MEMORANDUM

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Appendices	Excel file UDG Relational database - v 2.5_Quickscan Excel file UDG Relational database - v 2.5

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1 INTRODUCTION

To assess for a specific geothermal project which risks apply from the generic UDG and EGS risks described in the KEM-06 report (Witteveen+Bos, reference 105911/20-005.135 dated 3 April 2020), a risk classification scheme has been developed. This document is the user manual for this risk classification scheme.

Goal of the risk classification scheme

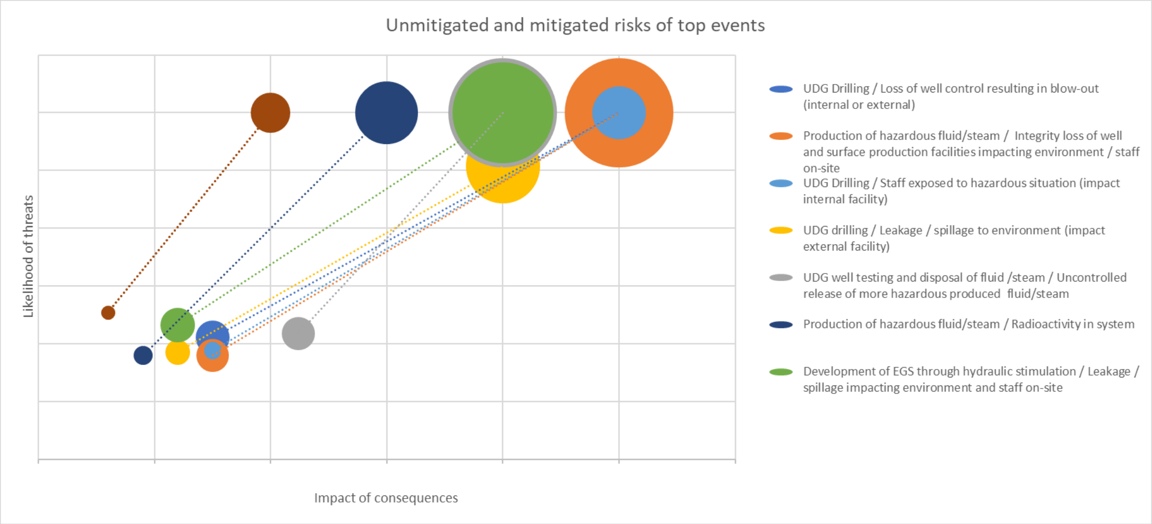
The classification scheme is intended to assist SSM (State Supervision of Mines) in their advisory role to the Ministry of Economic Affairs and Climate on aspects of safety and environmental impact with regards to exploration plans.

The risk classification scheme allows the user to identify and rank project specific risks, taking into consideration the project specific prevention and mitigation measures. The ranking of unmitigated risks indicates which risks need special attention and requires more detailed risk assessments. The ranking of mitigated risks indicates the effectiveness of the proposed measures and what risks are difficult to mitigate.

Output of the risk classification scheme

The output of the risk classification scheme is a project specific risk ranking which is visualized in a risk matrix, see figure 1.1. The purpose of this risk matrix is to provide a visual overview of the significance of risks for a specific project in terms of likelihood and impact. The risk matrix does not indicate whether risks are acceptable or not, therefore the axes of the risk matrix have not been labelled. The acceptability is a political decision that needs to be made by governmental bodies.

Figure 1.1 Example of mitigated and unmitigated top events plotted in a risk matrix for specific project parameters



Reading guidelines

Chapter 2 summarizes the approach of the risk classification scheme for non-seismic and seismic risks.
Chapter 3 explains the excel-based relational database which has been developed for non-seismic risks.
Chapter 4 presents an example case of the project specific classification scheme for the non-seismic (section 4.1) and the seismic risks (section 4.2) using the Balmatt site in Belgium as an example.
Chapter 5 explains the limitations of the risk classification scheme and provides recommendations on the usage and improvements.

2 APPROACH RISK CLASSIFICATION

Section 2.1 summarizes the approach for the non-seismic risks assessment and section 2.2 summarizes the approach for the seismic risk assessment.

2.1 Non-seismic risks assessment

The project specific classification of the non-seismic risks is worked out in an Excel-based relational database. By providing project specific parameters, the user can immediately see how the unmitigated top events plot relative to each other in the risk matrix. By activating measures (barriers and recovery barriers), the user can also see how the mitigated top events plot relative to the corresponding unmitigated top event (connected by a dotted line) and the other mitigated top events (Figure 1.1).

In the relational database, all the elements or objects are related to each other following the bowtie structures (Appendix VII Witteveen+Bos, reference 105911/20-005.135 dated 3 April 2020), a general example is given in figure 2.1. The central object in the database is the top event. Linked to the top event are the threats and consequences, equivalent to the bowtie structure. The threats and consequences can be mitigated by implementing (recovery) barriers. The threats are linked to the project specific parameters.

Figure 2.1 Bowtie structure

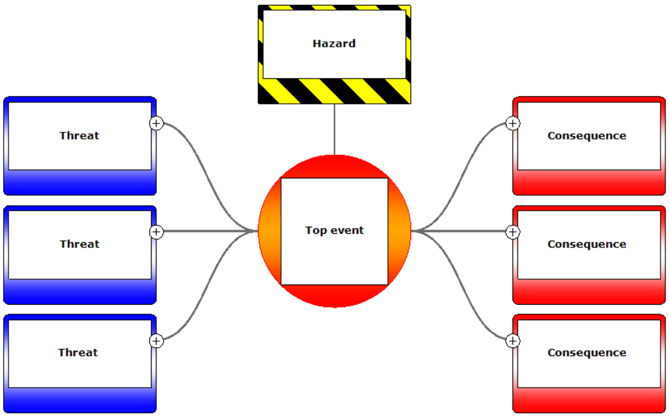


Figure 2.2 provides a schematic overview of the methodology to determine the naked, unmitigated risk. Figure 2.3 shows it for the mitigated risk. In the next sections each element is described in more detail.

Figure 2.2 Schematic overview of methodology to determine the naked risk in the classification scheme

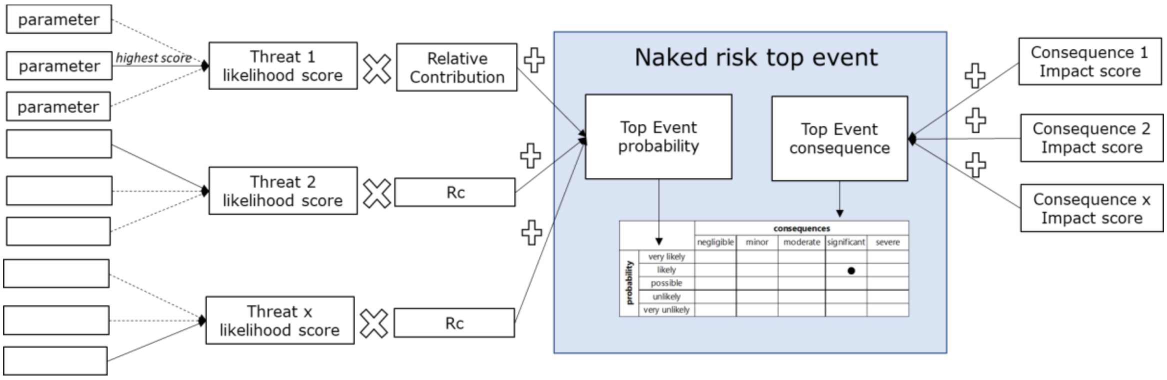
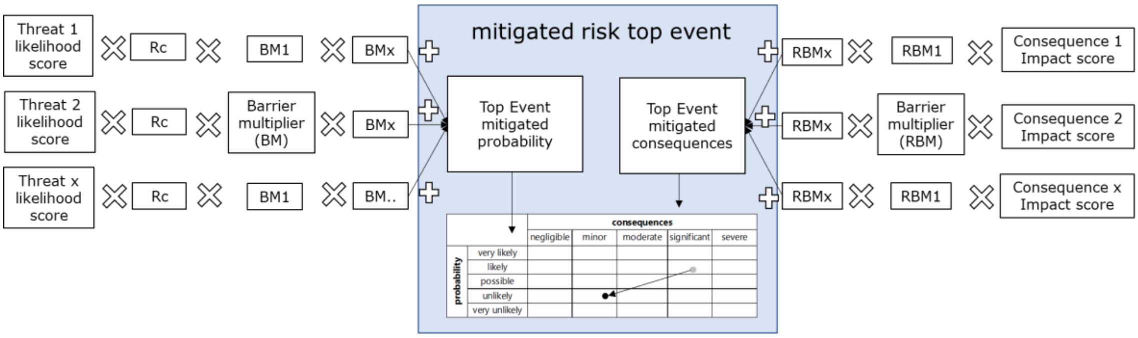


Figure 2.3 Schematic overview of methodology to determine the mitigated risk in the classification scheme



Likelihood of top event

The likelihood assessment for drilling, testing, stimulation and production risks uses a set of parameters that characterise the UDG/EGS project. Each parameter is subdivided into a maximum of 5 classes: from very low to very high. The parameters and their ranges are provided in table 2.1.

