
 FracRisk Reporting form for deliverables		
Deliverable Number:	D4.1	
Work package number:	4	
Deliverable title	Ranked FEP list	
Type	Report	
Dissemination Level	PU	
Lead participant	EWRE	
Contributing scientists and other personnel	Hagit Wiener, Yoni Goren, Jacob Bensabat, Alexandru Tatomir, Katriona Edlmann, Christopher McDermott With data provided by most participants of the FracRisk project (www.fracrisk.eu).	
Schedules delivery date from DOW	1/12/2015	
Actual / forecast delivery data	24/12/2015	
Comments (optional)	Click here to enter text.	
Deliverable summary text:		
<p>The deliverable presents a list of highest ranked features, events and processes for each focused scenario.</p> <p>The aim of this work is to identify the most relevant FEPs from the comprehensive list of possible environmental impacts that was presented in D3.1.</p> <p>This ranked list will be used as the basis for modelling the critical combinations of subsurface geology, operational practice of hydraulic fracturing.</p>		
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Final submission	Click here to enter text.	

FracRisk: Furthering the Knowledge Base for Reducing the Environmental Footprint of Shale Gas Development

Ranked FEPs list

December 2015



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Introduction

One of the aims of FracRisk (and of this particular work-package) is to investigate the environmental impacts of potential hazardous events. This aim will be achieved by, first, attaching key FEPs to each focussed scenario; later by translating the combination of FEPs and focused scenario into a bowtie diagram (as discussed in D3.1) and last, modelling these specific scenarios.

The definition of FEP (in the context of FracRisk) and the FEPs list itself were introduced in D 3.1 (submitted in December 2015). In short, FEPs refers to the identification and selection of the relevant factors for hydraulic fracturing safety: characterization of the main system (natural and anthropogenic) features, definition of key events and understanding of main processes occurring during the exploration and exploitation of shale gas.

The FEPs are used to assist in the identification of critical combinations of subsurface geology, operational practice of hydraulic fracturing and associated hazard and risk assessment for the natural and human environment.

The concept of bowtie diagram was also described in detail in D 3.1. The consequences part in a bowtie diagram will be used as the base for construction of the models in WP5 and also the base of the SG-RBCA to be developed on later stages in WP4.

The purpose of the current deliverable is to present the FEPs appraisal tables – how they were constructed and evaluated – and to determine the highest ranked FEPs per scenario.

The deliverable is constructed of three sections:

1. The appraisal methodology.
2. The analysis of the appraisal.
3. List of highest ranked FEPs per scenario.



1. Methodology

2.1 The FEPs appraisal table

The FEP appraisal table (appendix 1) is basically a headline-only version of the FEPs list from D3.1, copied into an Excel file with 3 sheets (one for features, one for events and one for processes). In addition to the FEPs items (columns A and B), 6 columns were assigned for the appraisal of the 6 focused scenarios.

We used a 5 point interval scale, with the following level of importance of each FEP to each scenario:

- 1– Least critical
- 2– Slightly critical
- 3– Critical
- 4– Considerably critical
- 5– Most critical

This response scale is a qualitative approach changed to numbers in order to compute an average. Equal intervals are required to represent the same difference between levels of perceived quality (more on the response scale in section 1.2.1).

For each scenario, the participants were asked to assign an importance value (from 1 to 5) for every FEP. The appraisal is per scenario, that is, one can choose similar values for different scenarios (see tables in Appendix 1).

The appraisal tables were sent to all members of the project. There was no limit on the number of tables that each group can send. In some cases there are 2 tables from the same group and in other cases, 2 group members contributed to a single table. For the evaluation part, all tables were given the same weight, without consideration on the amount of contributors or the total amount of tables from the same group.

2.2 Ranking methodology

There are several ways to assign the most relevant elements (in our case items in the FEPs list) to each focused scenarios:

- a. Conducting field tests for assessing the importance of each item in the FEPs list.
- b. Collect data from hydraulic fracturing sites to produce the most common and/or most important elements.
- c. Use the wisdom of the crowd for ranking.

Option "a" and "b" are irrelevant because of the enormous size of such a project and the lack of data, respectively.

Option "c" uses the wisdom of the crowd, in our case the knowledge and experience of the project's participants, to rank the items. Oldendick (2008) defined ranking as a question response format used when a researcher is interested in establishing some type of priority among a set of objects. The aim of the survey is to associate to each item in the FEP list an indicator of importance/relevance in connection to each one of the six focus scenarios (presented in the DOW and in D3.1).

1.1.1 Scale points

The type of construct described above is a unipolar construct that ranges from least critical (zero importance) to most critical (maximum importance) and there is no precise midpoint. For unipolar construct, Krosnik and Fabrigar (1997) suggest the optimal scale should comprise between 4 to 7 points. It seems likely that people can readily conceive of zero, a slight amount, a moderate amount and a great deal along any unipolar continuum.



There are a number of arguments in favour of a five-points scale:

- a. It's easier to describe five quality levels: least, moderate, important, very, extreme. On a seven point scale it will be too specific and might cause confusion and non-uniformity between the respondents.
- b. The survey is very long with three tables, each with tens of items. If using a longer scale, the response task might become too demanding, and with too many scale points, the experts might resort to rounding their answers (Maitland, 2009).

It is important to notice that the literatures cited above refer to surveys measuring attitudes¹, for which there are data quality standards such as reliability. However, the FEP appraisal tables were not constructed to include repetitive questions for reliability assessments (although there might be some inherent repetition in the FEPs list).

2.3 Evaluation methodology

The purpose of the FEP appraisal table is to identify among the whole ensemble of FEP's the ones that are most critical for each focus scenario. We performed this identification via a normal average function (see explanations below).

For each item in the FEPs list an average value of importance per scenario was computed.

The ranking of the scenarios is carried in an independent manner, i.e., there should not be any link between the ranking process of the different scenarios.

2.4 Collection of the data

All participants of the project received the Excel file and the FEPs list (D3.1) and were asked to fill in the tables and return by email.

Once all the tables were gathered, EWRE staff ran the analyses (average normal, standard deviation and frequency on the average values). The results are described in the next chapter.

¹ abstract constructs that are not directly observable and exist only in the respondent's mind (Maitland 2009)



2. Results

14 appraisal tables were collected.

The following general observations can be made:

- A. The FEPs listed in section 2.1 are those which received an average grade of 4 or 5. The standard deviations of these grades range from 0.5 to 1.8 (see figures below), which indicate that some FEPs are more agreeable between the respondents than other.
- B. Features of the bearing formation and the overburden received, in general, higher rankings than those of the underburden and the near surface environment. This is mostly due to the definition of the focused scenarios, which mainly address the processes that occur in these compartments.
- C. Most operational events received an average grade of 3 ("critical") or lower. This may be the result of two factors: 1) the definitions of operational events were not clear enough for the participants to properly evaluate them; 2) these events are not critically important in the modelling to be undertaken in FracRisk.

Natural events and accidents on the other hand, which are more straightforward to understand, received higher scores.

- D. Processes received an average higher ranking than the other two tables. To our opinion this is because (in contrast to Features and Events), the list of processes is much more bound to the frame work of FracRisk and the questions the focused scenarios are aimed to answer. This will be taken under consideration as the project evolves, since the FEPs list is aimed to be a general list regarding most (if not all) facies of hydraulic fracturing.

2.1 Highest ranked FEPs

The FEPs with an average grade of 4 or 5 are presented below for each focused scenario. In brackets, the title of the section under which the feature appears and the relative numbering of the feature (see D3.1 for more information).

2.1.1 Highest ranked Features

FS 1:

- i. Stress and Mechanical properties (Hydrocarbon bearing formation, 1.1.4)
- ii. Fractures and faults within the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.6)
- iii. Lithology (Hydrocarbon bearing formation, 1.1.3.1)
- iv. Rock / Petrophysical properties of the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.3)
- v. Heterogeneity of the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.5)
- vi. Intrinsic permeability (Hydrocarbon bearing formation, 1.1.3.8)
- vii. Intrinsic permeability of the fracture (Hydrocarbon bearing formation, 1.1.6.2)
- viii. Horizontal wells (Site operation, 3.1.1)
- ix. Well orientation (Site operation, 3.1.7)

FS 2:

- i. Rock / Petrophysical properties of the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.3)
- ii. Fractures and faults within the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.6)
- iii. Lithology (Hydrocarbon bearing formation, 1.1.3.1)
- iv. Intrinsic permeability of the fracture (Hydrocarbon bearing formation, 1.1.6.2)
- v. Relative Permeability of the fractures (Hydrocarbon bearing formation, 1.1.6.3)



- vi. Fracture geometry (Hydrocarbon bearing formation, 1.1.6.4)
- vii. Entry pressure (Hydrocarbon bearing formation, 1.1.3.10)
- viii. Intrinsic permeability (Hydrocarbon bearing formation, 1.1.3.8)
- ix. Relative permeability (Hydrocarbon bearing formation, 1.1.3.9)
- x. Fracture geometry (Overburden 1.3.7.4)
- xi. Fractures and faults within the overburden (Overburden, 1.3.7)
- xii. Horizontal wells (3.1.1)

FS 3:

- i. Fractures and faults within the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.6)
- ii. Lithology (Hydrocarbon bearing formation, 1.1.3.1)
- iii. Entry pressure (Hydrocarbon bearing formation, 1.1.3.10)
- iv. Relative permeability (Hydrocarbon bearing formation, 1.1.3.9)
- v. Fluids (Hydrocarbon bearing formation, 1.2) – all the sub sections under fluids received an average grade of 4.
- vi. Hydraulic injection fluid properties (Unconventional Hydrocarbon Extraction, 1.1)
- vii. Injection fluid additives (Unconventional Hydrocarbon Extraction, 1.2.1)

FS 4:

- i. Fracture geometry (Overburden, 1.3.7.4)
- ii. Relative Permeability of the fractures (Overburden, 1.3.7.3)
- iii. Fractures and faults within the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.6) – all sub-sections received an average grade of 4.
- iv. Lithology (Hydrocarbon bearing formation, 1.1.3.1)
- v. Entry pressure (Hydrocarbon bearing formation, 1.1.3.10)
- vi. Relative permeability (Hydrocarbon bearing formation, 1.1.3.9)
- vii. Intrinsic permeability (Hydrocarbon bearing formation, 1.1.3.8)
- viii. Porosity of the (Overburden, 1.3.2.5)
- ix. Abandoned wells (4.2)

FS 5:

- i. Fractures and faults within the hydrocarbon bearing formation (Hydrocarbon bearing formation, 1.1.6)
- ii. Relative Permeability of the fractures (Hydrocarbon bearing formation, 1.1.6.3)
- iii. Undetected features within the overburden (Overburden, 1.3.8)
- iv. Relative permeability (Hydrocarbon bearing formation, 1.1.3.9)
- v. Intrinsic permeability (Hydrocarbon bearing formation, 1.1.3.8)
- vi. Near-surface aquifers and surface water bodies (Near surface environment, 2.1.3)

FS 6:

- i. Lithology (Hydrocarbon bearing formation, 1.1.3.1)
- ii. Near-surface aquifers and surface water bodies (Near surface environment, 2.1.3)

It is worth noting, that just 2 features received an average grade of 4 (none of 5) with a relatively high SD of 1.4 and 1.7 (see Figure 6 below). This may indicate that the current Features are not related enough (to the experts' opinion) to the 6th focused scenario. The FEPs list is a work in progress and more features might be added at a later stage of the project.



Figure 1 - Correlation between a feature's average grade and STDEV., FS1

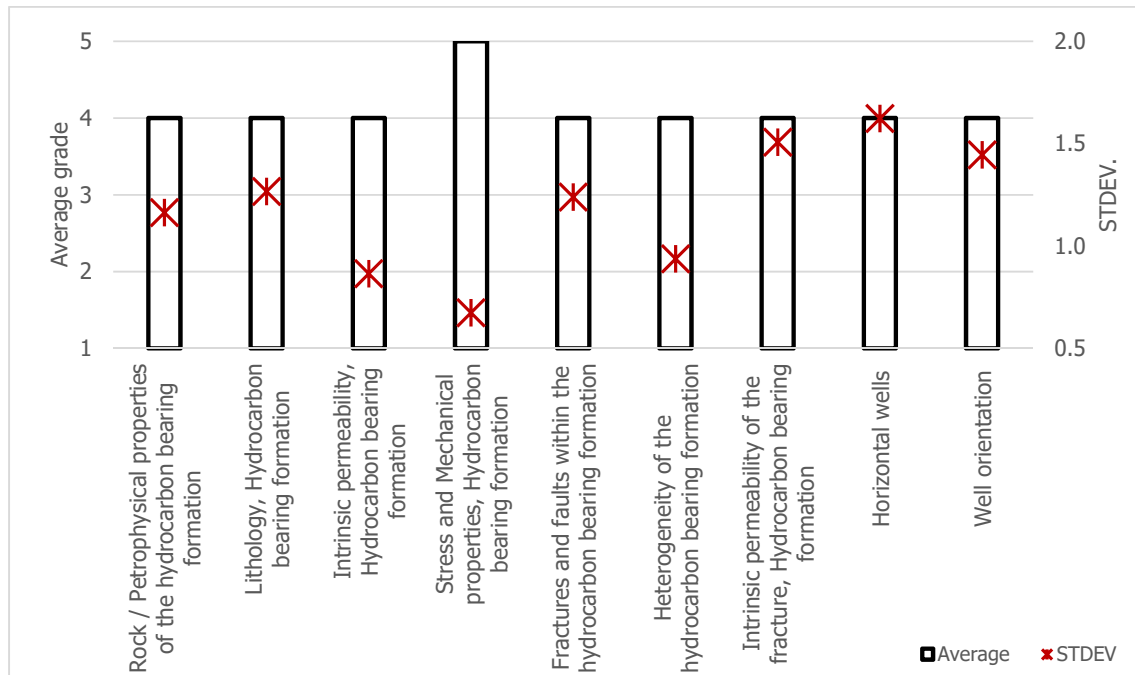


Figure 2 - Correlation between a feature's average grade and STDEV., FS2

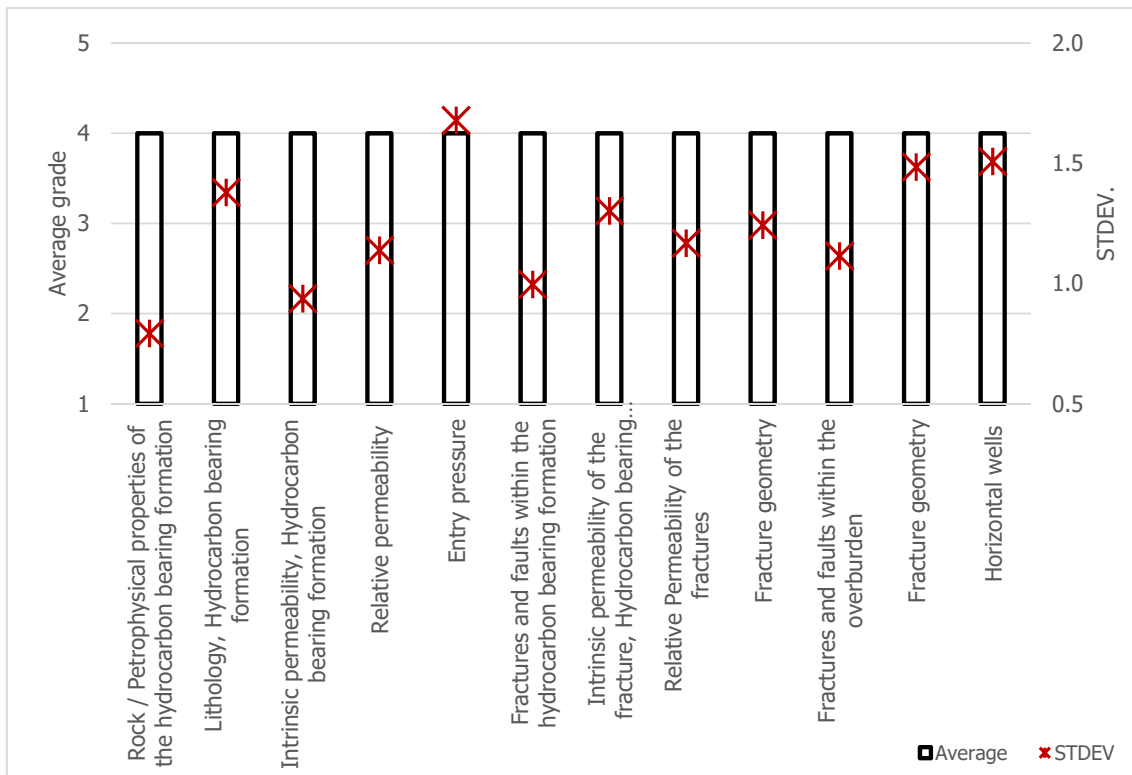


Figure 3 - Correlation between a feature's average grade and STDEV., FS3

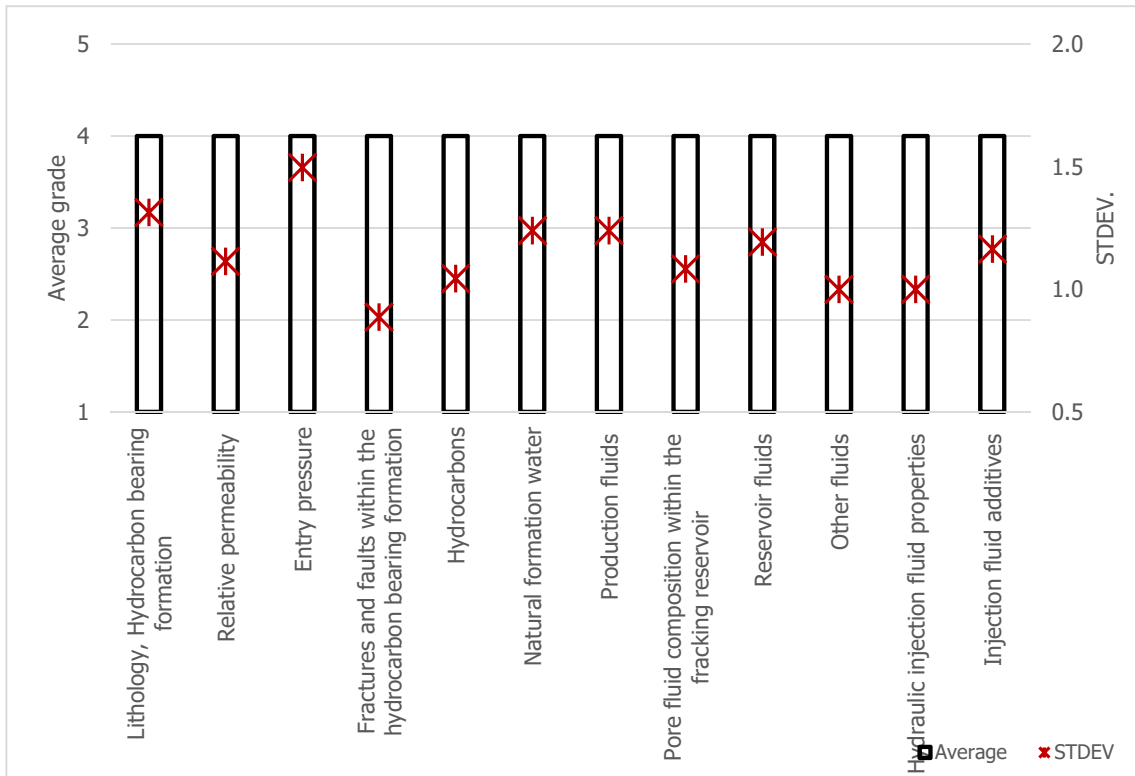


Figure 4 - Correlation between a feature's average grade and STDEV., FS4

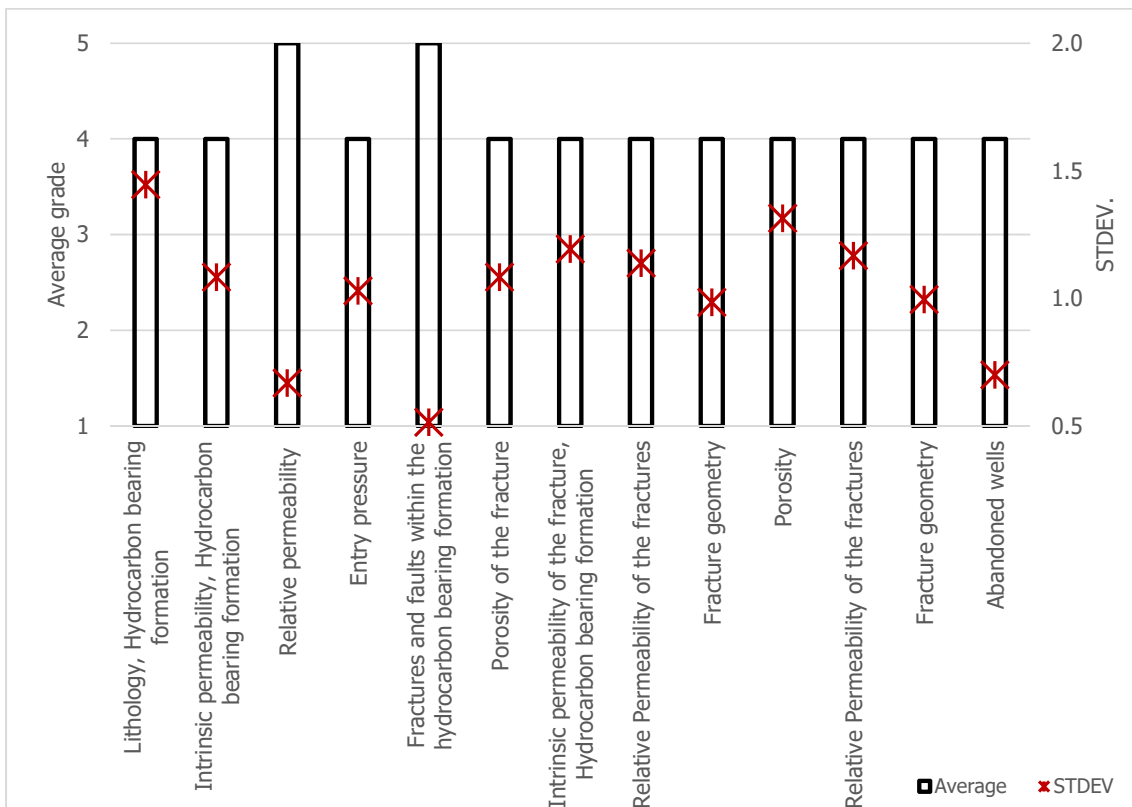


Figure 5 - Correlation between a feature's average grade and STDEV., FS5

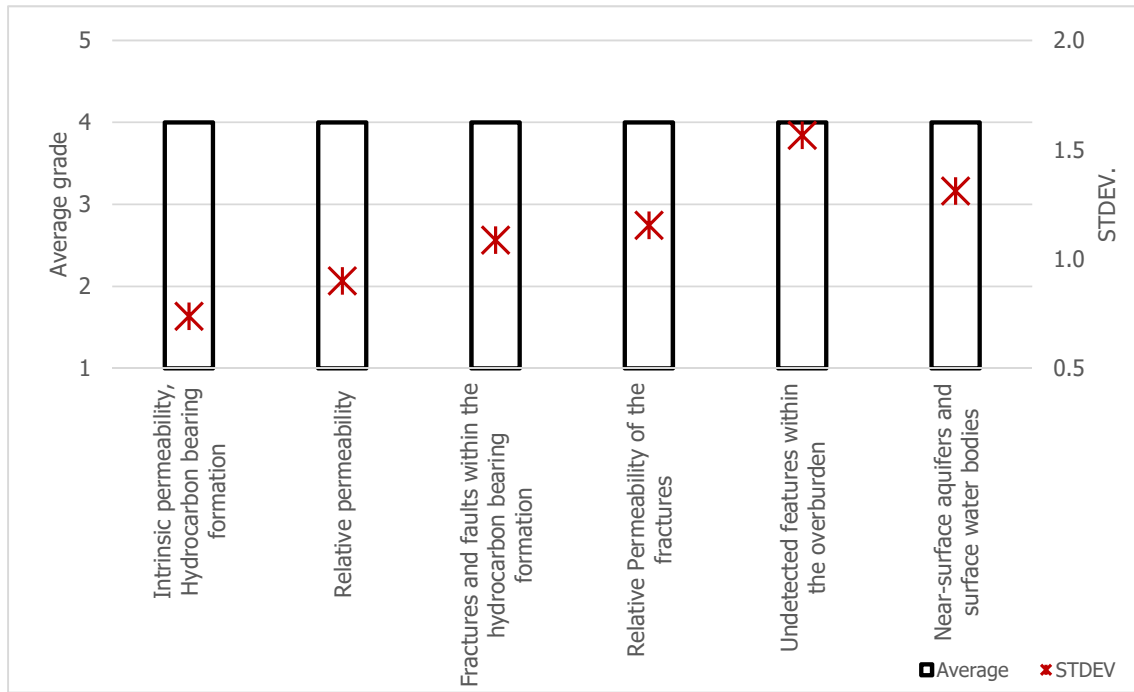
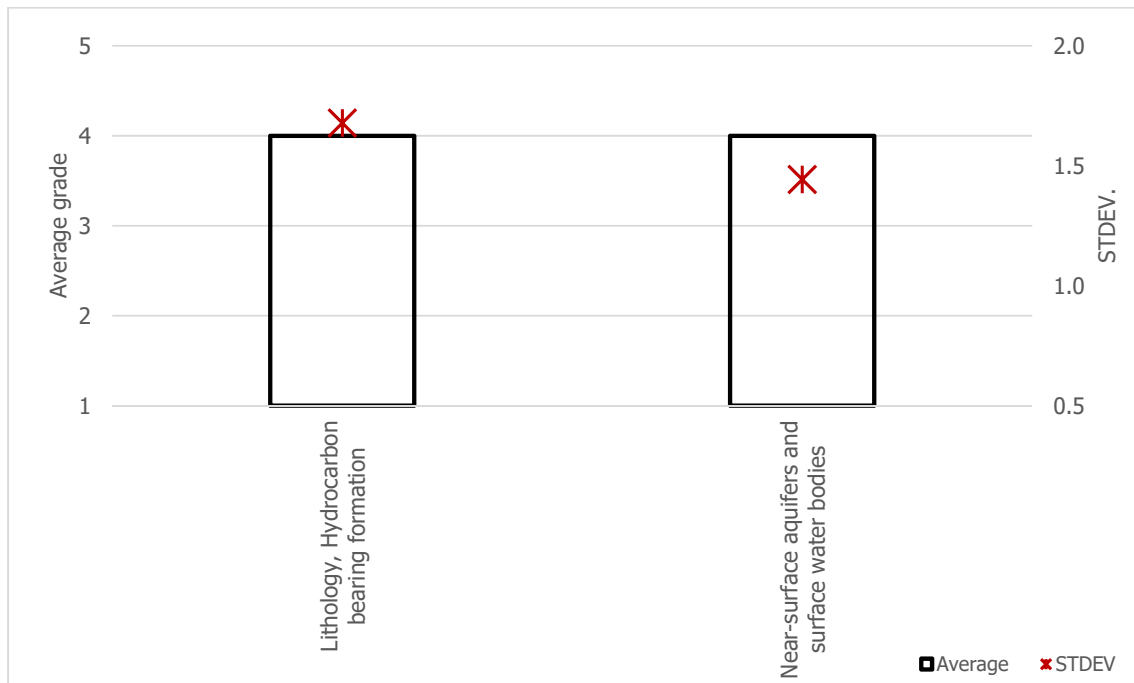


Figure 6 - Correlation between a feature's average grade and STDEV., FS6



2.1.2 Highest ranked Events

The highest ranked Events are very similar for all 6 focused scenarios, as can be seen in the lists below.

FS 1:

- i. Hydraulic fracturing (Operational events, 1.5)
- ii. Earthquakes (Natural events, 2.1)
- iii. Overpressuring (Accidents and unplanned events, 3.2)

FS 2:

- i. Hydraulic fracturing (Operational events, 1.5)
- ii. Overpressuring (Accidents and unplanned events, 3.2)
- iii. Production (Operational events, 1.7)
- iv. Seal failure (Operational events, 1.9)
- v. Cap rock failure (Natural events, 2.4)
- vi. Poor site characterization (Accidents and unplanned events, 3.3)
- vii. Cementation poorly undertaken (Accidents and unplanned events, 3.5)

FS 3:

- i. Hydraulic fracturing (Operational events, 1.5)
- ii. Overpressuring (Accidents and unplanned events, 3.2)
- iii. Production (Operational events, 1.7)
- iv. Poor site characterization (Accidents and unplanned events, 3.3)
- v. Cementation poorly undertaken (Accidents and unplanned events, 3.5)
- vi. Incorrect chemical mix released into fracking fluid (Accidents and unplanned events, 3.4)

FS 4:

- i. Hydraulic fracturing (Operational events, 1.5)
- ii. Overpressuring (Accidents and unplanned events, 3.2)
- iii. Production (Operational events, 1.7)
- iv. Poor site characterization (Accidents and unplanned events, 3.3)
- v. Cap rock failure (Natural events, 2.4)
- vi. Seal failure (Operational events, 1.9)
- vii. Out of zone / beyond pumping (Operational events, 1.5)
- viii. Cementation poorly undertaken (Accidents and unplanned events, 3.5)

FS 5:

- i. Poor site characterization (Accidents and unplanned events, 3.3)
- ii. Out of zone / beyond pumping (Operational events, 1.5)

FS 6:

- i. Out of zone / beyond pumping (Operational events, 1.5)



