 model for the latest SHRA models (SodM documents with reference ADV-7833, 20/12/2022 and 30829127, 14/07/2023).
- the KEM36 project (finalized in 2024) has provided interesting results on the various issues that were mentioned in our previous advice.
    1. KEM36 proposes an explanation for the apparent underestimation of PGA in the GMMV7 model. They postulate that the underestimation is a result of inadequate use of algorithms to compute response spectra, which fail for time series with too much high-frequency content (which is the case for ground motion predictions at NS_B level and short distance, small to moderate magnitude events). Although the NAM experts in their response in 2024 are not convinced by this explanation (without providing the exact information detailing the software and the parameters used in their response spectra computation), the KEM sub-panel considers the KEM36 hypothesis as a likely one. This provides an additional argument for the use of GMMV7 in the official SHRA model, as it is based on a parameter (Sa_{avg}) which is not impacted by this shortcoming of the V7 model.
    2. KEM36 also performed investigations on the non-linearity model used in the GMMV7 model and some alternative non-linearity models and concluded that it is not the likely explanation for the underestimation of very short period ground motion in GMMV7.
    3. KEM36 also analysed the p2p correlation model used in GMMV7 (Baker and Jarayam 2008), through an analysis of residuals from Groningen data for 11 earthquakes. They suggest that the V7 model could be improved by replacing the BJ08 model with the Kotha et al (2017) results for between-event and single-site residuals. The NAM GMM team, in their response (2024), does not share this view. The KEM sub-panel considers that the main remaining issue about p2p correlation does not lie so much in the p2p correlation model used in the GMMV7, but essentially in the lack of consistency between the V7 model and the p2p assumptions used for the derivation of the consequence model (FCMV7, 2020) which is based on GMMV5 model.
    4. Finally, the KEM36 team proposed a limited investigation on the impact of elongated sources constrained within the thin reservoir and concluded that it does not reproduce the observations for a (past) magnitude 3.4 earthquake. Nevertheless, as this conclusion is conditioned on several assumptions and computational limitations (see the KEM36 final advice: uniform slip, uniform rise time, 12 Hz high-frequency limit), the sub-panel considers the issue to be still open. This discrepancy remains hence a potential issue for the consistency between the SSM and GMM components.

6.2. Suggestion for an update of the GMM model component: GMM26

In conclusion, also based on the KEM36 conclusions, the recommendation for the SHRA model to be used in the consolidation and likely also the surveillance phase remains to use GMMV7. It would take a substantial effort, based on additional data, to build a GMM that significantly exceeds V7, given also the lack of new data, subsiding seismicity rate, and lack of transferability to other regions in the Netherlands. However, we repeat that GMMV7 should not be used for applications other than those using Sa_{avg}, and that some potential issues regarding the interface consistency of the three main SHRA components may still exist. It is also to note that GMMV7 cannot be used without major changes or complex tuning to other parts of the Netherlands or other technologies, such as geothermal.

To finalise the GMMV7 implementation for the proposed consolidation and surveillance phases, the sub-panel recommends considering the following limited-scale actions.

1. Investigating the interfaces with the SSM and FCM components to ensure their consistency.

- As mentioned in previous advices, the within-reservoir character of the seismic sources invoked to justify the significant changes in the distribution of Mmax in the SSM, is not fully consistent with the source geometries considered in the GMMV7 model. The investigations performed within the framework of KEM36 bring only partial and unconvincing results, due to the strong assumptions required by the three-dimensional model limitations. The sub-panel believes that the remaining questions could be answered by a limited number of simpler, faster simulations, involving horizontally stratified crustal structures. This could furthermore pave the way for the development of ground motion models in other parts of the Netherlands.
- The presently used FCM model was ultimately updated in 2020 based on the GMMV5 model and relied on different assumptions regarding the p2p correlation. The sub-panel recommends assessing the potential impact of this lack of consistency. If found to be potentially impactful, it would be timely to consider alternative ways to develop FCM models, which could, as an extra benefit, also be used elsewhere in the Netherlands-

2. Initiating the development of a Dutch-specific GMM, that builds on lessons learned from GMMV7, but would be simpler, flexible and more easily adjustable to other kinds of source models and fragility and consequence models.

Either or both could in our opinion be considered as part of a future KEM project in the consolidation phase.

7. Status of the FCM Component

7.1. General considerations

Overall, the KEM sub-panel considers the FCM (which although related, can be considered as two different model components) of the SHRA to be in general mature, well documented, and fit for purpose. However, as we have pointed out repeatedly in the past advice, while the FCM has been developed with substantial efforts in the initiation phase of the SHRA, it has received minimal attention nor critical review in the transition phase. Currently, there is a marked difference in the (QA/QC) efforts of TNO between the FCM and other components. Several possible issues that could be readily addressed during a consolidation phase, based on existing roadmaps, have been identified. The efforts invested into improving the FCM offer benefits of advanced knowledge important for seismic hazard and risk assessment in regions beyond the Groningen region (see also Chapter 8). This could eventually lead to state-of-the-art integrated *national hazard and risk models* for the Netherlands, as it exists in other European countries such as Italy and Switzerland.