In the classification scheme each threat is linked to one or more parameters to determine the likelihood score of a specific threat, following the same categorisation: a 'high' qualitative risk category for the parameter automatically leads to a 'high' score category. A threat that is linked to more than one parameter will receive the highest risk category of the linked parameters. So even if there are 5 parameters linked to a threat and 4 of the 5 parameters have a category 'low' and the 5th parameter a category 'high', then the threat would still receive the score 'high'.

The next step is to assign a 'relative contribution' (RC) to each threat. Not all threats are equally important to cause its top event. By assigning a RC value, the relative importance of each threat can be specified. Similar to the parameters, the RC is divided into five classes ranging from 'very low' to 'very high'. The RC is expressed as a percentage in relation to the other threats that can cause the top event. The RC is considered to be independent of the characteristics of the project. The sum of threat scores multiplied with each threat's RC gives the unmitigated likelihood of occurrence of the top event.

Table 2.1 Parameters to characterise the UDG/EGS project[1]

Parameter	Unit	Qualitative risk categorisation				
		Very high	High	Medium	Low	Very low
Reservoir pressure	Bar	>1,250	1,000-1,250	750-1,000	500-750	<500
Reservoir temperature	°C	>180	150-180	120-150	90-120	<90
Chemistry	ppm	Presence CO_2 or H_2S				No CO_2 < # ppm and H_2S < 7 ppm
NORM in brine	Bq/l	>100	50-100	5-50	1-5	<1
NORM in scales/fines	Bq/g	>100	50-100	0.5-50	0.1-0.5	<0.1
Hydrocarbons presence		Presence of hydrocarbons				No hydrocarbons
Gas content brine	Nm^3/m^3	Free gas	>5	2.5-5	1-2.5	<1
Mud weight	Kg/m^3	>1/6		1.2-1.6		1-1.2
Offset wells	Nr. offset wells	< = 1	2 to 3	3 to 4	4 to 5	>5
Experience	Nr. HPHT/Explo projects	< = 1	2 to 3	3 to 4	4 to 5	> = 5
Preparation time	Months	<6		6 to 12		>12
Working pressure (hydraulic stimulation)	Bar	>680	590-680	500-590	500-410	<410
Population density	Inhabitants/km^2	>2,000	1,000-2,000	500-1,000	250-500	<250

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[1] The list of parameters in this table is not complete. Other parameters can be identified (such as H2S and resources like budget constraints) that influence UDG and EGS threats. The user of the relational database can easily adjust the classification scheme and add parameters themselves.

Impact of the consequences

The consequences are provided with a qualitative impact value, also ranging between 'very low' to 'very high'. The impact of a top event is determined by the sum of the impacts of the linked consequences. In the risk matrix, the highest impact of a consequence is plotted on the matrix as the impact of the top event.

Reduction by barriers

The likelihood of threats can be reduced by implementing barriers. The impact of consequences can be reduced by implementing recovery barriers. The effectiveness of the barrier is determined with a reduction factor (RF). A barrier that is highly effective receives a low reduction factor (e.g. BM = 0.5) and a barrier that is not effective receives a reduction factor close to or equal to 1.

On the left side of the bowtie diagram, the barrier reduction factor is multiplied with the likelihood of the related threat. On the right side of the bowtie diagram the effectiveness of the recovery barriers is also provided with a reduction factor, the recovery reduction factor (RRF), similar to the preventive barriers. The summed consequences of each top event is re-calculated into a reduced impact of top event.

For each threat and consequence, various barriers are defined. Not all barriers may be applicable or used in a project. In the relational database, the user must choose whether or not to employ certain barriers.

Risk of top event

Generally, all threats influence the likelihood of a top event and could result in all consequences linked to the top event. The unmitigated risk of a top event is calculated by multiplying the unmitigated likelihood of occurrence of the top event with the unmitigated impact of the top event. The mitigated risk of a top event is calculated by multiplying the mitigated likelihood of occurrence of the top event with the unmitigated impact of the top event.

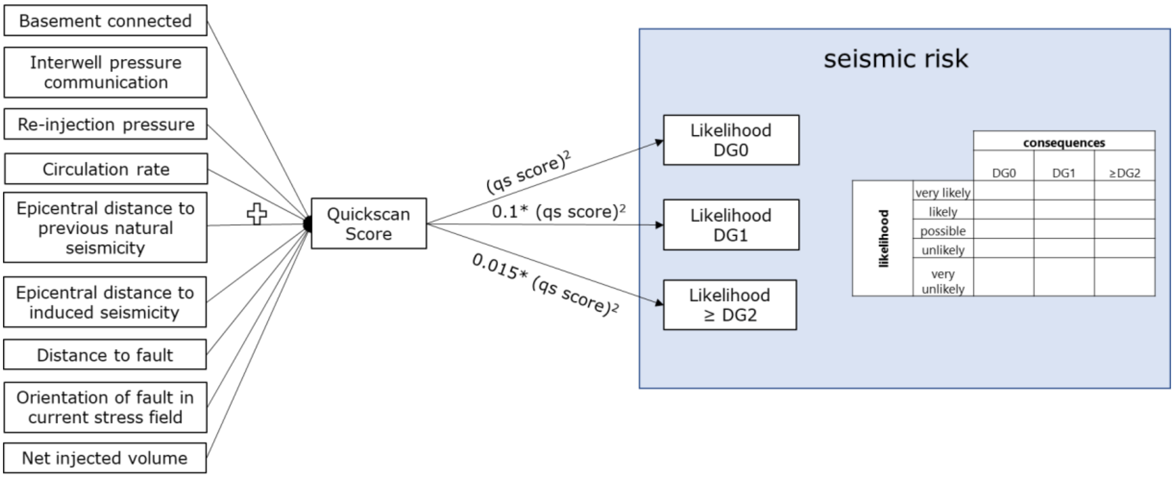
For the top event 'Staff exposed to hazardous situation (impact internal facility)' each threat is connected directly to a consequence. The top event 'UDG drilling/Leakage/spillage to environment (impact external facility)' is a hybrid top event, meaning threats are connected to either the top event or directly to a consequence. Because of this structure the risk of these specific top events is calculated differently from the other top events. Instead of calculating the risk of a top event by multiplying the sum of the threats with the sum of the consequences, the likelihood score of a threat is multiplied with the impact of a consequence that it is linked to. This is done for all the directly linked threats and consequences, and these values are added together to arrive at the risk for a top event. The position of the top event in the risk matrix is plotted for each top event in the same way.

2.2 Seismic risk assessment

The basis for the proposed classification scheme for induced seismicity is the QuickScan score. The purpose of the classification is to quickly assess for a specific project whether seismicity is a risk that needs managing and further study is required.

figure 2.4 provides a schematic overview on the methodology used to assess the seismic risk for a specific project, the different elements are explained in section 4.4 of the KEM-06 report (Witteveen+Bos, reference 105911/20-005.135 dated 3 April 2020).

Figure 2.4 Schematic overview of methodology used in classification scheme to determine seismic risk



3 WORKFLOW OF THE EXCEL DATABASE FOR NON-SEISMIC RISKS

The QuickScan version of the relational database allows the user to get a quick overview of a specific project with the standard settings. The first sheet in the Excel database, named **Manual**, explains how to use the QuickScan version.

The effectiveness of (recovery) barriers, the contribution of each threat to a top event, the parameters that affect a threat, and the impact factor of each consequence are given as standard settings but can be adjusted by the user if desired. This chapter describes how to use the full relational database and how to adjust all the separate objects in the database.

3.1 Getting started

The first sheet of the Excel database contains a short manual. This sheet explains how to use the relational database to investigate threats, consequences and risks for a UDG project. The steps mentioned in the manual are explained in more detail below (see section 3.2).

There are a number of Excel sheets after the manual, which are marked with colours that indicate what the sheets are meant for and who can use them (Figure 3.1). The colours indicate the following.

Figure 3.1 Colour codes and related sheets/columns and intended users

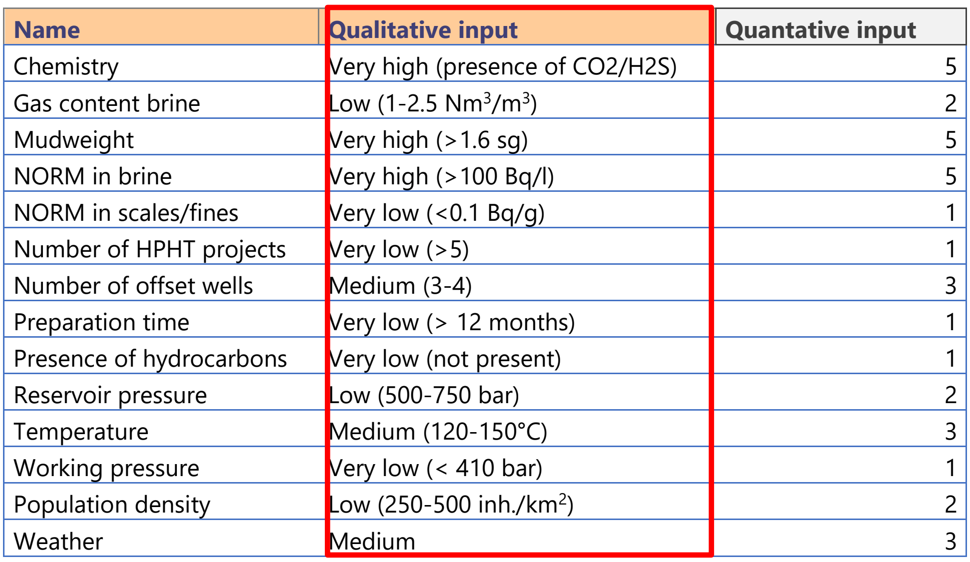
Colour	Type of sheet/column	Intended user
🟩	Input sheet	End user
🟦	Output sheet	End user
🟥	List of objects	Advanced user
🟪	Relations sheet	Advanced user
🟨	Configuration sheet	Advanced user
🟧	Input column	End or advanced user
Calculation	Calculation column	Contains code, do not change or delete content
Output	Output column	Contains code, do not change or delete content

3.2 Regular workflow

The regular workflow of using the database to generate a risk classification is described here step-by-step:

1. Define the parameters of the UDG project in the input sheet **Project parameters & risk matrix**. The second column, **Qualitative input**, is an input column where you can choose between a number of options varying from 'very low' to 'very high' (Figure 3.2). The quantitative input will change accordingly.