Figure 7 – Correlation between an event's average grade and STDEV., FS1

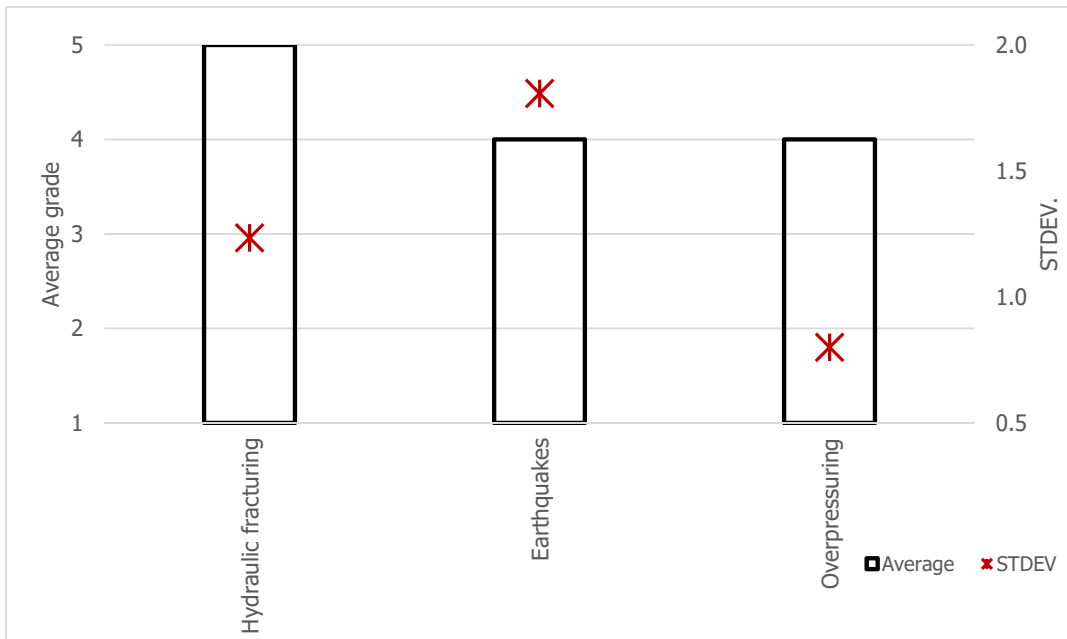


Figure 8 - Correlation between an event's average grade and STDEV., FS2

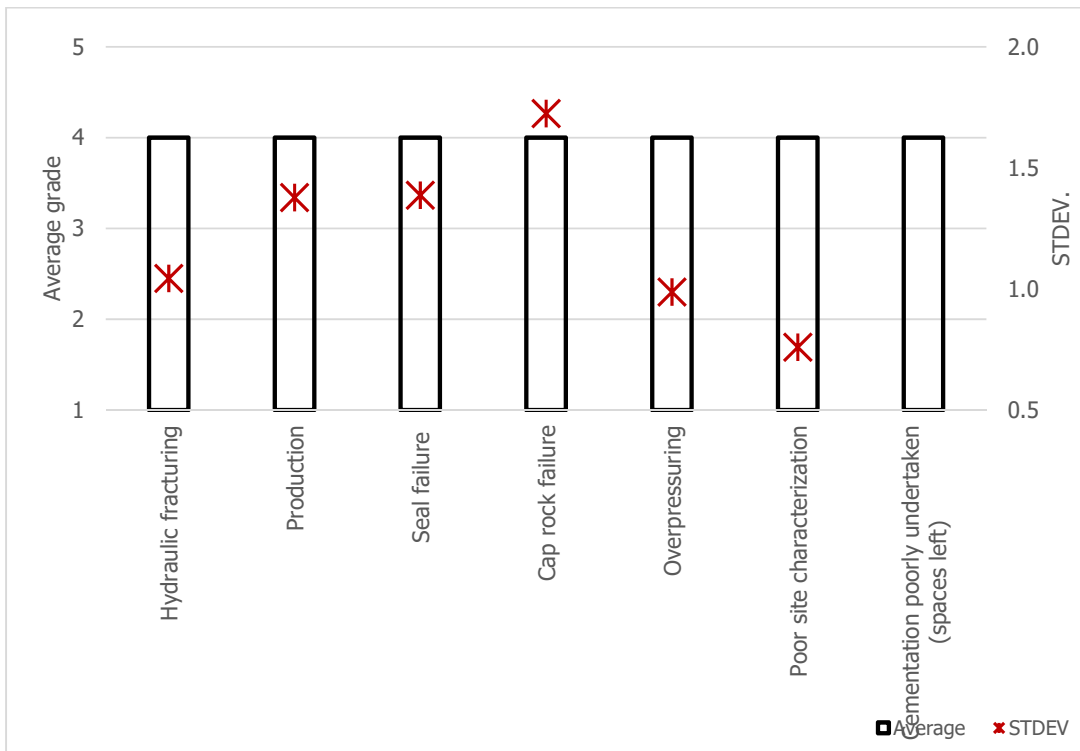


Figure 9 – Correlation between an event's average grade and STDEV., FS3

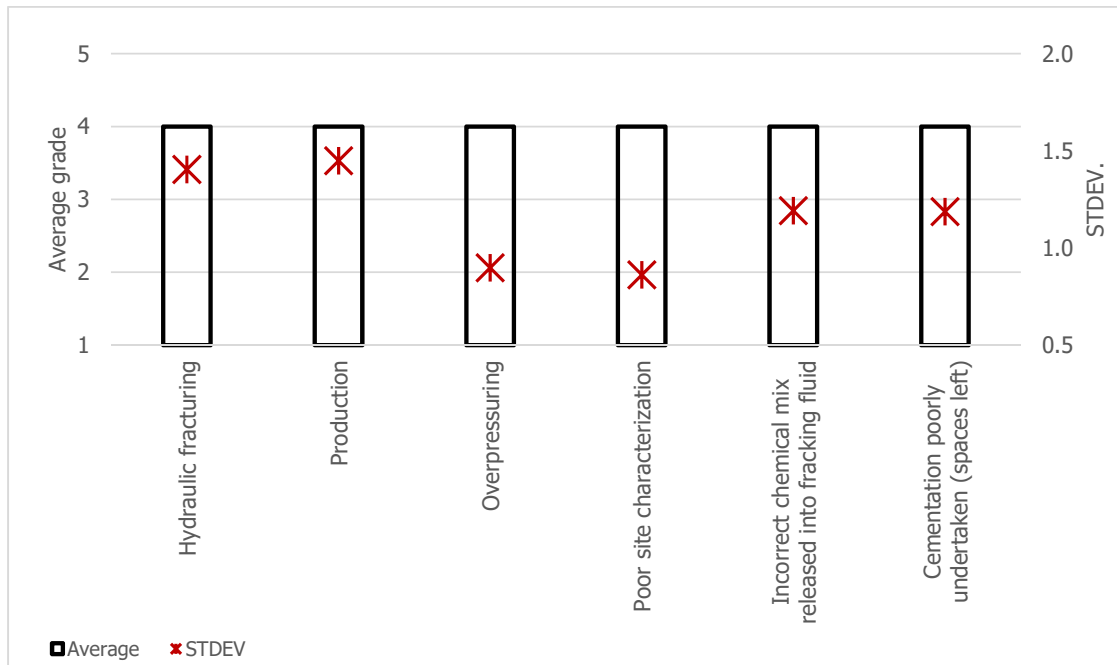


Figure 10 – Correlation between an event's average grade and STDEV., FS4

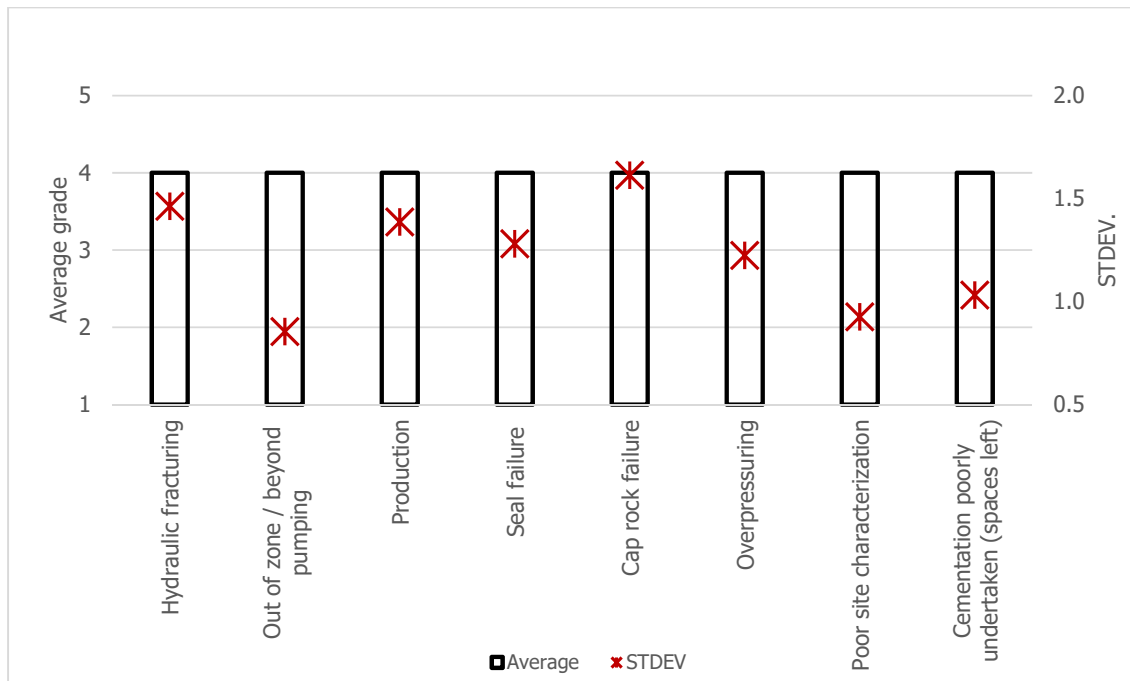


Figure 11 - Correlation between an event's average grade and STDEV., FS5

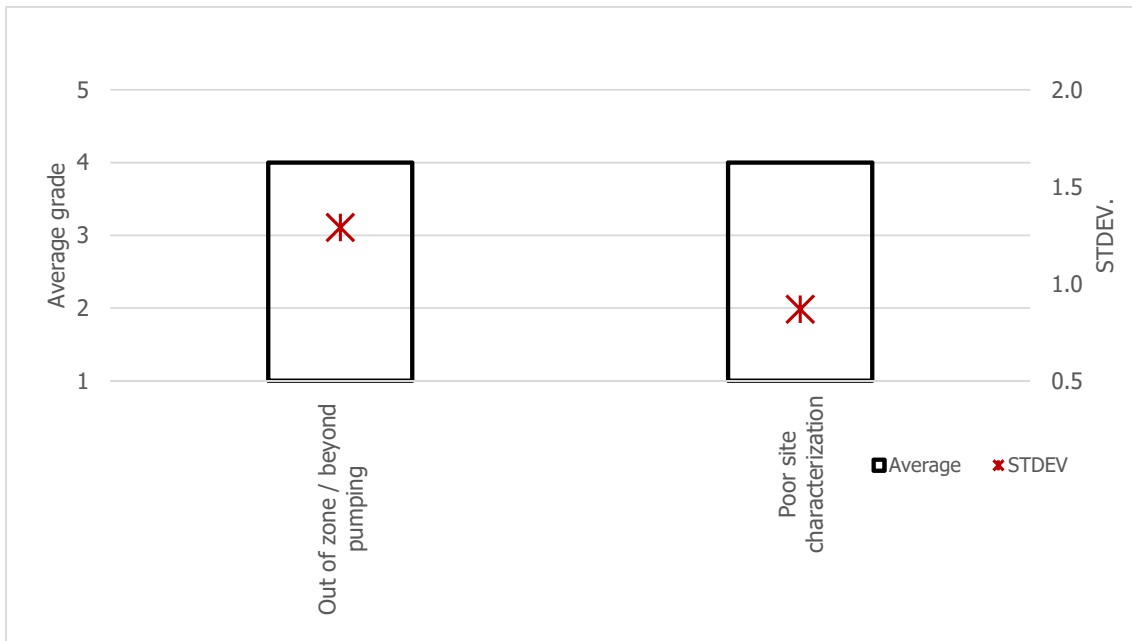
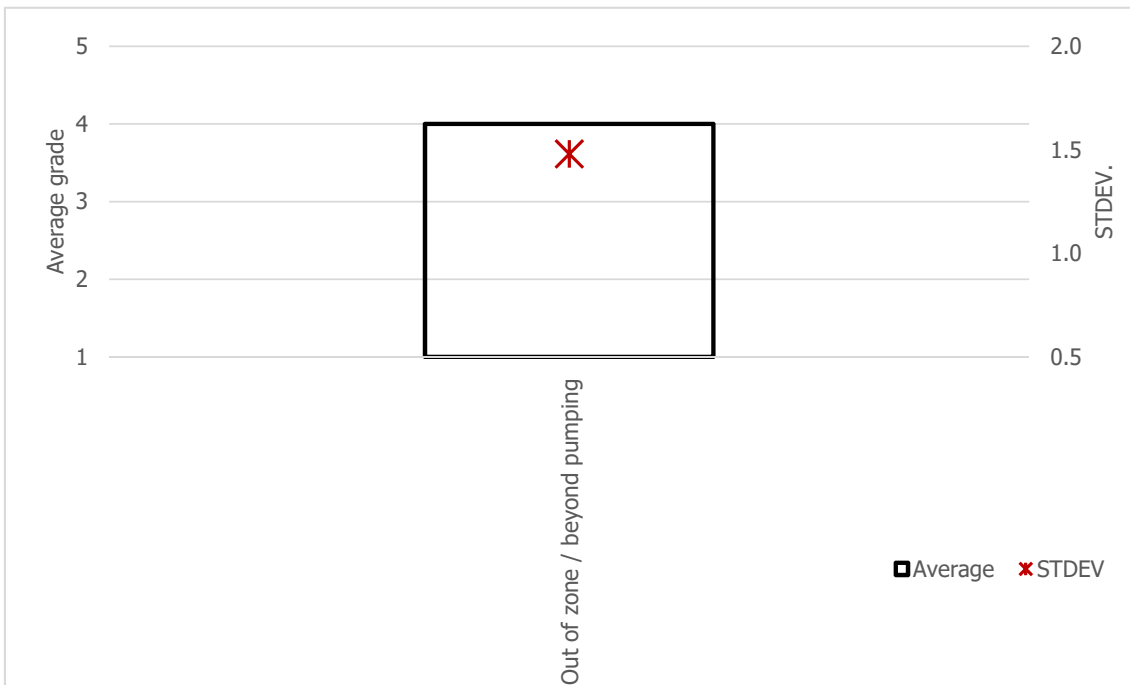


Figure 12 – Correlation between an event's average grade and STDEV., FS6



2.1.3 Highest ranked Processes

As with the Events, the highest ranked Processes are very similar between the six focused scenarios.

FS 1:

- i. Fluid pressure exceeds rock fracturing pressures generating new fractures (Hydraulics / Fluid Pressure Dominated, 2.1)
- ii. Fluid exceeds fault sealing pressures (Hydraulics / Fluid Pressure Dominated, 2.2)
- iii. Fluid pressure exceeds stability of part of the plant construction (Hydraulics / Fluid Pressure Dominated, 2.3)
- iv. Soil and rock deformation around boreholes (Mechanical, 4.1)
- v. Propagation of fractures beyond the target zone (Mechanical, 4.2)
- vi. Fluid exceeds fault sealing pressures (Mechanical, 4.3)
- vii. Fault valving (Mechanical, 4.4)

FS 2:

- i. Fluid pressure exceeds rock fracturing pressures generating new fractures (Hydraulics / Fluid Pressure Dominated, 2.1)
- ii. Fluid exceeds fault sealing pressures (Hydraulics / Fluid Pressure Dominated, 2.2)
- iii. Fluid pressure exceeds stability of part of the plant construction (Hydraulics / Fluid Pressure Dominated, 2.3)
- iv. Soil and rock deformation around boreholes (Mechanical, 4.1)
- v. Propagation of fractures beyond the target zone (Mechanical, 4.2)
- vi. Fluid exceeds fault sealing pressures (Mechanical, 4.3)
- vii. Fault valving (Mechanical, 4.4)
- viii. Displacement of surrounding formation fluids (Hydraulics / Fluid Pressure Dominated, 2.4)
- ix. Buoyancy-driven flow (Hydraulics / Fluid Pressure Dominated, 2.5)
- x. Micro-cracking in the casing cements (Mechanical, 4.6)

FS 3:

- i. Propagation of fractures beyond the target zone (Mechanical, 4.2)
- ii. Advection (Hydraulics / Fluid Pressure Dominated, 2.8.1)
- iii. Diffusion (Hydraulics / Fluid Pressure Dominated, 2.8.3)
- iv. Hydraulic and production fluids and the associated contaminants release processes (Hydraulics / Fluid Pressure Dominated, 2.9)
- v. Corrosive mixture attacks plant (Chemical, 3.1)
- vi. Corrosive mixture attacks geology (Chemical, 3.2)
- vii. Mineral dissolution (Chemical, 3.4)
- viii. Advection and co-migration of other gas (Hydraulics / Fluid Pressure Dominated, 2.6)
- ix. Water mediated transport (Hydraulics / Fluid Pressure Dominated, 2.8)
- x. Sorption and desorption (Chemical, 3.3)
- xi. Heavy metal release (Chemical, 3.5)

FS 4:

- i. Propagation of fractures beyond the target zone (Mechanical, 4.2)
- ii. Fluid exceeds fault sealing pressures (4.3)
- iii. Advection (Hydraulics / Fluid Pressure Dominated, 2.8.1)
- iv. Hydraulic and production fluids and the associated contaminants release processes (Hydraulics / Fluid Pressure Dominated, 2.9)
- v. Mineral dissolution (Chemical, 3.4)
- vi. Heavy metal release (Chemical, 3.5)



- vii. Fluid pressure exceeds rock fracturing pressures generating new fractures (Hydraulics / Fluid Pressure Dominated, 2.1)
- viii. Fluid exceeds fault sealing pressures (Hydraulics / Fluid Pressure Dominated, 2.2)
- ix. Fault valving (Mechanical, 4.4)
- x. Displacement of surrounding formation fluids (Hydraulics / Fluid Pressure Dominated, 2.4)
- xi. Buoyancy-driven flow (Hydraulics / Fluid Pressure Dominated, 2.5)
- xii. Micro-cracking in the casing cements (Mechanical, 4.6)
- xiii. Dispersion (Hydraulics / Fluid Pressure Dominated, 2.8.2)
- xiv. Soil and rock deformation around boreholes (Mechanical, 4.1)

FS 5:

- i. Advection (Hydraulics / Fluid Pressure Dominated, 2.8.1)
- ii. Hydraulic and production fluids and the associated contaminants release processes (Hydraulics / Fluid Pressure Dominated, 2.9)
- iii. Displacement of surrounding formation fluids (Hydraulics / Fluid Pressure Dominated, 2.4)
- iv. Buoyancy-driven flow (Hydraulics / Fluid Pressure Dominated, 2.5)
- v. Dispersion (Hydraulics / Fluid Pressure Dominated, 2.8.2)
- vi. Water mediated transport (Hydraulics / Fluid Pressure Dominated, 2.8)

FS 6:

- i. Advection (Hydraulics / Fluid Pressure Dominated, 2.8.1)
- ii. Hydraulic and production fluids and the associated contaminants release processes (Hydraulics / Fluid Pressure Dominated, 2.9)
- iii. Buoyancy-driven flow (Hydraulics / Fluid Pressure Dominated, 2.5)
- iv. Dispersion (Hydraulics / Fluid Pressure Dominated, 2.8.2)
- v. Diffusion (Hydraulics / Fluid Pressure Dominated, 2.8.3)



Figure 13 - Correlation between a process' average grade and STDEV., FS1

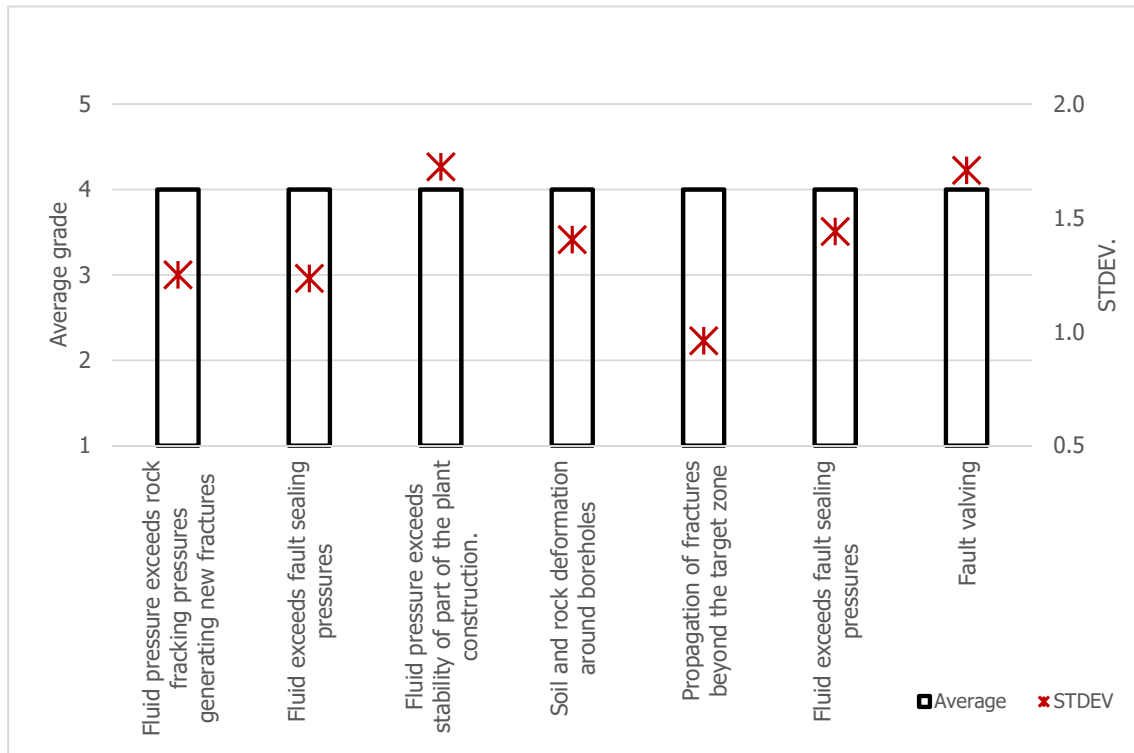


Figure 14 - Correlation between a process' average grade and STDEV., FS2

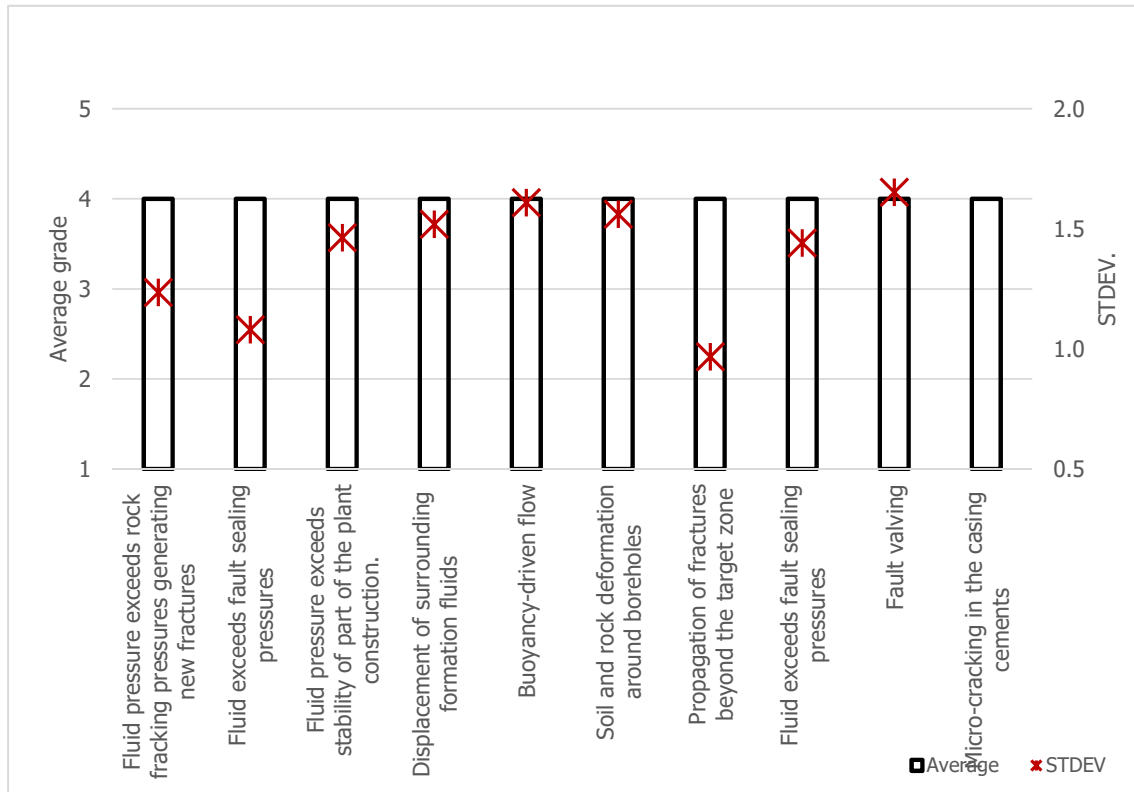


Figure 15 - Correlation between a process' average grade and STDEV., FS3

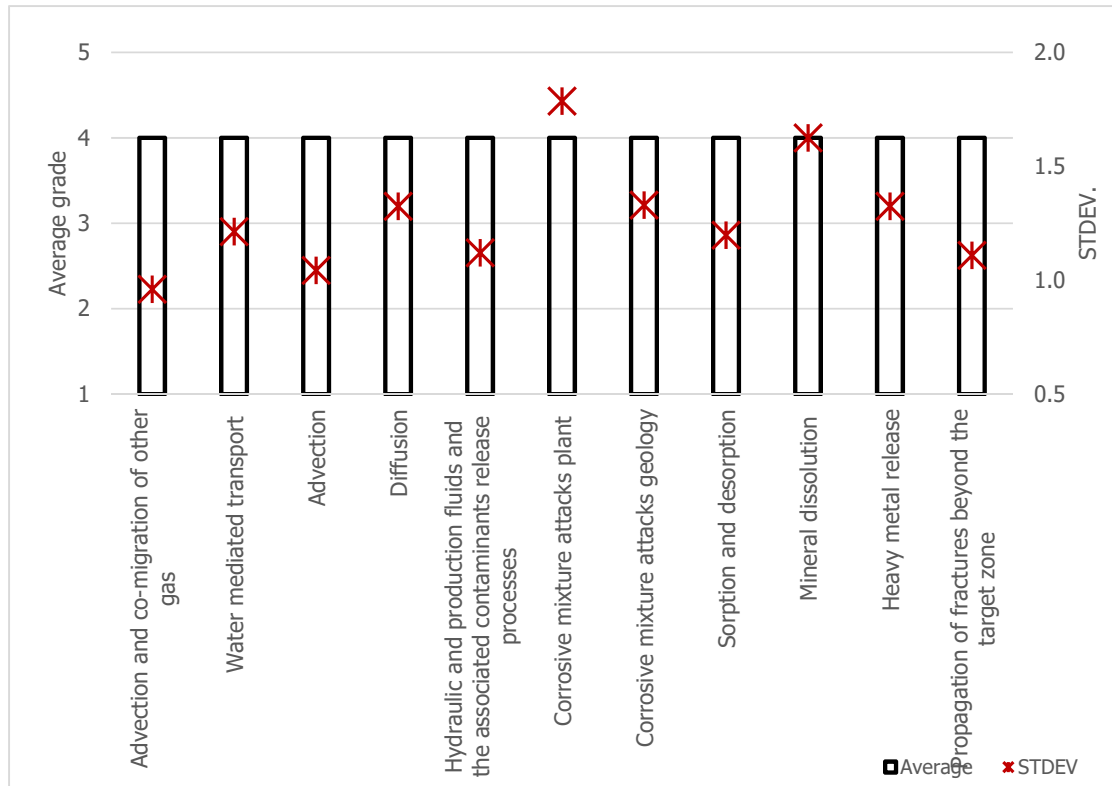


Figure 16 - Correlation between a process' average grade and STDEV., FS4

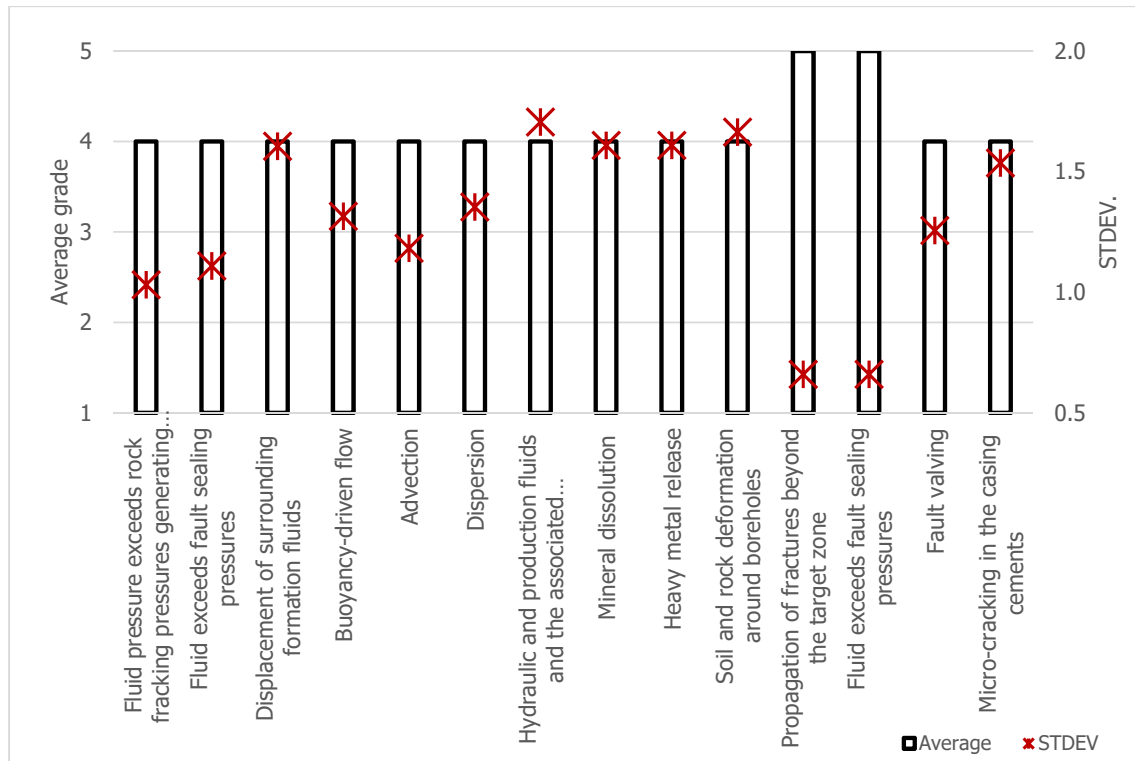


Figure 17 – Correlation between a process' average grade and STDEV., FS5

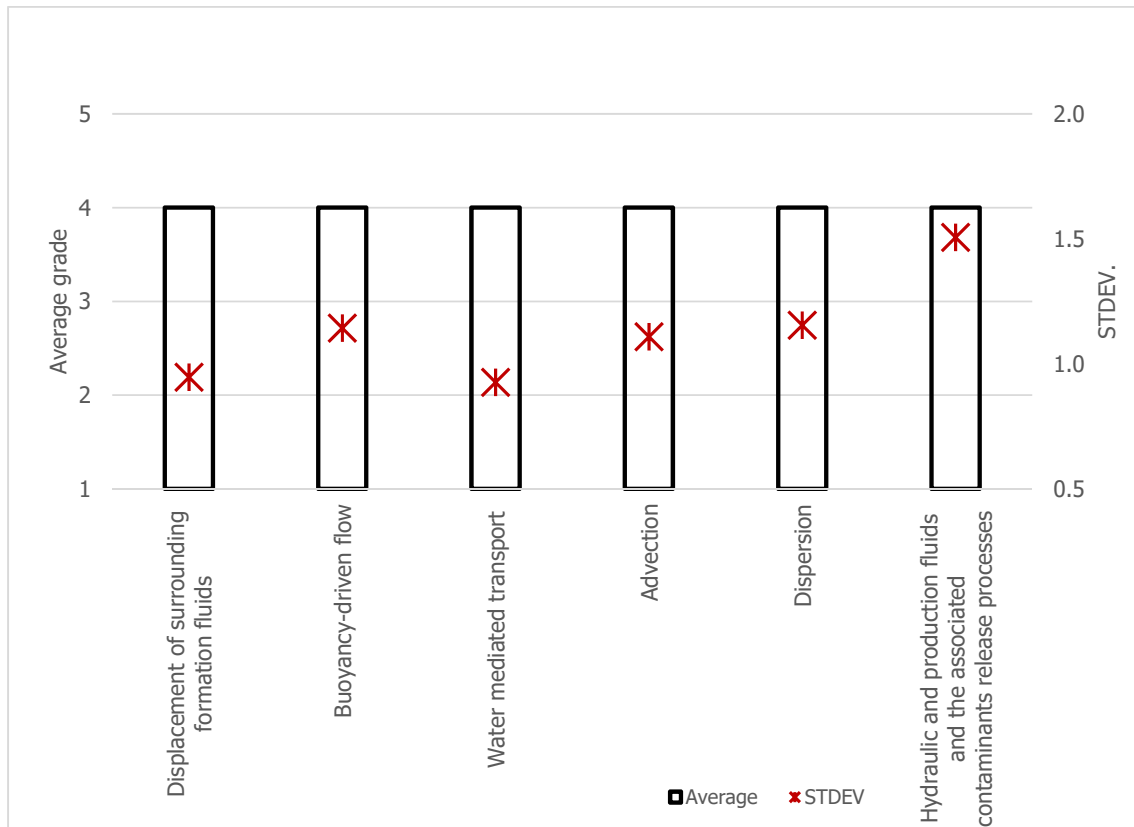
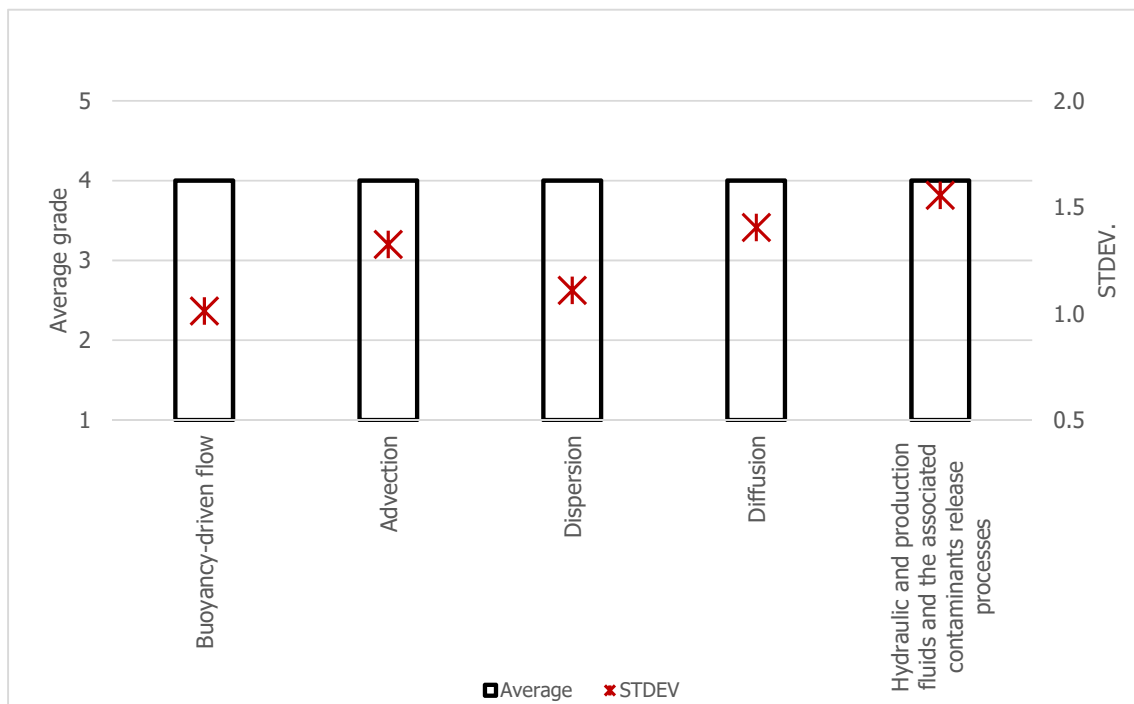
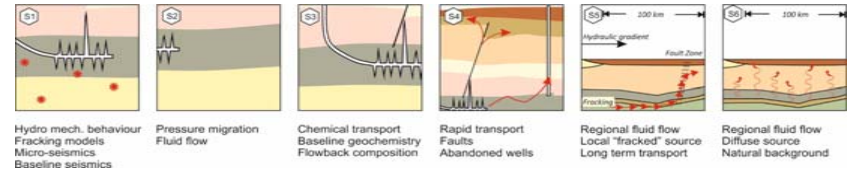


Figure 18 – Correlation between a process' average grade and STDEV., FS6





List of Features

A. Features of the Natural System

1 Hydrogeology

1.1. Hydrocarbon bearing formation (Source)

- 1.1.1. Type of the hydrocarbon bearing formation
- 1.1.2. Geometry of the hydrocarbon bearing formation
 - 1.1.2.1 Thickness
- 1.1.3. Rock / Petrophysical properties of the hydrocarbon bearing formation
 - 1.1.3.1 Lithology
 - 1.1.3.2 Diagenesis
 - 1.1.3.3 Pore architecture
 - 1.1.3.4 Mineralogy
 - 1.1.3.5 Kerogen type
 - 1.1.3.6 Thermal maturation of source rock
 - 1.1.3.7 Porosity
 - 1.1.3.8 Intrinsic permeability
 - 1.1.3.9 Relative permeability
 - 1.1.3.10 Entry pressure
 - 1.1.3.11 Residual saturation
 - 1.1.3.12 Hysteresis
- 1.1.4. Stress and Mechanical properties
- 1.1.5. Heterogeneity of the hydrocarbon bearing formation
- 1.1.6. Fractures and faults within the hydrocarbon bearing formation
 - 1.1.6.1 Porosity of the fracture
 - 1.1.6.2 Intrinsic permeability of the fracture
 - 1.1.6.3 Relative Permeability of the fractures
 - 1.1.6.4 Fracture geometry
- 1.1.7. Undetected features within the hydrocarbon bearing formation
- 1.1.8. Vertical geothermal gradient of the hydrocarbon bearing formation
- 1.1.9. Formation pressure of the hydrocarbon bearing formation

