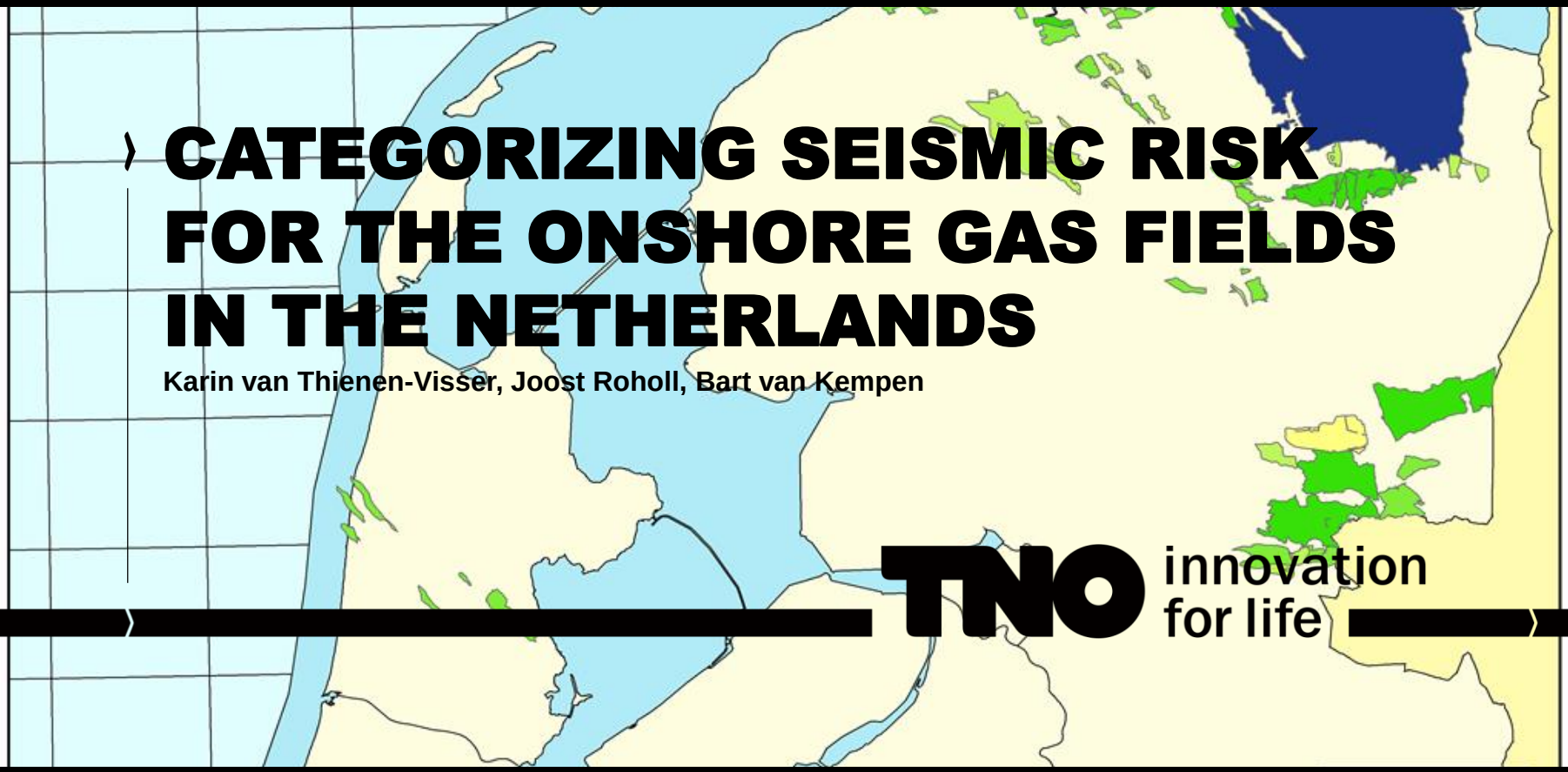


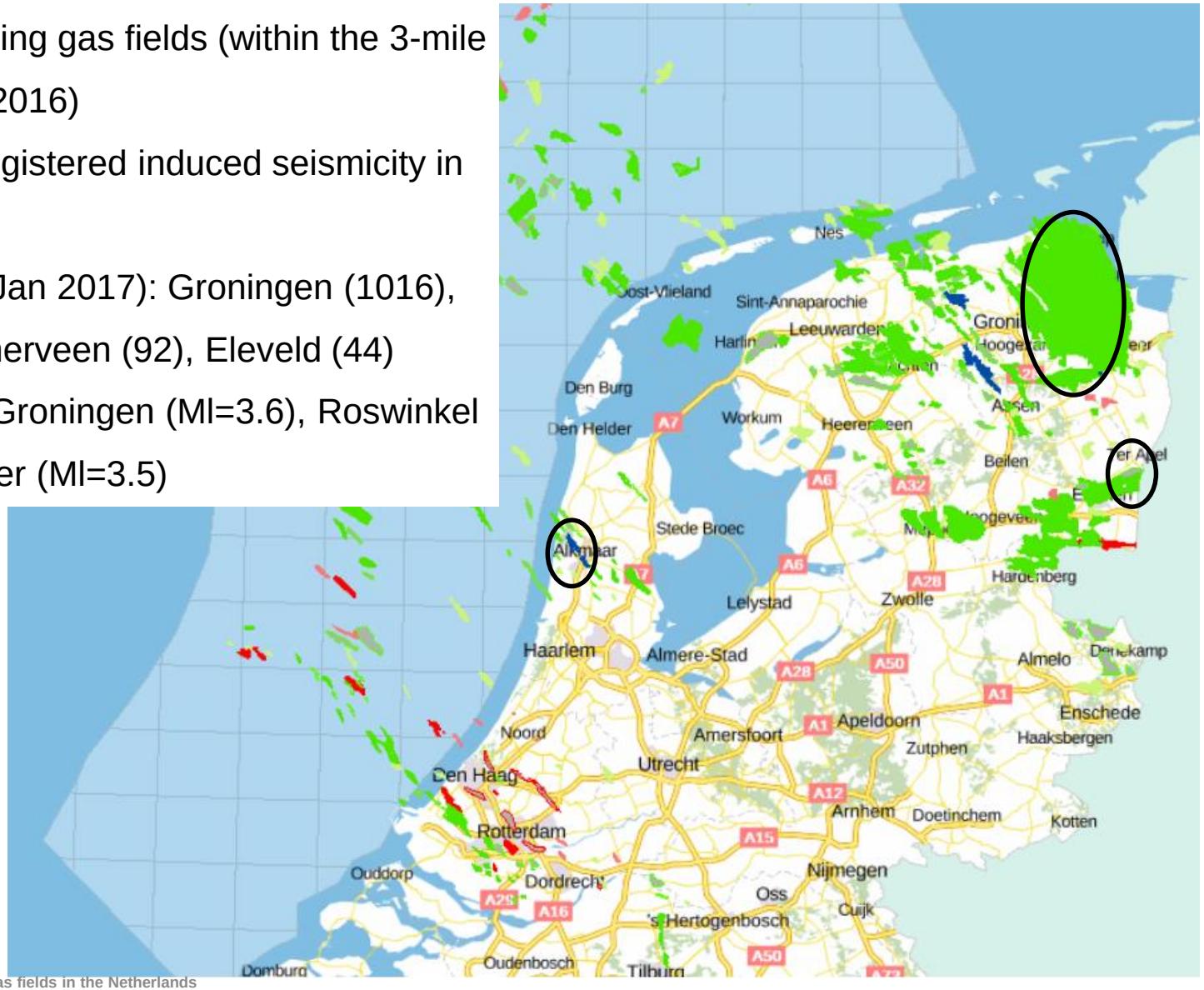
CATEGORIZING SEISMIC RISK FOR THE ONSHORE GAS FIELDS IN THE NETHERLANDS

Karin van Thienen-Visser, Joost Roholl, Bart van Kempen

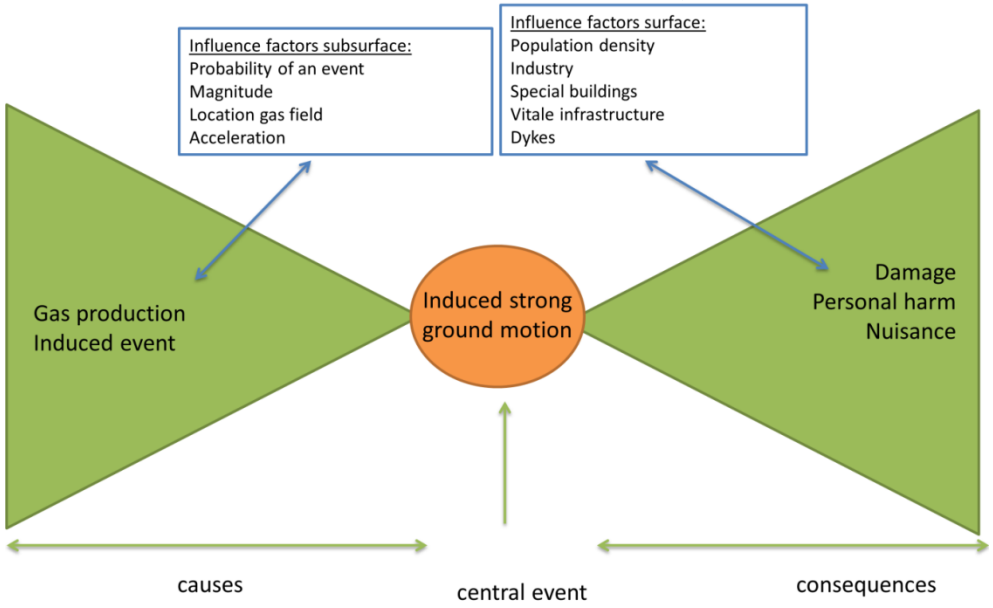
TNO innovation for life

GAS PRODUCTION IN THE NETHERLANDS

- 114 onshore producing gas fields (within the 3-mile zone, date: Jan 1st 2016)
- 31 gas fields with registered induced seismicity in the past
- Number of events (Jan 2017): Groningen (1016), Roswinkel (39), Annerveen (92), Eleveld (44)
- Largest seismicity: Groningen (Ml=3.6), Roswinkel (Ml=3.5), Bergermeer (Ml=3.5)



RISK=HAZARD*CONSEQUENCE



Guideline for seismic risk (SodM 2016)

- Based on known information/studies
- 2 cases risk evaluation not necessary:
  - Negligible probability of inducing an event
  - Mmax < 2,5

58 gas fields with negligible probability of an event
83 gas fields with a probability of inducing a event

SUBSURFACE FACTORS

- Probability and occurrence of inducing a seismic event
- Maximum magnitude
- In-situ stress/zechstein salt layer (line Amsterdam-Arnhem)
- Site response

SURFACE FACTORS

- Population density
- Industry
- Special buildings and vital infrastructure
- Dykes