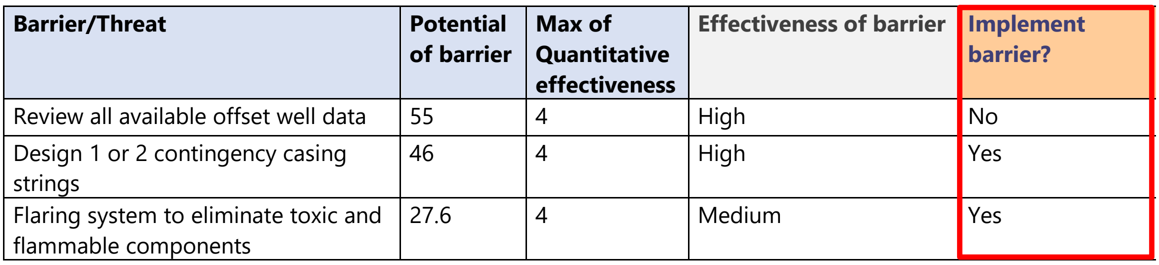
Figure 3.2 Parameters for a UDG/EGS project. The qualitative input can be adjusted here



Name	Qualitative input	Quantative input
Chemistry	Very high (presence of CO2/H2S)	5
Gas content brine	Low (1-2.5 Nm^3/m^3)	2
Mudweight	Very high (>1.6 sg)	5
NORM in brine	Very high (>100 Bq/l)	5
NORM in scales/fines	Very low (<0.1 Bq/g)	1
Number of HPHT projects	Very low (>5)	1
Number of offset wells	Medium (3-4)	3
Preparation time	Very low (> 12 months)	1
Presence of hydrocarbons	Very low (not present)	1
Reservoir pressure	Low (500-750 bar)	2
Temperature	Medium (120-150°C)	3
Working pressure	Very low (< 410 bar)	1
Population density	Low (250-500 inh./km^2)	2
Weather	Medium	3

2. Refresh all the data in the Excel workbook by clicking Refresh all under the tab Data.
3. View the results in output sheets Unmitigated threats, Unmitigated consequences and Unmitigated risks. Read more about the results in section 3.3.1.
4. Implement barriers in the input sheet Barrier implementation. Here, you can indicate whether a barrier has been applied by choosing 'yes' or 'no' in the input column Implement barrier? (Figure 3.3). A barrier is automatically applied to all linked threats. The effectiveness of the barrier has been documented elsewhere but can be changed by the user. Read more about how to change effectiveness of barriers in section 3.6.

Figure 3.3 Barriers that can be implemented to mitigate threats. The user can choose if the barrier is implemented in this project



Barrier/Threat	Potential of barrier	Max of Quantitative effectiveness	Effectiveness of barrier	Implement barrier?
Review all available offset well data	55	4	High	No
Design 1 or 2 contingency casing strings	46	4	High	Yes
Flaring system to eliminate toxic and flammable components	27.6	4	Medium	Yes

5. Implement recovery barriers in the sheet Recovery implementation. Similarly to the previous step, you can indicate whether a barrier has been applied by choosing 'yes' or 'no' in the input column Implement recovery? Also, the effectiveness of recovery barriers are documented elsewhere, and can be changed by the user (see section 3.6).
6. Refresh all the data in the Excel workbook by clicking Refresh all under the tab Data.

7 View the results in output sheets Mitigated threats, Mitigated consequences and Mitigated risks. Read more about the results in section 3.3.2.

3.3 Results

The output of the classification scheme is a ranking of the top events for both the unmitigated risk and the mitigated risk. The ranking of unmitigated risks indicates which risks need special attention. Moreover, the output provides insight in which threats and consequences contribute the most to the rank of specific top events and provides insight in the effectiveness of the proposed measures. This helps to identify what risks are difficult to mitigate and why.

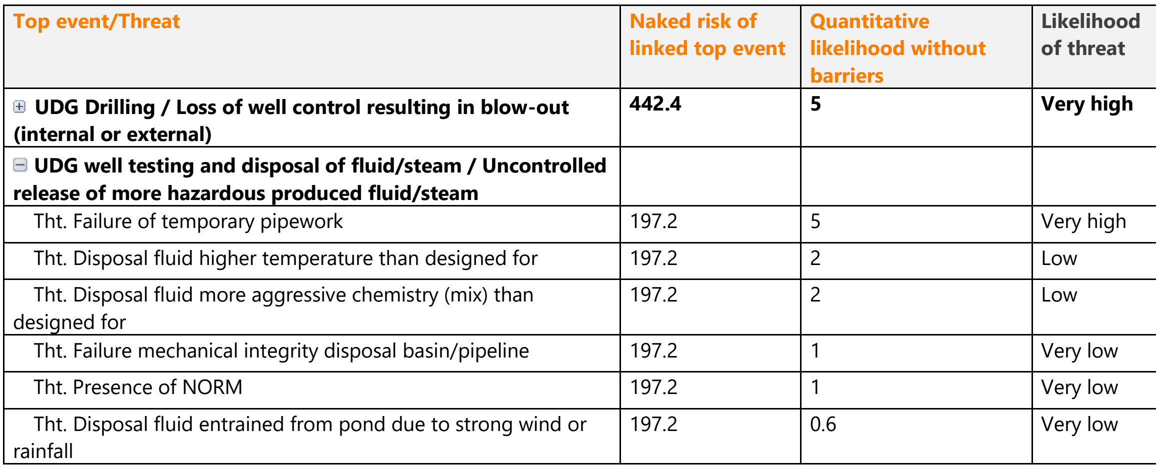
3.3.1 Unmitigated risks

The output for the unmitigated risks (before implementation of barriers) can be viewed in the output sheets **Unmitigated threats**, **Unmitigated consequences** and **Unmitigated risks**.

The output sheet **Unmitigated threats** describes the likelihood of each threat and the naked risk of the related top events (Figure 3.4). The top events (in bold) are assigned a naked risk which is represented by a number, resulting from calculations elsewhere in the database. This number is used to rank the top events. The numbers do not have a unit and do not encompass anything concrete, but show the relative risk of a top event compared to the other top events.

By unfolding a top event, the threats will become visible that are linked to that specific top event. Each threat has been assigned a likelihood. By studying these likelihoods and the naked risk of the top event, the user will be able to evaluate which threats contribute the most to the risk of a top event and which threats need to be mitigated.

Figure 3.4 Output for unmitigated threats. The threats are assigned a certain likelihood and the top events are ranked on the basis of the risk scores of the threats



Top event/Threat	Naked risk of linked top event	Quantitative likelihood without barriers	Likelihood of threat
⊞ **UDG Drilling / Loss of well control resulting in blow-out (internal or external)**	**442.4**	**5**	**Very high**
⊟ **UDG well testing and disposal of fluid/steam / Uncontrolled release of more hazardous produced fluid/steam**			
Tht. Failure of temporary pipework	197.2	5	Very high
Tht. Disposal fluid higher temperature than designed for	197.2	2	Low
Tht. Disposal fluid more aggressive chemistry (mix) than designed for	197.2	2	Low
Tht. Failure mechanical integrity disposal basin/pipeline	197.2	1	Very low
Tht. Presence of NORM	197.2	1	Very low
Tht. Disposal fluid entrained from pond due to strong wind or rainfall	197.2	0.6	Very low

Similarly, the output sheet **Unmitigated consequences** shows the impact of each consequence and the naked risk of the related top events. This sheet can be used to evaluate which consequences contribute most to the impact of a top event and which consequences need to be mitigated. The output sheet **Unmitigated risks** describes the threats related to top events that lead directly to certain consequences.

3.3.2 Mitigated risks

The output for the mitigated risks (after implementation of barriers) can be viewed in the output sheets **Mitigated risks**, **Mitigated consequences** and **Mitigated risks**.

The output sheet **Mitigated threats** (Figure 3.5) now shows the reduced likelihood of each threat and the mitigated risk of the related top event. If barriers have been implemented that affect these threats, the likelihood is reduced and therefore the risk of the related top event is reduced.