1.2. Fluids

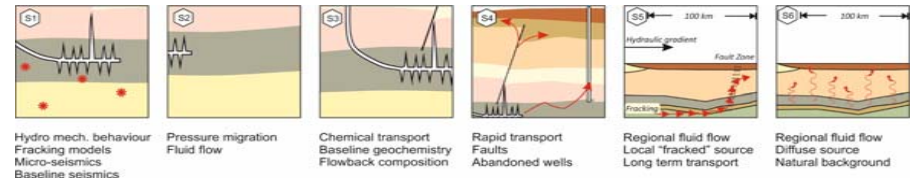
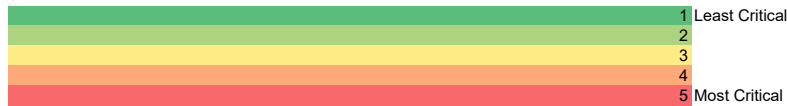
- 1.2.1. Hydrocarbons
- 1.2.2. Natural formation water
- 1.2.3. Production fluids
- 1.2.4. Pore fluid composition within the fracking reservoir
- 1.2.5. Reservoir fluids
- 1.2.6. Other fluids

Relevance to Scenario

	S1	S2	S3	S4	S5	S6
1.1.1. Type of the hydrocarbon bearing formation	3	3	3	2	2	2
1.1.2. Geometry of the hydrocarbon bearing formation	3	3	2	2	2	2
1.1.2.1 Thickness	3	3	2	2	2	2
1.1.3. Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	3	3	3	3
1.1.3.1 Lithology	4	4	4	4	3	4
1.1.3.2 Diagenesis	2	2	3	3	3	2
1.1.3.3 Pore architecture	2	3	3	2	2	2
1.1.3.4 Mineralogy	2	2	3	2	3	3
1.1.3.5 Kerogen type	2	2	3	2	3	2
1.1.3.6 Thermal maturation of source rock	1	1	2	2	2	2
1.1.3.7 Porosity	3	3	3	2	3	3
1.1.3.8 Intrinsic permeability	4	4	3	4	4	3
1.1.3.9 Relative permeability	3	4	4	5	4	3
1.1.3.10 Entry pressure	3	4	4	4	3	3
1.1.3.11 Residual saturation	2	2	2	1	1	2
1.1.3.12 Hysteresis	2	1	1	1	2	1
1.1.4. Stress and Mechanical properties	5	3	1	2	2	2
1.1.5. Heterogeneity of the hydrocarbon bearing formation	4	3	3	3	3	3
1.1.6. Fractures and faults within the hydrocarbon bearing formation	4	4	4	5	4	3
1.1.6.1 Porosity of the fracture	3	3	3	4	3	2
1.1.6.2 Intrinsic permeability of the fracture	4	4	3	4	3	2
1.1.6.3 Relative Permeability of the fractures	3	4	3	4	4	2
1.1.6.4 Fracture geometry	3	4	3	4	3	2
1.1.7. Undetected features within the hydrocarbon bearing formation	2	3	3	3	3	2
1.1.8. Vertical geothermal gradient of the hydrocarbon bearing formation	1	2	3	2	2	2
1.1.9. Formation pressure of the hydrocarbon bearing formation	3	3	3	3	2	2
1.2. Fluids						
1.2.1. Hydrocarbons	2	2	4	2	3	3
1.2.2. Natural formation water	2	2	4	2	2	2
1.2.3. Production fluids	2	3	4	2	2	2
1.2.4. Pore fluid composition within the fracking reservoir	2	3	4	2	3	2
1.2.5. Reservoir fluids	2	2	4	2	2	2
1.2.6. Other fluids	2	2	4	2	2	2

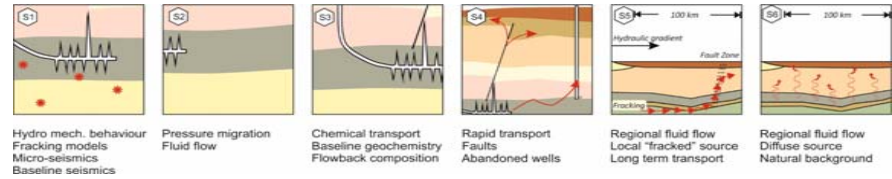
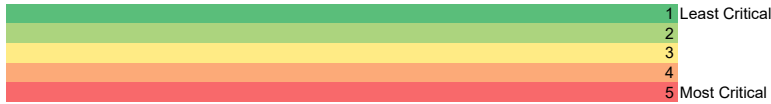
	S1	S2	S3	S4	S5	S6
1.3. Overburden						
1.3.1. Geometry of the overburden	3	2	2	2	2	3
1.3.1.1. Thickness	3	3	2	2	3	3
1.3.2. Rock / Petrophysical properties of the overburden	3	2	2	2	2	3
1.3.2.1. Lithology	2	2	3	3	3	3
1.3.2.2. Diagenesis	2	1	3	3	3	2
1.3.2.3. Pore architecture	1	2	3	2	3	2
1.3.2.4. Mineralogy	1	1	3	2	2	2
1.3.2.5. Porosity	3	2	2	4	3	3
1.3.2.6. Intrinsic permeability	2	3	2	3	3	3
1.3.2.7. Relative permeability	2	2	2	3	3	3
1.3.2.8. Entry pressure	2	2	2	2	2	2
1.3.2.9. Residual saturation	1	2	1	2	2	2
1.3.2.10. Hysteresis	1	1	1	2	2	2
1.3.3. Free gas pocket within the overburden	2	2	2	2	2	2
1.3.4. Additional seals within the overburden	1	2	1	2	2	3
1.3.5. Unconformities within the overburden	2	3	2	2	2	2
1.3.6. Heterogeneity within the overburden	2	3	2	2	2	2
1.3.7. Fractures and faults within the overburden	3	4	3	3	3	3
1.3.7.1. Porosity of the fracture	2	3	3	3	3	3
1.3.7.2. Intrinsic permeability of the fracture	2	3	3	3	3	2
1.3.7.3. Relative Permeability of the fractures	2	3	3	4	3	2
1.3.7.4. Fracture geometry	2	4	3	4	3	2
1.3.8. Undetected features within the overburden	2	2	3	3	4	3
1.3.9. Vertical geothermal gradient of the overburden	2	2	2	2	3	2
1.3.10. Formation "overburden" pressure	2	3	3	2	3	2
1.3.11. Overburden pressure	2	2	2	3	2	2
1.4. Underburden						
1.4.1. Geometry of the underburden	2	2	1	1	2	1
1.4.1.1. Thickness	2	2	1	1	1	2
1.4.2. Rock / Petrophysical properties of the underburden	2	2	2	2	2	2
1.4.2.1. Lithology	2	2	2	3	2	2
1.4.2.2. Diagenesis	2	2	2	2	2	1
1.4.2.3. Pore architecture	1	2	2	2	2	2
1.4.2.4. Mineralogy	1	2	2	2	2	2
1.4.2.5. Porosity	2	2	2	2	2	2
1.4.2.6. Intrinsic permeability	2	2	2	2	2	1
1.4.2.7. Relative permeability	2	2	2	2	2	1
1.4.2.8. Entry pressure	1	2	1	2	2	1
1.4.2.9. Residual saturation	1	2	2	2	2	1
1.4.2.10. Hysteresis	1	2	2	2	1	1
1.4.3. Unconformities within the underburden	1	2	2	2	2	2
1.4.4. Heterogeneity within the underburden	2	2	2	2	2	2
1.4.5. Fractures and faults within the underburden	2	2	2	2	2	2
1.4.6. Undetected features within the underburden	2	2	2	2	2	2
1.4.7. Vertical geothermal gradient within the underburden	2	2	2	2	2	2
1.4.8. Formation "underburden" pressure	2	2	2	2	2	2
2. Near surface environment (Receptors)						
2.1. Terrestrial environment						
2.1.1. Geographical location	2	1	2	3	3	2
2.1.2. Soils and sediments	2	2	2	3	3	3
2.1.3. Near-surface aquifers and surface water bodies	2	2	3	3	4	4
2.1.4. Terrestrial flora and fauna	1	1	2	2	2	2
2.1.5. Terrestrial ecological systems	1	2	2	2	2	2
2.1.6. Buildings	2	2	2	2	2	2
2.2. Marine environment						
2.2.1. Local oceanography	2	2	2	2	1	2
2.2.2. Marine sediments	2	2	2	2	2	2
2.2.3. Marine Stratification and Mixing	2	2	2	2	2	2
2.2.4. Marine flora and fauna	1	1	1	2	2	2
2.2.5. Marine ecological systems	1	1	2	2	1	2

	S1	S2	S3	S4	S5	S6
2.3. Human Environment						
2.3.1. Human characteristics	2	1	2	1	2	2
2.3.2. Diet and food processing	1	1	1	2	2	2
2.3.3. Lifestyles	1	2	1	2	2	1
2.3.4. Land and water use	2	1	2	2	2	2
2.3.5. Community characteristics	2	1	2	2	2	1
2.4. Atmosphere and meteorology						
B. Unconventional Hydrocarbon Extraction						
1. Hydro-fracturing fluid						
1.1. Hydraulic injection fluid properties	3	3	4	2	3	2
1.2. Physical properties of injection fluid						
1.2.1. Injection fluid additives	3	2	4	3	3	3
1.2.2. Hydro-fracturing fluids interactions	3	2	3	2	2	2
2. Site development						
2.1. Logistics above ground	2	2	2	1	2	1
2.2. Baseline monitoring	3	2	3	2	3	3
3. Site operation						
3.1. Drilling and completion	3	2	5	1	2	4
3.1.1. Horizontal wells	4	4	3	3	2	2
3.1.2. Formation damage	3	3	3	3	3	3
3.1.3. Well lining and completion	2	2	2	2	2	2
3.1.4. Workover	2	1	1	2	1	1
3.1.5. Monitoring wells	3	2	3	3	3	3
3.1.6. Well records	2	2	3	3	2	3
3.1.7. Well orientation	4	3	3	2	2	3
3.1.8. Well engineering	2	2	2	2	2	2
4. Site decommissioning						
4.1. Closure and sealing of boreholes	2	3	3	3	3	3
4.2. Abandoned wells	2	2	3	4	3	3



List of Events

	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Operational Events						
1.1. Multiple well drilling from same platform	3	3	3	3	2	3
1.2. Initial drilling to given below water table (Open Hole)	3	3	3	3	3	3
1.2. Casing emplacement	3	3	3	3	2	3
1.2. Cementation with wiper plug	2	2	2	2	2	2
1.2. Drilling through wiper plug and casing shoe	2	3	2	2	3	3
1.2. Additional cementation	2	3	2	2	2	2
1.3. Logging Borehole	2	3	2	3	2	2
1.4. Drilling horizontal borehole	3	3	3	2	3	3
1.4. Casing horizontal borehole	2	3	3	3	3	3
1.4. Cementation	2	3	2	2	2	3
1.4. Perforation	3	3	2	3	2	2
1.5. Hydraulic fracturing	5	4	4	4	3	2
1.5. Out of zone / beyond pumping	3	3	3	4	4	4
1.6. Plugging & drilling out of plugs	2	2	2	2	2	2
1.7. Flow back	2	3	3	3	3	2
1.7. Production	3	4	4	4	3	3
1.8. Abandonment	2	3	3	3	3	3
1.9. Seal failure	3	4	3	4	3	3
2 Natural events						
2.1. Earthquakes	4	3	2	3	2	2
2.2. Large scale erosion	3	2	2	3	2	2
2.3. Hydrological and hydrogeological response to geological changes	2	3	3	3	3	3
2.4. Cap rock failure	3	4	3	4	3	3
2.5. Unexpected large scale scenario	2	3	3	3	2	2
3 Accidents and unplanned events						
3.1. Surface chemical spills	2	2	3	3	2	2
3.2. Overpressuring	4	4	4	4	3	3
3.3. Poor site characterization	3	4	4	4	4	3
3.4. Incorrect chemical mix released into fracking fluid	3	3	4	3	2	3
3.5. Cementation poorly undertaken (spaces left)	3	4	4	4	3	3
3.6. Well lining too limited, open hole left	2	3	3	3	2	3
3.7. Inappropriate management of drill cuttings and spent drilling muds.	2	2	2	2	2	2
3.8. Unlikely significant event	2	3	3	3	2	2



List of Processes

	<u>Relevance to Scenario</u>					
	<u>S1</u>	<u>S2</u>	<u>S3</u>	<u>S4</u>	<u>S5</u>	<u>S6</u>
1 Thermal effects on the borehole						
1.1. Thermal effects on borehole and seal integrity.	3	3	3	3	3	3
1.2. Thermal effects on the injection point	3	2	2	1	2	2
2 Hydraulics / Fluid Pressure Dominated						
2.1. Fluid pressure exceeds rock fracturing pressures generating new fractures	4	4	3	4	3	2
2.2. Fluid exceeds fault sealing pressures	4	4	3	4	2	2
2.3. Fluid pressure exceeds stability of part of the plant construction.	4	4	2	3	3	2
2.4. Displacement of surrounding formation fluids	3	4	3	4	4	3
2.5. Buoyancy-driven flow	3	4	3	4	4	4
2.6. Advection and co-migration of other gas	2	3	4	3	3	3
2.7. Formation of Gas hydrates	3	3	3	2	2	3
2.8. Water mediated transport	2	3	4	3	4	3
2.8.1. Advection	3	3	4	4	4	4
2.8.2. Dispersion	3	3	3	4	4	4
2.8.3. Diffusion	3	3	4	3	3	4
2.9. Hydraulic and production fluids and the associated contaminants release processes	3	3	4	4	4	4
3 Chemical						
3.1. Corrosive mixture attacks plant	3	3	4	3	2	2
3.2. Corrosive mixture attacks geology	3	3	4	3	3	3
3.3. Sorption and desorption	2	3	4	3	3	3
3.4. Mineral dissolution	3	3	4	4	3	3
3.5. Heavy metal release	2	3	4	4	3	3
4 Mechanical						
4.1. Soil and rock deformation around boreholes	4	4	2	4	2	3
4.1.1 Subsidence of ground related to gas extraction	3	3	3	3	3	3
4.2. Propagation of fractures beyond the target zone	4	4	4	5	3	3
4.3. Fluid exceeds fault sealing pressures	4	4	3	5	3	3
4.4. Fault valving	4	4	3	4	3	2
4.5. Generation of excavation disturbed zone around well	3	3	3	3	2	2
4.6. Micro-cracking in the casing cements	3	4	3	4	3	3

References

Krosnick, J.A. and Fabrigar L.R. (1997) "Designing rating scales for effective measurement in surveys". *In: (L. Lyberg, P. Biemer, M. Collins, E. de Leeuw, C. Dippo, N. Schwarz and D. Trewin, eds.) Survey measurement and process quality*. John Wiley and Sons, Inc., New York, NY. pp. 141–164.

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Appendix A – FEP appraisal tables from members of the project

The full appraisal tables are attached to this deliverable as Excel files.

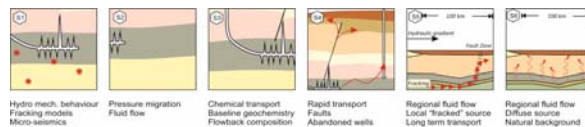
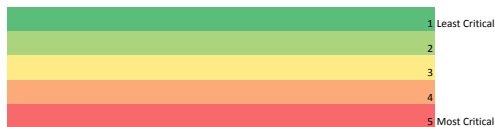




FracRisk
Reporting form for deliverables



Deliverable Number:	D4.1
Work package number:	4
Deliverable title	Ranked FEP list , Data Tables
Type	Report
Dissemination Level	PU
Lead participant	EWRE
Contributing scientists and other personnel	Hagit Wiener, Yoni Goren, Jacob Bensabat, Alexandru Tatomir, Katriona Edlmann, Christopher McDermott With data provided by most participants of the FracRisk project (www.fracrisk.eu).
Schedules delivery date from DOW	1/12/2015
Actual / forecast delivery data	6/01/2016
Comments (optional)	Click here to enter text.
Deliverable summary text:	<p>FEP Appraisal data tables, raw data</p> <p>The following tables have been anonymised as at this stage of the analysis the person // institution presenting the table is not of relevance.</p>
Submitted	06/01/2016
Reviewed	Click here to enter text.
Final submission	Click here to enter text.



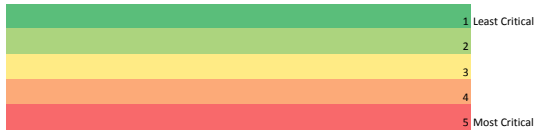
List of Features

A. Features of the Natural System

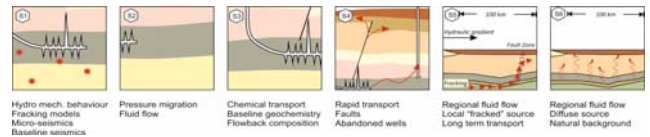
ID	Feature Name	Overall Importance In Risk Analysis	Relevance to Scenario						
			S1	S2	S3	S4	S5	S6	
1	Hydrogeology								
1.1	Hydrocarbon bearing formation (Source)								
1.1.1	Type of the hydrocarbon bearing formation	3	3	2	2	2	2	1	1
1.1.2	Geometry of the hydrocarbon bearing formation	2	2	2	2	2	2	2	2
1.1.2.1	Thickness	4	4	4	4	4	4	4	4
1.1.3	Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	4	4	4	4	4	4
1.1.3.1	Lithology	4	4	4	4	4	4	4	4
1.1.3.2	Diagenesis	3	3	3	3	3	3	3	3
1.1.3.3	Pore architecture	1	1	1	1	1	1	1	1
1.1.3.4	Mineralogy	3	1	1	3	1	1	1	3
1.1.3.5	Kerogen type	2	1	1	2	1	2	2	2
1.1.3.6	Thermal maturation of source rock	1	1	1	1	1	1	1	1
1.1.3.7	Porosity	4	2	2	4	3	3	3	3
1.1.3.8	Intrinsic permeability	4	4	4	4	4	4	4	4
1.1.3.9	Relative permeability	4	4	4	4	4	3	3	3
1.1.3.10	Entry pressure	5	4	5	5	5	3	3	3
1.1.3.11	Residual saturation	2	2	1	1	1	1	1	1
1.1.3.12	Hysteresis	2	2	1	1	1	1	1	1
1.1.4	Stress and Mechanical properties	5	5	1	1	1	1	3	3
1.1.5	Heterogeneity of the hydrocarbon bearing formation	5	3	4	4	5	4	4	4
1.1.6	Fractures and faults within the hydrocarbon bearing formation	4	4	4	4	4	2	2	2
1.1.6.1	Porosity of the fracture	4	2	2	4	4	4	2	2
1.1.6.2	Intrinsic permeability of the fracture	4	4	4	4	4	4	4	4
1.1.6.3	Relative Permeability of the fractures	4	4	4	4	4	3	3	3
1.1.6.4	Fracture geometry	4	4	4	4	4	2	2	2
1.1.7	Undetected features within the hydrocarbon bearing formation	2	2	2	2	2	2	2	2
1.1.8	Vertical geothermal gradient of the hydrocarbon bearing formation	3	1	1	1	1	3	3	3
1.1.9	Formation pressure of the hydrocarbon bearing formation	3	3	3	3	3	2	2	2
1.2	Fluids								
1.2.1	Hydrocarbons	2	2	2	2	1	1	1	1
1.2.2	Natural formation water	2	2	2	2	1	1	1	1
1.2.3	Production fluids	2	2	2	2	1	1	1	1
1.2.4	Pore fluid composition within the fracking reservoir	2	2	2	2	1	1	1	1
1.2.5	Reservoir fluids	2	2	2	2	2	2	2	2
1.2.6	Other fluids	2	2	2	2	2	2	2	2
1.3	Overburden								
1.3.1	Geometry of the overburden	4	4	1	3	1	3	3	3
1.3.1.1	Thickness	4	4	1	3	1	3	3	3
1.3.2	Rock / Petrophysical properties of the overburden	2	2	1	2	1	1	1	1
1.3.2.1	Lithology	2	2	1	2	1	2	2	2
1.3.2.2	Diagenesis	3	3	1	2	2	3	3	3
1.3.2.3	Pore architecture	1	1	1	1	1	1	1	1
1.3.2.4	Mineralogy	1	1	1	1	1	1	1	1
1.3.2.5	Porosity	2	2	2	2	2	2	2	2
1.3.2.6	Intrinsic permeability	2	2	2	2	2	2	2	2
1.3.2.7	Relative permeability	2	2	2	2	2	2	2	2
1.3.2.8	Entry pressure	1	1	1	1	1	1	1	1
1.3.2.9	Residual saturation	1	1	1	1	1	1	1	1
1.3.2.10	Hysteresis	1	1	1	1	1	1	1	1
1.3.3	Free gas pocket within the overburden	3	3	3	3	1	2	2	2
1.3.4	Additional seals within the overburden	1	1	1	1	1	1	1	1
1.3.5	Unconformities within the overburden	2	2	2	1	1	2	2	2
1.3.6	Heterogeneity within the overburden	2	2	2	2	2	2	2	2
1.3.7	Fractures and faults within the overburden	5	5	5	5	1	5	5	5
1.3.7.1	Porosity of the fracture	3	3	3	3	3	3	3	3
1.3.7.2	Intrinsic permeability of the fracture	2	2	2	2	2	2	2	2
1.3.7.3	Relative Permeability of the fractures	2	2	2	2	2	2	2	2
1.3.7.4	Fracture geometry	5	1	5	4	5	1	1	1
1.3.8	Undetected features within the overburden	4	1	2	4	2	1	1	1
1.3.9	Vertical geothermal gradient of the overburden	1	1	1	1	1	1	1	1
1.3.10	Formation "overburden" pressure	1	1	1	1	1	1	1	1
1.3.11	Overburden pressure	1	1	1	1	1	1	1	1
1.4	Underburden								
1.4.1	Geometry of the underburden	1	1	1	1	1	1	1	1
1.4.1.1	Thickness	1	1	1	1	1	1	1	1
1.4.2	Rock / Petrophysical properties of the underburden	2	2	2	2	2	2	2	2
1.4.2.1	Lithology	2	2	2	2	2	2	2	2
1.4.2.2	Diagenesis	1	1	1	1	1	1	1	1
1.4.2.3	Pore architecture	1	1	1	1	1	1	1	1
1.4.2.4	Mineralogy	2	2	2	2	2	2	2	2
1.4.2.5	Porosity	1	1	1	1	1	1	1	1
1.4.2.6	Intrinsic permeability	1	1	1	1	1	1	1	1
1.4.2.7	Relative permeability	1	1	1	1	1	1	1	1
1.4.2.8	Entry pressure	1	1	1	1	1	1	1	1
1.4.2.9	Residual saturation	1	1	1	1	1	1	1	1
1.4.2.10	Hysteresis	1	1	1	1	1	1	1	1
1.4.3	Unconformities within the underburden	1	1	1	1	1	1	1	1
1.4.4	Heterogeneity within the underburden	1	1	1	1	1	1	1	1
1.4.5	Fractures and faults within the underburden	1	1	1	1	1	1	1	1
1.4.6	Undetected features within the underburden	1	1	1	1	1	1	1	1
1.4.7	Vertical geothermal gradient within the underburden	2	2	2	2	2	2	2	2
1.4.8	Formation "underburden" pressure	1	1	1	1	1	1	1	1
2	Near surface environment (Receptors)								
2.1	Terrestrial environment								
2.1.1	Geographical location	3	1	1	1	1	3	3	3
2.1.2	Soils and sediments	4	1	1	1	3	4	4	4
2.1.3	Near-surface aquifers and surface water bodies	4	3	2	1	1	4	4	4
2.1.4	Terrestrial flora and fauna	1	1	1	1	1	1	1	1
2.1.5	Terrestrial ecological systems	1	1	1	1	1	1	1	1
2.1.6	Buildings	1	1	1	1	1	1	1	1
2.2	Marine environment								
2.2.1	Local oceanography	1	1	1	1	1	1	1	1
2.2.2	Marine sediments	1	1	1	1	1	1	1	1
2.2.3	Marine Stratification and Mixing	1	1	1	1	1	1	1	1
2.2.4	Marine flora and fauna	1	1	1	1	1	1	1	1
2.2.5	Marine ecological systems	1	1	1	1	1	1	1	1
2.3	Human Environment								
2.3.1	Human characteristics	1	1	1	1	1	1	1	1
2.3.2	Diet and food processing	1	1	1	1	1	1	1	1
2.3.3	Lifestyles	1	1	1	1	1	1	1	1
2.3.4	Land and water use	1	1	1	1	1	1	1	1
2.3.5	Community characteristics	1	1	1	1	1	1	1	1
2.4	Atmosphere and meteorology								

B. Unconventional Hydrocarbon Extraction

1	Hydro-fracturing fluid								
1.1	Hydraulic injection fluid properties	4	2	2	4	1	3	3	3
1.2	Physical properties of injection fluid								
1.2.1	Injection fluid additives	4	2	2	4	1	3	3	3
1.2.2	Hydro-fracturing fluids interactions	1	1	1	1	1	1	1	1
2	Site development								
2.1	Logistics above ground	1	1	1	1	1	1	1	1
2.2	Baseline monitoring	3	1	1	1	1	3	3	3
3	Site operation								
3.1	Drilling and completion								
3.1.1	Horizontal wells	5	5	5	5	5	1	1	1
3.1.2	Formation damage	4	4	4	4	4	2	2	2



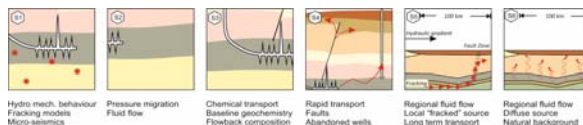
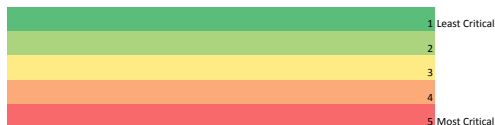
Importance



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	1	1	1	1	1	1	1
1.2 Thermal effects on the injection point	1	1	1	1	1	1	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	5	5	5	3	3
2.2 Fluid exceeds fault sealing pressures	5	5	5	5	5	3	3
2.3 Fluid pressure exceeds stability of part of the plant construction.	5	5	5	5	5	3	3
2.4 Displacement of surrounding formation fluids	5	5	5	5	5	3	3
2.5 Buoyancy-driven flow	5	5	5	5	5	3	3
2.6 Advection and co-migration of other gas	2	1	2	2	2	2	2
2.7 Formation of Gas hydrates	1	1	1	1	1	1	1
2.8 Water mediated transport	3	1	2	2	2	3	3
2.8.1 Advection	3	1	2	2	2	3	3
2.8.2 Dispersion	3	1	2	2	2	3	3
2.8.3 Diffusion	3	1	2	2	2	3	3
2.9 Hydraulic and production fluids and the associated contaminants release processes	1	1	1	1	1	1	1
3 Chemical							
3.1 Corrosive mixture attacks plant	1	1	1	1	1	1	1
3.2 Corrosive mixture attacks geology	1	1	1	1	1	1	1
3.3 Sorption and desorption	1	1	1	1	1	1	1
3.4 Mineral dissolution	1	1	1	1	1	1	1
3.5 Heavy metal release	1	1	1	1	1	1	1
4 Mechanical							
4.1 Soil and rock deformation around boreholes	4	3	3	3	4	2	2
4.1.1 Subsidence of ground related to gas extraction	1	1	1	1	1	1	1
4.2 Propagation of fractures beyond the target zone	5	5	5	5	5	4	4
4.3 Fluid exceeds fault sealing pressures	5	5	5	5	5	4	4
4.4 Fault valving	2	1	1	2	2	1	1
4.5 Generation of excavation disturbed zone around well	1	1	1	1	1	1	1
4.6 Micro-cracking in the casing cements	5	5	5	5	5	4	4

1	17	12	12	11	12	12
2	0	5	5	6	2	2
3	1	1	1	0	9	9
4	0	0	0	1	3	3
5	8	8	8	8	0	0



List of Features

A. Features of the Natural System

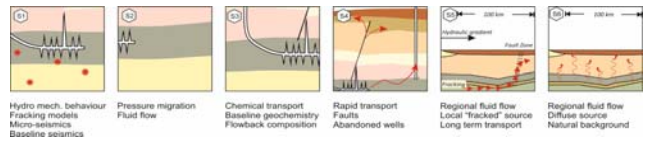
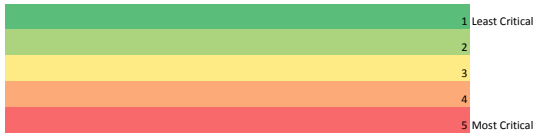
ID	Feature Name	Overall Importance In Risk Analysis	Relevance to Scenario					
			S1	S2	S3	S4	S5	S6
1	Hydrogeology							
1.1	Hydrocarbon bearing formation (Source)							
1.1.1	Type of the hydrocarbon bearing formation	2	2	2	2	2	2	2
1.1.2	Geometry of the hydrocarbon bearing formation	3	2	3	3	3	3	3
1.1.2.1	Thickness	3	2	3	3	3	3	3
1.1.3	Rock / Petrophysical properties of the hydrocarbon bearing formation	3	2	3	3	3	3	3
1.1.3.1	Lithology	3	2	3	3	3	3	3
1.1.3.2	Diagenesis	1	1	1	1	1	1	1
1.1.3.3	Pore architecture	3	2	2	3	3	3	3
1.1.3.4	Mineralogy	3	2	2	3	3	3	3
1.1.3.5	Kerogen type	3	1	1	3	3	3	3
1.1.3.6	Thermal maturation of source rock	1	1	1	1	1	1	1
1.1.3.7	Porosity	5	4	5	5	5	5	5
1.1.3.8	Intrinsic permeability	5	4	5	5	5	5	5
1.1.3.9	Relative permeability	5	4	5	5	5	5	5
1.1.3.10	Entry pressure	5	5	3	4	4	4	4
1.1.3.11	Residual saturation	1	1	1	1	1	1	1
1.1.3.12	Hysteresis	1	1	1	1	1	1	1
1.1.4	Stress and Mechanical properties	5	5	5	5	5	5	5
1.1.5	Heterogeneity of the hydrocarbon bearing formation	3	2	3	3	3	3	3
1.1.6	Fractures and faults within the hydrocarbon bearing formation	5	5	5	5	5	5	5
1.1.6.1	Porosity of the fracture	5	4	5	5	5	5	5
1.1.6.2	Intrinsic permeability of the fracture	5	4	5	5	5	5	5
1.1.6.3	Relative Permeability of the fractures	5	3	5	5	5	5	5
1.1.6.4	Fracture geometry	5	5	5	5	5	5	5
1.1.7	Undetected features within the hydrocarbon bearing formation	3	3	3	3	3	3	3
1.1.8	Vertical geothermal gradient of the hydrocarbon bearing formation	1	1	1	1	1	1	1
1.1.9	Formation pressure of the hydrocarbon bearing formation	3	3	3	3	3	3	3
1.2	Fluids							
1.2.1	Hydrocarbons	4	1	1	4	2	2	2
1.2.2	Natural formation water	4	1	1	4	2	2	2
1.2.3	Production fluids	4	1	1	4	2	2	2
1.2.4	Pore fluid composition within the fracking reservoir	4	1	1	4	2	2	2
1.2.5	Reservoir fluids	4	1	1	4	2	2	2
1.2.6	Other fluids	4	1	1	4	2	2	2
1.3	Overburden							
1.3.1	Geometry of the overburden	3	2	3	3	3	3	3
1.3.1.1	Thickness	3	2	3	3	3	3	3
1.3.2	Rock / Petrophysical properties of the overburden	2	2	2	2	2	1	1
1.3.2.1	Lithology	2	2	2	2	2	1	1
1.3.2.2	Diagenesis	2	2	2	2	2	1	1
1.3.2.3	Pore architecture	2	2	2	2	2	1	1
1.3.2.4	Mineralogy	2	2	2	2	2	1	1
1.3.2.5	Porosity	3	2	3	3	3	3	3
1.3.2.6	Intrinsic permeability	3	2	3	3	3	3	3
1.3.2.7	Relative permeability	3	2	3	3	3	3	3
1.3.2.8	Entry pressure	3	2	3	3	3	3	3
1.3.2.9	Residual saturation	3	1	1	1	3	3	3
1.3.2.10	Hysteresis	1	1	1	1	1	1	1
1.3.3	Free gas pocket within the overburden	3	1	3	3	3	2	2
1.3.4	Additional seals within the overburden	3	2	3	3	3	2	2
1.3.5	Unconformities within the overburden	3	2	3	3	3	3	3
1.3.6	Heterogeneity within the overburden	3	3	3	3	3	3	3
1.3.7	Fractures and faults within the overburden	3	3	3	3	3	3	3
1.3.7.1	Porosity of the fracture	3	3	3	3	3	3	3
1.3.7.2	Intrinsic permeability of the fracture	3	3	3	3	3	3	3
1.3.7.3	Relative Permeability of the fractures	3	3	3	3	3	3	3
1.3.7.4	Fracture geometry	3	3	3	3	3	3	3
1.3.8	Undetected features within the overburden	3	3	3	3	3	3	3
1.3.9	Vertical geothermal gradient of the overburden	1	1	1	1	1	1	1
1.3.10	Formation "overburden" pressure	3	3	3	3	3	3	3
1.3.11	Overburden pressure	4	4	4	4	4	4	4
1.4	Underburden							
1.4.1	Geometry of the underburden	1	1	1	1	1	1	1
1.4.1.1	Thickness	1	1	1	1	1	1	1
1.4.2	Rock / Petrophysical properties of the underburden	1	1	1	1	1	1	1
1.4.2.1	Lithology	1	1	1	1	1	1	1
1.4.2.2	Diagenesis	1	1	1	1	1	1	1
1.4.2.3	Pore architecture	1	1	1	1	1	1	1
1.4.2.4	Mineralogy	1	1	1	1	1	1	1
1.4.2.5	Porosity	1	1	1	1	1	1	1
1.4.2.6	Intrinsic permeability	1	1	1	1	1	1	1
1.4.2.7	Relative permeability	1	1	1	1	1	1	1
1.4.2.8	Entry pressure	1	1	1	1	1	1	1
1.4.2.9	Residual saturation	1	1	1	1	1	1	1
1.4.2.10	Hysteresis	1	1	1	1	1	1	1
1.4.3	Unconformities within the underburden	1	1	1	1	1	1	1
1.4.4	Heterogeneity within the underburden	1	1	1	1	1	1	1
1.4.5	Fractures and faults within the underburden	1	1	1	1	1	1	1
1.4.6	Undetected features within the underburden	1	1	1	1	1	1	1
1.4.7	Vertical geothermal gradient within the underburden	1	1	1	1	1	1	1
1.4.8	Formation "underburden" pressure	1	1	1	1	1	1	1
2	Near surface environment (Receptors)							
2.1	Terrestrial environment							
2.1.1	Geographical location							
2.1.2	Soils and sediments							
2.1.3	Near-surface aquifers and surface water bodies							
2.1.4	Terrestrial flora and fauna							
2.1.5	Terrestrial ecological systems							
2.1.6	Buildings							
2.2	Marine environment							
2.2.1	Local oceanography							
2.2.2	Marine sediments							
2.2.3	Marine Stratification and Mixing							
2.2.4	Marine flora and fauna							
2.2.5	Marine ecological systems							
2.3	Human Environment							
2.3.1	Human characteristics							
2.3.2	Diet and food processing							
2.3.3	Lifestyles							
2.3.4	Land and water use							
2.3.5	Community characteristics							
2.4	Atmosphere and meteorology							