7.2. Suggestion for an update of the FCM model component: FCM26

In the short term, the KEM-sub-panel advises performing a critical review of the FCM models to enhance the trust and confidence in the approaches and models employed so far, and/or find ways of improvements. Such a critical review and sensitivity analysis could be conducted as a KEM research question and, for example, include the following aspects.

- Approach to building inventory categorization in classes and modelling of intra- and inter-building uncertainties modelling.
- Mechanical modelling of archetypical building and exploration of the meta-fragility modelling approach.
- Approach to building-damage-to-fatality modelling and coherency with the numerical structural modelling.
- Modelling of the epistemic uncertainty in fragility modelling.
- Consideration of estimation uncertainty in fragility modelling.
- Modelling of aleatory uncertainty of fatality (consequence) modelling.
- Including a yearly update building class database following the strengthening program (making it possible to show the (relative) decrease in seismic risks).

- Investigating the link between GMM and FCM, specifically the p2p correlation, as already outlined in section 6.

In this context, it is worthwhile to refer back to the KEM sub-panel advice released at the end of 2021 and 2022. For example, it has been repeatedly stated that the current model only considers fatalities and consequences from a single event. This is mainly due to the fragility modelling, developed by NAM, which is of the classical fragility type, that considers failure in one event only. This is acceptable only in the case when the time between damaging events is large enough to enable full recovery of the buildings. This is not necessarily the case for Groningen, and the SSM models explicitly consider time- and space-clustered seismicity (e.g., via ETAS models). It is still an open question whether accounting for damage accumulation would lead to a non-negligible risk increase in Groningen. If so, the FCM components might require a substantial effort to switch from classical fragilities to so-called *state-dependent* fragilities.

Finally, the Groningen FCM is naturally a candidate as the basis for a national risk model for the Netherlands. In particular, the classification of the inventory, and the approach to quantify the fragility of the built environment can help develop a model to be used at a national scale to compare risk from different hazards while interacting with coherent vulnerability models. This national effort to build up exposure, fragility and consequences would ideally be linked to the national cadastre to be sustainable and up to date with limited effort.

8. Summary of recommendations

8.1. Two-year Consolidation Phase

A dedicated, yet limited, integration effort that brings together all available knowledge, models and data into a state-of-the-art, open-access and well-documented model that captures the centre, body, and range of technically defensible interpretations, is recommended. This consolidation effort would inherently also address all the concerns and questions raised by SodM as well as NAM and researchers and provide a solid basis to then move into a surveillance phase with a high-quality and hopefully widely scientifically accepted model. It would bring adequate closure to more than fifteen years of intensive research, development, data collection and model building and, if designed well, can also inform and accelerate seismic hazard and risk assessment for natural and induced earthquakes in other regions of the Netherlands, possibly from other usages of the subsurface (geothermal energy, gas storage, …). The consolidation effort could be structured in the following way.

1. As project sponsors (see section 5.1), KGG and SodM need to develop a clear project plan, specifying the QA/QC expectations (see our suggestions in Chapter 4) and timelines, as well as providing the necessary financing. The main focus should be on a SSM26 project plan, which should be closely coordinated with TNO, and on finding a well-qualified project manager named from TNO who can dedicate at least 50% of his or her time to the consolidation phase.
2. The project should then identify within TNO a small supporting team of hazard modellers with expertise in the Groningen SHRA that can support the project. In addition, the project appoints a Participatory Peer Review Panel and then selects a team of experts and evaluators who will ultimately decide on the final model and take full ownership of it. An independent expert team in charge of the SSM model branches and weights will overcome the controversies burdening the model development right now
3. The SSM26 project should not generally gather new data, and new model developments should be limited to a minimum, considering that so much has already been done and that the existing model is doing well in forecasting seismicity. Scanning DeepNL and NAM-funded research results would, however, be required.
4. The experts will be informed by sensitivity calculations executed by the technical support team, by literature study, sensitivity feedback and formal testing, and by at least one workshop with external experts, before formulating and documenting a final SSM logic tree. The PPRP will then also review the model and issue a concluding statement, accepting - or rejecting - the model.
5. In parallel with the ongoing SSM model development, the KEM sub-panel suggests initiating two projects, possibly funded through KEM, that focus on the remaining issues in the GMM and FCM outlined in Chapters 6 and 7, and the potential interface issues between SSM, GMM and FCM.
6. In line with organizing QA/QC for SSM model components, TNO is encouraged to include and ensure (if needed from outside TNO) all necessary expertise's for the GMM and FCM teams, possibly including expert review panels.

7. Once SSM26, and these additional efforts are concluded, the official SHRA including latest developments can be assembled consisting of SSM26, GMMV7 and FCMV7. The final model chain must be carefully sanity-checked and validated as much as feasible; it must also be open-access, reproducible, and published.