Figure 3.5 Output for mitigated threats. The threats are assigned a certain likelihood after implementation of barriers and the top events are ranked on the basis of the risk scores of the threats

Top event/Threat	**Mitigated risk of linked top event**	**Quantitative likelihood with barriers**	**Likelihood of threat**
⊞ **UDG Drilling / Loss of well control resulting in blow-out (internal or external)**	**62.76802**	**1.96**	**Low**
⊟ **UDG well testing and disposal of fluid /steam / Uncontrolled release of more hazardous produced fluid/steam**			
Tht. Failure of temporary pipework	37.03519334	2.45	Medium
Tht. Disposal fluid more aggressive chemistry (mix) than designed for	37.03519334	0.9072	Very low
Tht. Failure mechanical integrity disposal basin/pipeline	37.03519334	0.81	Very low
Tht. Disposal fluid higher temperature than designed for	37.03519334	0.54432	Very low
Tht. Disposal fluid entrained from pond due to strong wind or rainfall	37.03519334	0.243	Very low
Tht. Presence of NORM	37.03519334	0.0294	Very low

Similarly, the output sheet **Mitigated consequences** shows the mitigated impact of each consequence and the mitigated risk of the related top events. The output sheet **Mitigated risks** describes the threats related to top events that lead directly to certain consequences.

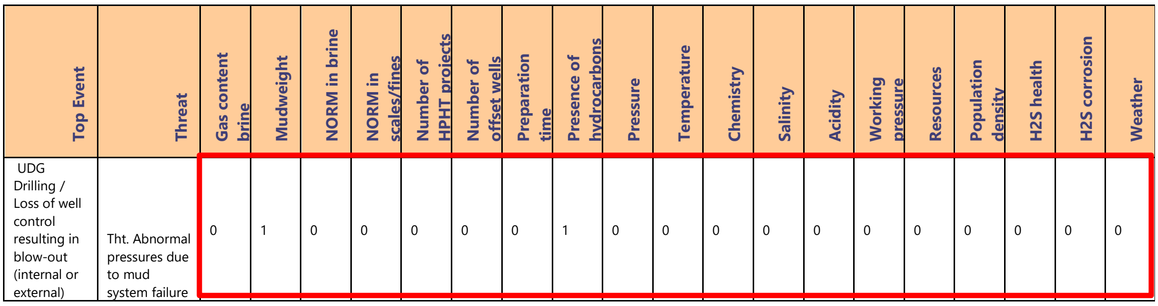
3.4 Adjust likelihood of threats

The identified threats that are listed in the object sheet **Threats** are linked to the top events in the relations sheet **Top Events - Threats**. Here, threats are linked to specific top events and linked to the project parameters identified in the input sheet **Project parameters**. A threat will be assigned a likelihood (threat score) that is linked to the score of the linked parameters. The threats are assigned a qualitative contribution to the top event.

The user can adjust the link between threat and parameters. In the columns following the threat linked to a specific top event, the project parameters are listed. By choosing a 0 (=no) or a 1 (=yes), the user is able to indicate whether the threat is affected by the project parameters that were identified before (Figure 3.6).

The user can also adjust the qualitative contribution of a threat to a top event. In the column **Qualitative contribution to top event**, the user can choose the relative importance of a threat, ranging from 'very low' to 'very high' (Figure 3.7). The quantitative contribution will change accordingly, as will the likelihood of the threat.

Figure 3.6 Link between threat and parameters. The user can adjust whether the threat is affected by the project parameters (0 = no, 1 = yes)



Top Event	Threat	Gas content brine	Mudweight	NORM in brine	NORM in scales/fines	Number of HPHT projects	Number of offset wells	Preparation time	Presence of hydrocarbons	Pressure	Temperature	Chemistry	Salinity	Acidity	Working pressure	Resources	Population density	H2S health	H2S corrosion	Weather
UDG Drilling / Loss of well control resulting in blow-out (internal or external)	Tht. Abnormal pressures due to mud system failure	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

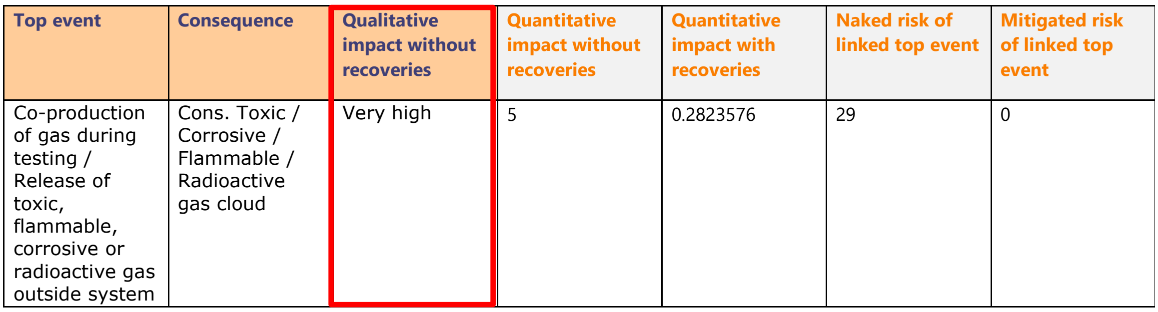
Figure 3.7 Relation between top event and threat. The user can adjust the qualitative contribution of the threat to the top event

Top Event	Threat	Score without barriers	Score with barriers	Qualitative contribution to top event	Quantitative contribution to top event	Quantitative likelihood without barriers	Quantitative likelihood with barriers	Naked risk of linked top event	Mitigated risk of linked top event
UDG Drilling / Loss of well control resulting in blow-out (internal or external)	Tht. Abnormal pressures due to mud system failure	5	2.8	Very low	1	1	0.56	442.4	62.76802

3.5 Adjust impact of consequences

Similarly to adjusting the likelihood of threats, the impact of consequences can be changed. The identified consequences that are listed in the object sheet **Consequences** are linked to the top events in the relations sheet **Top Events - Consequences**. The consequences are assigned a qualitative impact to the top event. The user can adjust the qualitative impact of a consequence to a top event. In the column **Qualitative impact without recoveries**, the user can choose the impact of a consequence, ranging from 'very low' to 'very high' (Figure 3.8). The quantitative impact will change accordingly.

Figure 3.8 Relation between top event and consequence. The user can adjust the qualitative impact of the consequence to the top event



Top event	Consequence	Qualitative impact without recoveries	Quantitative impact without recoveries	Quantitative impact with recoveries	Naked risk of linked top event	Mitigated risk of linked top event
Co-production of gas during testing / Release of toxic, flammable, corrosive or radioactive gas outside system	Cons. Toxic / Corrosive / Flammable / Radioactive gas cloud	Very high	5	0.2823576	29	0

Sometimes, one consequence is related to just one threat. For example, the threat 'hot surface/fluid' will directly lead to the consequence 'burns'. This consequence will not be caused by another threat in the database. For these cases, the user can adjust the likelihood of the threats and impact of consequences in the relations sheet **Threats - Consequences** in a similar manner as described above.

3.6 Adjust effectiveness of barriers and recovery barriers

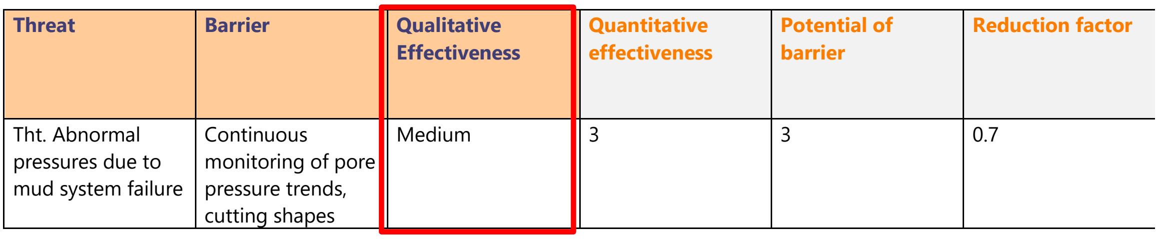
The likelihood of threats can be reduced by implementing barriers. The barriers that are listed in the object sheet **Barriers** are linked to threats that they are applied to in the relations sheet **Threats** - **Barriers**. Here, the barriers are assigned a qualitative effectiveness that determines the reduction factor of the barrier. A highly effective barrier will receive a low reduction factor.

The qualitative effectiveness of a barrier can be adjusted by choosing the effectiveness, ranging from 'very low' to 'very high' (Figure 3.9). The quantitative effectiveness will change accordingly, as will the reduction factor.

Also, a minimum likelihood of a threat with barriers can be defined. The user can choose a percentage in the column **Minimum likelihood with barriers (%)** in the sheet **Top Events** - **Threats** (Figure 3.10). This option will make sure that the quantitative likelihood with barriers will not be lower than the defined percentage of the unmitigated likelihood.

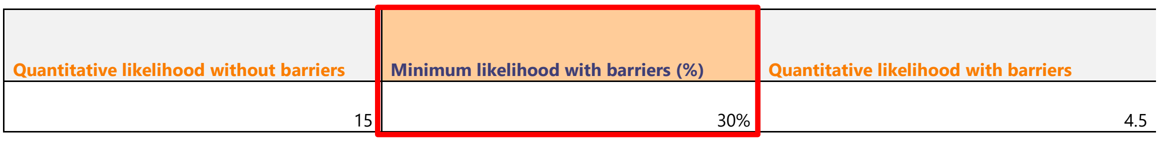
The impact of consequences can be reduced by implementing recovery barriers. Recovery barriers are linked to consequences in the relations sheet **Consequences** - **Recoveries** and are also assigned a qualitative effectiveness. Adjusting relations between consequences and recovery barriers and the effectiveness of recovery barriers can be done in the same way as described above for barriers and threats.