B. Unconventional Hydrocarbon Extraction

1	Hydro-fracturing fluid							
1.1	Hydraulic injection fluid properties							
1.2	Physical properties of injection fluid							
1.2.1	Injection fluid additives							
1.2.2	Hydro-fracturing fluids interactions							
2	Site development							
2.1	Logistics above ground							
2.2	Baseline monitoring							
3	Site operation							
3.1	Drilling and completion							
3.1.1	Horizontal wells							
3.1.2	Formation damage							

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning**
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

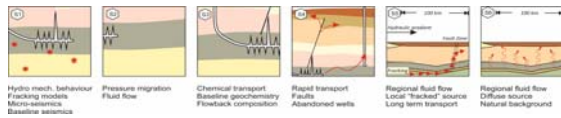
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3	11	22	27	28	26	26
4	6	1	8	2	2	2
5	4	9	9	9	9	9



List of Events

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	1	1	1	1	1	1	1
1.2. Initial drilling to given below water table (Open Hole)	1	1	1	1	1	1	1
1.2. Casing emplacement	1	1	1	1	1	1	1
1.2. Cementation with wiper plug	1	1	1	1	1	1	1
1.2. Drilling through wiper plug and casing shoe	1	1	1	1	1	1	1
1.2. Additional cementation	1	1	1	1	1	1	1
1.3. Logging Borehole	1	1	1	1	1	1	1
1.4. Drilling horizontal borehole	1	1	1	1	1	1	1
1.4. Casing horizontal borehole	1	1	1	1	1	1	1
1.4. Cementation	3	1	3	3	1	1	1
1.4. Perforation	2	2	2	1	1	1	1
1.5. Hydraulic fracturing	5	5	5	5	3	2	2
1.5. Out of zone / beyond pumping	5	4	5	5	5	5	5
1.6. Plugging & drilling out of plugs	1	1	1	1	1	1	1
1.7. Flow back	1	1	1	1	1	1	1
1.7. Production	1	1	1	1	1	1	1
1.8. Abandonment	1	1	1	1	1	1	1
1.9. Seal failure	1	1	1	1	1	1	1
2 Natural events							
2.1. Earthquakes	1	1	1	1	1	1	1
2.2. Large scale erosion	1	1	1	1	1	1	1
2.3. Hydrological and hydrogeological response to geological changes	1	1	1	1	1	1	1
2.4. Cap rock failure	2	1	1	1	2	2	2
2.5. Unexpected large scale scenario	1	1	1	1	1	1	1
3 Accidents and unplanned events							
3.1. Surface chemical spills	1	1	1	1	1	1	1
3.2. Overpressuring	5	5	5	5	5	5	5
3.3. Poor site characterization	3	3	3	3	3	3	3
3.4. Incorrect chemical mix released into fracking fluid	1	1	1	1	1	1	1
3.5. Cementation poorly undertaken (spaces left)	5	1	5	5	5	5	5
3.6. Well lining too limited, open hole left	5	1	5	5	5	5	5
3.7. Inappropriate management of drill cuttings and spent drilling muds.	1	1	1	1	1	1	1
3.8. Unlikely significant event	1	1	1	1	1	1	1
		26	0	0	0	0	0
		1	1	0	0	1	2
		1	2	2	2	2	1
		1	0	0	0	0	0
		2	5	5	5	4	4

1 Least Critical
2
3
4
5 Most Critical



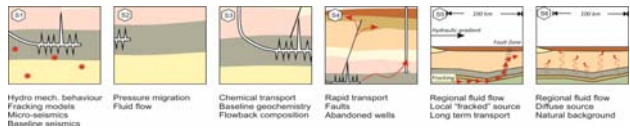
List of Features

A. Features of the Natural System

Overall Importance In Risk Analysis		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1	Hydrogeology						
1.1.	Hydrocarbon bearing formation (Source)						
1.1.1.	Type of the hydrocarbon bearing formation	4	5	5	5	2	2
1.1.2.	Geometry of the hydrocarbon bearing formation	3	4	4	3	1	1
1.1.2.1	Thickness	4	4	4	3	2	1
1.1.3.	Rock / Petrophysical properties of the hydrocarbon bearing formation	4	5	3	2	2	1
1.1.3.1	Lithology	3	4	2	1	1	1
1.1.3.2	Diagenesis	2	4	2	2	1	1
1.1.3.3	Pore architecture	3	4	2	3	1	1
1.1.3.4	Mineralogy	2	2	1	4	1	1
1.1.3.5	Kerogen type	1	1	1	1	1	1
1.1.3.6	Thermal maturation of source rock	1	1	1	1	1	1
1.1.3.7	Porosity	4	4	3	4	1	1
1.1.3.8	Intrinsic permeability	4	4	4	3	3	2
1.1.3.9	Relative permeability	4	4	4	4	3	2
1.1.3.10	Entry pressure	4	3	5	3	2	1
1.1.3.11	Residual saturation	2	3	3	2	1	1
1.1.3.12	Hysteresis	2	2	2	1	1	1
1.1.4.	Stress and Mechanical properties	4	5	3	2	1	1
1.1.5.	Heterogeneity of the hydrocarbon bearing formation	5	5	4	3	2	1
1.1.6.	Fractures and faults within the hydrocarbon bearing formation	5	5	5	5	3	2
1.1.6.1	Porosity of the fracture	5	4	4	5	1	1
1.1.6.2	Intrinsic permeability of the fracture	5	5	5	5	2	1
1.1.6.3	Relative Permeability of the fractures	4	5	4	4	2	2
1.1.6.4	Fracture geometry	5	5	5	4	3	2
1.1.7.	Undetected features within the hydrocarbon bearing formation	5	5	5	5	2	2
1.1.8.	Vertical geothermal gradient of the hydrocarbon bearing formation	5	5	2	5	4	2
1.1.9.	Formation pressure of the hydrocarbon bearing formation	5	5	2	4	3	2
1.2.	Fluids						
1.2.1.	Hydrocarbons	5	2	3	5	1	2
1.2.2.	Natural formation water	5	2	2	5	4	4
1.2.3.	Production fluids	5	2	2	5	1	1
1.2.4.	Pore fluid composition within the fracking reservoir	5	2	2	5	4	4
1.2.5.	Reservoir fluids	5	2	2	5	4	4
1.2.6.	Other fluids	4	2	2	4	2	2
1.3.	Overburden						
1.3.1.	Geometry of the overburden	2	1	2	2	2	2
1.3.1.1	Thickness	5	3	4	3	5	5
1.3.2.	Rock / Petrophysical properties of the overburden	4	2	3	4	4	4
1.3.2.1	Lithology	3	1	1	4	2	2
1.3.2.2	Diagenesis	3	1	1	4	2	2
1.3.2.3	Pore architecture	3	1	1	4	2	2
1.3.2.4	Mineralogy	1	1	1	4	2	2
1.3.2.5	Porosity	5	3	3	5	5	5
1.3.2.6	Intrinsic permeability	5	3	3	5	5	5
1.3.2.7	Relative permeability	5	2	3	4	3	5
1.3.2.8	Entry pressure	5	2	3	4	5	3
1.3.2.9	Residual saturation	5	1	2	3	5	3
1.3.2.10	Hysteresis	1	1	1	1	2	2
1.3.3.	Free gas pocket within the overburden	5	1	1	5	4	3
1.3.4.	Additional seals within the overburden	5	1	1	1	5	4
1.3.5.	Unconformities within the overburden	3	1	3	1	2	2
1.3.6.	Heterogeneity within the overburden	5	1	3	1	3	5
1.3.7.	Fractures and faults within the overburden	5	1	5	4	5	5
1.3.7.1	Porosity of the fracture	5	1	2	4	5	3
1.3.7.2	Intrinsic permeability of the fracture	5	1	2	4	5	3
1.3.7.3	Relative Permeability of the fractures	5	1	2	4	5	3
1.3.7.4	Fracture geometry	5	1	5	4	5	3
1.3.8.	Undetected features within the overburden	5	1	2	4	5	5
1.3.9.	Vertical geothermal gradient of the overburden	5	1	2	4	5	4
1.3.10.	Formation 'overburden' pressure	5	1	2	4	5	4
1.3.11.	Overburden pressure	5	1	2	4	5	3
1.4.	Underburden						
1.4.1.	Geometry of the underburden	1	1	1	1	1	1
1.4.1.1	Thickness	4	3	4	3	1	1
1.4.2.	Rock / Petrophysical properties of the underburden	3	3	3	2	1	1
1.4.2.1	Lithology	2	2	2	3	1	1
1.4.2.2	Diagenesis	2	2	2	3	1	1
1.4.2.3	Pore architecture	2	1	1	3	1	1
1.4.2.4	Mineralogy	2	1	1	3	1	1
1.4.2.5	Porosity	4	3	3	4	1	1
1.4.2.6	Intrinsic permeability	5	4	4	4	1	1
1.4.2.7	Relative permeability	2	2	3	2	1	1
1.4.2.8	Entry pressure	3	2	3	2	1	1
1.4.2.9	Residual saturation	3	1	3	2	1	1
1.4.2.10	Hysteresis	1	1	1	1	1	1
1.4.3.	Unconformities within the underburden	1	1	1	1	1	1
1.4.4.	Heterogeneity within the underburden	2	2	2	2	1	1
1.4.5.	Fractures and faults within the underburden	2	2	2	1	1	1
1.4.6.	Undetected features within the underburden	2	2	2	2	1	1
1.4.7.	Vertical geothermal gradient within the underburden	2	2	2	2	1	1
1.4.8.	Formation 'underburden' pressure	2	2	2	2	1	1
2	Near surface environment (Receptors)						
2.1.	Terrestrial environment						
2.1.1.	Geographical location	4	1	1	1	3	4
2.1.2.	Soils and sediments	3	1	1	1	3	4
2.1.3.	Near-surface aquifers and surface water bodies	4	1	1	1	4	5
2.1.4.	Terrestrial flora and fauna	3	1	1	1	1	1
2.1.5.	Terrestrial ecological systems	2	1	1	1	1	1
2.1.6.	Buildings	2	1	1	1	1	1
2.2.	Marine environment						
2.2.1.	Local oceanography	2	1	1	1	1	1
2.2.2.	Marine sediments	3	1	1	1	1	1
2.2.3.	Marine Stratification and Mixing	3	1	1	1	1	1
2.2.4.	Marine flora and fauna	1	1	1	1	1	1
2.2.5.	Marine ecological systems	2	1	1	1	1	1
2.3.	Human Environment						
2.3.1.	Human characteristics	4	1	1	1	1	1
2.3.2.	Diet and food processing	2	1	1	1	1	1
2.3.3.	Lifestyles	1	1	1	1	1	1
2.3.4.	Land and water use	3	1	1	1	1	1
2.3.5.	Community characteristics	3	1	1	1	1	1
2.4.	Atmosphere and meteorology						
1	Hydro-fracturing fluid						
1.1.	Hydraulic injection fluid properties	4	4	3	4	2	2
1.2.	Physical properties of injection fluid						
1.2.1.	Injection fluid additives	5	2	3	5	3	3
1.2.2.	Hydro-fracturing fluids interactions	4	3	2	3	1	1
2	Site development						
2.1.	Logistics above ground	3	3	3	3	4	4
2.2.	Baseline monitoring	4	4	4	3	3	3
3	Site operation						
3.1.	Drilling and completion						
3.1.1.	Horizontal wells	5	4	5	3	3	2
3.1.2.	Formation damage	5	5	5	3	3	2
3.1.3.	Well lining and completion	5	1	1	1	1	1
3.1.4.	Workover	5	3	1	3	1	1
3.1.5.	Monitoring wells	5	1	1	1	1	1
3.1.6.	Well records	5	1	1	1	1	1
3.1.7.	Well orientation	5	5	3	2	1	1
3.1.8.	Well engineering	5	1	1	1	1	1
4	Site decommissioning						
4.1.	Closure and sealing of boreholes		3	4	3	4	5
4.2.	Abandoned wells		1	2	2	5	4
			1	50	36	52	60
			2	20	28	16	20
			3	13	22	14	10
			4	13	12	10	10
			5	12	10	14	12

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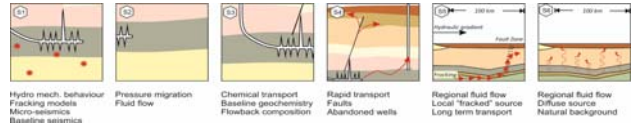
1 Least Critical
2
3
4
5 Most Critical



List of Events

		Relevance to Scenario						
		S1	S2	S3	S4	S5	S6	
1 Operational Events								
1.1. Multiple well drilling from same platform	4	2	2	2	3	2	2	
1.2. Initial drilling to given below water table (Open Hole)	4	3	4	4	4	4	4	
1.2. Casing emplacement	2	2	2	2	1	1	1	
1.2. Cementation with wiper plug	4	1	1	1	1	1	1	
1.2. Drilling through wiper plug and casing shoe	1	1	1	1	1	1	1	
1.2. Additional cementation	5	1	1	1	1	1	1	
1.3. Logging Borehole	1	1	1	1	1	1	1	
1.4. Drilling horizontal borehole	3	2	3	3	1	1	1	
1.4. Casing horizontal borehole	3	2	3	3	1	1	1	
1.4. Cementation	3	2	3	3	1	1	1	
1.4. Perforation	5	4	4	3	2	1	1	
1.5. Hydraulic fracturing	5	5	5	5	4	3	2	
1.5. Out of zone / beyond pumping	5	5	5	5	5	5	4	
1.6. Plugging & drilling out of plugs	4	1	1	1	1	1	1	
1.7. Flow back	4	1	3	4	3	4	3	
1.7. Production	5	2	5	5	2	2	1	
1.8. Abandonment	5	1	1	1	1	1	1	
1.9. Seal failure	5	5	5	5	5	5	5	
2 Natural events								
2.1. Earthquakes	4	1	1	1	1	1	1	
2.2. Large scale erosion	4	1	1	1	1	1	1	
2.3. Hydrological and hydrogeological response to geological changes	4	3	4	3	3	3	3	
2.4. Cap rock failure	5	1	1	1	1	1	1	
2.5. Unexpected large scale scenario	5	1	1	1	1	1	1	
3 Accidents and unplanned events								
3.1. Surface chemical spills	1	1	1	1	1	1	1	
3.2. Overpressuring	4	3	4	4	4	3	2	
3.3. Poor site characterization	4	3	4	4	4	3	3	
3.4. Incorrect chemical mix released into fracking fluid	5	3	3	5	3	3	3	
3.5. Cementation poorly undertaken (spaces left)	3	1	1	1	3	3	3	
3.6. Well lining too limited, open hole left	3	1	1	1	3	3	3	
3.7. Inappropriate management of drill cuttings and spent drilling muds.	3	1	1	1	1	3	1	
3.8. Unlikely significant event	5	3	5	5	5	3	3	
		1	15	14	14	16	16	18
		2	6	2	2	2	2	3
		3	6	5	5	6	9	7
		4	1	5	4	4	2	2
		5	3	5	6	3	2	1

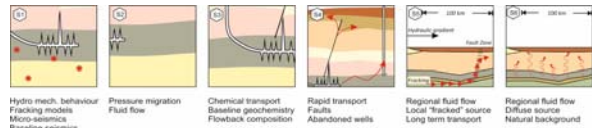
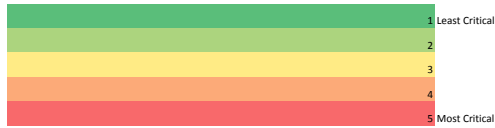
- 1 Least Critical
 - 2
 - 3
 - 4
 - 5 Most Critical
- Importance



List of Processes

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1	Thermal effects on the borehole						
1.1.	Thermal effects on borehole and seal integrity.	4	4	2	3	2	1
1.2.	Thermal effects on the injection point	4	4	2	3	2	1
2	Hydraulics / Fluid Pressure Dominated						
2.1.	Fluid pressure exceeds rock fracturing pressures generating new fractures	1	5	2	2	1	1
2.2.	Fluid exceeds fault sealing pressures	5	5	4	3	3	2
2.3.	Fluid pressure exceeds stability of part of the plant construction.	4	5	4	4	4	3
2.4.	Displacement of surrounding formation fluids	5	5	3	5	4	2
2.5.	Buoyancy-driven flow	5	2	3	3	5	4
2.6.	Advection and co-migration of other gas	3	2	2	3	2	2
2.7.	Formation of Gas hydrates	2	5	3	3	3	3
2.8.	Water mediated transport	5	2	4	5	5	5
2.8.1.	Advection	5	2	4	5	5	5
2.8.2.	Dispersion	5	4	4	5	5	5
2.8.3.	Diffusion	5	1	2	5	2	5
2.9.	Hydraulic and production fluids and the associated contaminants release processes	5	1	1	5	1	1
3	Chemical						
3.1	Corrosive mixture attacks plant	3	1	1	5	1	1
3.2	Corrosive mixture attacks geology	3	1	2	5	2	2
3.3	Sorption and desorption	5	1	2	5	2	3
3.4	Mineral dissolution	3	1	2	5	2	2
3.5	Heavy metal release	4	1	2	5	3	2
4	Mechanical						
4.1	Soil and rock deformation around boreholes	3	5	3	2	2	1
4.1.1	Subsidence of ground related to gas extraction	1	1	1	1	1	1
4.2	Propagation of fractures beyond the target zone	5	5	5	5	4	3
4.3	Fluid exceeds fault sealing pressures	5	5	5	4	5	3
4.4	Fault valving	5	5	5	3	5	3
4.5	Generation of excavation disturbed zone around well	5	5	5	4	1	1
4.6	Micro-cracking in the casing cements	1	1	1	1	1	1

1	9	4	2	5	9	9
2	4	9	2	9	5	6
3	0	3	8	3	3	6
4	3	5	3	1	4	0
5	10	5	11	8	5	5



List of Features

A. Features of the Natural System

Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	5	5	3	3	3	4
1.1.2 Geometry of the hydrocarbon bearing formation	4	4	1	3	4	3
1.1.2.1 Thickness	4	4	1	3	4	3
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	1	3	4	3
1.1.3.1 Lithology	5	5	2	4	4	5
1.1.3.2 Diagenesis	4	2	4	4	4	2
1.1.3.3 Pore architecture	4	2	2	3	2	3
1.1.3.4 Mineralogy	4	1	3	4	4	3
1.1.3.5 Kerogen type	5	1	2	5	4	3
1.1.3.6 Thermal maturation of source rock	4	1	2	4	3	3
1.1.3.7 Porosity	3	2	3	3	2	3
1.1.3.8 Intrinsic permeability	4	3	4	4	4	2
1.1.3.9 Relative permeability	5	1	3	2	5	2
1.1.3.10 Entry pressure	5	2	2	1	5	2
1.1.3.11 Residual saturation	2	1	1	1	2	2
1.1.3.12 Hysteresis	2	1	1	1	2	2
1.1.4 Stress and Mechanical properties	4	3	4	1	2	2
1.1.5 Heterogeneity of the hydrocarbon bearing formation	3	2	3	2	3	2
1.1.6 Fractures and faults within the hydrocarbon bearing formation	4	3	4	2	4	2
1.1.6.1 Porosity of the fracture	3	2	3	1	3	3
1.1.6.2 Intrinsic permeability of the fracture	4	3	4	1	4	2
1.1.6.3 Relative Permeability of the fractures	5	1	3	1	5	2
1.1.6.4 Fracture geometry	5	2	4	1	4	3
1.1.7 Undetected features within the hydrocarbon bearing formation	5	2	5	3	5	4
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	3	1	2	3	2	3
1.1.9 Formation pressure of the hydrocarbon bearing formation	2	2	2	2	2	2
1.2 Fluids						
1.2.1 Hydrocarbons	4	2	2	4	3	3
1.2.2 Natural formation water	5	2	3	5	4	3
1.2.3 Production fluids	4	3	4	4	3	3
1.2.4 Pore fluid composition within the fracking reservoir	4	2	3	4	3	2
1.2.5 Reservoir fluids	4	2	2	4	3	2
1.2.6 Other fluids	4	2	2	4	2	2
1.3 Overburden						
1.3.1 Geometry of the overburden	3	2	3	1	3	3
1.3.1.1 Thickness	4	2	3	1	3	4
1.3.2 Rock / Petrophysical properties of the overburden	3	2	3	1	3	3
1.3.2.1 Lithology	4	2	4	3	4	4
1.3.2.2 Diagenesis	5	1	2	4	5	2
1.3.2.3 Pore architecture	3	1	3	2	2	3
1.3.2.4 Mineralogy	4	1	2	4	3	3
1.3.2.5 Porosity	4	2	2	2	4	3
1.3.2.6 Intrinsic permeability	4	2	4	1	4	2
1.3.2.7 Relative permeability	5	1	2	1	5	2
1.3.2.8 Entry pressure	2	1	1	1	1	2
1.3.2.9 Residual saturation	2	1	1	1	2	2
1.3.2.10 Hysteresis	3	1	1	1	3	2
1.3.3 Free gas pocket within the overburden	3	2	2	2	3	3
1.3.4 Additional seals within the overburden	3	2	3	2	3	3
1.3.5 Unconformities within the overburden	4	2	4	1	3	2
1.3.6 Heterogeneity within the overburden	4	2	4	1	3	2
1.3.7 Fractures and faults within the overburden	5	2	5	2	4	2
1.3.7.1 Porosity of the fracture	3	1	2	3	4	2
1.3.7.2 Intrinsic permeability of the fracture	4	2	3	2	3	2
1.3.7.3 Relative Permeability of the fractures	5	2	2	2	4	2
1.3.7.4 Fracture geometry	5	2	5	2	5	3
1.3.8 Undetected features within the overburden	5	1	3	4	5	3
1.3.9 Vertical geothermal gradient of the overburden	3	2	3	3	2	2
1.3.10 Formation "overburden" pressure	4	1	4	2	2	2
1.3.11 Overburden pressure	5	1	2	2	5	2
1.4 Underburden						
1.4.1 Geometry of the underburden	2	1	1	1	2	2
1.4.1.1 Thickness	3	1	1	1	2	3
1.4.2 Rock / Petrophysical properties of the underburden	3	1	2	3	2	3
1.4.2.1 Lithology	4	2	3	4	4	3
1.4.2.2 Diagenesis	4	1	2	4	2	2
1.4.2.3 Pore architecture	3	1	2	2	3	3
1.4.2.4 Mineralogy	4	1	2	4	4	2
1.4.2.5 Porosity	4	1	2	2	4	3
1.4.2.6 Intrinsic permeability	3	2	3	1	3	2
1.4.2.7 Relative permeability	4	1	1	1	3	2
1.4.2.8 Entry pressure	2	1	1	1	2	2
1.4.2.9 Residual saturation	2	1	2	1	2	2
1.4.2.10 Hysteresis	3	1	3	1	2	1
1.4.3 Unconformities within the underburden	3	2	2	2	3	3
1.4.4 Heterogeneity within the underburden	3	1	2	2	3	3
1.4.5 Fractures and faults within the underburden	3	2	3	2	3	3
1.4.6 Undetected features within the underburden	3	1	2	3	3	3
1.4.7 Vertical geothermal gradient within the underburden	3	1	2	3	2	2
1.4.8 Formation "underburden" pressure	3	1	2	2	3	2
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	4	1	2	3	4	2
2.1.2 Soils and sediments	4	2	3	4	3	3
2.1.3 Near-surface aquifers and surface water bodies	5	3	4	5	5	4
2.1.4 Terrestrial flora and fauna	4	2	3	4	4	3
2.1.5 Terrestrial ecological systems	4	2	3	4	4	3
2.1.6 Buildings	4	1	2	4	4	3
2.2 Marine environment						
2.2.1 Local oceanography	3	1	2	3	3	2
2.2.2 Marine sediments	4	2	3	4	3	2
2.2.3 Marine Stratification and Mixing	3	2	3	3	3	3
2.2.4 Marine flora and fauna	4	2	3	4	3	3
2.2.5 Marine ecological systems	4	1	2	4	3	3
2.3 Human Environment						
2.3.1 Human characteristics	3	1	2	3	2	2
2.3.2 Diet and food processing	4	1	2	4	4	3
2.3.3 Lifestyles	3	2	3	2	2	1
2.3.4 Land and water use	5	2	3	5	4	3
2.3.5 Community characteristics	3	1	2	3	3	2
2.4 Atmosphere and meteorology						

B. Unconventional Hydrocarbon Extraction

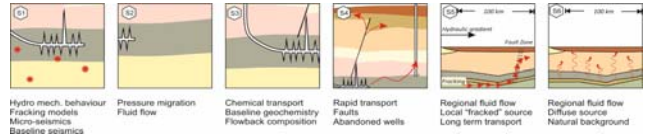
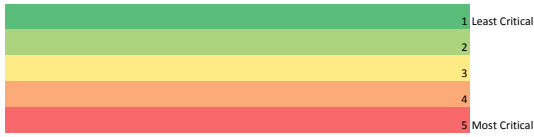
1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties						
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	5	5	4	5	3	3
1.2.2 Hydro-fracturing fluids interactions	5	5	4	5	3	3
2 Site development						
2.1 Logistics above ground	3	3	2	2	2	1
2.2 Baseline monitoring	4	3	2	4	2	1
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	4	4	3	2	3	2
3.1.2 Formation damage	4	4	3	2	3	2

- 3.1.3. Well lining and completion 4
- 3.1.4. Workover 3
- 3.1.5. Monitoring wells 4
- 3.1.6. Well records 3
- 3.1.7. Well orientation 4
- 3.1.8. Well engineering 4
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes 3
- 4.2. Abandoned wells 3

4
3
4
3
4
4
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3

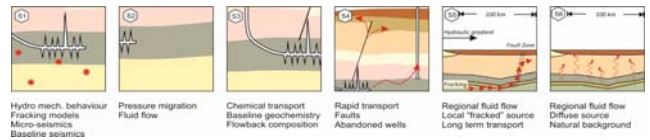
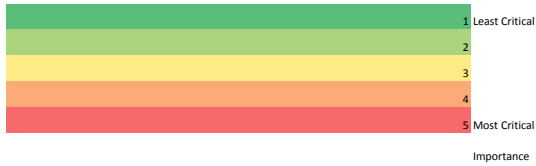
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4	3	2	2	2	2
3	2	2	3	2	3
2	2	3	3	3	3

1	43	9	27	4	5	6
2	43	41	33	22	39	46
3	13	35	17	50	41	49
4	5	17	24	22	16	5
5	3	5	6	9	6	1



List of Events

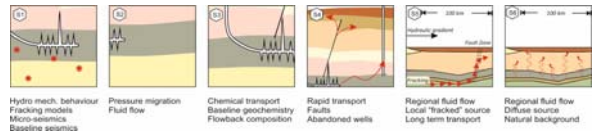
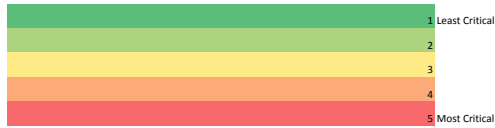
		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	4	4	3	3	3	2	2
1.2. Initial drilling to given below water table (Open Hole)	4	3	4	4	4	2	2
1.2. Casing emplacement	4	3	4	3	2	2	3
1.2. Cementation with wiper plug	4	4	4	4	2	2	2
1.2. Drilling through wiper plug and casing shoe	3	3	3	3	3	2	2
1.2. Additional cementation	4	4	4	3	2	3	2
1.3. Logging Borehole	4	3	4	2	4	3	2
1.4. Drilling horizontal borehole	4	2	3	3	2	4	4
1.4. Casing horizontal borehole	4	2	3	3	2	4	4
1.4. Cementation	4	3	3	3	1	3	4
1.4. Perforation	4	4	2	1	3	4	2
1.5. Hydraulic fracturing	5	5	3	2	4	3	3
1.5. Out of zone / beyond pumping	4	3	2	3	4	2	2
1.6. Plugging & drilling out of plugs	3	2	3	1	2	2	2
1.7. Flow back	4	1	3	3	3	4	3
1.7. Production	4	3	4	4	2	3	4
1.8. Abandonment	4	3	4	3	2	3	4
1.9. Seal failure	4	4	3	3	2	3	3
2 Natural events							
2.1. Earthquakes	5	4	5	2	3	3	3
2.2. Large scale erosion	4	4	4	4	4	4	4
2.3. Hydrological and hydrogeological response to geological changes	5	3	4	5	5	5	4
2.4. Cap rock failure	5	4	5	3	5	4	3
2.5. Unexpected large scale scenario	5	3	5	5	5	3	2
3 Accidents and unplanned events							
3.1. Surface chemical spills	5	2	2	5	3	3	4
3.2. Overpressuring	4	4	3	3	3	2	2
3.3. Poor site characterization	5	4	4	5	5	4	4
3.4. Incorrect chemical mix released into fracking fluid	5	3	4	5	4	3	5
3.5. Cementation poorly undertaken (spaces left)	4	4	3	4	3	3	4
3.6. Well lining too limited, open hole left	3	3	3	3	3	2	3
3.7. Inappropriate management of drill cuttings and spent drilling muds.	3	3	3	3	3	2	2
3.8. Unlikely significant event	5	5	5	5	5	5	5
		1	0	2	1	0	0
		2	3	3	8	9	12
		3	13	15	11	13	7
		4	11	11	5	7	10
		5	2	4	6	5	2



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	4	4	2	2	3	3	1
1.2 Thermal effects on the injection point	3	3	1	2	1	2	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	4	2	3	3	1
2.2 Fluid exceeds fault sealing pressures	5	5	4	2	3	1	1
2.3 Fluid pressure exceeds stability of part of the plant construction.	5	5	5	2	2	1	1
2.4 Displacement of surrounding formation fluids	5	5	5	3	4	4	3
2.5 Buoyancy-driven flow	5	5	5	2	5	5	3
2.6 Advection and co-migration of other gas	5	3	4	4	5	5	2
2.7 Formation of Gas hydrates	4	3	3	4	3	3	4
2.8 Water mediated transport	5	4	4	4	4	5	3
2.8.1 Advection	5	5	4	3	5	5	2
2.8.2 Dispersion	5	4	4	4	5	5	3
2.8.3 Diffusion	5	3	3	5	3	5	5
2.9 Hydraulic and production fluids and the associated contaminants release processes	5	5	3	5	5	5	5
3 Chemical							
3.1 Corrosive mixture attacks plant	5	2	1	5	3	3	2
3.2 Corrosive mixture attacks geology	5	1	2	5	5	4	4
3.3 Sorption and desorption	5	1	2	5	5	5	5
3.4 Mineral dissolution	5	2	2	5	5	5	5
3.5 Heavy metal release	5	1	3	5	5	5	5
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	1	2	1	2
4.1.1 Subsidence of ground related to gas extraction	5	4	5	3	3	2	2
4.2 Propagation of fractures beyond the target zone	5	5	5	2	4	2	1
4.3 Fluid exceeds fault sealing pressures	5	5	5	1	4	2	1
4.4 Fault valving	5	5	5	2	3	2	3
4.5 Generation of excavation disturbed zone around well	5	5	5	2	4	1	2
4.6 Micro-cracking in the casing cements	5	5	4	2	5	2	4