8.2. Surveillance Phase

Once the consolidation phase is concluded, the final model should be operationalized such that it can be re-calibrated with seismicity observation routinely and used to check automatically if the seismicity is outside of the expected range, or anomalous in other respects. KNMI and TNO should jointly address these tasks. The seismicity and seismic hazard will likely continue to subside, possibly with small-scale fluctuations and the interest in Groningen seismicity will continue to decrease. The risk will subside proportionally or even more as the strengthening programme progresses. However, the risk decay will take many years, and surprising developments are not impossible, so it is important to keep up with seismic, geodetic, pressure etc. monitoring and surveillance for anomalous behaviour for many years, even if active SHRA development of new model components is not needed any longer.

8.3. Towards a national seismic hazard and risk approach

The KEM sub-panel would like to emphasize that the Groningen model chain and experience offer a great launching point for building a state-of-the-art, holistic national seismic hazard and risk approach for natural and induced earthquakes. Just like in the case of seismic monitoring, a national scale and risk-based approach offers substantial benefits and synergies that should be exploited.

9. Conclusions

The KEM sub-panel was provided with a list of six questions by SodM. It was considered beneficial to answer the questions in a somewhat broader context than SodM might have anticipated, because these questions are closely interrelated, because they touch on fundamental aspects of governance more than on technical issues, and last but not least because the fundamentals of the Groningen SHRA have changed with the definite stop of production. We, therefore, considered it timely to lay out a vision that not only addresses the questions raised but embeds it into a 10-year-plus roadmap for the post-production phase.

It is worthwhile to briefly refer back to the original questions and link them to the responses provided.

1. *In previous advices the KEM-sub-panel (further panel) has explicitly expressed the importance of utilizing a systematic, extensive QA/QC procedure, including external reviews or structured expert elicitation, for all SHRA model development and implementation of model components in the official SHRA. Can the panel elaborate on the extent of the QA/QC of the different studies reported by both TNO and contracted by NAM?*

The KEM-sub-panel has indeed frequently commented on QA/QC procedures, and in Chapter 4 it was recalled and commented on how much suggestions of past advices have been fulfilled. It is not the intended role of KEM sub-panel to comment on the QA/QC of each individual study. Our summary feedback remains somewhat mixed: While the progress made in the work of TNO and NAM in ensuring open access are appreciable, there are remaining challenges in peer-reviewed documentation of model parts, and in formal testing. These are less at the level of individual studies but harmoniously comparing them, since for example each study adopts slightly different boundary conditions, data set and testing procedures. This is one of the motivations why the proposed consolidation phase is considered a necessary effort that will judge all data and available models holistically, using one set of QA/&QC procedures that are transparently defined and pre-agreed

2. *Which processes/insights have been identified in either the studies by TNO or contacted by NAM that could provide an explanation of the discrepancy between observed and modelled seismicity rates.*

The KEM sub-panel is not concerned about the difference between observed and forecasted rates. Even the standard model does a surprisingly good job in forecasting the seismicity rate (Figure 2), and the inclusion of time dependency in SSM sub-models (such as RTiCM, RT, etc.) provides an adequate explanation for the slight and temporary discrepancy in recent years. Various implementations of these time dependencies result in comparable outcomes, and the TNO implementation would be a viable option according to the KEM sub-panel. What is lacking, however, is a structured process that defines how to add model components such that the final model captures the centre, body, and range of technically defensible interpretations. This is so for the rate forecast, but even more so for model components related to the frequency magnitude destination and its truncation.

3. *What would be required to incorporate the various identified processes and/or new insights for the deviation in the SHRA model train?*
4. *What would be required to incorporate alternative, published models/processes in the SHRA?*

Questions 3 and 4 are addressed by proposing in sections 5 and 8 a possible workflow for how to integrate new processes, new insights and new models into the SSM model. The SSM model - except for the Mmax distribution - so far has been the component least exposed to broader communication feedback or structured workshops; the model has been continuously refined and is fit for purpose, but the past few years have seen alternative processes and models pop up in different places, a highly welcome development. As suggested indirectly by SodM, lacking is now a widely accepted way to incorporate these objectively and defensibly. A structured process similar to the one employed by NAM in the past for the GMM and Mmax components, inspired by the NUREG (2018 framework), is suggested. This also involves changes in the current RACI distribution of responsibilities, and it requires some funding for two years.

5. *If the panel cannot easily answer these two questions, would the panel recommend a KEM study to investigate and advise on this?*

The process of building a PSHA model that captures the centre, body, and range of technically defensible interpretations is well-established and often applied, for natural but also induced seismicity. A project work plan can be readily developed by KGG, SodM, with support from TNO and possibly the KEM sub-panel or a similar PPRP. Therefore, we believe that a KEM question is not required.

However, we have in sections 6 and 7 outlined remaining questions regarding the GMM and FCM components of the SHRA. These could well be addressed in the context of two KEM projects.

6. *What is the overall recommendation(s) of the panel on how to proceed with the implementation and/or adaptation of all studies for the purpose of incorporation in the official and public SHRA?*

We have proposed in Chapters 5 - 8 a comprehensive plan for completing the SHRA in a model consolidation phase, leading to a surveillance phase with much reduced effort required. The KEM sub-panel considers this ´final push ‘to complete the official and open SHRA an effort worth the required investment; it would ideally wrap up loose ends, resolve the remaining controversies and make sure the SHRA would all in all components be state of the art.

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