Figure 3.9 Relation between threats and barriers. The user is able to adjust the qualitative effectiveness



Threat	Barrier	Qualitative Effectiveness	Quantitative effectiveness	Potential of barrier	Reduction factor
Tht. Abnormal pressures due to mud system failure	Continuous monitoring of pore pressure trends, cutting shapes	Medium	3	3	0.7

Figure 3.10 Likelihood of threat. The user is able to choose the minimum likelihood of the threat with barriers as a percentage of the likelihood without barriers



Quantitative likelihood without barriers	Minimum likelihood with barriers (%)	Quantitative likelihood with barriers
15	30%	4.5

4 EXAMPLE CASE

Here, we give an example of a geothermal project that was tested with our classification scheme to illustrate the use of the database and confirm that the database works. The site discussed here is the Balmatt project in Mol (Belgium). The Balmatt geothermal project in Mol, close to the border with the Netherlands, produces water with a temperature of 120-128 °C from the Dinantian play situated here at 3.2-3.8 km depth. The first well was drilled in 2015, reaching a depth of 3.6 km, and the last well was drilled in 2018, reaching a depth of 4.2 km [lit. 1]. All wells were acid stimulated to improve flow rate. The parameters of the geothermal project were incorporated into the classification scheme in order to evaluate if the results are consistent with observations.

4.1 Non-seismic risks

The non-seismic project parameters for the Balmatt site are presented in table 4.1. The parameters **Chemistry, NORM in brine** and **Number of HPHT projects** have been classified as very high for the Balmatt site. The parameter **Mudweight** is classified as medium. It is important to note that the Balmatt reservoir is solely a high temperature reservoir and not a high pressure reservoir. The parameter **Temperature** is classified as medium and **Reservoir pressure** is classified as very low. For this reason, no specific measures against threats related to high reservoir pressure were implemented. Furthermore, although CO_2 is present in the system (leading to a very high risk related to chemistry), H_2S is not present. Hence, no measures were taken specifically against threats related to leakage of H_2S. Groundwater monitoring (e.g. glass fiber) was not applied as a barrier, since it was not technically achievable to incorporate in the casing plan. The well design with three casing strings is considered a sufficient barrier to prevent formation fluid leakage to groundwater layers. The associated barriers and recoveries have been deactivated in the sheet **Barrier Implementation**.

Table 4.1 Project parameters for the Balmatt geothermal project in Mol, Belgium translated to qualitative input excel database

Parameter	Balmatt project	Qualitative input
Chemistry	75-80 % CO_2, no H_2S detected	Very high (presence of CO_2/H_2S)
Gas Content Brine	2-2.5 Nm^3/m^3	Low (1-2.5)
Mudweight	1.45 sg	Medium (1.2-1.6)
NORM in brine	95 ± 18 Bq/l ^{226}Ra[1]	Very high (>100 Bq/l)[2]
NORM in scales/fines	0.52 ± Bq/g ^{226}Ra[3]	Very low (<0.1 Bq/g)
Number of HPHT projects	0	Very high (≤1)
Number of offset wells	7 (Turnhout, Poederlee, Merksplas, Halen, Wijvenheide, Rijkevorsel, Heibaart)	Very low (>5)
Preparation time	~ 5 years	Very low (>12 months)
Presence of hydrocarbons	Not present	Very low (not present)
Reservoir pressure	330 bar at 3200m depth	Very low (<500 bar)
Temperature	138-142°C	Medium (120-150°C)
Working Pressure Hydraulic Stimulation	Not applicable	Not applicable
Population density	324 inh./km^2	Low (250-500 inh/km^2)
Weather	Medium	Medium

The unmitigated and mitigated top events plot in the risk matrix as illustrated in figure 4.1. Since hydraulic stimulation is not applied at the Balmatt site the top event concerning hydraulic stimulation is excluded manually from the plot.

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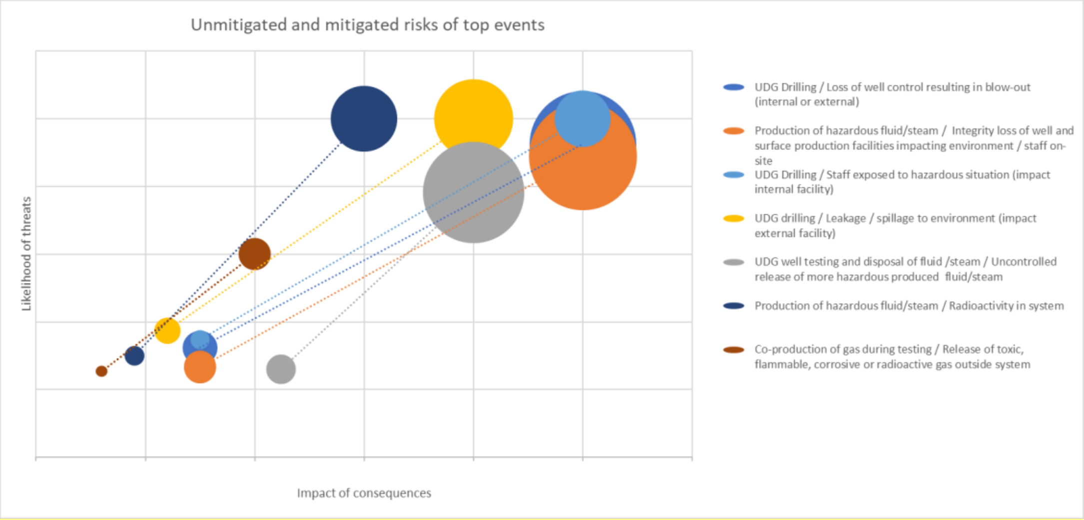
[1] Highest activity concentration measured [lit. 2].

[2] The parameter NORM in brine is classified very high taking into account the uncertainty range [lit. 2].

[3] Radioactivity measured in the residue of 1 liter test water collected in the disposal basin [lit. 2].

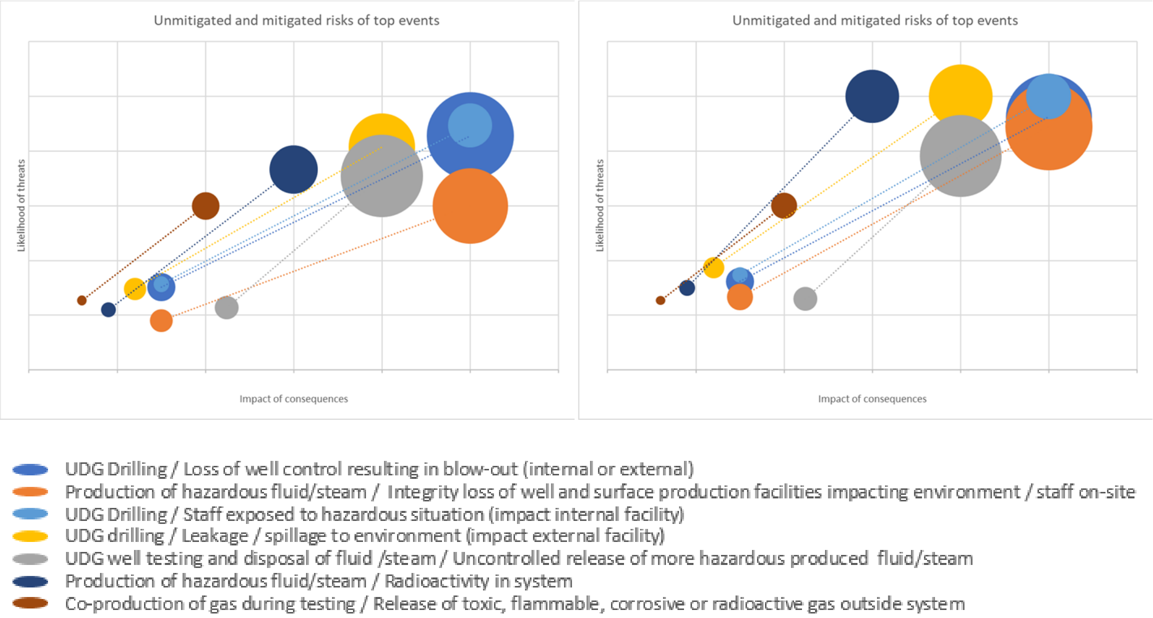
Figure 4.1 Unmitigated and mitigated top events for Balmatt project plotted in a risk matrix



The resulting risk matrix is best explained by a sensitivity analysis of the parameters which have been characterized very high for the Balmatt site.