1	3	2	2	1	4	7
2	2	4	10	2	6	6
3	5	4	3	8	4	5
4	3	7	4	5	2	3
5	13	9	7	10	10	5



List of Features

A. Features of the Natural System

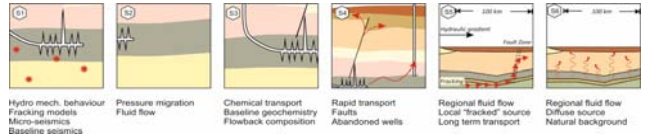
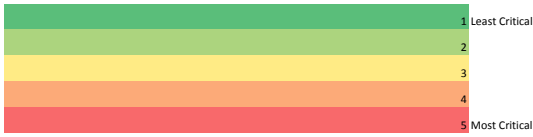
ID	Feature Name	Overall Importance In Risk Analysis	Relevance to Scenario					
			S1	S2	S3	S4	S5	S6
1	Hydrogeology							
1.1	Hydrocarbon bearing formation (Source)							
1.1.1	Type of the hydrocarbon bearing formation	3	5	2	3	3	1	1
1.1.2	Geometry of the hydrocarbon bearing formation	4	5	3	4	2	4	4
1.1.2.1	Thickness	2	3	4	1	1	5	5
1.1.3	Rock / Petrophysical properties of the hydrocarbon bearing formation	4	5	3	2	3	2	5
1.1.3.1	Lithology	5	5	3	5	4	2	5
1.1.3.2	Diagenesis	3	5	3	1	3	4	2
1.1.3.3	Pore architecture	5	1	5	3	3	1	3
1.1.3.4	Mineralogy	5	2	1	1	5	5	4
1.1.3.5	Kerogen type	5	3	3	3	3	3	3
1.1.3.6	Thermal maturation of source rock	4	3	1	1	3	5	4
1.1.3.7	Porosity	5	4	1	1	3	5	4
1.1.3.8	Intrinsic permeability	4	3	2	2	1	4	4
1.1.3.9	Relative permeability	5	5	4	4	5	5	4
1.1.3.10	Entry pressure	4	2	1	4	2	3	4
1.1.3.11	Residual saturation	2	4	1	3	3	2	4
1.1.3.12	Hysteresis	4	4	4	1	4	4	1
1.1.4	Stress and Mechanical properties	4	4	3	3	4	2	1
1.1.5	Heterogeneity of the hydrocarbon bearing formation	5	4	5	3	2	1	4
1.1.6	Fractures and faults within the hydrocarbon bearing formation	5	5	5	4	4	2	3
1.1.6.1	Porosity of the fracture	5	5	5	1	4	4	3
1.1.6.2	Intrinsic permeability of the fracture	5	2	4	5	2	1	1
1.1.6.3	Relative Permeability of the fractures	5	1	1	1	1	5	2
1.1.6.4	Fracture geometry	5	3	4	4	5	1	1
1.1.7	Undetected features within the hydrocarbon bearing formation	5	1	2	2	1	5	1
1.1.8	Vertical geothermal gradient of the hydrocarbon bearing formation	4	1	1	1	4	2	2
1.1.9	Formation pressure of the hydrocarbon bearing formation	4	3	4	2	4	2	1
1.2	Fluids							
1.2.1	Hydrocarbons	5	3	1	4	1	5	1
1.2.2	Natural formation water	5	3	1	2	5	3	3
1.2.3	Production fluids	4	4	4	2	3	4	1
1.2.4	Pore fluid composition within the fracking reservoir	4	1	4	4	2	4	1
1.2.5	Reservoir fluids	4	1	4	2	1	1	2
1.2.6	Other fluids	5	5	4	2	5	4	2
1.3	Overburden							
1.3.1	Geometry of the overburden	4	4	4	4	3	2	3
1.3.1.1	Thickness	5	3	5	5	5	2	2
1.3.2	Rock / Petrophysical properties of the overburden	5	2	4	3	5	3	5
1.3.2.1	Lithology	5	3	1	2	5	4	2
1.3.2.2	Diagenesis	4	1	3	4	4	2	1
1.3.2.3	Pore architecture	5	1	4	5	5	4	5
1.3.2.4	Mineralogy	5	3	1	3	5	2	1
1.3.2.5	Porosity	5	4	1	3	5	5	3
1.3.2.6	Intrinsic permeability	4	1	1	3	2	4	3
1.3.2.7	Relative permeability	5	1	1	3	3	5	4
1.3.2.8	Entry pressure	5	3	3	5	4	5	1
1.3.2.9	Residual saturation	5	2	3	1	2	5	5
1.3.2.10	Hysteresis	5	5	4	3	2	1	4
1.3.3	Free gas pocket within the overburden	4	1	4	3	1	2	1
1.3.4	Additional seals within the overburden	4	1	1	4	2	2	1
1.3.5	Unconformities within the overburden	5	3	4	4	2	5	1
1.3.6	Heterogeneity within the overburden	4	4	4	4	4	2	1
1.3.7	Fractures and faults within the overburden	5	4	3	5	1	1	2
1.3.7.1	Porosity of the fracture	5	5	1	2	4	3	5
1.3.7.2	Intrinsic permeability of the fracture	5	5	5	5	1	1	3
1.3.7.3	Relative Permeability of the fractures	4	4	1	4	2	2	4
1.3.7.4	Fracture geometry	4	1	1	4	2	2	4
1.3.8	Undetected features within the overburden	5	5	1	2	5	4	3
1.3.9	Vertical geothermal gradient within the overburden	5	5	5	1	1	1	4
1.3.10	Formation "overburden" pressure	5	3	3	5	2	2	4
1.3.11	Overburden pressure	5	5	3	1	1	2	1
1.4	Underburden							
1.4.1	Geometry of the underburden	5	4	5	3	3	4	2
1.4.1.1	Thickness	5	3	4	3	5	3	5
1.4.2	Rock / Petrophysical properties of the underburden	5	4	1	2	2	2	3
1.4.2.1	Lithology	5	5	1	4	5	3	1
1.4.2.2	Diagenesis	5	5	5	3	4	4	1
1.4.2.3	Pore architecture	5	1	2	4	4	3	5
1.4.2.4	Mineralogy	5	1	2	3	5	2	5
1.4.2.5	Porosity	4	1	1	1	4	3	4
1.4.2.6	Intrinsic permeability	4	2	4	3	3	2	1
1.4.2.7	Relative permeability	5	3	4	5	4	3	2
1.4.2.8	Entry pressure	5	1	4	3	4	5	3
1.4.2.9	Residual saturation	4	3	1	2	4	1	2
1.4.2.10	Hysteresis	4	1	4	3	3	1	1
1.4.3	Unconformities within the underburden	5	2	4	4	3	3	5
1.4.4	Heterogeneity within the underburden	5	5	2	5	2	4	3
1.4.5	Fractures and faults within the underburden	5	4	3	4	5	5	2
1.4.6	Undetected features within the underburden	5	3	1	1	5	1	4
1.4.7	Vertical geothermal gradient within the underburden	5	5	4	3	4	4	1
1.4.8	Formation "underburden" pressure	3	5	4	5	1	3	4
2	Near surface environment (Receptors)							
2.1	Terrestrial environment							
2.1.1	Geographical location	4	1	1	4	4	3	2
2.1.2	Soils and sediments	3	2	2	2	5	2	2
2.1.3	Near-surface aquifers and surface water bodies	4	1	1	5	2	5	5
2.1.4	Terrestrial flora and fauna	2	2	2	5	5	3	1
2.1.5	Terrestrial ecological systems	2	5	5	3	3	4	3
2.1.6	Buildings	3	1	1	4	1	1	4
2.2	Marine environment							
2.2.1	Local oceanography	2	4	2	2	1	1	1
2.2.2	Marine sediments	3	3	4	4	5	3	1
2.2.3	Marine Stratification and Mixing	3	2	4	1	3	5	2
2.2.4	Marine flora and fauna	2	1	1	1	2	5	3
2.2.5	Marine ecological systems	4	5	2	4	5	1	4
2.3	Human Environment							
2.3.1	Human characteristics	3	5	4	5	1	4	5
2.3.2	Diet and food processing	1	3	1	1	3	4	5
2.3.3	Lifestyles	2	2	5	2	5	4	2
2.3.4	Land and water use	3	5	1	5	4	4	1
2.3.5	Community characteristics	2	3	3	2	1	5	1
2.4	Atmosphere and meteorology							
			2	3	1	1	3	1
			1	3	4	1	2	1
			5	5	4	4	4	4
			4	4	3	2	2	2
1.2	Physical properties of injection fluid							
1.2.1	Injection fluid additives	4	3	2	2	3	5	3
1.2.2	Hydro-fracturing fluids interactions	4	5	2	2	4	2	2
2	Site development							
2.1	Logistics above ground	5	5	3	5	1	1	2
2.2	Baseline monitoring	5	5	2	1	2	2	5
3	Site operation							
3.1	Drilling and completion							
3.1.1	Horizontal wells	5	1	3	1	1	3	3
3.1.2	Formation damage	5	3	3	4	2	2	5

B. Unconventional Hydrocarbon Extraction

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

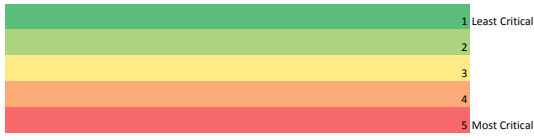
5	3	5	2	4	2	2
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4	5	4	3	5	2	4
3	2	5	3	4	1	5
4	5	3	3	2	2	5
5	3	3	5	3	5	1
4	5	5	1	1	4	2
4	4	3	1	4	5	3

1	24	30	22	24	19	31
2	13	14	19	21	30	21
3	26	24	25	21	18	18
4	18	28	26	23	23	23
5	31	16	20	23	22	19

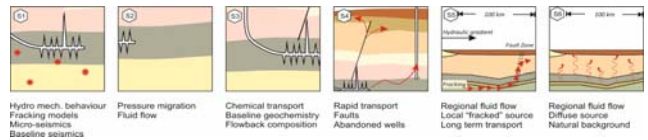


List of Events

		Relevance to Scenario						
		S1	S2	S3	S4	S5	S6	
1 Operational Events								
1.1. Multiple well drilling from same platform	4	4	4	3	3	2	4	
1.2. Initial drilling to given below water table (Open Hole)	5	4	5	4	4	4	4	
1.2. Casing emplacement	5	4	4	3	2	3	5	
1.2. Cementation with wiper plug	5	3	4	3	3	4	5	
1.2. Drilling through wiper plug and casing shoe	5	4	4	3	4	5	5	
1.2. Additional cementation	5	3	5	3	2	4	5	
1.3. Logging Borehole	5	4	5	5	4	5	5	
1.4. Drilling horizontal borehole	3	3	3	3	2	4	4	
1.4. Casing horizontal borehole	5	4	3	3	2	4	4	
1.4. Cementation	4	4	3	3	1	3	4	
1.4. Perforation	4	3	3	1	2	1	1	
1.5. Hydraulic fracturing	5	2	2	2	1	3	2	
1.5. Out of zone / beyond pumping	5	4	1	3	4	5	5	
1.6. Plugging & drilling out of plugs	4	4	2	1	2	2	3	
1.7. Flow back	4	4	2	3	3	4	3	
1.7. Production	5	3	5	4	5	3	3	
1.8. Abandonment	5	3	4	5	5	4	3	
1.9. Seal failure	5	3	5	4	5	3	3	
2 Natural events								
2.1. Earthquakes	5	5	4	3	5	3	3	
2.2. Large scale erosion	3	3	5	4	4	3	3	
2.3. Hydrological and hydrogeological response to geological changes	5	3	3	5	5	5	3	
2.4. Cap rock failure	4	4	5	4	3	3	3	
2.5. Unexpected large scale scenario	3	3	4	5	5	4	3	
3 Accidents and unplanned events								
3.1. Surface chemical spills	5	4	4	5	5	3	3	
3.2. Overpressuring	5	5	3	5	3	4	3	
3.3. Poor site characterization	5	3	5	4	5	3	3	
3.4. Incorrect chemical mix released into fracking fluid	5	3	5	3	5	2	3	
3.5. Cementation poorly undertaken (spaces left)	5	4	4	5	2	3	3	
3.6. Well lining too limited, open hole left	5	5	5	5	4	4	3	
3.7. Inappropriate management of drill cuttings and spent drilling muds.	4	3	4	4	5	3	3	
3.8. Unlikely significant event	3	3	5	3	5	5	3	
		1	0	1	2	2	1	1
		2	1	3	1	7	3	1
		3	14	6	13	5	12	18
		4	13	10	7	6	10	5
		5	3	11	8	11	5	6



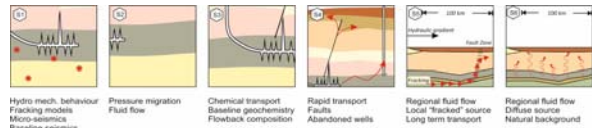
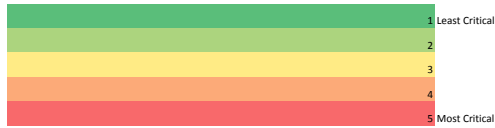
Importance



List of Processes

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1.	Thermal effects on borehole and seal integrity.	5	4	2	1	2	5
1.2.	Thermal effects on the injection point	5	4	5	5	2	3
2 Hydraulics / Fluid Pressure Dominated							
2.1.	Fluid pressure exceeds rock fracking pressures generating new fractures	5	1	1	2	4	5
2.2.	Fluid exceeds fault sealing pressures	4	3	4	4	1	3
2.3.	Fluid pressure exceeds stability of part of the plant construction.	5	3	4	1	2	5
2.4.	Displacement of surrounding formation fluids	5	1	4	4	2	5
2.5.	Buoyancy-driven flow	3	1	4	5	4	5
2.6.	Advection and co-migration of other gas	5	4	4	3	5	5
2.7.	Formation of Gas hydrates	4	5	5	3	3	3
2.8.	Water mediated transport	5	1	5	5	2	5
2.8.1.	Advection	5	4	5	3	3	5
2.8.2.	Dispersion	5	4	3	4	4	5
2.8.3.	Diffusion	5	4	5	4	5	4
2.9.	Hydraulic and production fluids and the associated contaminants release processes	5	1	4	4	5	4
3 Chemical							
3.1.	Corrosive mixture attacks plant	5	4	5	1	3	3
3.2.	Corrosive mixture attacks geology	3	4	2	5	3	5
3.3.	Sorption and desorption	5	1	2	5	3	4
3.4.	Mineral dissolution	5	5	1	1	5	5
3.5.	Heavy metal release	4	1	4	4	4	4
4 Mechanical							
4.1.	Soil and rock deformation around boreholes	5	5	1	1	1	3
4.1.1.	Subsidence of ground related to gas extraction	5	5	4	3	3	5
4.2.	Propagation of fractures beyond the target zone	5	4	5	3	5	3
4.3.	Fluid exceeds fault sealing pressures	5	2	2	2	4	3
4.4.	Fault valving	4	2	2	5	2	3
4.5.	Generation of excavation disturbed zone around well	5	1	1	5	4	5
4.6.	Micro-cracking in the casing cements	5	2	5	1	5	4

1	8	5	6	2	0	4
2	3	5	2	6	0	3
3	2	0	6	6	10	6
4	9	8	5	6	5	4
5	4	8	7	6	11	9



List of Features

A. Features of the Natural System

ID	Feature Name	Overall Importance In Risk Analysis	Relevance to Scenario						
			S1	S2	S3	S4	S5	S6	
1	Hydrogeology								
1.1	Hydrocarbon bearing formation (Source)								
1.1.1	Type of the hydrocarbon bearing formation	3	3	1	1	2	1	1	1
1.1.2	Geometry of the hydrocarbon bearing formation	3	2	3	3	3	1	1	1
1.1.2.1	Thickness	4	4	4	4	4	2	2	2
1.1.3	Rock / Petrophysical properties of the hydrocarbon bearing formation	3	3	2	2	3	3	3	3
1.1.3.1	Lithology	3	3	2	2	3	3	3	3
1.1.3.2	Diagenesis	3	3	3	3	3	3	3	3
1.1.3.3	Pore architecture	1	1	1	1	1	1	1	1
1.1.3.4	Mineralogy	3	1	1	3	1	1	1	1
1.1.3.5	Kerogen type	3	1	1	3	1	1	1	1
1.1.3.6	Thermal maturation of source rock	1	1	1	1	1	1	1	1
1.1.3.7	Porosity	3	2	2	3	3	3	3	3
1.1.3.8	Intrinsic permeability	3	3	4	4	4	4	4	4
1.1.3.9	Relative permeability	4	3	4	4	4	4	3	3
1.1.3.10	Entry pressure	5	5	5	5	4	4	4	4
1.1.3.11	Residual saturation	1	1	1	1	1	1	1	1
1.1.3.12	Hysteresis	1	1	1	1	1	1	1	1
1.1.4	Stress and Mechanical properties	4	4	2	2	2	2	3	3
1.1.5	Heterogeneity of the hydrocarbon bearing formation	5	2	3	3	5	4	4	4
1.1.6	Fractures and faults within the hydrocarbon bearing formation	5	2	3	3	5	4	4	4
1.1.6.1	Porosity of the fracture	4	2	2	4	4	2	2	2
1.1.6.2	Intrinsic permeability of the fracture	4	2	4	4	4	4	4	4
1.1.6.3	Relative Permeability of the fractures	4	2	4	4	4	3	3	3
1.1.6.4	Fracture geometry	5	3	3	3	5	2	2	2
1.1.7	Undetected features within the hydrocarbon bearing formation	2	2	2	2	2	2	2	2
1.1.8	Vertical geothermal gradient of the hydrocarbon bearing formation	2	1	2	2	2	2	2	2
1.1.9	Formation pressure of the hydrocarbon bearing formation	3	2	3	3	3	2	2	2
1.2	Fluids								
1.2.1	Hydrocarbons	2	1	2	2	1	1	1	1
1.2.2	Natural formation water	2	1	2	2	1	1	1	1
1.2.3	Production fluids	2	1	2	2	1	1	1	1
1.2.4	Pore fluid composition within the fracking reservoir	2	1	2	2	1	1	1	1
1.2.5	Reservoir fluids	2	1	2	2	1	1	1	1
1.2.6	Other fluids	2	1	2	2	1	1	1	1
1.3	Overburden								
1.3.1	Geometry of the overburden	4	4	1	3	1	3	3	3
1.3.1.1	Thickness	4	4	1	3	1	3	3	3
1.3.2	Rock / Petrophysical properties of the overburden	2	2	1	2	1	1	1	1
1.3.2.1	Lithology	2	2	1	2	2	2	2	2
1.3.2.2	Diagenesis	3	3	1	2	2	3	3	3
1.3.2.3	Pore architecture	1	1	1	1	1	1	1	1
1.3.2.4	Mineralogy	1	1	1	1	1	1	1	1
1.3.2.5	Porosity	2	2	2	2	2	2	2	2
1.3.2.6	Intrinsic permeability	2	2	2	2	2	2	2	2
1.3.2.7	Relative permeability	2	2	2	2	2	2	2	2
1.3.2.8	Entry pressure	1	1	1	1	1	1	1	1
1.3.2.9	Residual saturation	1	1	1	1	1	1	1	1
1.3.2.10	Hysteresis	1	1	1	1	1	1	1	1
1.3.3	Free gas pocket within the overburden	3	3	3	3	1	2	2	2
1.3.4	Additional seals within the overburden	1	1	1	1	1	1	1	1
1.3.5	Unconformities within the overburden	2	2	2	1	1	2	2	2
1.3.6	Heterogeneity within the overburden	2	2	2	2	2	2	2	2
1.3.7	Fractures and faults within the overburden	5	5	5	5	1	5	5	5
1.3.7.1	Porosity of the fracture	3	3	3	3	3	3	3	3
1.3.7.2	Intrinsic permeability of the fracture	2	2	2	2	2	2	2	2
1.3.7.3	Relative Permeability of the fractures	2	2	2	2	2	2	2	2
1.3.7.4	Fracture geometry	5	1	5	4	5	1	1	1
1.3.8	Undetected features within the overburden	4	1	2	4	2	1	1	1
1.3.9	Vertical geothermal gradient of the overburden	1	1	1	1	1	1	1	1
1.3.10	Formation "overburden" pressure	1	1	1	1	1	1	1	1
1.3.11	Overburden pressure	1	1	1	1	1	1	1	1
1.4	Underburden								
1.4.1	Geometry of the underburden	1	1	1	1	1	1	1	1
1.4.1.1	Thickness	1	1	1	1	1	1	1	1
1.4.2	Rock / Petrophysical properties of the underburden	2	2	2	2	2	2	2	2
1.4.2.1	Lithology	2	2	2	2	2	2	2	2
1.4.2.2	Diagenesis	1	1	1	1	1	1	1	1
1.4.2.3	Pore architecture	1	1	1	1	1	1	1	1
1.4.2.4	Mineralogy	2	2	2	2	2	2	2	2
1.4.2.5	Porosity	1	1	1	1	1	1	1	1
1.4.2.6	Intrinsic permeability	1	1	1	1	1	1	1	1
1.4.2.7	Relative permeability	1	1	1	1	1	1	1	1
1.4.2.8	Entry pressure	1	1	1	1	1	1	1	1
1.4.2.9	Residual saturation	1	1	1	1	1	1	1	1
1.4.2.10	Hysteresis	1	1	1	1	1	1	1	1
1.4.3	Unconformities within the underburden	1	1	1	1	1	1	1	1
1.4.4	Heterogeneity within the underburden	1	1	1	1	1	1	1	1
1.4.5	Fractures and faults within the underburden	1	1	1	1	1	1	1	1
1.4.6	Undetected features within the underburden	1	1	1	1	1	1	1	1
1.4.7	Vertical geothermal gradient within the underburden	2	2	2	2	2	2	2	2
1.4.8	Formation "underburden" pressure	1	1	1	1	1	1	1	1
2	Near surface environment (Receptors)								
2.1	Terrestrial environment								
2.1.1	Geographical location	3	1	1	1	1	3	3	3
2.1.2	Soils and sediments	4	1	1	1	3	4	4	4
2.1.3	Near-surface aquifers and surface water bodies	4	3	2	1	1	4	4	4
2.1.4	Terrestrial flora and fauna	1	1	1	1	1	1	1	1
2.1.5	Terrestrial ecological systems	1	1	1	1	1	1	1	1
2.1.6	Buildings	1	1	1	1	1	1	1	1
2.2	Marine environment								
2.2.1	Local oceanography	1	1	1	1	1	1	1	1
2.2.2	Marine sediments	1	1	1	1	1	1	1	1
2.2.3	Marine Stratification and Mixing	1	1	1	1	1	1	1	1
2.2.4	Marine flora and fauna	1	1	1	1	1	1	1	1
2.2.5	Marine ecological systems	1	1	1	1	1	1	1	1
2.3	Human Environment								
2.3.1	Human characteristics	1	1	1	1	1	1	1	1
2.3.2	Diet and food processing	1	1	1	1	1	1	1	1
2.3.3	Lifestyles	1	1	1	1	1	1	1	1
2.3.4	Land and water use	1	1	1	1	1	1	1	1
2.3.5	Community characteristics	1	1	1	1	1	1	1	1
2.4	Atmosphere and meteorology								

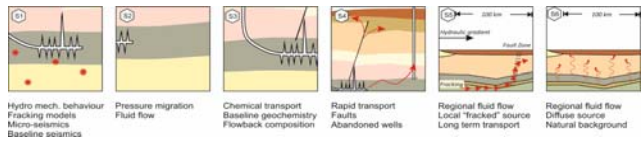
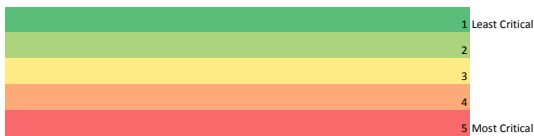
B. Unconventional Hydrocarbon Extraction

1	Hydro-fracturing fluid								
1.1	Hydraulic injection fluid properties	4	2	2	4	1	3	3	3
1.2	Physical properties of injection fluid								
1.2.1	Injection fluid additives	4	2	2	4	1	3	3	3
1.2.2	Hydro-fracturing fluids interactions	1	1	1	1	1	1	1	1
2	Site development								
2.1	Logistics above ground	1	1	1	1	1	1	1	1
2.2	Baseline monitoring	3	1	1	1	1	3	3	3
3	Site operation								
3.1	Drilling and completion								
3.1.1	Horizontal wells	5	5	5	5	5	1	1	1
3.1.2	Formation damage	4	4	4	4	4	2	2	2

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

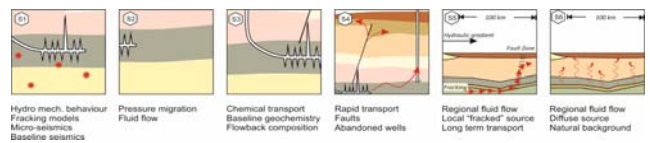
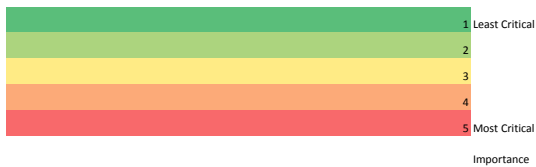
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5	4	4	4	4	5	5
5	4	4	4	4	5	5
5	4	4	4	4	5	5
1	1	1	1	1	1	1
4	4	4	4	4	2	2
4	4	4	4	4	2	2

1	60	57	52	65	60	60
2	24	27	23	18	23	23
3	10	8	13	8	14	14
4	11	12	17	12	7	7
5	3	4	3	5	4	4



List of Events

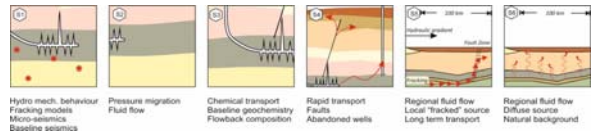
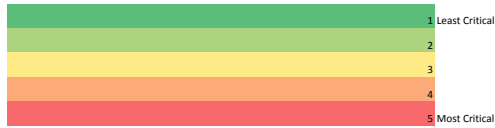
		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	5	3	4	3	5	2	2
1.2. Initial drilling to given below water table (Open Hole)	4	3	4	4	4	2	2
1.2. Casing emplacement	4	3	3	3	4	2	2
1.2. Cementation with wiper plug	4	1	1	1	4	1	1
1.2. Drilling through wiper plug and casing shoe	3	3	3	3	3	2	2
1.2. Additional cementation	3	1	1	1	3	1	1
1.3. Logging Borehole	3	1	1	1	3	1	1
1.4. Drilling horizontal borehole	3	3	3	3	2	2	2
1.4. Casing horizontal borehole	4	3	3	3	4	2	2
1.4. Cementation	4	1	1	1	4	1	1
1.4. Perforation	3	3	3	3	3	2	2
1.5. Hydraulic fracturing	5	5	5	5	5	2	2
1.5. Out of zone / beyond pumping	4	1	1	1	4	4	4
1.6. Plugging & drilling out of plugs	1	1	1	1	1	1	1
1.7. Flow back	4	2	2	2	4	2	2
1.7. Production	5	2	2	2	5	2	2
1.8. Abandonment	5	2	2	2	5	2	2
1.9. Seal failure	5	2	2	2	5	2	2
2 Natural events							
2.1. Earthquakes	5	5	5	5	5	3	3
2.2. Large scale erosion	3	3	3	3	3	3	3
2.3. Hydrological and hydrogeological response to geological changes	2	2	2	2	2	2	2
2.4. Cap rock failure	5	4	5	5	5	3	3
2.5. Unexpected large scale scenario	3	3	3	3	3	3	3
3 Accidents and unplanned events							
3.1. Surface chemical spills	3	1	1	1	1	3	3
3.2. Overpressuring	4	4	4	4	4	3	3
3.3. Poor site characterization	4	3	3	3	3	4	4
3.4. Incorrect chemical mix released into fracking fluid	5	2	2	5	2	2	2
3.5. Cementation poorly undertaken (spaces left)	3	2	3	3	3	1	1
3.6. Well lining too limited, open hole left	1	1	1	1	1	1	1
3.7. Inappropriate management of drill cuttings and spent drilling muds.	1	1	1	1	1	1	1
3.8. Unlikely significant event	1	1	1	1	1	1	1
		10	10	10	5	9	9
		7	6	5	3	14	14
		10	9	10	8	6	6
		2	3	2	8	2	2
		2	3	4	7	0	0



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	4	3	2	4	2	2	2
1.2 Thermal effects on the injection point	2	2	1	2	1	1	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	3	4	3	5	2	2
2.2 Fluid exceeds fault sealing pressures	5	4	4	4	5	3	3
2.3 Fluid pressure exceeds stability of part of the plant construction.	1	1	1	1	1	1	1
2.4 Displacement of surrounding formation fluids	3	1	1	1	3	3	3
2.5 Buoyancy-driven flow	3	1	1	1	3	3	3
2.6 Advection and co-migration of other gas	4	3	3	4	3	2	2
2.7 Formation of Gas hydrates	3	1	1	3	3	2	2
2.8 Water mediated transport	4	2	2	2	4	3	3
2.8.1 Advection	4	2	2	2	4	4	4
2.8.2 Dispersion	4	2	4	3	4	4	4
2.8.3 Diffusion	5	2	2	5	1	1	1
2.9 Hydraulic and production fluids and the associated contaminants release processes	4	1	1	4	4	4	4
3 Chemical							
3.1 Corrosive mixture attacks plant	5	5	5	5	2	2	2
3.2 Corrosive mixture attacks geology	5	5	5	5	2	2	2
3.3 Sorption and desorption	5	5	5	5	2	2	2
3.4 Mineral dissolution	5	5	5	5	2	2	2
3.5 Heavy metal release	5	5	5	5	2	2	2
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	5	5	4	4
4.1.1 Subsidence of ground related to gas extraction	5	5	5	5	5	4	4
4.2 Propagation of fractures beyond the target zone	5	4	4	4	5	4	4
4.3 Fluid exceeds fault sealing pressures	5	4	4	4	5	3	3
4.4 Fault valving	5	4	4	4	5	2	2
4.5 Generation of excavation disturbed zone around well	4	4	4	4	3	2	2
4.6 Micro-cracking in the casing cements	3	3	3	3	2	1	1

1	5	6	3	3	4	4
2	4	4	2	7	11	11
3	5	2	5	5	5	5
4	5	7	8	4	6	6
5	7	7	8	7	0	0



List of Features

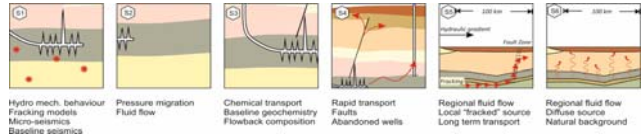
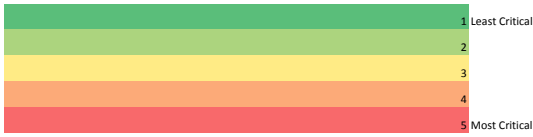
A. Features of the Natural System

Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	2	1	2	2	1	2
1.1.2 Geometry of the hydrocarbon bearing formation	3	3	2	1	1	3
1.1.2.1 Thickness	4	3	3	3	4	3
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	5	5	3	1	5	5
1.1.3.1 Lithology	3	3	1	2	1	1
1.1.3.2 Diagenesis	2	2	1	2	1	1
1.1.3.3 Pore architecture	3	2	2	3	3	3
1.1.3.4 Mineralogy	4	3	1	4	3	3
1.1.3.5 Kerogen type	1	1	1	1	1	1
1.1.3.6 Thermal maturation of source rock	3	1	1	1	1	3
1.1.3.7 Porosity	4	1	2	4	2	2
1.1.3.8 Intrinsic permeability	4	3	3	4	2	4
1.1.3.9 Relative permeability	5	2	1	5	5	4
1.1.3.10 Entry pressure	5	1	5	5	5	3
1.1.3.11 Residual saturation	1	1	1	1	1	1
1.1.3.12 Hysteresis	1	1	1	1	1	1
1.1.4 Stress and Mechanical properties	4	4	1	1	2	2
1.1.5 Heterogeneity of the hydrocarbon bearing formation	4	3	2	4	3	4
1.1.6 Fractures and faults within the hydrocarbon bearing formation	6	4	4	5	3	5
1.1.6.1 Porosity of the fracture	5	4	4	5	4	4
1.1.6.2 Intrinsic permeability of the fracture	2	1	1	2	2	2
1.1.6.3 Relative Permeability of the fractures	4	1	3	1	4	3
1.1.6.4 Fracture geometry	2	1	1	2	2	2
1.1.7 Undetected features within the hydrocarbon bearing formation	4	3	3	3	3	4
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	1	1	1	1	1	1
1.1.9 Formation pressure of the hydrocarbon bearing formation	4	2	4	4	4	3
1.2 Fluids						
1.2.1 Hydrocarbons	5	2	2	5	1	5
1.2.2 Natural formation water	4	1	2	4	1	1
1.2.3 Production fluids	5	1	5	5	2	2
1.2.4 Pore fluid composition within the fracking reservoir	5	1	3	5	4	4
1.2.5 Reservoir fluids	5	2	2	5	1	3
1.2.6 Other fluids	3	1	1	3	2	2
1.3 Overburden						
1.3.1 Geometry of the overburden	3	3	3	1	1	1
1.3.1.1 Thickness	3	3	3	1	2	1
1.3.2 Rock / Petrophysical properties of the overburden	4	4	2	2	2	2
1.3.2.1 Lithology	1	1	1	1	1	1
1.3.2.2 Diagenesis	5	2	1	5	2	3
1.3.2.3 Pore architecture	4	1	1	2	2	4
1.3.2.4 Mineralogy	3	1	1	3	1	2
1.3.2.5 Porosity	3	3	3	2	1	3
1.3.2.6 Intrinsic permeability	1	1	1	1	1	1
1.3.2.7 Relative permeability	2	1	1	2	1	1
1.3.2.8 Entry pressure	3	1	2	3	3	2
1.3.2.9 Residual saturation	1	1	1	1	1	1
1.3.2.10 Hysteresis	3	1	1	1	3	2
1.3.3 Free gas pocket within the overburden	3	3	3	1	2	2
1.3.4 Additional seals within the overburden	3	1	1	1	1	2
1.3.5 Unconformities within the overburden	4	2	4	2	1	2
1.3.6 Heterogeneity within the overburden	4	3	4	1	4	3
1.3.7 Fractures and faults within the overburden	5	3	3	3	5	4
1.3.7.1 Porosity of the fracture	4	1	3	4	4	3
1.3.7.2 Intrinsic permeability of the fracture	3	1	1	3	3	1
1.3.7.3 Relative Permeability of the fractures	4	1	2	3	4	3
1.3.7.4 Fracture geometry	3	1	3	2	3	1
1.3.8 Undetected features within the overburden	5	1	2	5	3	4
1.3.9 Vertical geothermal gradient within the overburden	3	1	3	3	3	2
1.3.10 Formation "overburden" pressure	5	4	4	5	4	3
1.3.11 Overburden pressure	4	3	3	3	3	2
1.4 Underburden						
1.4.1 Geometry of the underburden	4	3	3	3	4	3
1.4.1.1 Thickness	1	1	1	1	1	1
1.4.2 Rock / Petrophysical properties of the underburden	3	3	2	2	3	2
1.4.2.1 Lithology	3	3	1	1	2	2
1.4.2.2 Diagenesis	5	1	1	5	3	2
1.4.2.3 Pore architecture	3	2	3	3	3	3
1.4.2.4 Mineralogy	3	1	2	3	3	3
1.4.2.5 Porosity	2	1	2	2	2	1
1.4.2.6 Intrinsic permeability	1	1	1	1	1	1
1.4.2.7 Relative permeability	1	1	1	1	1	1
1.4.2.8 Entry pressure	1	1	1	1	1	1
1.4.2.9 Residual saturation	5	1	2	5	4	2
1.4.2.10 Hysteresis	4	1	2	4	4	3
1.4.3 Unconformities within the underburden	3	1	3	2	3	1
1.4.4 Heterogeneity within the underburden	3	1	3	3	2	1
1.4.5 Fractures and faults within the underburden	4	3	3	4	3	3
1.4.6 Undetected features within the underburden	3	3	2	3	2	1
1.4.7 Vertical geothermal gradient within the underburden	4	1	1	4	3	3
1.4.8 Formation "underburden" pressure	4	3	3	3	3	2
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	5	5	3	3	3	3
2.1.2 Soils and sediments	5	5	4	5	3	3
2.1.3 Near-surface aquifers and surface water bodies	5	3	4	5	3	2
2.1.4 Terrestrial flora and fauna						
2.1.5 Terrestrial ecological systems	1	1	1	1	1	1
2.1.6 Buildings	5	3	3	5	2	1
2.2 Marine environment						
2.2.1 Local oceanography	4	4	4	4	3	3
2.2.2 Marine sediments	4	4	3	3	2	2
2.2.3 Marine Stratification and Mixing	5	4	3	5	2	3
2.2.4 Marine flora and fauna						
2.2.5 Marine ecological systems	5	1	1	5	1	1
2.3 Human Environment						
2.3.1 Human characteristics	1	1	1	1	1	1
2.3.2 Diet and food processing	1	1	1	1	1	1
2.3.3 Lifestyles	1	1	1	1	1	1
2.3.4 Land and water use	5	5	1	1	1	1
2.3.5 Community characteristics	3	3	1	1	1	1
2.4 Atmosphere and meteorology						
B. Unconventional Hydrocarbon Extraction						
1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties						
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	4	4	2	4	3	3
1.2.2 Hydro-fracturing fluids interactions	5	4	3	5	4	3
2 Site development						
2.1 Logistics above ground	4	1	1	1	1	1
2.2 Baseline monitoring	4	4	2	2	2	2
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	4	4	3	4	3	3
3.1.2 Formation damage	5	3	5	4	4	4