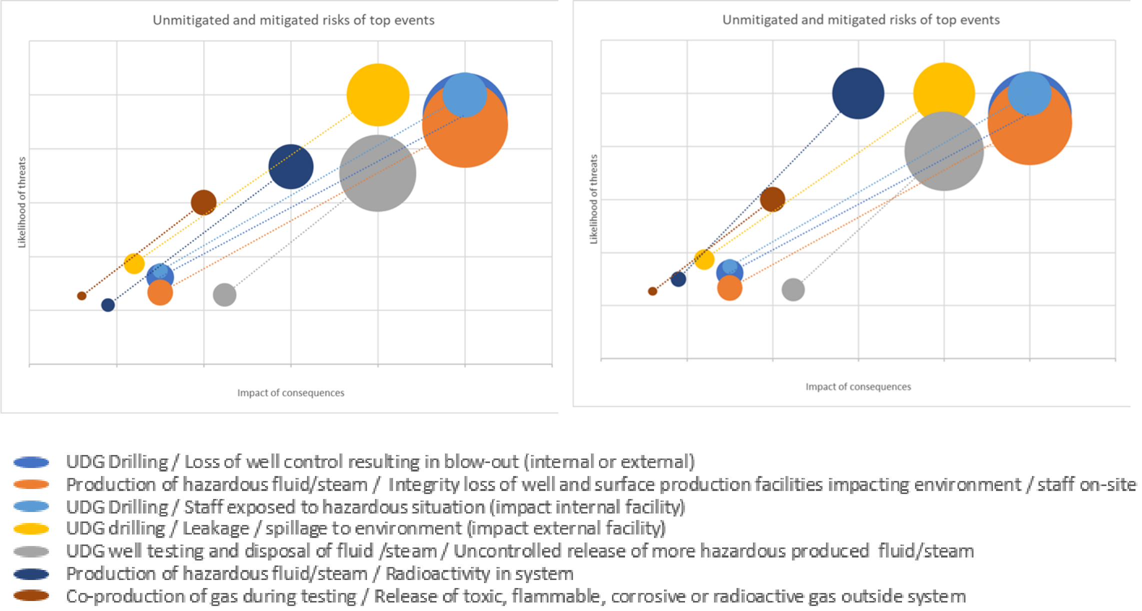
Because of the **very high chemistry** scores, the top events ‘Integrity loss of well and surface production facilities impacting environment/staff on-site’, ‘Leakage/spillage to environment (impact external facility)’, ‘Uncontrolled release of more hazardous produced fluid/steam’ and ‘Radioactivity in system’ plot relatively high compared to the other top events (see figure 4.2). This example illustrates that the top event ‘Radioactivity in system’ is not only influenced by the parameters related to NORM. Although the parameter **NORM in scales/fines** is classified very low, the threat scaling potential of the brine is very high because the parameter **chemistry** is classified very high.

Figure 4.2 Risk matrix Balmatt site. Left: Parameter chemistry classified very low. Right: Parameter chemistry classified very high



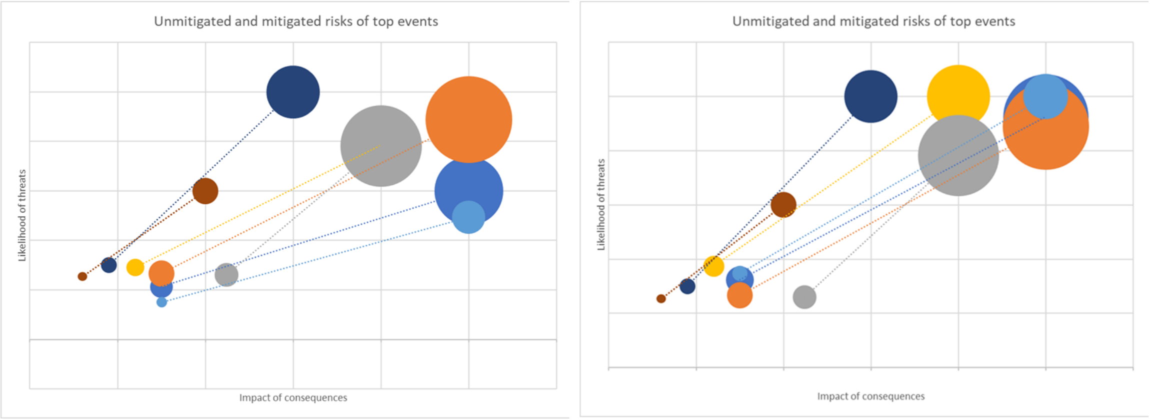
Because of the **very high NORM in brine** score, the top event ‘Radioactivity in system’ plots relatively high compared to the other top events. Also the top event ‘Uncontrolled release of more hazardous produced fluid/steam’ plots slightly higher (see figure 4.3). This is because NORM in reservoir fluids is identified as a threat in this top event.

Figure 4.3 Risk matrix Balmatt site. Left: Parameter NORM in brine classified very low. Right: Parameter NORM in brine classified very high



Because of the **very high classification of the parameter number of HPHT projects**, the top events ‘Loss of well control resulting in blow-out (internal or external)’, ‘Staff exposed to hazardous situation (impact internal facility) and Leakage/spillage to environment (impact external facility)’ plot relatively high compared to the other top events (see figure 4.4).

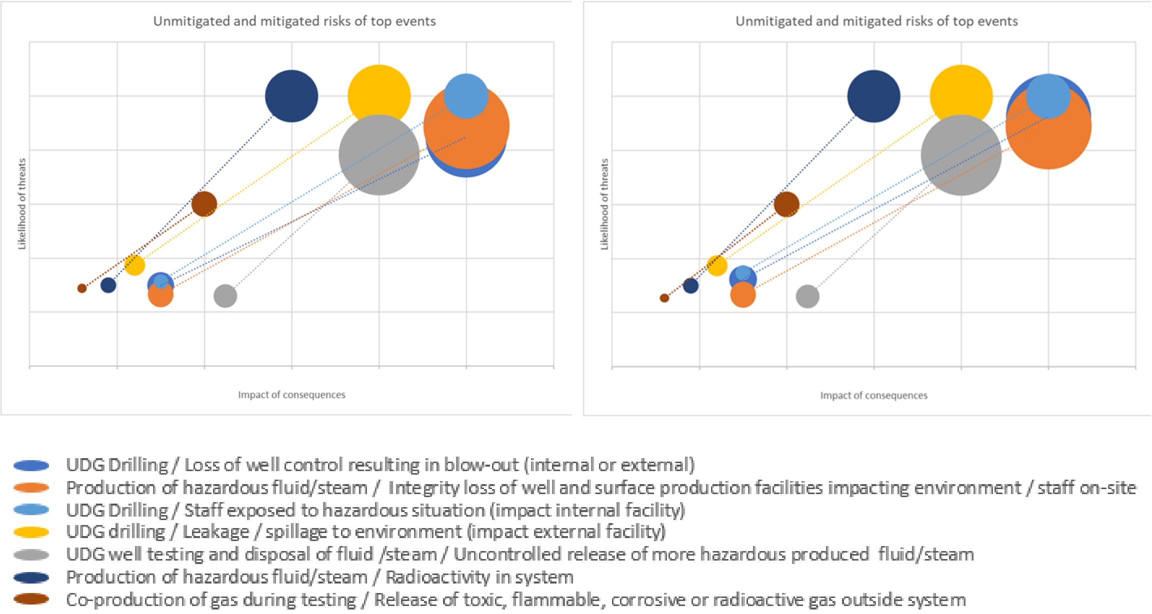
Figure 4.4 Risk matrix Balmatt site. Left: Parameter Number of HPHT projects classified very low. Right: Parameter Number of HPHT projects classified very high



● UDG Drilling / Loss of well control resulting in blow-out (internal or external)
● Production of hazardous fluid/steam / Integrity loss of well and surface production facilities impacting environment / staff on-site
● UDG Drilling / Staff exposed to hazardous situation (impact internal facility)
● UDG drilling / Leakage / spillage to environment (impact external facility)
● UDG well testing and disposal of fluid /steam / Uncontrolled release of more hazardous produced fluid/steam
● Production of hazardous fluid/steam / Radioactivity in system
● Co-production of gas during testing / Release of toxic, flammable, corrosive or radioactive gas outside system

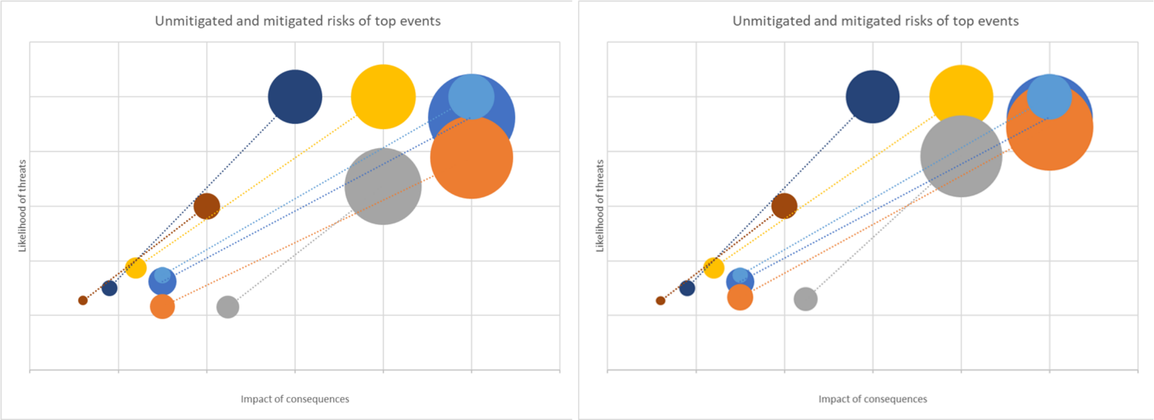
Because of the **medium mudweight** score, the top event 'Loss of well control resulting in blow-out (internal or external)' plots slightly higher compared to the other top events (see figure 4.5).

Figure 4.5 Risk matrix Balmatt site. Left: Parameter Mudweight classified very low. Right: Parameter Mudweight classified medium



Because of the **medium Temperature** score, the top events 'Integrity loss of well and surface production facilities impacting environment/staff on-site' and 'Uncontrolled release of more hazardous produced fluid/steam' plot higher compared to the other top events (see Figure 4.6). The top event 'Staff exposed to hazardous situation (impact external facility)' is also influenced by the parameter Temperature, but this influence is not observed since other parameters also affecting this top event (Number of HPHT projects and Chemistry) are classified higher in this example.

Figure 4.6 Risk matrix Balmatt site. Left: Parameter Temperature classified very low. Right: Parameter Temperature classified medium



● UDG Drilling / Loss of well control resulting in blow-out (internal or external)
● Production of hazardous fluid/steam / Integrity loss of well and surface production facilities impacting environment / staff on-site
● UDG Drilling / Staff exposed to hazardous situation (impact internal facility)
● UDG drilling / Leakage / spillage to environment (impact external facility)
● UDG well testing and disposal of fluid /steam / Uncontrolled release of more hazardous produced fluid/steam
● Production of hazardous fluid/steam / Radioactivity in system
● Co-production of gas during testing / Release of toxic, flammable, corrosive or radioactive gas outside system

4.2 Seismic risks

The seismic QuickScan parameters for the Balmatt site are presented in table 4.2. The seismic risk assessment is carried out following the methodology of section 4.4 in the KEM-06 report.

Table 4.2 QuickScan for the Balmatt geothermal project (Mol, Belgium)

Score	Basement connected	Distance to fault (km)	Orientation of faults in current stress field	Net injected volume (1,000 m^3)	Inter-well pressure communication	Reinjection pressure (MPa)	circulation rate (m^3/h)	Epicentral distance to natural earthquakes (km)	Epicentral distance to induced seismicity (km)	
10	yes	<0.1	favourable	>20	no	>7	>360	<1	<1	
7	possible	0.1-0.5	shearing possible	5-20	unlikely	4-7	180-360	1-5	1-5	
3	unlikely	0.5-1.5	shearing unlikely	0.1-5	likely	1-4	50-180	5-10	5-10	
0	no	>1.5	locked	<0.1	yes	<1	<50	>10	>10	
Score	7	7	10	3	3	10	3	0	0	43

Basement connected

The Balmatt geothermal project targets the Lower Carboniferous Limestone Group at a depth between 3.1 and 4.0 km. In the Campine area, the Lower Carboniferous deposits are separated from the Caledonian basement by sediments of Devonian age. The thickness of the Devonian strata is highly variable [lit. 1]. Devonian strata drilled in offset wells consist of an upper sequence of cemented psammitic sandstones and shales. These siliciclastic deposits belong to the Evieux Formation [lit. 4]. Locally, the Evieux rests upon a sequence of calcareous shales, nodular limestones and carbonates. Based on a re-evaluation of seismic data, the estimated thickness of the Devonian sequence at the project site is 620 m [lit. 5]. Mol-GT-03 drilled about 100 m of psammitic sandstones and shales belonging to the Evieux Formation. Communication with the Caledonian basement is likely through faults [lit. 1].

Distance to faults

MOL-GT-01 cut through a number of faults in the Carboniferous. Target for the production well was a fault zone near the top of the Lower Carboniferous Limestone Group [lit. 1]. The well cut through normal fault at a depth of about 2.400 m, or 800 m above the first loss zone. No clear fault plane is visible on the FMI log of the reservoir section, but analysis of diplog characteristics are indicating fault-tip folding in the upper part of the well [lit. 7].

Injection well MOL-GT-02 deviated away from faults visible on the seismic data. No indications for the presence of faults were found in the Lower Carboniferous section of the well. Well MOL-GT-03 targeted a fault near the base of the Lower Carboniferous. From the FMI data, it was found that a fault might be present in MOL-GT-03-S1 at depths between 4,300 m and 4,450 m. However, as the other wells did not reach the same depth and stratigraphic interval, changes in thickness and bedding orientation cannot be used to confirm the FMI data [lit. 6].

Orientation of faults in current stress field

The Belgian part of the Campine-Brabant Basin is characterised by a pattern of mainly (N)NW-(S)SE striking normal faults resulted in segmentation of the Lower Carboniferous carbonates into fault blocks [lit. 3]. In the direct vicinity of the Balmatt project, normal faults are mostly NNW-SSE to almost N-S oriented [lit. 1, 5]. Most of these normal faults were already active during the Devonian and/or early Carboniferous and many of them were reactivated during the late Jurassic extensional phase and later activity of the Roer Valley Graben [lit. 3, 5, 8]. Natural seismicity in the Roer Valley Graben is concentrated along the main (N)NW-(S)SE striking fault zones. For almost all earthquakes, fault mechanisms indicate normal faulting implying that the area is currently undergoing E-W extension [lit. 9]. The NNW-SSE trending faults near Balmatt are hence susceptible to shear.

Net injected volume and Inter-well pressure communication

The Balmatt project produces and injects in the upper section of the Lower Carboniferous Limestone Group (Loenhout Formation and Velp Formation). Pressure communication between wells MOL-GT-01 (production) and MOL-GT-02 (injection) was observed during the circulation test from 11 June till 21 June 2019. About 17,000 m^3 of brine was circulated during this test. Shorter test (<5,000 m^3) did not reveal clear evidence for pressure communication between both wells.

Reinjection pressure

The maximal injection pressure reached during the circulation tests performed from December 2018 till June 2019 was 11.4 MPa. At the end of the last circulation test, injection pressure was slowly declining. The project aims to lower the maximal injection pressure to 8 MPa or less.

Circulation rate

The installations are designed for a stable flow rate of 150 m^3/h. Flow rates during the circulation tests performed from December 2018 till June 2019 varied between 60 and 125 m^3/h.

Epicentral distance to natural earthquakes

The nearest recorded earthquakes occurred at:

- Lage Mierde (ML = 3.5) on 2 November 1932, at a distance of 30 km;
- Bocholt (ML = 2.7) on 12 August 1990, at a distance of 31 km;
- Wuustwezel (ML = 1.8) on 1 August 2001, at a distance of 39 km.

Epicentral distance to induced earthquakes

Prior to the injection tests at Balmatt no induced seismic events were reported in the vicinity of the project site.

Result

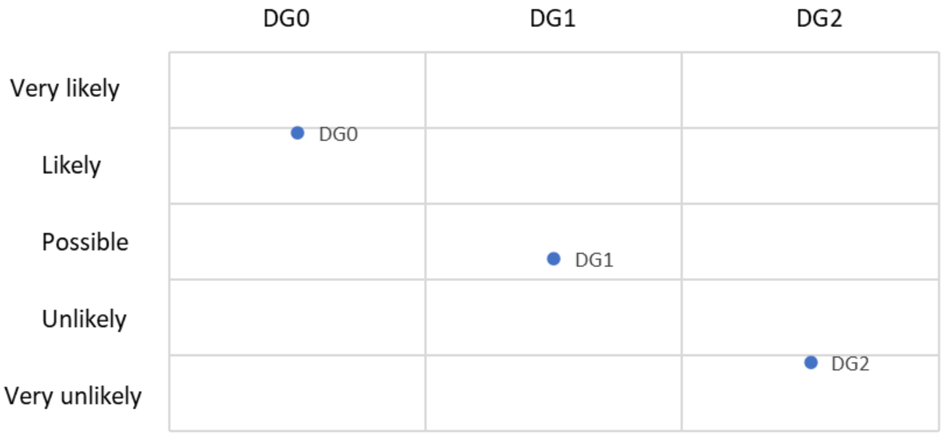
The results of the QuickScan for the Balmatt project are shown in Table 4.1. The fields with red shading are the most likely results based on the arguments given above. The total score is 43. The total normalised QS score equals 43/90 = 0.48. The corresponding probability proxies for the different damage scenarios are given in Table 4.3.

Table 4.3 Probability of proxies for the different damage scenarios for the Balmatt project

Damage scenario	Probability proxy for causing damage scenario once per year (without barriers)
DG0 (PGV=0.3 mm/s)	QS score^2 = 0.48 (0.56)^2 = 0.2283 (0.31)*
DG1 (PGV=3 mm/s)	0.1 * QS score^2 = 0.02283 (0.031)*
DG2 (PGV=20 mm/s)	0.015* QS score^2 = 0.0034 (0.0046)*

A different scoring is possible when taking into account the uncertainty in the data. This possible scoring is indicated in orange (Table 4.1). The intersection of faults in the reservoir section of wells cannot be excluded based on the available observations. Moreover, the pressure communication between MOL-GT-01 and MOL-GT-02 occurred during the 11 June till 21 June 2019 circulation test. During this test more than 5,000 m^3 of brine was circulated. Considering the highest score for each parameter leads to a total normalised QS score of 0.56. The corresponding probability proxies for the different damage scenarios are shown between brackets in Table 4.3. These results can be plotted in a risk matrix as illustrated in figure 4.7.