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
 - 4.1. Closure and sealing of boreholes
 - 4.2. Abandoned wells

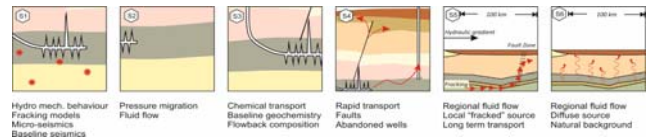
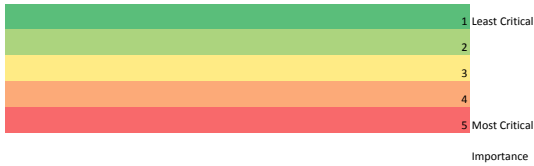
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4	4	1	4	3	3	2
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5	5	3	4	4	3	4

1	49	41	32	34	32	38
2	9	21	15	20	30	23
3	24	27	18	26	29	26
4	13	9	17	16	8	12
5	7	4	20	6	3	3



List of Events

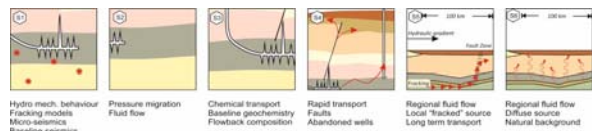
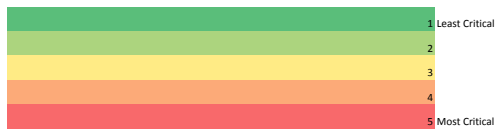
		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	5	5	4	5	4	4	4
1.2. Initial drilling to given below water table (Open Hole)	5	4	4	5	4	3	4
1.2. Casing emplacement	4	3	4	4	3	4	4
1.2. Cementation with wiper plug	4	4	4	4	3	4	4
1.2. Drilling through wiper plug and casing shoe	5	2	4	3	2	5	5
1.2. Additional cementation	4	2	4	3	3	4	4
1.3. Logging Borehole	2	2	2	2	2	2	2
1.4. Drilling horizontal borehole	4	4	4	4	4	4	4
1.4. Casing horizontal borehole	1	3	3	3	4	4	4
1.4. Cementation	3	3	3	1	2	3	3
1.4. Perforation	5	5	5	5	5	5	5
1.5. Hydraulic fracturing	5	4	5	3	3	3	3
1.5. Out of zone / beyond pumping	4	1	2	4	2	2	2
1.6. Plugging & drilling out of plugs	3	1	2	2	2	3	3
1.7. Flow back	3	1	2	3	3	2	3
1.7. Production	5	5	3	5	4	4	5
1.8. Abandonment	5	1	4	4	4	4	5
1.9. Seal failure	4	1	4	4	4	4	4
2 Natural events							
2.1. Earthquakes	4	4	4	3	2	1	1
2.2. Large scale erosion	3	3	1	2	1	1	1
2.3. Hydrological and hydrogeological response to geological changes	5	3	5	5	5	3	3
2.4. Cap rock failure	5	3	4	5	4	4	4
2.5. Unexpected large scale scenario	5	1	5	5	5	2	2
3 Accidents and unplanned events							
3.1. Surface chemical spills	5	1	4	5	5	1	1
3.2. Overpressuring	5	3	5	4	5	3	4
3.3. Poor site characterization	5	5	5	5	5	5	5
3.4. Incorrect chemical mix released into fracking fluid	5	4	4	5	5	3	4
3.5. Cementation poorly undertaken (spaces left)	5	5	5	5	5	4	5
3.6. Well lining too limited, open hole left	5	3	3	3	5	2	2
3.7. Inappropriate management of drill cuttings and spent drilling muds.	4	1	4	1	1	1	1
3.8. Unlikely significant event	5	1	4	5	3	3	3
		11	1	1	3	4	4
		3	3	3	5	6	4
		6	5	7	7	8	6
		5	16	7	7	10	11
		6	6	13	9	3	6



List of Processes

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1	Thermal effects on the borehole						
1.1.	Thermal effects on borehole and seal integrity.	5	3	3	5	3	3
1.2.	Thermal effects on the injection point	3	3	2	1	2	2
2	Hydraulics / Fluid Pressure Dominated	5	3	2	3	5	4
2.1.	Fluid pressure exceeds rock fracking pressures generating new fractures	5	3	3	4	5	4
2.2.	Fluid exceeds fault sealing pressures	5	3	4	3	4	5
2.3.	Fluid pressure exceeds stability of part of the plant construction.	5	5	4	2	4	5
2.4.	Displacement of surrounding formation fluids	5	5	5	3	5	4
2.5.	Buoyancy-driven flow	5	3	5	5	4	4
2.6.	Advection and co-migration of other gas	3	3	3	3	2	2
2.7.	Formation of Gas hydrates	2	2	1	2	1	2
2.8.	Water mediated transport	4	4	2	4	3	3
2.8.1.	Advection	4	4	2	3	3	4
2.8.2.	Dispersion	4	5	3	5	4	4
2.8.3.	Diffusion	5	5	5	5	4	4
2.9.	Hydraulic and production fluids and the associated contaminants release processes	5	5	5	5	4	4
3	Chemical						
3.1.	Corrosive mixture attacks plant	5	3	4	5	2	2
3.2.	Corrosive mixture attacks geology	5	5	5	5	5	5
3.3.	Sorption and desorption	5	5	5	5	4	4
3.4.	Mineral dissolution	5	5	5	5	2	3
3.5.	Heavy metal release	5	5	5	5	2	2
4	Mechanical						
4.1	Soil and rock deformation around boreholes	4	3	2	3	4	4
4.1.1 Sub		2	5	5	5	4	4
4.2	Propagation of fractures beyond the target zone	4	3	3	4	3	2
4.3	Fluid exceeds fault sealing pressures	4	3	3	4	3	2
4.4	Fault valving	5	5	5	5	4	4
4.5	Generation of excavation disturbed zone around well	5	3	5	5	5	3
4.6	Micro-cracking in the casing cements	5	5	5	5	5	5

1	0	0	1	1	1	0
2	1	5	2	1	7	6
3	12	6	6	6	3	4
4	3	2	5	4	14	13
5	11	14	13	15	2	4



List of Features

A. Features of the Natural System

Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	1	1	1	1	1	1
1.1.2 Geometry of the hydrocarbon bearing formation	2	2	1	1	1	1
1.1.2.1 Thickness	1	2	1	1	1	2
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	3	4	4	4
1.1.3.1 Lithology	5	5	3	4	5	5
1.1.3.2 Diagenesis	4	2	4	4	4	3
1.1.3.3 Pore architecture	4	4	4	2	3	3
1.1.3.4 Mineralogy	5	2	5	2	2	2
1.1.3.5 Kerogen type	5	2	5	2	4	3
1.1.3.6 Thermal maturation of source rock	3	2	2	2	3	3
1.1.3.7 Porosity	5	3	5	2	4	5
1.1.3.8 Intrinsic permeability	5	5	3	5	5	4
1.1.3.9 Relative permeability	5	4	5	5	4	3
1.1.3.10 Entry pressure	5	5	5	5	4	5
1.1.3.11 Residual saturation	4	2	4	1	1	1
1.1.3.12 Hysteresis	2	2	1	1	1	1
1.1.4 Stress and Mechanical properties	2	2	1	1	1	1
1.1.5 Heterogeneity of the hydrocarbon bearing formation	5	4	1	4	4	1
1.1.6 Fractures and faults within the hydrocarbon bearing formation	5	4	4	3	4	4
1.1.6.1 Porosity of the fracture	5	4	3	5	4	2
1.1.6.2 Intrinsic permeability of the fracture	5	5	3	5	3	2
1.1.6.3 Relative Permeability of the fractures	5	5	3	3	4	2
1.1.6.4 Fracture geometry	5	4	4	4	2	2
1.1.7 Undetected features within the hydrocarbon bearing formation	2	1	2	1	2	2
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	3	1	3	1	1	1
1.1.9 Formation pressure of the hydrocarbon bearing formation	4	1	4	2	2	3
1.2 Fluids						
1.2.1 Hydrocarbons	4	2	1	4	1	2
1.2.2 Natural formation water	4	1	1	4	1	2
1.2.3 Production fluids	4	1	1	4	1	2
1.2.4 Pore fluid composition within the fracking reservoir	5	1	1	5	1	2
1.2.5 Reservoir fluids	5	2	2	1	2	2
1.2.6 Other fluids	4	1	1	4	1	2
1.3 Overburden						
1.3.1 Geometry of the overburden	5	4	5	1	1	3
1.3.1.1 Thickness	5	4	5	1	2	3
1.3.2 Rock / Petrophysical properties of the overburden	4	4	4	1	1	1
1.3.2.1 Lithology	4	4	4	2	3	1
1.3.2.2 Diagenesis	4	1	1	4	2	4
1.3.2.3 Pore architecture	4	3	3	4	2	3
1.3.2.4 Mineralogy	4	1	1	4	2	3
1.3.2.5 Porosity	4	3	3	4	3	4
1.3.2.6 Intrinsic permeability	4	3	4	3	2	2
1.3.2.7 Relative permeability	4	3	4	3	2	2
1.3.2.8 Entry pressure	5	4	5	1	3	3
1.3.2.9 Residual saturation	4	2	4	2	1	2
1.3.2.10 Hysteresis	2	2	1	1	2	2
1.3.3 Free gas pocket within the overburden	3	1	3	1	2	2
1.3.4 Additional seals within the overburden	3	1	2	1	2	3
1.3.5 Unconformities within the overburden	2	1	2	1	1	2
1.3.6 Heterogeneity within the overburden	3	2	3	1	1	2
1.3.7 Fractures and faults within the overburden	2	1	2	2	1	1
1.3.7.1 Porosity of the fracture	4	1	4	3	1	3
1.3.7.2 Intrinsic permeability of the fracture	4	1	4	3	2	2
1.3.7.3 Relative Permeability of the fractures	4	1	4	3	4	2
1.3.7.4 Fracture geometry	5	1	3	2	5	1
1.3.8 Undetected features within the overburden	5	1	1	1	2	5
1.3.9 Vertical geothermal gradient within the overburden	5	1	1	2	2	5
1.3.10 Formation "overburden" pressure	4	2	4	1	2	4
1.3.11 Overburden pressure	5	2	4	1	5	3
1.4 Underburden						
1.4.1 Geometry of the underburden	1	1	1	1	1	1
1.4.1.1 Thickness	2	1	1	1	1	2
1.4.2 Rock / Petrophysical properties of the underburden	2	1	2	2	1	1
1.4.2.1 Lithology	2	1	2	2	1	2
1.4.2.2 Diagenesis	3	1	2	2	3	1
1.4.2.3 Pore architecture	3	1	2	2	3	1
1.4.2.4 Mineralogy	2	1	2	2	1	1
1.4.2.5 Porosity	3	1	2	2	3	2
1.4.2.6 Intrinsic permeability	4	1	1	2	4	1
1.4.2.7 Relative permeability	4	1	1	1	4	1
1.4.2.8 Entry pressure	4	1	1	1	4	3
1.4.2.9 Residual saturation	2	1	2	1	2	1
1.4.2.10 Hysteresis	2	1	2	1	1	1
1.4.3 Unconformities within the underburden	2	1	2	1	1	1
1.4.4 Heterogeneity within the underburden	2	1	2	1	1	1
1.4.5 Fractures and faults within the underburden	3	1	1	1	3	2
1.4.6 Undetected features within the underburden	1	1	1	1	1	1
1.4.7 Vertical geothermal gradient within the underburden	3	1	2	1	3	1
1.4.8 Formation "underburden" pressure	3	1	3	1	2	3
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	2	1	1	2	2	1
2.1.2 Soils and sediments	2	1	1	1	1	2
2.1.3 Near-surface aquifers and surface water bodies	3	1	1	3	2	2
2.1.4 Terrestrial flora and fauna	2	1	1	1	1	2
2.1.5 Terrestrial ecological systems	2	1	1	2	1	2
2.1.6 Buildings	1	1	1	1	1	1
2.2 Marine environment						
2.2.1 Local oceanography	2	1	2	1	2	2
2.2.2 Marine sediments	3	2	2	3	2	2
2.2.3 Marine Stratification and Mixing	3	2	1	3	2	2
2.2.4 Marine flora and fauna	1	1	1	1	1	1
2.2.5 Marine ecological systems	1	1	1	1	1	1
2.3 Human Environment						
2.3.1 Human characteristics	2	1	1	1	1	1
2.3.2 Diet and food processing	1	1	1	1	1	1
2.3.3 Lifestyles	1	1	1	1	1	1
2.3.4 Land and water use	2	1	1	2	2	1
2.3.5 Community characteristics	1	1	1	1	1	1
2.4 Atmosphere and meteorology						

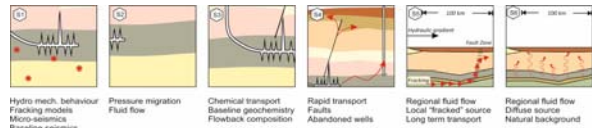
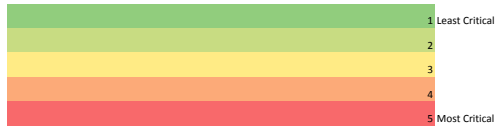
B. Unconventional Hydrocarbon Extraction

1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties	4	4	4	3	3	2
1.2 Physical properties of injection fluid	4	4	4	4	3	4
1.2.1 Injection fluid additives	5	1	1	5	4	1
1.2.2 Hydro-fracturing fluids interactions	4	4	4	2	2	4
2 Site development						
2.1 Logistics above ground	2	1	1	1	1	2
2.2 Baseline monitoring	3	2	2	3	3	3
3 Site operation						
3.1 Drilling and completion		1	1	1	2	3
3.1.1 Horizontal wells	4	4	3	1	2	2
3.1.2 Formation damage	4	4	2	2	2	3

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

3	1	1	1	1	1	3
1	1	1	1	1	1	1
3	1	1	1	1	3	3
3	1	1	1	2	1	3
3	3	3	2	1	1	2
4	2	1	2	1	2	4
3	1	1	2	3	3	3
4	1	1	2	4	4	4

1	65	43	48	41	36	35
2	16	28	22	35	41	42
3	7	9	16	14	15	21
4	14	20	16	12	14	9
5	8	10	8	8	4	3



List of Features

A. Features of the Natural System

Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	4	3	3	1	4	4
1.1.2 Geometry of the hydrocarbon bearing formation	3	2	2	1	3	3
1.1.2.1 Thickness	4	2	2	1	3	3
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	2	2	4	4
1.1.3.1 Lithology	5	5	4	5	5	5
1.1.3.2 Diagenesis	2	1	2	2	2	2
1.1.3.3 Pore architecture	2	1	2	2	2	2
1.1.3.4 Mineralogy	3	1	2	2	3	3
1.1.3.5 Kerogen type	4	1	2	2	4	4
1.1.3.6 Thermal maturation of source rock	4	1	2	2	4	4
1.1.3.7 Porosity	3	3	2	2	3	3
1.1.3.8 Intrinsic permeability	5	5	5	5	4	3
1.1.3.9 Relative permeability	5	5	5	5	4	3
1.1.3.10 Entry pressure	3	3	3	3	3	3
1.1.3.11 Residual saturation	3	1	1	1	3	3
1.1.3.12 Hysteresis	5	1	1	1	3	3
1.1.4 Stress and Mechanical properties	5	5	1	1	3	2
1.1.5 Heterogeneity of the hydrocarbon bearing formation	3	3	2	3	3	2
1.1.6 Fractures and faults within the hydrocarbon bearing formation	5	5	2	3	5	4
1.1.6.1 Porosity of the fracture	3	3	2	3	3	1
1.1.6.2 Intrinsic permeability of the fracture	5	5	2	3	5	5
1.1.6.3 Relative Permeability of the fractures	5	5	2	3	5	5
1.1.6.4 Fracture geometry	4	4	2	3	4	3
1.1.7 Undetected features within the hydrocarbon bearing formation	4	3	2	3	2	2
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	2	1	2	2	2	2
1.1.9 Formation pressure of the hydrocarbon bearing formation	5	5	4	4	4	4
1.2 Fluids						
1.2.1 Hydrocarbons	4	4	3	4	4	4
1.2.2 Natural formation water	4	3	3	4	3	3
1.2.3 Production fluids	4	2	2	4	4	4
1.2.4 Pore fluid composition within the fracking reservoir	4	3	2	4	2	4
1.2.5 Reservoir fluids	4	3	2	4	4	4
1.2.6 Other fluids	4	1	1	4	1	2
1.3 Overburden						
1.3.1 Geometry of the overburden	4	3	1	1	1	4
1.3.1.1 Thickness	5	3	3	1	1	5
1.3.2 Rock / Petrophysical properties of the overburden	5	5	2	2	2	5
1.3.2.1 Lithology	5	5	4	4	4	5
1.3.2.2 Diagenesis	4	4	1	3	2	4
1.3.2.3 Pore architecture	4	2	1	3	2	4
1.3.2.4 Mineralogy	3	1	1	3	2	2
1.3.2.5 Porosity	4	3	3	3	3	4
1.3.2.6 Intrinsic permeability	5	5	3	4	4	5
1.3.2.7 Relative permeability	5	5	5	4	4	5
1.3.2.8 Entry pressure	2	2	2	2	2	2
1.3.2.9 Residual saturation	4	2	2	2	4	4
1.3.2.10 Hysteresis	2	1	1	1	2	2
1.3.3 Free gas pocket within the overburden	3	3	1	1	2	2
1.3.4 Additional seals within the overburden	4	4	3	3	1	4
1.3.5 Unconformities within the overburden	4	4	3	3	1	2
1.3.6 Heterogeneity within the overburden	2	2	2	2	2	2
1.3.7 Fractures and faults within the overburden	5	5	5	4	5	5
1.3.7.1 Porosity of the fracture	2	2	2	2	2	1
1.3.7.2 Intrinsic permeability of the fracture	5	5	5	4	5	5
1.3.7.3 Relative Permeability of the fractures	5	5	5	4	5	5
1.3.7.4 Fracture geometry	5	4	4	4	5	5
1.3.8 Undetected features within the overburden	4	2	2	2	2	4
1.3.9 Vertical geothermal gradient within the overburden	2	1	2	2	2	2
1.3.10 Formation "overburden" pressure	5	5	2	2	4	4
1.3.11 Overburden pressure	5	5	2	2	2	2
1.4 Underburden						
1.4.1 Geometry of the underburden	2	2	1	1	1	1
1.4.1.1 Thickness	2	2	1	1	1	1
1.4.2 Rock / Petrophysical properties of the underburden	3	3	2	2	2	2
1.4.2.1 Lithology	3	3	3	3	2	2
1.4.2.2 Diagenesis	3	1	1	2	1	2
1.4.2.3 Pore architecture	2	1	1	3	1	2
1.4.2.4 Mineralogy	3	1	1	3	1	2
1.4.2.5 Porosity	2	2	2	2	2	2
1.4.2.6 Intrinsic permeability	4	4	3	3	2	4
1.4.2.7 Relative permeability	4	4	3	3	2	4
1.4.2.8 Entry pressure	3	3	2	2	2	1
1.4.2.9 Residual saturation	4	1	2	2	4	2
1.4.2.10 Hysteresis	1	1	1	1	1	1
1.4.3 Unconformities within the underburden	2	2	2	2	1	1
1.4.4 Heterogeneity within the underburden	2	2	2	2	1	1
1.4.5 Fractures and faults within the underburden	3	3	2	2	2	1
1.4.6 Undetected features within the underburden	2	2	2	2	2	2
1.4.7 Vertical geothermal gradient within the underburden	1	1	1	1	1	1
1.4.8 Formation "underburden" pressure	4	4	2	2	3	3
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	4	3	1	1	4	4
2.1.2 Soils and sediments	4	1	1	1	4	4
2.1.3 Near-surface aquifers and surface water bodies	5	1	1	1	5	5
2.1.4 Terrestrial flora and fauna	4	1	1	1	4	4
2.1.5 Terrestrial ecological systems	4	1	1	1	4	4
2.1.6 Buildings	5	3	1	1	5	5
2.2 Marine environment						
2.2.1 Local oceanography	1	1	1	1	1	1
2.2.2 Marine sediments	1	1	1	1	1	1
2.2.3 Marine Stratification and Mixing	1	1	1	1	1	1
2.2.4 Marine flora and fauna	1	1	1	1	1	1
2.2.5 Marine ecological systems	1	1	1	1	1	1
2.3 Human Environment						
2.3.1 Human characteristics	2	1	1	1	2	2
2.3.2 Diet and food processing	4	1	1	1	4	4
2.3.3 Lifestyles	2	1	1	1	2	2
2.3.4 Land and water use	4	3	1	1	4	4
2.3.5 Community characteristics	3	3	1	1	2	2
2.4 Atmosphere and meteorology						

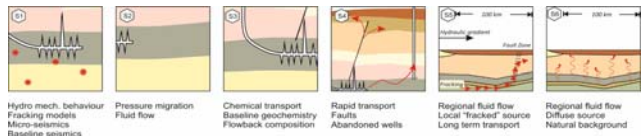
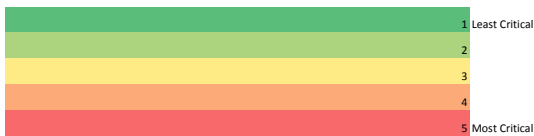
B. Unconventional Hydrocarbon Extraction

1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties	5	4	4	5	5	3
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	5	5	4	5	5	4
1.2.2 Hydro-fracturing fluids interactions	2	2	1	1	1	1
2 Site development						
2.1 Logistics above ground	4	4	1	1	1	1
2.2 Baseline monitoring	5	5	5	5	5	5
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	5	5	5	5	4	4
3.1.2 Formation damage	3	3	3	3	3	3

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

5	5	5	5	5	5	5
3	2	2	2	2	2	2
5	5	5	5	5	5	5
3	3	3	3	3	3	3
4	2	2	2	2	2	2
4	3	3	3	3	3	3
5	3	3	5	5	5	5
5	3	3	5	5	5	5

1	31	35	28	32	14	25
2	15	38	30	35	35	28
3	24	18	26	8	20	15
4	15	6	16	13	25	27
5	23	11	8	20	14	13



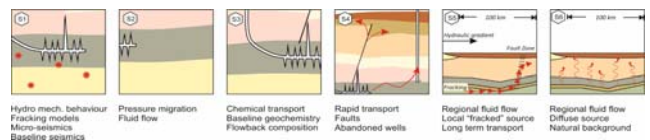
List of Events

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	4	3	3	3	3	3	4
1.2. Initial drilling to given below water table (Open Hole)	1	1	1	1	1	1	1
1.2. Casing emplacement	4	3	4	3	2	2	2
1.2. Cementation with wiper plug	2	2	2	2	2	2	2
1.2. Drilling through wiper plug and casing shoe	2	2	2	2	2	2	2
1.2. Additional cementation	4	4	4	4	2	2	2
1.3. Logging Borehole	4	4	4	4	2	2	2
1.4. Drilling horizontal borehole	5	5	2	2	2	4	4
1.4. Casing horizontal borehole	5	5	2	2	2	4	2
1.4. Cementation	5	5	2	2	2	4	2
1.4. Perforation	5	5	2	2	2	1	1
1.5. Hydraulic fracturing	5	5	2	5	3	3	3
1.5. Out of zone / beyond pumping	5	5	2	5	5	5	5
1.6. Plugging & drilling out of plugs	2	2	2	2	1	1	1
1.7. Flow back	5	5	5	3	2	2	2
1.7. Production	5	5	5	3	3	3	3
1.8. Abandonment	3	3	3	3	3	3	3
1.9. Seal failure	3	3	3	3	1	1	1
2 Natural events							
2.1. Earthquakes	5	1	1	1	1	5	3
2.2. Large scale erosion	3	1	1	1	1	3	3
2.3. Hydrological and hydrogeological response to geological changes	3	1	1	1	1	3	3
2.4. Cap rock failure	3	1	1	1	1	3	2
2.5. Unexpected large scale scenario	1	1	1	1	1	1	1
3 Accidents and unplanned events							
3.1. Surface chemical spills	5	5	1	5	1	1	1
3.2. Overpressuring	4	4	2	2	1	1	1
3.3. Poor site characterization	5	3	3	3	5	3	3
3.4. Incorrect chemical mix released into fracking fluid	5	3	3	5	4	3	3
3.5. Cementation poorly undertaken (spaces left)	5	5	5	5	4	2	2
3.6. Well lining too limited, open hole left	3	3	3	2	2	2	2
3.7. Inappropriate management of drill cuttings and spent drilling muds.	1	1	1	1	1	1	1
3.8. Unlikely significant event	1	1	1	1	1	1	1

1	8	9	8	10	9	9
2	3	5	11	11	8	11
3	7	6	5	5	9	8
4	3	3	2	2	3	2
5	10	8	5	3	2	1



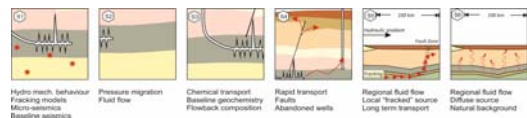
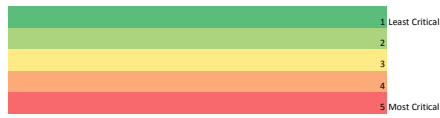
Importance



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	5	5	5	5	2	5	5
1.2 Thermal effects on the injection point	2	2	2	2	1	1	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	5	1	5	1	1
2.2 Fluid exceeds fault sealing pressures	5	1	1	1	5	2	1
2.3 Fluid pressure exceeds stability of part of the plant construction.	5	5	5	3	2	2	1
2.4 Displacement of surrounding formation fluids	5	1	5	3	5	4	4
2.5 Buoyancy-driven flow	5	1	1	1	2	4	5
2.6 Advection and co-migration of other gas	5	1	5	4	5	5	5
2.7 Formation of Gas hydrates	2	2	1	1	1	2	2
2.8 Water mediated transport	5	1	5	4	5	5	5
2.8.1 Advection	5	4	5	4	5	5	5
2.8.2 Dispersion	3	2	3	3	3	3	3
2.8.3 Diffusion	5	2	1	5	1	4	4
2.9 Hydraulic and production fluids and the associated contaminants release processes	5	5	5	5	5	4	4
3 Chemical							
3.1 Corrosive mixture attacks plant	5	3	3	5	2	2	2
3.2 Corrosive mixture attacks geology	5	3	3	5	2	2	2
3.3 Sorption and desorption	5	2	3	5	3	4	4
3.4 Mineral dissolution	5	2	3	5	3	4	4
3.5 Heavy metal release	5	2	2	5	2	4	4
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	3	5	1	1
4.1.1 Subsidence of ground related to gas extraction	4	1	1	3	1	4	4
4.2 Propagation of fractures beyond the target zone	5	5	5	3	5	1	1
4.3 Fluid exceeds fault sealing pressures	5	1	1	1	5	2	1
4.4 Fault valving	3	1	1	1	3	2	1
4.5 Generation of excavation disturbed zone around well	2	1	1	1	2	2	2
4.6 Micro-cracking in the casing cements	5	5	5	5	2	5	5

1	9	8	7	4	4	8
2	7	2	1	8	8	4
3	2	5	6	4	1	1
4	1	0	3	0	8	7
5	7	11	9	10	5	6

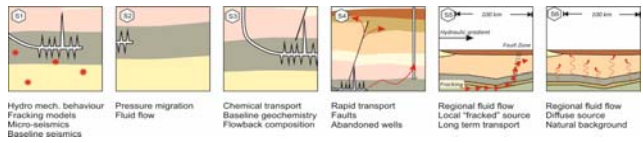
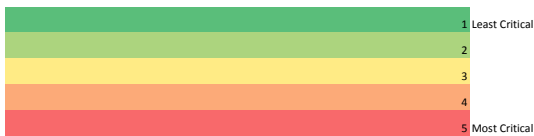


List of Features

A. Features of the Natural System

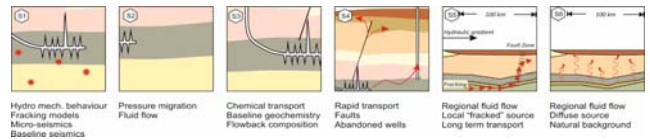
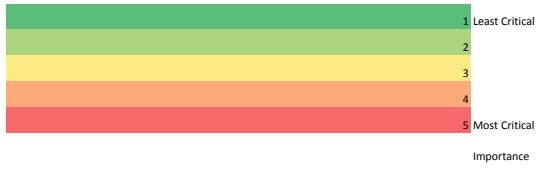
Overall Importance in Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	4	3	1	1	1	1
1.1.2 Geometry of the hydrocarbon bearing formation	4	1	1	1	1	1
1.1.2.1 Thickness	5	1	1	1	1	1
1.1.2 Rock / Petrophysical properties of the hydrocarbon bearing formation	5	5	5	4	5	4
1.1.2.1 Lithology	5	4	5	5	5	5
1.1.2.2 Diagenesis	4	3	1	4	4	3
1.1.2.3 Pore architecture	5	5	4	2	3	3
1.1.2.4 Mineralogy	5	1	4	5	2	4
1.1.2.5 Kerogen type	4	1	2	2	4	3
1.1.2.6 Thermal maturation of source rock	3	1	2	2	2	3
1.1.2.7 Porosity	5	5	4	2	3	3
1.1.2.8 Intrinsic permeability	5	5	3	5	4	3
1.1.2.9 Relative permeability	5	4	3	5	4	3
1.1.2.10 Entry pressure	5	1	3	5	4	3
1.1.2.11 Residual saturation	4	3	4	1	1	1
1.1.2.12 Hysteresis	1	1	1	1	1	1
1.1.4 Stress and Mechanical properties	5	4	1	1	2	1
1.1.5 Heterogeneity of the hydrocarbon bearing formation	5	4	3	3	3	3
1.1.6 Fractures and faults within the hydrocarbon bearing formation	5	5	4	5	3	3
1.1.6.1 Porosity of the fracture	5	5	4	5	3	3
1.1.6.2 Intrinsic permeability of the fracture	5	5	4	5	3	3
1.1.6.3 Relative Permeability of the fractures	4	4	4	4	3	3
1.1.6.4 Fracture geometry	5	5	4	4	3	3
1.1.7 Undetected features within the hydrocarbon bearing formation	3	1	3	2	2	3
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	1	1	3	4	2	3
1.1.9 Formation pressure of the hydrocarbon bearing formation	4	1	3	2	2	3
1.2 Fluids						
1.2.1 Hydrocarbons	5	2	2	5	1	2
1.2.2 Natural formation water	5	2	2	5	1	2
1.2.3 Production fluids	5	2	2	5	1	2
1.2.4 Pore fluid composition within the fracking reservoir	5	2	2	5	1	2
1.2.5 Reservoir fluids	5	2	2	5	1	2
1.2.6 Other fluids	5	2	2	5	1	2
1.3 Overburden						
1.3.1 Geometry of the overburden	3	3	1	1	1	2
1.3.1.1 Thickness	3	1	1	1	1	2
1.3.2 Rock / Petrophysical properties of the overburden	5	5	1	5	1	2
1.3.2.1 Lithology	5	4	1	5	2	2
1.3.2.2 Diagenesis	4	1	1	3	4	3
1.3.2.3 Pore architecture	3	1	1	3	2	2
1.3.2.4 Mineralogy	5	1	1	5	2	2
1.3.2.5 Porosity	5	5	1	5	4	2
1.3.2.6 Intrinsic permeability	5	5	1	5	1	2
1.3.2.7 Relative permeability	4	4	1	4	1	2
1.3.2.8 Entry pressure	2	1	1	1	1	2
1.3.2.9 Residual saturation	3	3	1	3	1	2
1.3.2.10 Hysteresis	2	1	1	1	1	2
1.3.3 Free gas pocket within the overburden	3	1	1	3	1	2
1.3.4 Additional seals within the overburden	3	1	1	1	1	2
1.3.5 Unconformities within the overburden	3	1	3	1	1	2
1.3.6 Heterogeneity within the overburden	3	3	4	2	4	2
1.3.7 Fractures and faults within the overburden	5	5	4	4	1	2
1.3.7.1 Porosity of the fracture	5	3	4	4	2	2
1.3.7.2 Intrinsic permeability of the fracture	5	3	4	4	2	2
1.3.7.3 Relative Permeability of the fractures	4	3	4	4	2	2
1.3.7.4 Fracture geometry	5	5	4	5	2	2
1.3.8 Undetected features within the overburden	5	1	3	2	3	2
1.3.9 Vertical geothermal gradient within the overburden	5	1	3	4	2	2
1.3.10 Formation "overburden" pressure	4	1	4	4	2	4
1.3.11 Overburden pressure	5	1	3	4	5	3
1.4 Underburden						
1.4.1 Geometry of the underburden	1	1	1	1	1	1
1.4.1.1 Thickness	1	1	1	1	1	1
1.4.2 Rock / Petrophysical properties of the underburden	5	5	2	1	4	2
1.4.2.1 Lithology	4	4	2	1	4	1
1.4.2.2 Diagenesis	2	1	2	1	2	1
1.4.2.3 Pore architecture	3	1	2	1	3	2
1.4.2.4 Mineralogy	4	1	2	1	4	2
1.4.2.5 Porosity	5	5	2	1	4	2
1.4.2.6 Intrinsic permeability	5	5	1	1	1	2
1.4.2.7 Relative permeability	4	4	1	1	1	2
1.4.2.8 Entry pressure	2	3	1	1	2	1
1.4.2.9 Residual saturation	3	3	2	1	3	2
1.4.2.10 Hysteresis	3	1	2	1	3	2
1.4.3 Unconformities within the underburden	3	1	2	1	3	2
1.4.4 Heterogeneity within the underburden	3	3	2	1	2	2
1.4.5 Fractures and faults within the underburden	5	5	2	1	2	1
1.4.6 Undetected features within the underburden	5	2	1	3	2	1
1.4.7 Vertical geothermal gradient within the underburden	4	1	2	1	4	2
1.4.8 Formation "underburden" pressure	4	1	2	1	4	2
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	1	1	1	1	1	1
2.1.2 Soils and sediments	1	1	1	1	1	1
2.1.3 Near-surface aquifers and surface water bodies	1	1	2	1	1	1
2.1.4 Terrestrial flora and fauna	1	1	1	1	1	1
2.1.5 Terrestrial ecological systems	1	1	1	1	1	1
2.1.6 Buildings	1	1	1	1	1	1
2.2 Marine environment						
2.2.1 Local oceanography	1	1	1	1	1	1
2.2.2 Marine sediments	1	1	1	1	1	1
2.2.3 Marine Stratification and Mixing	1	1	1	1	1	1
2.2.4 Marine flora and fauna	1	1	1	1	1	1
2.2.5 Marine ecological systems	1	1	1	1	1	1
2.3 Human Environment						
2.3.1 Human characteristics	1	1	1	1	1	1
2.3.2 Diet and food processing	1	1	1	1	1	1
2.3.3 Lifestyles	1	1	1	1	1	1
2.3.4 Land and water use	3	1	3	1	1	1
2.3.5 Community characteristics	1	1	1	1	1	1
2.4 Atmosphere and meteorology						
B. Unconventional Hydrocarbon Extraction						
1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties						
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	5	1	1	5	1	1
1.2.2 Hydro-fracturing fluids interactions	5	1	1	5	1	1
2 Site development						
2.1 Logistics above ground	1	1	1	1	1	1
2.2 Baseline monitoring	5	1	1	5	1	1
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	1	1	1	1	1	1
3.1.2 Formation damage	1	1	1	1	1	1
3.1.3 Well lining and completion	1	1	1	1	1	1
3.1.4 Workover	1	1	1	1	1	1
3.1.5 Monitoring wells	1	1	1	1	1	1
3.1.6 Well records	4	1	1	4	1	1
3.1.7 Well orientation	1	1	1	1	1	1
3.1.8 Well engineering	1	1	1	1	1	1
4 Site decommissioning						
4.1 Closure and sealing of boreholes	1	1	1	4	3	1
4.2 Abandoned wells	1	1	1	4	4	1