Figure 4.7 Example of how the probability proxies for the Balmatt site can be plotted in a risk matrix using a logarithmic scale



Observed induced seismic events

Since the start of the circulation tests in December 2018, 267 seismic events were recorded by the seismometer network installed around the Balmatt geothermal plant[1] (figure 4.8). The magnitude of the events ranges from M_L -1.0 to 2.1. The events are located near the injection well MOL-GT-02. The epicenters are located at depths between -2.5 and -4.1 km TAW. The first events were recorded during injection tests in September 2016. The seismic activity is interpreted to be associated with injection of cold fluids. Observations indicate a correlation between induced seismicity and variation of injection temperature.

On Sunday 23 June 2019, 2 days after terminating the longest operational period, an earthquake with a magnitude M_L=2.1 was measured. This event was felt in the vicinity of Balmatt[2]. Peak ground velocity of the event was 1.01 mm/s at a depth of 30 m. The maximum estimated PGV at surface is about 1.7 mm/s. This value is higher due to ground amplification in the upper 30 m. Peak ground acceleration of the event was 0.78 m/s^2. The event was graded III on the Mercalli scale. With a maximum estimated peak ground velocity of 1.7 mm/s this event is classified as a DG0 following Table 4.2 of the KEM-06 report (Witteveen+Bos, reference 105911/20-005.135, dated 3 April 2020). In this study a DG0 event is defined as felt ground motions not resulting in damage.

The estimated probability proxy for felt ground motions not resulting in damage (DG0) once per year (without barriers) is 0.2283 (Table 4.3) and plots as likely, just on the border with very likely, in the risk matrix (Figure 4.7). This first observation fits the estimated probability, however the measurement period is too short to draw any conclusions.

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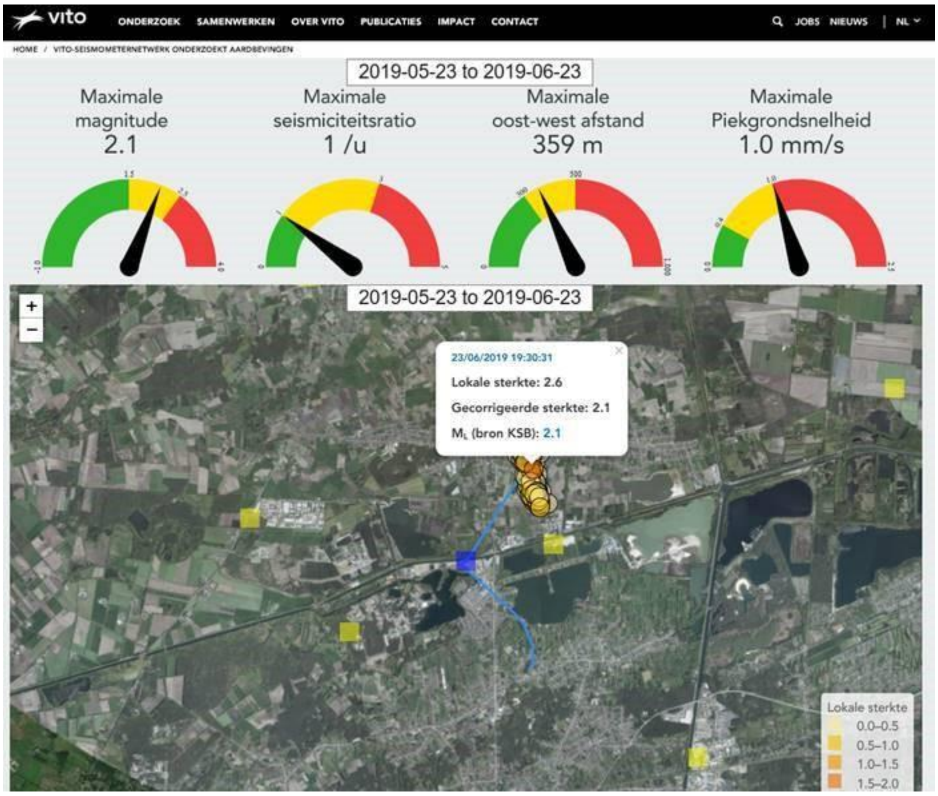
[1] Https://vito.be/nl/vito-seismometernetwerk-onderzoekt-aardbevingen.

[2] Http://www.seismologie.be/en/seismology/earthquakes-in-belgium/ny2r4xl1q.

Figure 4.8 Local strength of seismic events measured by VITO



2019-05-23 to 2019-06-23

Maximale magnitude 2.1

Maximale seismiciteitsratio 1 /u

Maximale oost-west afstand 359 m

Maximale Piekgrondsnelheid 1.0 mm/s

2019-05-23 to 2019-06-23

23/06/2019 19:30:31
Lokale sterkte: 2.6
Gecorrigeerde sterkte: 2.1
M_L (bron KSB): 2.1

5 LIMITATIONS AND RECOMMENDATIONS

Although the methodology for the risk classification is based on the commonly applied principles of bowties and risk matrices, the implementation is different and the output should therefore be carefully interpreted. The risk classification is a high level assessment to be able to quickly assess the main risks and identify for what further detailed assessment is required. The risk classification scheme is based on the general bowtie structure in which several risks are combined to main risks (Appendix VII Witteveen+Bos, reference 105911/20-005.135 dated 3 April 2020). Since combining risks may result in an average risk which is lower than the actual risk and underestimation of the risk should be avoided, we chose to visualise the highest value and not the average. The size of the circle reflects the risk of the top event which is calculated by multiplying the sum of the threats with the sum of the consequences.

The risk matrix that is provided as output does not indicate whether risks are acceptable or not, therefore the axes of the risk matrix have not been labelled. The acceptability is a political decision that needs to be made by the regulator.

In the classification scheme, the ranking of the risks and the effectiveness of the proposed measures is based on a qualitative approach. The classification scheme requires actual project data in order to make it more quantitative. Because of the absence of reliable project data in the Netherlands, it will require time in order to quantify the risks accurately. It is recommended to develop a database in which statistics can be collected to update and improve the classification scheme as presented.

The identified risk and the classification scheme should be used by the UDG/EGS regulator and operators alike as a check or methodology for the risk management strategy of the project. However, it should be emphasized that the risk analysis provided in this study is likely not complete and possibly inaccurate. The UDG/EGS operator is thus still responsible to perform their own assessment and critically evaluate the proposed measures and threats. Where required and if appropriate, additions or modifications can be made to the classification scheme.

6 REFERENCES

1 Bos. S. & Laenen B., 2017. Development of the first deep geothermal doublet in the Campine Basin of Belgium European Geologist Journal 43: 15-19.

2 Vasile M., Bruggeman M., Van Meensel S., Bos S., Laenen B. (2017) Characterization of the natural radioactivity of the first deep geothermal doublet in Flanders, Belgium. Applied Radion and Isotopes 126, p300-303.

3 Langenaeker, V.: The Campine Basin: stratigraphy, structural geology, coalification and hydrocarbon potential of the Devonian to Jurassic, Aardkundige Mededelingen, 10, (2000), 1-142.

4 Lagrou D. & Coun-Aubert, 2017. Update of the Devonian lithostratigraphic subdivision in the subsurface of the Campine Basin (northern Belgium). Geologica Belgica 20/1-2: 1-13.

5 Deckers J., De Koninck R., Bos S., Broothaers M., Dirix K., Hambsch L., Lagrou, D., Lanckacker T., Matthijs, J., Rombaut B., Van Baelen K. & Van Haren T., 2019. Geologisch (G3Dv3) en hydrogeologisch (H3D) 3D-lagenmodel van Vlaanderen - versie 3. Studie uitgevoerd in opdracht van: Vlaams Planbureau voor Omgeving (Departement Omgeving) en Vlaamse Milieumaatschappij 2018/RMA/R/1569, 286p. + bijlagen.

6 Broothaers M., Bos S., Lagrou D., Harcouët-Menou V. & Ben Laenen B., 2019. Lower Carboniferous limestone reservoir in northern Belgium: structural insights from the Balmatt project in Mol. European Geothermal Congress 2019, Den Haag, The Netherlands, 11-14 June 2019.

7 Van der Voet E., Laenen B., Rombaut B., Kourta M. & Swennen R., in press. Fracture characteristics of Lower Carboniferous carbonates in northern Belgium based on FMI log analyses. Netherlands Journal of Geosciences.

8 Muchez, P. & Langenaeker, V., 1993. Middle Devonian to Dinantian sedimentation in the Campine Basin (Northern Belgium): Its Relation to Variscan Tectonism. Special publications of the International Association of Sedimentologists 20, 171-181.

9 Camelbeeck Th., Vanneste K., Alexandre P., Verbeeck K., Petermans T., Rosset P., Everaerts M., Warnant R. & Van Camp M., 2007. Relevance of active faulting and seismicity studies to assessments of long-term earthquake activity and maximum magnitude in intraplate northwest Europe, between the Lower Rhine Embayment and the North Sea. In Stein S. & Mazotti S. (eds.), Continental Intraplate Earthquakes: Science, Hazard and Policy Issues. Geological Society of America Special Paper 425, 193-224.