1	61	54	58	58	40	54
2	6	21	5	18	42	32
3	7	13	7	7	12	17
4	9	9	22	13	8	2
5	23	9	15	10	4	1



List of Events

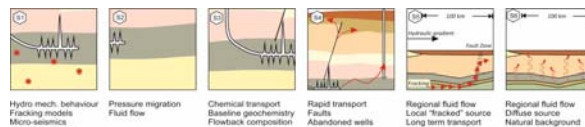
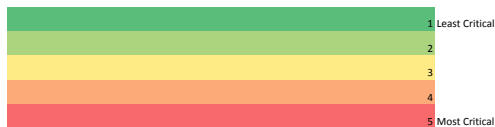
		Relevance to Scenario						
		S1	S2	S3	S4	S5	S6	
1 Operational Events								
1.1. Multiple well drilling from same platform	4	3	3	1	3	2	4	
1.2. Initial drilling to given below water table (Open Hole)	4	3	3	1	3	4	4	
1.2. Casing emplacement	5	3	3	1	3	4	5	
1.2. Cementation with wiper plug	5	3	3	1	3	5	5	
1.2. Drilling through wiper plug and casing shoe	5	3	3	1	3	4	5	
1.2. Additional cementation	5	3	3	1	3	5	5	
1.3. Logging Borehole	5	3	3	1	3	5	5	
1.4. Drilling horizontal borehole	4	3	3	1	3	4	4	
1.4. Casing horizontal borehole	4	3	3	1	3	4	4	
1.4. Cementation	4	3	3	1	3	4	4	
1.4. Perforation	3	3	3	1	3	1	1	
1.5. Hydraulic fracturing	5	5	5	5	5	3	2	
1.5. Out of zone / beyond pumping	5	5	5	5	5	5	5	
1.6. Plugging & drilling out of plugs	5	5	5	5	5	4	3	
1.7. Flow back	5	5	5	5	5	4	3	
1.7. Production	5	5	5	5	5	3	3	
1.8. Abandonment	5	5	5	1	5	3	3	
1.9. Seal failure	5	5	5	4	5	3	3	
2 Natural events								
2.1. Earthquakes	5	5	5	1	5	3	3	
2.2. Large scale erosion	5	5	5	1	5	3	3	
2.3. Hydrological and hydrogeological response to geological changes	5	5	5	5	5	3	3	
2.4. Cap rock failure	5	5	5	3	5	3	3	
2.5. Unexpected large scale scenario	5	5	5	1	5	3	3	
3 Accidents and unplanned events								
3.1. Surface chemical spills	5	1	1	1	5	3	3	
3.2. Overpressuring	5	5	5	5	5	3	3	
3.3. Poor site characterization	5	5	5	5	5	3	3	
3.4. Incorrect chemical mix released into fracking fluid	5	3	3	5	5	3	3	
3.5. Cementation poorly undertaken (spaces left)	5	3	3	5	5	3	3	
3.6. Well lining too limited, open hole left	5	3	3	5	5	3	3	
3.7. Inappropriate management of drill cuttings and spent drilling muds.	5	3	3	1	5	3	3	
3.8. Unlikely significant event	5	3	3	2	5	3	3	
		1	1	1	17	0	1	1
		2	0	0	1	0	1	1
		3	16	16	1	11	17	18
		4	0	0	1	0	9	5
		5	14	14	11	20	3	6



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	5	4	4	1	3	5	5
1.2 Thermal effects on the injection point	4	4	4	1	1	4	4
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	5	1	5	4	4
2.2 Fluid exceeds fault sealing pressures	5	5	5	1	3	3	3
2.3 Fluid pressure exceeds stability of part of the plant construction.	5	5	5	1	4	5	5
2.4 Displacement of surrounding formation fluids	5	5	5	5	5	4	4
2.5 Buoyancy-driven flow	5	5	5	5	4	5	5
2.6 Advection and co-migration of other gas	5	2	2	5	3	5	5
2.7 Formation of Gas hydrates	4	3	3	4	3	4	4
2.8 Water mediated transport	5	3	3	5	3	5	5
2.8.1 Advection	5	4	4	5	3	5	5
2.8.2 Dispersion	5	4	4	5	5	5	5
2.8.3 Diffusion	5	4	4	5	5	5	5
2.9 Hydraulic and production fluids and the associated contaminants release processes	5	5	5	5	5	5	5
3 Chemical							
3.1 Corrosive mixture attacks plant	5	5	5	1	5	4	4
3.2 Corrosive mixture attacks geology	5	5	5	5	5	4	4
3.3 Sorption and desorption	5	5	5	5	5	4	4
3.4 Mineral dissolution	5	5	5	5	5	4	4
3.5 Heavy metal release	5	5	5	5	5	4	4
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	1	5	4	4
4.1.1 Subsidence of ground related to gas extraction	5	5	5	1	5	4	4
4.2 Propagation of fractures beyond the target zone	5	5	5	5	5	4	4
4.3 Fluid exceeds fault sealing pressures	5	5	5	1	5	4	4
4.4 Fault valving	5	5	5	5	5	4	4
4.5 Generation of excavation disturbed zone around well	5	5	5	1	5	4	4
4.6 Micro-cracking in the casing cements	5	5	5	3	5	4	4

1	0	0	10	1	0	0
2	1	1	0	0	0	0
3	2	2	1	6	1	1
4	5	5	1	2	16	16
5	18	18	14	17	9	9



List of Features

A. Features of the Natural System

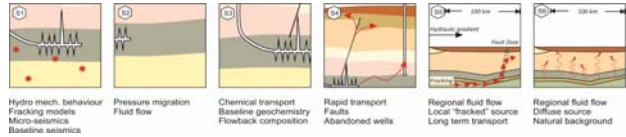
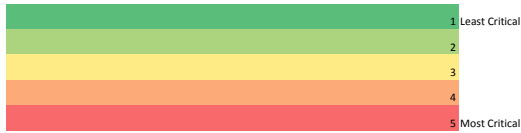
Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	5	4	2	5	1	2
1.1.2 Geometry of the hydrocarbon bearing formation	4	1	2	1	2	4
1.1.2.1 Thickness	3	3	2	1	2	4
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	5	4	2	4	5	5
1.1.3.1 Lithology	5	4	2	3	4	4
1.1.3.2 Diagenesis	4	1	4	1	4	4
1.1.3.3 Pore architecture	5	5	4	2	4	3
1.1.3.4 Mineralogy	5	1	1	5	1	1
1.1.3.5 Kerogen type	5	1	1	5	1	1
1.1.3.6 Thermal maturation of source rock	4	3	2	4	2	2
1.1.3.7 Porosity	5	5	4	2	4	3
1.1.3.8 Intrinsic permeability	5	5	4	2	4	3
1.1.3.9 Relative permeability	5	5	4	2	4	3
1.1.3.10 Entry pressure	5	5	5	2	5	4
1.1.3.11 Residual saturation	3	1	3	1	2	2
1.1.3.12 Hysteresis	1	1	1	1	1	1
1.1.4 Stress and Mechanical properties	5	3	2	3	2	1
1.1.5 Heterogeneity of the hydrocarbon bearing formation	3	3	3	3	3	3
1.1.6 Fractures and faults within the hydrocarbon bearing formation	5	5	2	5	5	3
1.1.6.1 Porosity of the fracture	5	5	2	5	5	3
1.1.6.2 Intrinsic permeability of the fracture	5	5	2	5	5	3
1.1.6.3 Relative Permeability of the fractures	5	5	2	5	5	3
1.1.6.4 Fracture geometry	2	2	1	2	2	2
1.1.7 Undetected features within the hydrocarbon bearing formation	5	4	3	5	5	3
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	3	1	1	1	1	3
1.1.9 Formation pressure of the hydrocarbon bearing formation	3	3	1	2	2	2
1.2 Fluids						
1.2.1 Hydrocarbons	4	4	4	4	4	4
1.2.2 Natural formation water	4	2	4	2	3	3
1.2.3 Production fluids	4	4	4	4	2	2
1.2.4 Pore fluid composition within the fracking reservoir	4	4	4	4	2	2
1.2.5 Reservoir fluids	4	4	4	4	2	2
1.2.6 Other fluids	4	4	4	4	2	2
1.3 Overburden						
1.3.1 Geometry of the overburden	3	2	3	2	1	2
1.3.1.1 Thickness	2	1	1	1	1	2
1.3.2 Rock / Petrophysical properties of the overburden	5	2	2	1	5	2
1.3.2.1 Lithology	5	3	4	5	3	4
1.3.2.2 Diagenesis	4	1	1	4	1	4
1.3.2.3 Pore architecture	5	5	4	2	4	3
1.3.2.4 Mineralogy	5	1	1	5	1	1
1.3.2.5 Porosity	5	1	1	5	1	1
1.3.2.6 Intrinsic permeability	4	3	2	4	2	2
1.3.2.7 Relative permeability	5	5	4	2	4	3
1.3.2.8 Entry pressure	5	5	4	2	4	3
1.3.2.9 Residual saturation	5	5	4	2	4	3
1.3.2.10 Hysteresis	5	5	5	2	5	4
1.3.3 Free gas pocket within the overburden	4	4	2	3	1	3
1.3.4 Additional seals within the overburden	4	2	3	2	2	3
1.3.5 Unconformities within the overburden	4	2	3	2	2	3
1.3.6 Heterogeneity within the overburden	3	1	1	1	1	2
1.3.7 Fractures and faults within the overburden	4	4	3	2	4	4
1.3.7.1 Porosity of the fracture	4	4	3	2	4	4
1.3.7.2 Intrinsic permeability of the fracture	4	4	3	2	4	4
1.3.7.3 Relative Permeability of the fractures	4	4	3	2	4	4
1.3.7.4 Fracture geometry	2	2	2	1	2	2
1.3.8 Undetected features within the overburden	5	4	3	5	5	3
1.3.9 Vertical geothermal gradient of the overburden	3	1	1	1	1	3
1.3.10 Formation "overburden" pressure	3	3	1	2	2	2
1.3.11 Overburden pressure	3	3	1	2	2	2
1.4 Underburden						
1.4.1 Geometry of the underburden	1	1	1	1	1	1
1.4.1.1 Thickness	1	1	1	1	1	1
1.4.2 Rock / Petrophysical properties of the underburden	3	2	1	3	1	1
1.4.2.1 Lithology	1	1	1	1	1	1
1.4.2.2 Diagenesis	1	1	1	1	1	1
1.4.2.3 Pore architecture	3	2	3	1	1	1
1.4.2.4 Mineralogy	3	2	1	3	1	1
1.4.2.5 Porosity	3	2	1	3	1	1
1.4.2.6 Intrinsic permeability	3	2	1	3	1	1
1.4.2.7 Relative permeability	3	2	1	3	1	1
1.4.2.8 Entry pressure	3	2	1	3	1	1
1.4.2.9 Residual saturation	1	1	1	1	1	1
1.4.2.10 Hysteresis	1	1	1	1	1	1
1.4.3 Unconformities within the underburden	1	1	1	1	1	1
1.4.4 Heterogeneity within the underburden	1	1	1	1	1	1
1.4.5 Fractures and faults within the underburden	3	3	2	1	3	3
1.4.6 Undetected features within the underburden	4	3	2	4	3	3
1.4.7 Vertical geothermal gradient within the underburden	1	1	1	1	1	1
1.4.8 Formation "underburden" pressure	3	3	2	1	3	2
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	2	2	2	4	4	3
2.1.2 Soils and sediments	1	1	3	1	3	4
2.1.3 Near-surface aquifers and surface water bodies	1	3	2	3	4	4
2.1.4 Terrestrial flora and fauna	2	1	1	3	3	3
2.1.5 Terrestrial ecological systems	2	1	1	3	3	3
2.1.6 Buildings	2	1	1	3	3	3
2.2 Marine environment						
2.2.1 Local oceanography	1	1	3	1	2	2
2.2.2 Marine sediments	1	1	2	1	1	1
2.2.3 Marine Stratification and Mixing	1	1	2	1	1	1
2.2.4 Marine flora and fauna	2	1	1	3	3	3
2.2.5 Marine ecological systems	2	1	1	3	3	3
2.3 Human Environment						
2.3.1 Human characteristics	1	1	1	1	1	1
2.3.2 Diet and food processing	1	1	1	1	1	1
2.3.3 Lifestyles	1	1	1	1	1	1
2.3.4 Land and water use	1	1	1	2	2	2
2.3.5 Community characteristics	1	1	1	1	1	1
2.4 Atmosphere and meteorology	1	1	1	2	2	2

B. Unconventional Hydrocarbon Extraction

1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties	3	3	5	2	3	2
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	3	3	5	2	3	2
1.2.2 Hydro-fracturing fluids interactions	3	3	5	2	3	2
2 Site development						
2.1 Logistics above ground	1	1	1	3	3	1
2.2 Baseline monitoring	4	2	2	3	2	1
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	1	1	1	4	3	2
3.1.2 Formation damage	2	3	1	5	5	1

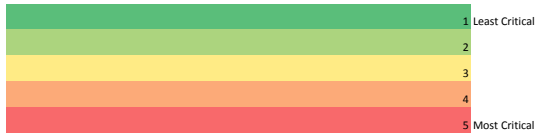
- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

2	3	1	5	5	1
1	2	1	3	3	1
3	3	2	3	3	2
2	1	4	1	1	1
4	2	1	1	1	1
2	3	1	3	2	1
1	3	2	5	3	1
1	3	2	5	3	1

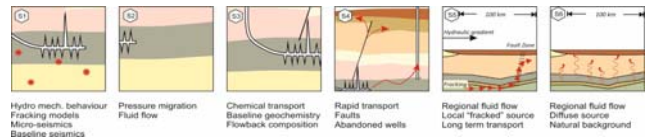


List of Events

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1	Operational Events						
1.1.	Multiple well drilling from same platform	3	2	1	2	2	1
1.2.	Initial drilling to given below water table (Open Hole)	2	2	2	2	2	2
1.2.1.	Casing emplacement	3	2	2	3	2	2
1.2.2.	Cementation with wiper plug	3	3	2	3	3	3
1.2.3.	Drilling through wiper plug and casing shoe	3	3	3	3	3	3
1.2.4.	Additional cementation	1	1	3	1	1	1
1.3.	Logging Borehole	2	2	2	2	1	1
1.4.	Drilling horizontal borehole	3	3	3	3	1	1
1.4.1.	Casing horizontal borehole	3	3	3	3	1	1
1.4.2.	Cementation	2	2	3	2	1	1
1.4.3.	Perforation	2	2	3	2	1	1
1.5.	Hydraulic fracturing	4	4	3	4	2	2
1.5.1.	Out of zone / beyond pumping	4	4	3	4	2	2
1.6.	Plugging & drilling out of plugs	2	2	4	3	1	1
1.7.	Flow back	2	2	5	2	2	2
1.7.1.	Production	2	2	5	2	2	2
1.8.	Abandonment	1	1	1	1	4	4
1.9.	Seal failure	4	4	4	4	2	2
2	Natural events						
2.1.	Earthquakes	4	2	1	3	3	1
2.2.	Large scale erosion	1	1	1	1	3	3
2.3.	Hydrological and hydrogeological response to geological changes	1	1	1	1	1	1
2.4.	Cap rock failure	5	4	2	3	5	4
2.5.	Unexpected large scale scenario	3	3	3	3	3	3
3	Accidents and unplanned events						
3.1.	Surface chemical spills	4	1	4	1	3	3
3.2.	Overpressuring	5	5	2	5	1	1
3.3.	Poor site characterization	4	4	4	4	4	4
3.4.	Incorrect chemical mix released into fracking fluid	2	2	5	1	1	1
3.5.	Cementation poorly undertaken (spaces left)	3	4	1	5	1	1
3.6.	Well lining too limited, open hole left	2	2	4	2	4	4
3.7.	Inappropriate management of drill cuttings and spent drilling muds.	1	1	4	4	4	4
3.8.	Unlikely significant event	3	3	3	3	3	3



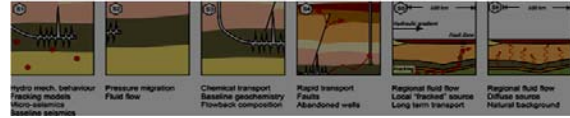
Importance



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1. Thermal effects on borehole and seal integrity.	4	4	3	2	4	2	2
1.2. Thermal effects on the injection point	5	4	4	2	5	2	2
2 Hydraulics / Fluid Pressure Dominated	0						
2.1. Fluid pressure exceeds rock fracturing pressures generating new fractures	5	4	5	2	5	2	2
2.2. Fluid exceeds fault sealing pressures	5	4	5	2	5	2	2
2.3. Fluid pressure exceeds stability of part of the plant construction.	4	4	4	2	4	2	2
2.4. Displacement of surrounding formation fluids	5	5	5	2	4	4	4
2.5. Buoyancy-driven flow	5	5	5	2	4	5	5
2.6. Advection and co-migration of other gas	5	5	4	2	4	4	4
2.7. Formation of Gas hydrates	2	2	2	2	2	2	2
2.8. Water mediated transport	5	2	3	4	2	5	5
2.8.1. Advection	5	2	3	4	2	5	5
2.8.2. Dispersion	5	2	3	4	2	5	5
2.8.3. Diffusion	5	2	3	4	2	5	5
2.9. Hydraulic and production fluids and the associated contaminants release processes	5	4	5	5	3	4	4
3 Chemical							
3.1. Corrosive mixture attacks plant	4	2	3	4	2	3	3
3.2. Corrosive mixture attacks geology	4	4	3	4	2	3	3
3.3. Sorption and desorption	5	4	3	5	2	4	4
3.4. Mineral dissolution	5	4	3	5	2	3	3
3.5. Heavy metal release	5	4	3	5	3	4	4
4 Mechanical							
4.1. Soil and rock deformation around boreholes	3	3	2	2	3	2	2
4.1.1 Subsidence of ground related to gas extraction	3	1	2	2	3	2	2
4.2. Propagation of fractures beyond the target zone	5	5	5	3	3	2	2
4.3. Fluid exceeds fault sealing pressures	5	4	5	3	4	4	4
4.4. Fault valving	5	3	3	3	5	2	2
4.5. Generation of excavation disturbed zone around well	4	4	4	4	4	1	1
4.6. Micro-cracking in the casing cements	5	5	5	4	5	2	2

- 1 Least Critical
- 2
- 3
- 4
- 5 Most Critical



List of Features

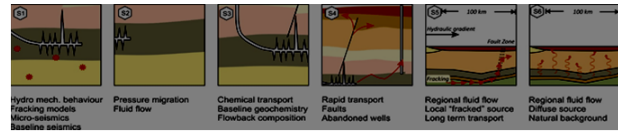
A. Features of the Natural System

Overall Importance In Risk Analysis		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1	Hydrogeology						
1.1	Hydrocarbon bearing formation (Source)						
1.1.1	Type of the hydrocarbon bearing formation	1	1	1	1	1	1
1.1.2	Geometry of the hydrocarbon bearing formation	1	1	1	1	1	1
1.1.2.1	Thickness	1	1	1	1	1	1
1.1.3	Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	4	4	4	3
1.1.3.1	Lithology	5	3	5	5	5	3
1.1.3.2	Diagenesis	4	2	4	4	4	2
1.1.3.3	Pore architecture	3	1	3	2	3	2
1.1.3.4	Mineralogy	3	1	2	2	3	2
1.1.3.5	Kerogen type	3	1	2	2	3	2
1.1.3.6	Thermal maturation of source rock	3	1	3	2	3	2
1.1.3.7	Porosity	4	2	3	4	3	3
1.1.3.8	Intrinsic permeability	5	3	5	4	4	3
1.1.3.9	Relative permeability	5	3	5	5	4	3
1.1.3.10	Entry pressure	4	2	4	4	4	2
1.1.3.11	Residual saturation	1	1	1	1	1	1
1.1.3.12	Hysteresis	1	1	1	1	1	1
1.1.4	Stress and Mechanical properties	4	4	4	1	2	1
1.1.5	Heterogeneity of the hydrocarbon bearing formation	4	2	4	3	3	2
1.1.6	Fractures and faults within the hydrocarbon bearing formation	5	4	3	4	5	2
1.1.6.1	Porosity of the fracture	4	2	3	4	4	2
1.1.6.2	Intrinsic permeability of the fracture	4	2	4	4	4	2
1.1.6.3	Relative Permeability of the fractures	4	2	4	4	4	2
1.1.6.4	Fracture geometry	3	1	2	3	2	2
1.1.7	Undetected features within the hydrocarbon bearing formation	3	1	2	3	2	2
1.1.8	Vertical geothermal gradient of the hydrocarbon bearing formation	4	1	2	4	2	2
1.1.9	Formation pressure of the hydrocarbon bearing formation	4	1	2	4	3	2
1.2	Fluids						
1.2.1	Hydrocarbons	4	3	3	4	2	2
1.2.2	Natural formation water	4	1	2	4	2	2
1.2.3	Production fluids	4	1	2	4	1	2
1.2.4	Pore fluid composition within the fracking reservoir	4	3	3	4	1	2
1.2.5	Reservoir fluids	4	3	2	4	1	2
1.2.6	Other fluids	4	1	2	4	1	2
1.3	Overburden						
1.3.1	Geometry of the overburden	1	1	1	1	1	1
1.3.1.1	Thickness	1	1	1	1	1	1
1.3.2	Rock / Petrophysical properties of the overburden	2	1	1	1	1	2
1.3.2.1	Lithology	4	1	1	4	3	4
1.3.2.2	Diagenesis	4	1	1	4	3	4
1.3.2.3	Pore architecture	4	1	1	4	3	3
1.3.2.4	Mineralogy	3	1	1	3	2	3
1.3.2.5	Porosity	5	1	3	4	5	4
1.3.2.6	Intrinsic permeability	3	1	3	3	3	3
1.3.2.7	Relative permeability	4	1	3	1	3	4
1.3.2.8	Entry pressure	3	1	3	1	3	3
1.3.2.9	Residual saturation	1	1	1	1	1	1
1.3.2.10	Hysteresis	1	1	1	1	1	1
1.3.3	Free gas pocket within the overburden	3	1	1	1	1	2
1.3.4	Additional seals within the overburden	3	1	1	1	1	3
1.3.5	Unconformities within the overburden	3	1	3	1	2	3
1.3.6	Heterogeneity within the overburden	4	1	4	1	4	1
1.3.7	Fractures and faults within the overburden	5	1	5	4	5	1
1.3.7.1	Porosity of the fracture	5	1	3	4	5	4
1.3.7.2	Intrinsic permeability of the fracture	4	1	3	4	4	4
1.3.7.3	Relative Permeability of the fractures	4	1	3	4	4	4
1.3.7.4	Fracture geometry	4	1	3	4	4	3
1.3.8	Undetected features within the overburden	3	1	2	3	2	3
1.3.9	Vertical geothermal gradient of the overburden	4	1	3	4	2	3
1.3.10	Formation "overburden" pressure	4	1	4	4	3	2
1.3.11	Overburden pressure	4	1	3	4	4	2
1.4	Underburden						
1.4.1	Geometry of the underburden	1	1	1	1	1	1
1.4.1.1	Thickness	1	1	1	1	1	1
1.4.2	Rock / Petrophysical properties of the underburden	3	1	2	3	2	1
1.4.2.1	Lithology	3	1	2	3	3	2
1.4.2.2	Diagenesis	3	1	2	3	3	2
1.4.2.3	Pore architecture	3	1	2	3	3	2
1.4.2.4	Mineralogy	3	1	2	3	3	2
1.4.2.5	Porosity	4	1	2	3	4	2
1.4.2.6	Intrinsic permeability	3	1	1	3	1	1
1.4.2.7	Relative permeability	3	1	1	3	1	1
1.4.2.8	Entry pressure	2	1	1	2	1	1
1.4.2.9	Residual saturation	3	1	2	3	2	1
1.4.2.10	Hysteresis	3	1	2	3	1	1
1.4.3	Unconformities within the underburden	3	1	2	3	1	1
1.4.4	Heterogeneity within the underburden	3	1	2	3	1	1
1.4.5	Fractures and faults within the underburden	3	1	2	3	2	1
1.4.6	Undetected features within the underburden	3	1	2	3	1	2
1.4.7	Vertical geothermal gradient within the underburden	3	1	2	3	1	2
1.4.8	Formation "underburden" pressure	3	1	2	3	2	1
2	Near surface environment (receptors)						
2.1	Terrestrial environment						
2.1.1	Geographical location	1	1	1	1	1	1
2.1.2	Soils and sediments	5	1	1	1	4	5
2.1.3	Near-surface aquifers and surface water bodies	5	1	1	1	4	4
2.1.4	Terrestrial flora and fauna	4	1	1	1	3	4
2.1.5	Terrestrial ecological systems	4	1	1	1	3	4
2.1.6	Buildings	3	1	1	1	3	2
2.2	Marine environment						
2.2.1	Local oceanography	4	1	1	1	2	4
2.2.2	Marine sediments	4	1	1	1	3	4
2.2.3	Marine Stratification and Mixing	4	1	1	1	3	4
2.2.4	Marine flora and fauna	4	1	1	1	3	4
2.2.5	Marine ecological systems	5	1	1	1	4	5
2.3	Human Environment						
2.3.1	Human characteristics	1	1	1	1	1	1
2.3.2	Diet and food processing	3	1	1	1	2	3
2.3.3	Lifestyles	1	1	1	1	1	1
2.3.4	Land and water use	3	1	1	1	1	3
2.3.5	Community characteristics	1	1	1	1	1	1
2.4	Atmosphere and meteorology	1	1	1	1	1	1

B. Unconventional Hydrocarbon Extraction

1	Hydro-fracturing fluid							
1.1	Hydraulic injection fluid properties	3	1	2	2	3	3	
1.2	Physical properties of injection fluid							
1.2.1	Injection fluid additives	4	1	1	2	4	3	
1.2.2	Hydro-fracturing fluids interactions	3	1	3	2	3	3	
2	Site development							
2.1	Logistics above ground	1	1	1	1	1	1	
2.2	Baseline monitoring	1	1	1	1	1	1	
3	Site operation							
3.1	Drilling and completion							
3.1.1	Horizontal wells	1	1	1	1	1	1	
3.1.2	Formation damage	4	1	1	1	4	3	
3.1.3	Well lining and completion	3	1	1	1	3	1	
3.1.4	Workover	1	1	1	1	1	1	
3.1.5	Monitoring wells	2	1	1	1	2	2	
3.1.6	Well records	2	1	1	1	2	2	
3.1.7	Well orientation	1	1	1	1	1	1	
3.1.8	Well engineering	1	1	1	1	1	1	
4	Site decommissioning							
4.1	Closure and sealing of boreholes	3	1	1	1	3	3	
4.2	Abandoned wells	4	1	1	1	3	4	
		1	96	54	51	42	35	45
		2	5	27	5	19	35	28
		3	6	18	21	25	17	22
		4	2	6	29	16	20	10

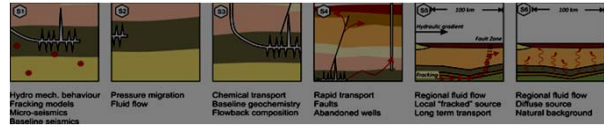
1 Least Critical
2
3
4
5 Most Critical



List of Events

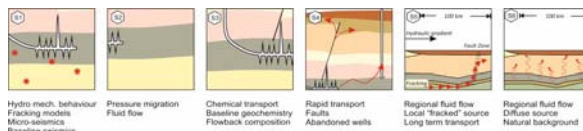
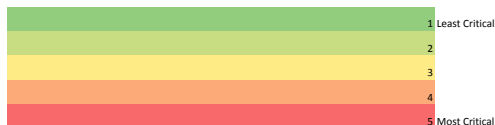
	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Operational Events						
1.1. Multiple well drilling from same platform	3	3	3	3	2	3
1.2. Initial drilling to given below water table (Open Hole)	4	3	3	4	4	4
1.2. Casing emplacement	5	1	3	3	2	5
1.2. Cementation with wiper plug	5	1	4	3	2	4
1.2. Drilling through wiper plug and casing shoe	5	1	4	3	2	5
1.2. Additional cementation	5	1	4	3	2	5
1.3. Logging Borehole	5	3	4	5	4	5
1.4. Drilling horizontal borehole	4	3	3	2	4	4
1.4. Casing horizontal borehole	4	1	3	3	4	4
1.4. Cementation	4	1	3	3	1	4
1.4. Perforation	1	1	1	1	1	1
1.5. Hydraulic fracturing	5	5	3	2	3	2
1.5. Out of zone / beyond pumping	5	1	2	3	4	5
1.6. Plugging & drilling out of plugs	4	1	2	1	2	3
1.7. Flow back	5	1	2	5	3	3
1.7. Production	5	3	5	5	3	3
1.8. Abandonment	5	3	5	5	3	3
1.9. Seal failure	5	3	5	4	5	3
2 Natural events						
2.1. Earthquakes	5	5	5	3	5	3
2.2. Large scale erosion	5	3	4	4	5	3
2.3. Hydrological and hydrogeological response to geological changes	5	3	5	4	5	3
2.4. Cap rock failure	5	4	5	4	5	3
2.5. Unexpected large scale scenario	5	3	4	4	5	3
3 Accidents and unplanned events						
3.1. Surface chemical spills	5	3	5	5	4	3
3.2. Overpressuring	5	3	5	3	5	3
3.3. Poor site characterization	5	1	4	4	5	3
3.4. Incorrect chemical mix released into fracking fluid	5	3	5	5	3	3
3.5. Cementation poorly undertaken (spaces left)	5	1	5	3	5	3
3.6. Well lining too limited, open hole left	5	1	4	3	5	3
3.7. Inappropriate management of drill cuttings and spent drilling muds.	5	1	3	3	5	3
3.8. Unlikely significant event	5	1	3	2	5	3
	1	15	1	2	3	1
	2	0	3	2	6	1
	3	13	9	14	3	14
	4	1	8	7	3	12
	5	2	10	6	16	3

- 1 Least Critical
2
3
4
5 Most Critical
Importance



List of Processes

	Importance	Relevance to Scenario						
		S1	S2	S3	S4	S5	S6	
1 Thermal effects on the borehole								
1.1. Thermal effects on borehole and seal integrity.	5	3	3	3	3	5	5	
1.2. Thermal effects on the injection point	4	1	1	1	1	3	4	
2 Hydraulics / Fluid Pressure Dominated	5	3	2	3	3	5	4	
2.1. Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	3	3	5	4	4	
2.2. Fluid exceeds fault sealing pressures	5	5	3	3	4	2	1	
2.3. Fluid pressure exceeds stability of part of the plant construction.	5	5	3	2	4	4	2	
2.4. Displacement of surrounding formation fluids	5	5	3	3	5	4	4	
2.5. Buoyancy-driven flow	5	4	4	3	4	4	5	
2.6. Advection and co-migration of other gas	5	3	3	4	3	5	5	
2.7. Formation of Gas hydrates	4	3	2	3	3	4	3	
2.8. Water mediated transport	4	3	2	4	3	3	3	
2.8.1. Advection	4	4	2	4	3	4	4	
2.8.2. Dispersion	5	4	3	4	5	4	4	
2.8.3. Diffusion	5	4	4	5	5	4	4	
2.9. Hydraulic and production fluids and the associated contaminants release processes	5	3	3	5	5	4	4	
3 Chemical								
3.1 Corrosive mixture attacks plant	5	1	1	5	5	4	4	
3.2 Corrosive mixture attacks geology	5	5	2	5	5	4	4	
3.3 Sorption and desorption	5	2	2	5	5	5	4	
3.4 Mineral dissolution	5	1	1	5	5	4	4	
3.5 Heavy metal release	5	1	1	5	5	4	4	
4 Mechanical								
4.1 Soil and rock deformation around boreholes	5	1	1	1	5	4	4	
4.1.1 Subsidence of ground related to gas extraction	5	1	1	1	5	4	4	
4.2 Propagation of fractures beyond the target zone	5	2	2	3	5	4	4	
4.3 Fluid exceeds fault sealing pressures	5	2	2	3	5	4	4	
4.4 Fault valving	5	2	2	2	5	4	4	
4.5 Generation of excavation disturbed zone around well	5	1	1	1	5	4	4	
4.6 Micro-cracking in the casing cements	5	1	1	1	5	4	4	
		1	8	8	5	1	0	1
		2	4	9	2	0	1	1
		3	6	8	9	5	2	2
		4	4	2	4	3	21	20
		5	5	0	7	18	3	3



List of Features

A. Features of the Natural System

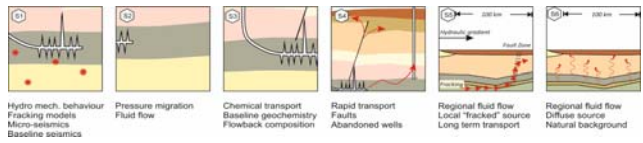
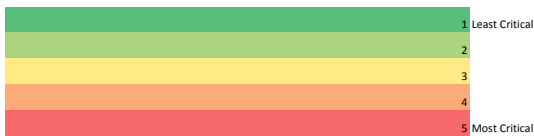
Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	5	4	4	3	2	1
1.1.2 Geometry of the hydrocarbon bearing formation	5	5	3	3	2	1
1.1.2.1 Thickness	5	5	3	3	2	1
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	5	3	4	2	1	1
1.1.3.1 Lithology	5	5	4	2	1	1
1.1.3.2 Diagenesis	2	2	3	1	1	1
1.1.3.3 Pore architecture	4	4	3	2	2	2
1.1.3.4 Mineralogy	3	2	4	1	1	2
1.1.3.5 Kerogen type	3	1	3	1	1	1
1.1.3.6 Thermal maturation of source rock	3	1	3	1	1	1
1.1.3.7 Porosity	3	3	3	3	2	2
1.1.3.8 Intrinsic permeability	5	5	3	4	5	2
1.1.3.9 Relative permeability	5	3	3	4	2	1
1.1.3.10 Entry pressure	4	3	4	4	2	1
1.1.3.11 Residual saturation	3	2	2	1	1	1
1.1.3.12 Hysteresis	2	3	1	1	1	1
1.1.4 Stress and Mechanical properties	5	3	1	1	1	1
1.1.5 Heterogeneity of the hydrocarbon bearing formation	5	3	3	3	2	2
1.1.6 Fractures and faults within the hydrocarbon bearing formation	5	5	3	5	2	2
1.1.6.1 Porosity of the fracture	3	4	3	3	1	1
1.1.6.2 Intrinsic permeability of the fracture	5	2	4	5	2	2
1.1.6.3 Relative Permeability of the fractures	5	5	3	3	2	1
1.1.6.4 Fracture geometry	5	4	3	3	2	2
1.1.7 Undetected features within the hydrocarbon bearing formation	3	3	3	3	1	1
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	2	1	2	1	1	2
1.1.9 Formation pressure of the hydrocarbon bearing formation	5	3	2	3	2	1
1.2 Fluids						
1.2.1 Hydrocarbons	4	2	4	1	1	1
1.2.2 Natural formation water	5	1	5	1	1	1
1.2.3 Production fluids	4	2	4	1	1	1
1.2.4 Pore fluid composition within the fracking reservoir	4	2	4	1	1	1
1.2.5 Reservoir fluids	4	2	4	1	1	1
1.2.6 Other fluids	4	1	4	1	1	1
1.3 Overburden						
1.3.1 Geometry of the overburden	4	1	3	3	3	4
1.3.1.1 Thickness	4	3	3	3	3	4
1.3.2 Rock / Petrophysical properties of the overburden	4	3	2	3	2	4
1.3.2.1 Lithology	4	1	1	2	3	4
1.3.2.2 Diagenesis	1	1	1	1	1	1
1.3.2.3 Pore architecture	2	1	1	1	2	2
1.3.2.4 Mineralogy	2	1	1	2	2	2
1.3.2.5 Porosity	2	1	2	2	2	2
1.3.2.6 Intrinsic permeability	5	1	2	1	5	5
1.3.2.7 Relative permeability	4	1	3	2	4	4
1.3.2.8 Entry pressure	3	1	1	1	3	3
1.3.2.9 Residual saturation	1	1	1	1	1	1
1.3.2.10 Hysteresis	1	1	1	1	1	1
1.3.3 Free gas pocket within the overburden	2	1	1	2	2	2
1.3.4 Additional seals within the overburden	3	1	1	2	3	3
1.3.5 Unconformities within the overburden	2	1	1	1	2	2
1.3.6 Heterogeneity within the overburden	2	1	1	1	2	2
1.3.7 Fractures and faults within the overburden	3	3	3	3	2	2
1.3.7.1 Porosity of the fracture	3	2	3	3	1	1
1.3.7.2 Intrinsic permeability of the fracture	3	1	3	3	2	2
1.3.7.3 Relative Permeability of the fractures	1	1	2	2	3	1
1.3.7.4 Fracture geometry	4	4	2	4	2	2
1.3.8 Undetected features within the overburden	4	2	2	4	3	3
1.3.9 Vertical geothermal gradient of the overburden	1	1	1	1	1	1
1.3.10 Formation "overburden" pressure	3	3	3	2	2	2
1.3.11 Overburden pressure	3	3	1	2	2	2
1.4 Underburden						
1.4.1 Geometry of the underburden	3	2	3	1	2	2
1.4.1.1 Thickness	3	1	3	1	2	2
1.4.2 Rock / Petrophysical properties of the underburden	2	1	2	1	2	2
1.4.2.1 Lithology	2	1	2	1	2	2
1.4.2.2 Diagenesis	1	1	1	1	1	1
1.4.2.3 Pore architecture	1	1	1	1	1	1
1.4.2.4 Mineralogy	2	1	1	1	1	2
1.4.2.5 Porosity	1	1	1	1	1	2
1.4.2.6 Intrinsic permeability	3	2	3	1	2	3
1.4.2.7 Relative permeability	2	1	2	1	2	2
1.4.2.8 Entry pressure	1	1	1	1	1	1
1.4.2.9 Residual saturation	2	1	1	1	2	1
1.4.2.10 Hysteresis	1	1	1	1	1	1
1.4.3 Unconformities within the underburden	1	1	1	1	1	1
1.4.4 Heterogeneity within the underburden	2	1	2	1	1	2
1.4.5 Fractures and faults within the underburden	3	3	2	1	1	2
1.4.6 Undetected features within the underburden	1	1	1	1	1	1
1.4.7 Vertical geothermal gradient within the underburden	1	1	1	1	1	1
1.4.8 Formation "underburden" pressure	1	1	1	1	1	1
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	5	5	1	2	3	2
2.1.2 Soils and sediments	3	1	1	2	2	3
2.1.3 Near-surface aquifers and surface water bodies	2	1	1	1	1	2
2.1.4 Terrestrial flora and fauna	1	1	1	1	1	1
2.1.5 Terrestrial ecological systems	1	1	1	1	1	1
2.1.6 Buildings	5	5	1	3	3	2
2.2 Marine environment						
2.2.1 Local oceanography	1	1	1	1	1	1
2.2.2 Marine sediments	2	1	1	1	1	2
2.2.3 Marine Stratification and Mixing	1	1	1	1	1	1
2.2.4 Marine flora and fauna	1	1	1	1	1	1
2.2.5 Marine ecological systems	1	1	1	1	1	1
2.3 Human Environment						
2.3.1 Human characteristics	3	3	1	3	3	2
2.3.2 Diet and food processing	3	1	1	2	3	2
2.3.3 Lifestyles	2	2	1	2	2	1
2.3.4 Land and water use	3	3	1	3	3	3
2.3.5 Community characteristics	4	4	1	3	3	3
2.4 Atmosphere and meteorology						
B. Unconventional Hydrocarbon Extraction						
1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties	3	3	3	3	1	2
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	4	4	3	3	2	1
1.2.2 Hydro-fracturing fluids interactions	3	3	3	3	1	1
2 Site development						
2.1 Logistics above ground	1	1	1	1	1	1
2.2 Baseline monitoring	3	3	3	3	3	3
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	3	3	3	3	3	2
3.1.2 Formation damage	3	3	3	3	3	2

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning**
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

2	1	1	2	2	2	1
1	1	1	1	1	1	1
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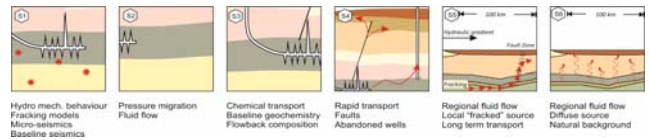
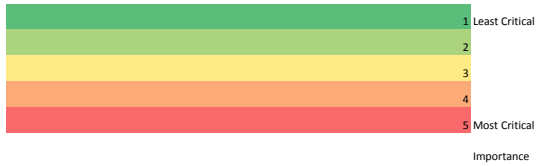
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1	55	54	53	55	52	56
2	12	18	15	18	39	35
3	20	25	27	25	11	10
4	4	4	10	5	3	5
5	16	6	2	4	2	1



List of Events

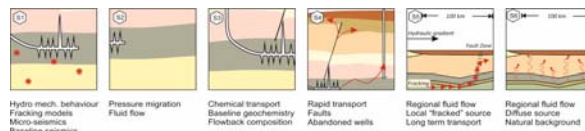
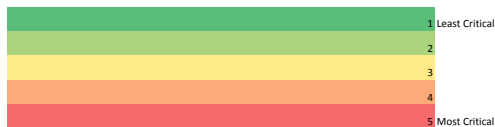
		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	3	3	3	3	3	3	2
1.2. Initial drilling to given below water table (Open Hole)	3	1	1	3	3	3	2
1.2. Casing emplacement	3	1	1	3	3	1	1
1.2. Cementation with wiper plug	1	1	1	1	1	1	1
1.2. Drilling through wiper plug and casing shoe	1	1	1	1	1	1	1
1.2. Additional cementation	3	1	1	3	1	1	1
1.3. Logging Borehole	1	1	1	1	1	1	1
1.4. Drilling horizontal borehole	3	3	3	3	3	2	2
1.4. Casing horizontal borehole	3	2	2	3	3	2	2
1.4. Cementation	3	3	3	3	2	2	2
1.4. Perforation	3	2	3	3	3	1	1
1.5. Hydraulic fracturing	5	5	5	5	5	1	1
1.5. Out of zone / beyond pumping	5	5	5	3	5	3	1
1.6. Plugging & drilling out of plugs	1	1	1	1	1	1	1
1.7. Flow back	5	3	4	5	3	2	2
1.7. Production	3	3	3	3	3	1	1
1.8. Abandonment	4	1	1	1	1	4	2
1.9. Seal failure	5	5	3	5	3	1	1
2 Natural events							
2.1. Earthquakes	2	1	1	1	1	1	2
2.2. Large scale erosion	2	1	1	1	1	2	2
2.3. Hydrological and hydrogeological response to geological changes	2	1	1	1	1	2	2
2.4. Cap rock failure	3	3	1	3	1	2	2
2.5. Unexpected large scale scenario	1	1	1	1	1	1	1
3 Accidents and unplanned events							
3.1. Surface chemical spills	5	1	2	5	1	1	1
3.2. Overpressuring	5	5	5	4	5	1	1
3.3. Poor site characterization	4	4	4	4	4	2	2
3.4. Incorrect chemical mix released into fracking fluid	4	3	2	4	1	1	1
3.5. Cementation poorly undertaken (spaces left)	4	3	4	4	3	1	1
3.6. Well lining too limited, open hole left	4	4	4	4	4	1	1
3.7. Inappropriate management of drill cuttings and spent drilling muds.	3	1	1	3	1	1	1
3.8. Unlikely significant event	1	1	1	1	1	1	1
		15	14	11	15	20	19
		2	3	0	0	6	12
		8	7	11	11	4	0
		2	4	5	2	1	0
		4	3	4	3	0	0



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	3	1	3	1	1	1	1
1.2 Thermal effects on the injection point	2	2	2	2	1	1	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	4	4	4	1	1
2.2 Fluid exceeds fault sealing pressures	5	5	5	4	4	1	1
2.3 Fluid pressure exceeds stability of part of the plant construction.	3	1	3	1	2	1	1
2.4 Displacement of surrounding formation fluids	5	1	5	3	5	2	1
2.5 Buoyancy-driven flow	2	1	2	1	1	1	2
2.6 Advection and co-migration of other gas	2	1	2	2	2	1	1
2.7 Formation of Gas hydrates	4	3	4	3	1	1	1
2.8 Water mediated transport	3	1	3	3	2	2	2
2.8.1 Advection	2	2	2	2	2	1	1
2.8.2 Dispersion	1	1	1	1	1	1	1
2.8.3 Diffusion	2	1	1	1	1	1	2
2.9 Hydraulic and production fluids and the associated contaminants release processes	4	1	1	4	1	1	1
3 Chemical							
3.1 Corrosive mixture attacks plant	2	1	2	2	1	1	1
3.2 Corrosive mixture attacks geology	2	2	2	2	1	1	1
3.3 Sorption and desorption	3	1	1	3	1	1	1
3.4 Mineral dissolution	2	1	1	2	1	2	1
3.5 Heavy metal release	2	1	1	2	1	2	2
4 Mechanical							
4.1 Soil and rock deformation around boreholes	3	2	3	1	1	1	1
4.1.1 Subsidence of ground related to gas extraction	1	1	1	1	1	1	1
4.2 Propagation of fractures beyond the target zone	4	4	4	3	4	1	1
4.3 Fluid exceeds fault sealing pressures	5	4	4	1	5	1	1
4.4 Fault valving	3	2	3	1	3	1	1
4.5 Generation of excavation disturbed zone around well	3	1	3	3	2	1	1
4.6 Micro-cracking in the casing cements	3	1	3	3	2	1	1

1	16	7	9	14	21	22
2	5	6	7	6	5	4
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List of Features

A. Features of the Natural System

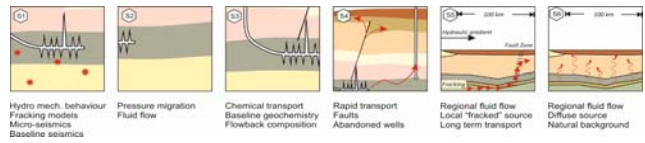
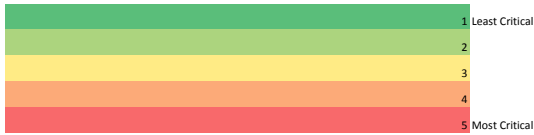
Overall Importance In Risk Analysis	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Hydrogeology						
1.1 Hydrocarbon bearing formation (Source)						
1.1.1 Type of the hydrocarbon bearing formation	5	5	5	2	2	2
1.1.2 Geometry of the hydrocarbon bearing formation	5	5	5	3	3	3
1.1.2.1 Thickness	4	4	1	2	2	2
1.1.3 Rock / Petrophysical properties of the hydrocarbon bearing formation	4	4	4	4	2	2
1.1.3.1 Lithology	3	5	4	4	3	4
1.1.3.2 Diagenesis	4	4	4	4	2	2
1.1.3.3 Pore architecture	4	4	2	3	2	3
1.1.3.4 Mineralogy	4	3	4	4	4	3
1.1.3.5 Kerogen type	5	3	5	4	3	3
1.1.3.6 Thermal maturation of source rock	4	1	2	4	3	3
1.1.3.7 Porosity	4	2	2	3	3	3
1.1.3.8 Intrinsic permeability	4	4	2	4	4	2
1.1.3.9 Relative permeability	4	1	3	2	5	4
1.1.3.10 Entry pressure	4	2	2	1	4	3
1.1.3.11 Residual saturation	3	1	1	1	2	3
1.1.3.12 Hysteresis	1	1	1	1	2	1
1.1.4 Stress and Mechanical properties	5	5	2	1	1	1
1.1.5 Heterogeneity of the hydrocarbon bearing formation	5	5	4	1	3	2
1.1.6 Fractures and faults within the hydrocarbon bearing formation	4	4	4	4	4	3
1.1.6.1 Porosity of the fracture	3	3	1	3	3	3
1.1.6.2 Intrinsic permeability of the fracture	4	3	4	1	4	2
1.1.6.3 Relative Permeability of the fractures	2	1	3	1	5	2
1.1.6.4 Fracture geometry	5	2	4	1	4	3
1.1.7 Undetected features within the hydrocarbon bearing formation	4	4	5	4	5	3
1.1.8 Vertical geothermal gradient of the hydrocarbon bearing formation	3	1	2	3	2	3
1.1.9 Formation pressure of the hydrocarbon bearing formation	3	3	4	2	3	3
1.2 Fluids						
1.2.1 Hydrocarbons	5	4	5	5	5	5
1.2.2 Natural formation water	5	4	5	5	5	5
1.2.3 Production fluids	5	5	5	4	4	4
1.2.4 Pore fluid composition within the fracking reservoir	5	5	5	4	4	4
1.2.5 Reservoir fluids	4	2	2	4	2	2
1.2.6 Other fluids	4	2	2	4	2	2
1.3 Overburden						
1.3.1 Geometry of the overburden	5	3	3	4	4	5
1.3.1.1 Thickness	4	3	3	3	3	4
1.3.2 Rock / Petrophysical properties of the overburden	4	4	4	4	3	3
1.3.2.1 Lithology	4	2	4	3	4	4
1.3.2.2 Diagenesis	3	1	2	3	3	3
1.3.2.3 Pore architecture	3	2	3	3	2	3
1.3.2.4 Mineralogy	4	1	2	4	2	3
1.3.2.5 Porosity	4	2	4	2	4	3
1.3.2.6 Intrinsic permeability	4	2	4	1	4	2
1.3.2.7 Relative permeability	5	1	2	1	5	5
1.3.2.8 Entry pressure	2	1	1	1	2	2
1.3.2.9 Residual saturation	2	1	1	1	2	1
1.3.2.10 Hysteresis	3	1	1	1	3	2
1.3.3 Free gas pocket within the overburden	3	2	2	2	2	3
1.3.4 Additional seals within the overburden	3	2	3	1	2	3
1.3.5 Unconformities within the overburden	3	2	3	2	3	3
1.3.6 Heterogeneity within the overburden	4	2	4	1	3	2
1.3.7 Fractures and faults within the overburden	5	2	5	2	4	2
1.3.7.1 Porosity of the fracture	3	1	2	2	3	2
1.3.7.2 Intrinsic permeability of the fracture	4	2	3	2	3	2
1.3.7.3 Relative Permeability of the fractures	2	1	2	2	4	2
1.3.7.4 Fracture geometry	5	2	5	2	5	2
1.3.8 Undetected features within the overburden	5	1	3	4	3	3
1.3.9 Vertical geothermal gradient of the overburden	3	2	3	3	2	2
1.3.10 Formation "overburden" pressure	4	3	4	2	2	2
1.3.11 Overburden pressure	3	3	2	2	3	3
1.4 Underburden						
1.4.1 Geometry of the underburden	2	2	2	1	1	1
1.4.1.1 Thickness	2	2	1	1	2	1
1.4.2 Rock / Petrophysical properties of the underburden	2	1	2	2	2	1
1.4.2.1 Lithology	2	2	2	2	2	1
1.4.2.2 Diagenesis	2	1	2	2	2	1
1.4.2.3 Pore architecture	2	1	2	2	2	1
1.4.2.4 Mineralogy	2	1	2	2	2	1
1.4.2.5 Porosity	1	1	2	2	2	1
1.4.2.6 Intrinsic permeability	2	2	2	1	2	2
1.4.2.7 Relative permeability	1	1	1	1	1	1
1.4.2.8 Entry pressure	1	1	1	1	1	1
1.4.2.9 Residual saturation	2	1	2	1	2	1
1.4.2.10 Hysteresis	2	1	2	1	2	1
1.4.3 Unconformities within the underburden	2	2	2	2	2	1
1.4.4 Heterogeneity within the underburden	2	1	2	2	2	2
1.4.5 Fractures and faults within the underburden	2	2	2	2	2	2
1.4.6 Undetected features within the underburden	2	1	2	2	2	2
1.4.7 Vertical geothermal gradient within the underburden	2	1	2	2	2	2
1.4.8 Formation "underburden" pressure	2	1	2	2	2	2
2 Near surface environment (Receptors)						
2.1 Terrestrial environment						
2.1.1 Geographical location	4	4	2	4	4	4
2.1.2 Soils and sediments	5	5	5	5	5	5
2.1.3 Near-surface aquifers and surface water bodies	4	2	2	4	4	4
2.1.4 Terrestrial flora and fauna	3	1	1	3	3	3
2.1.5 Terrestrial ecological systems	4	1	2	4	4	3
2.1.6 Buildings	4	2	3	4	3	3
2.2 Marine environment						
2.2.1 Local oceanography	1	1	1	1	1	1
2.2.2 Marine sediments	2	1	1	1	1	2
2.2.3 Marine Stratification and Mixing	1	1	1	1	1	1
2.2.4 Marine flora and fauna	1	1	1	1	1	1
2.2.5 Marine ecological systems	2	1	1	1	2	1
2.3 Human Environment						
2.3.1 Human characteristics	2	2	1	1	1	1
2.3.2 Diet and food processing	2	1	1	2	2	1
2.3.3 Lifestyles	2	2	1	2	2	1
2.3.4 Land and water use	3	2	2	2	3	3
2.3.5 Community characteristics	3	1	2	3	3	2
2.4 Atmosphere and meteorology						
B. Unconventional Hydrocarbon Extraction						
1 Hydro-fracturing fluid						
1.1 Hydraulic injection fluid properties	5	4	5	5	3	3
1.2 Physical properties of injection fluid						
1.2.1 Injection fluid additives	5	4	4	5	4	4
1.2.2 Hydro-fracturing fluids interactions	5	5	4	5	3	3
2 Site development						
2.1 Logistics above ground	3	3	2	2	2	1
2.2 Baseline monitoring	4	3	2	4	2	1
3 Site operation						
3.1 Drilling and completion						
3.1.1 Horizontal wells	5	5	5	5	4	5
3.1.2 Formation damage	5	5	5	4	3	2

- 3.1.3. Well lining and completion 4
- 3.1.4. Workover 3
- 3.1.5. Monitoring wells 4
- 3.1.6. Well records 4
- 3.1.7. Well orientation 5
- 3.1.8. Well engineering 4
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes 4
- 4.2. Abandoned wells 4

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4
4

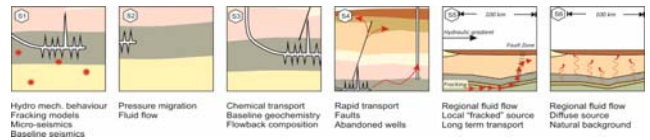
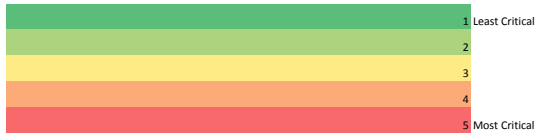
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4	4	4	4	3	3
3	4	4	3	3	3
2	4	4	4	3	3

1	36	17	29	10	17	25
2	32	40	31	32	34	33
3	14	16	9	32	30	36
4	17	20	26	25	19	9
5	9	15	13	9	8	5



List of Events

	Relevance to Scenario					
	S1	S2	S3	S4	S5	S6
1 Operational Events						
1.1. Multiple well drilling from same platform	5	5	5	5	4	4
1.2. Initial drilling to given below water table (Open Hole)	4	4	4	4	3	3
1.2. Casing emplacement	4	3	3	2	2	3
1.2. Cementation with wiper plug	4	4	4	2	2	2
1.2. Drilling through wiper plug and casing shoe	3	3	3	3	3	2
1.2. Additional cementation	4	4	3	2	3	2
1.3. Logging Borehole	4	3	2	4	3	2
1.4. Drilling horizontal borehole	5	5	2	4	4	4
1.4. Casing horizontal borehole	2	2	2	2	1	1
1.4. Cementation	3	2	2	1	3	2
1.4. Perforation	4	2	1	3	2	2
1.5. Hydraulic fracturing	5	5	3	3	4	3
1.5. Out of zone / beyond pumping	4	2	3	2	2	2
1.6. Plugging & drilling out of plugs	3	3	1	2	2	2
1.7. Flow back	4	1	3	3	3	4
1.7. Production	4	2	4	3	3	3
1.8. Abandonment	4	3	4	3	3	4
1.9. Seal failure	5	4	4	3	4	5
2 Natural events						
2.1. Earthquakes	4	4	3	1	1	1
2.2. Large scale erosion	4	1	2	1	1	1
2.3. Hydrological and hydrogeological response to geological changes	2	2	2	2	2	2
2.4. Cap rock failure	5	5	4	4	5	5
2.5. Unexpected large scale scenario	3	3	3	3	3	2
3 Accidents and unplanned events						
3.1. Surface chemical spills	5	1	1	5	3	4
3.2. Overpressuring	4	4	3	3	2	2
3.3. Poor site characterization	5	4	4	5	4	4
3.4. Incorrect chemical mix released into fracking fluid	5	3	4	5	3	4
3.5. Cementation poorly undertaken (spaces left)	4	4	3	4	3	4
3.6. Well lining too limited, open hole left	4	3	3	3	2	3
3.7. Inappropriate management of drill cuttings and spent drilling muds.	3	1	2	3	2	2
3.8. Unlikely significant event	2	2	2	2	2	2
1	3	2	3	3	3	3
2	6	7	7	8	10	13
3	8	7	13	12	12	5
4	10	11	4	6	5	8
5	4	4	4	2	1	2



List of Processes

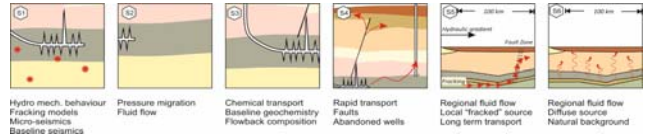
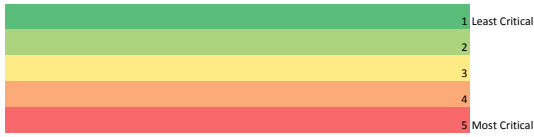
	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	4	4	2	2	3	2	1
1.2 Thermal effects on the injection point	3	3	1	1	1	1	1
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	5	4	2	3	2	1
2.2 Fluid exceeds fault sealing pressures	5	5	4	2	3	1	1
2.3 Fluid pressure exceeds stability of part of the plant construction.	5	5	5	2	2	1	1
2.4 Displacement of surrounding formation fluids	5	5	5	3	5	5	4
2.5 Buoyancy-driven flow	5	5	5	2	5	5	4
2.6 Advection and co-migration of other gas	5	3	4	4	5	5	2
2.7 Formation of Gas hydrates	4	3	3	4	4	3	4
2.8 Water mediated transport	5	3	4	5	5	5	3
2.8.1 Advection	5	5	4	3	5	5	2
2.8.2 Dispersion	5	4	4	4	5	5	3
2.8.3 Diffusion	5	3	3	5	3	5	5
2.9 Hydraulic and production fluids and the associated contaminants release processes	5	5	3	5	5	5	5
3 Chemical							
3.1 Corrosive mixture attacks plant	5	2	1	5	3	3	2
3.2 Corrosive mixture attacks geology	5	1	2	5	4	3	4
3.3 Sorption and desorption	4	1	2	4	3	3	3
3.4 Mineral dissolution	5	2	2	5	4	3	3
3.5 Heavy metal release	5	1	3	5	4	3	3
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	1	2	1	2
4.1.1 Subsidence of ground related to gas extraction	5	4	5	3	3	2	2
4.2 Propagation of fractures beyond the target zone	5	5	5	2	4	2	1
4.3 Fluid exceeds fault sealing pressures	5	5	5	1	4	2	1
4.4 Fault valving	5	5	5	2	3	2	3
4.5 Generation of excavation disturbed zone around well	5	5	5	2	4	1	2
4.6 Micro-cracking in the casing cements	5	4	4	2	5	2	3

1	3	2	3	1	5	7
2	2	4	9	2	7	6
3	5	4	3	8	6	7
4	4	7	4	7	0	4
5	12	9	7	8	8	2

- 3.1.3. Well lining and completion
- 3.1.4. Workover
- 3.1.5. Monitoring wells
- 3.1.6. Well records
- 3.1.7. Well orientation
- 3.1.8. Well engineering
- 4 Site decommissioning
- 4.1. Closure and sealing of boreholes
- 4.2. Abandoned wells

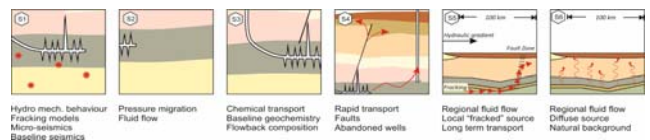
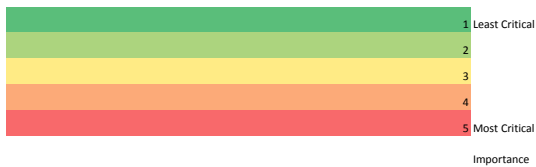
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5	4	4	4	4	5	5
5	4	4	4	4	5	5
1	1	1	1	1	1	1
4	4	4	4	4	2	2
4	4	4	4	4	2	2

1	52	58	53	65	55	54
2	27	26	23	19	27	27
3	8	4	7	6	15	16
4	18	16	22	14	7	7
5	3	4	3	4	4	4



List of Events

		Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Operational Events							
1.1. Multiple well drilling from same platform	5	3	4	3	5	2	2
1.2. Initial drilling to given below water table (Open Hole)	4	3	4	4	4	2	2
1.2. Casing emplacement	4	3	3	3	4	2	2
1.2. Cementation with wiper plug	4	1	1	1	4	1	1
1.2. Drilling through wiper plug and casing shoe	3	3	3	3	3	2	2
1.2. Additional cementation	3	1	1	1	3	1	1
1.3. Logging Borehole	3	1	1	1	3	1	1
1.4. Drilling horizontal borehole	3	3	3	3	2	2	2
1.4. Casing horizontal borehole	4	3	3	3	4	2	2
1.4. Cementation	4	1	1	1	4	1	1
1.4. Perforation	3	3	3	3	3	2	2
1.5. Hydraulic fracturing	5	5	5	5	5	2	2
1.5. Out of zone / beyond pumping	4	1	1	1	4	4	4
1.6. Plugging & drilling out of plugs	1	1	1	1	1	1	1
1.7. Flow back	4	2	2	2	4	2	2
1.7. Production	5	2	2	2	5	2	2
1.8. Abandonment	5	2	2	2	5	2	2
1.9. Seal failure	5	2	2	2	5	2	2
2 Natural events							
2.1. Earthquakes	5	5	5	5	5	3	3
2.2. Large scale erosion	3	3	3	3	3	3	3
2.3. Hydrological and hydrogeological response to geological changes	2	2	2	2	2	2	2
2.4. Cap rock failure	5	4	5	5	5	3	3
2.5. Unexpected large scale scenario	3	3	3	3	3	3	3
3 Accidents and unplanned events							
3.1. Surface chemical spills	3	1	1	1	1	3	3
3.2. Overpressuring	4	4	4	4	4	3	3
3.3. Poor site characterization	4	3	3	3	3	4	4
3.4. Incorrect chemical mix released into fracking fluid	5	2	2	5	2	2	2
3.5. Cementation poorly undertaken (spaces left)	3	2	3	3	3	1	1
3.6. Well lining too limited, open hole left	1	1	1	1	1	1	1
3.7. Inappropriate management of drill cuttings and spent drilling muds.	1	1	1	1	1	1	1
3.8. Unlikely significant event	1	1	1	1	1	1	1
		10	10	10	5	9	9
		7	6	5	3	14	14
		10	9	10	8	6	6
		2	3	2	8	2	2
		2	3	4	7	0	0



List of Processes

	Importance	Relevance to Scenario					
		S1	S2	S3	S4	S5	S6
1 Thermal effects on the borehole							
1.1 Thermal effects on borehole and seal integrity.	5	4	3	5	3	2	2
1.2 Thermal effects on the injection point	2	1	1	2	1	2	2
2 Hydraulics / Fluid Pressure Dominated							
2.1 Fluid pressure exceeds rock fracturing pressures generating new fractures	5	4	4	3	5	2	2
2.2 Fluid exceeds fault sealing pressures	4	4	4	4	4	1	1
2.3 Fluid pressure exceeds stability of part of the plant construction.	1	1	1	1	1	1	1
2.4 Displacement of surrounding formation fluids	4	1	1	1	1	4	4
2.5 Buoyancy-driven flow	4	2	2	1	2	4	4
2.6 Advection and co-migration of other gas	4	3	3	4	3	2	2
2.7 Formation of Gas hydrates	3	2	2	3	2	2	2
2.8 Water mediated transport	3	2	2	2	3	3	3
2.8.1 Advection	4	4	2	4	3	4	4
2.8.2 Dispersion	4	4	5	3	5	4	4
2.8.3 Diffusion	5	1	1	5	2	2	2
2.9 Hydraulic and production fluids and the associated contaminants release processes	4	1	1	4	4	4	4
3 Chemical							
3.1 Corrosive mixture attacks plant	5	5	5	5	5	1	1
3.2 Corrosive mixture attacks geology	5	5	5	5	5	4	4
3.3 Sorption and desorption	5	5	5	5	5	4	4
3.4 Mineral dissolution	5	5	5	5	5	4	4
3.5 Heavy metal release	5	5	5	5	5	4	4
4 Mechanical							
4.1 Soil and rock deformation around boreholes	5	5	5	5	5	4	4
4.1.1 Subsidence of ground related to gas extraction	5	5	5	5	5	4	4
4.2 Propagation of fractures beyond the target zone	5	5	5	5	5	4	4
4.3 Fluid exceeds fault sealing pressures	5	5	5	5	5	4	4
4.4 Fault valving	5	5	5	5	5	1	1
4.5 Generation of excavation disturbed zone around well	5	5	5	5	5	1	1
4.6 Micro-cracking in the casing cements	4	4	4	4	4	1	1

1	5	5	3	3	6	6
2	3	4	2	3	6	6
3	1	2	3	4	1	1
4	6	3	5	3	13	13
5	11	12	13	13	0	0