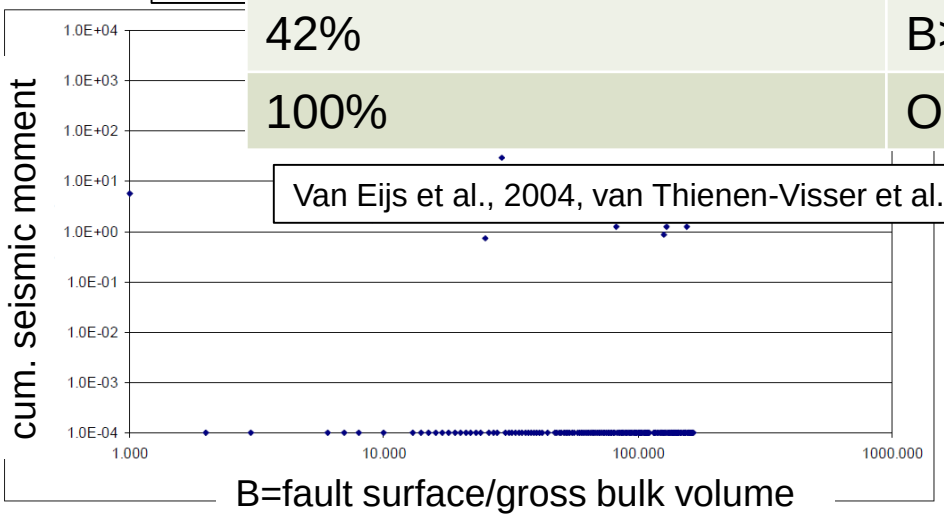
PROBABILITY OF INDUCING AN EVENT

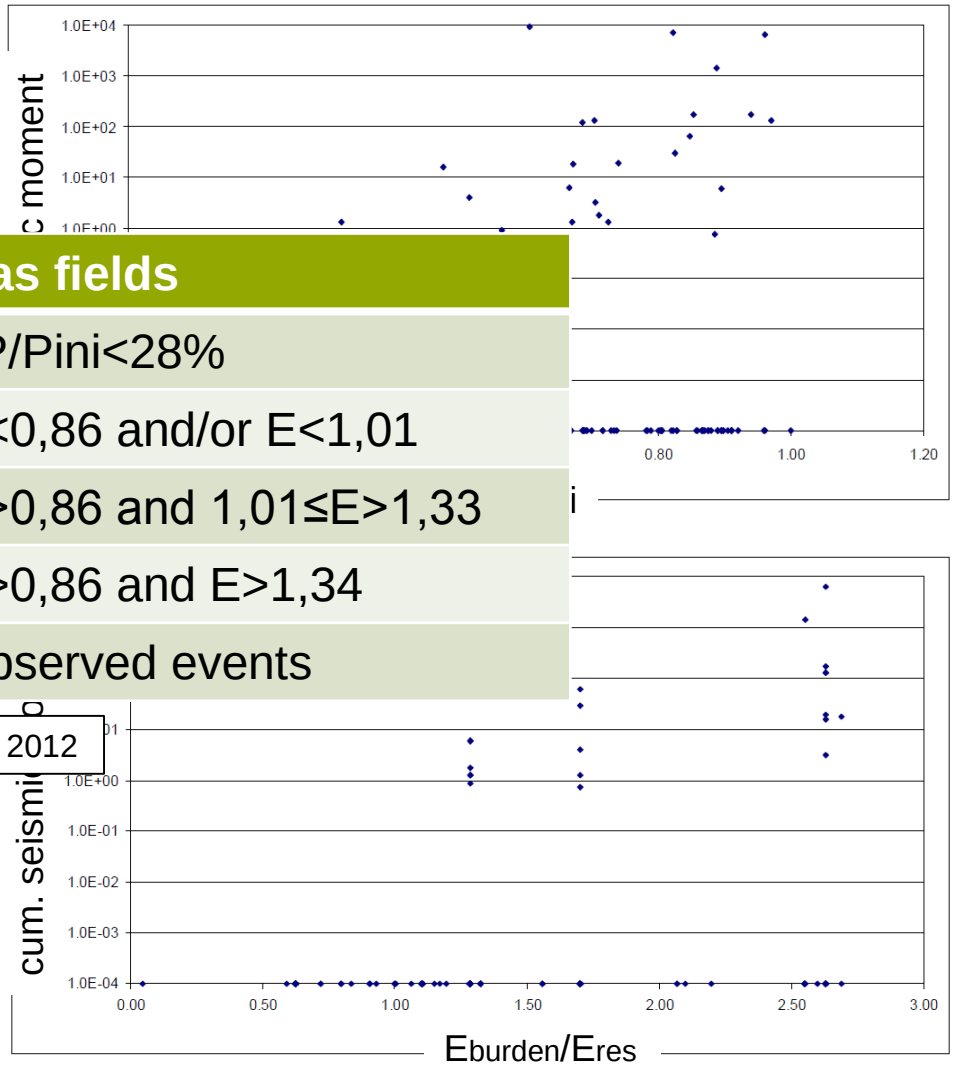
- Based on:
  - History of gas depletion in the Netherlands
  - Geol
  - Prod
  - Statis

Van E

Probability	Gas fields
Negligible	dP/Pini<28%
Negligible	B<0,86 and/or E<1,01
19%	B>0,86 and 1,01≤E>1,33
42%	B>0,86 and E>1,34
100%	Observed events

Van Eijs et al., 2004, van Thienen-Visser et al., 2012





DETERMINING MAXIMUM* MAGNITUDES

* deterministic maximum magnitude based on physics

Two methods

Based on fault length

$$M_0 = \frac{3\pi}{8}\Delta\sigma(w^2 L)$$

w = width
L = length
Δσ =stress drop

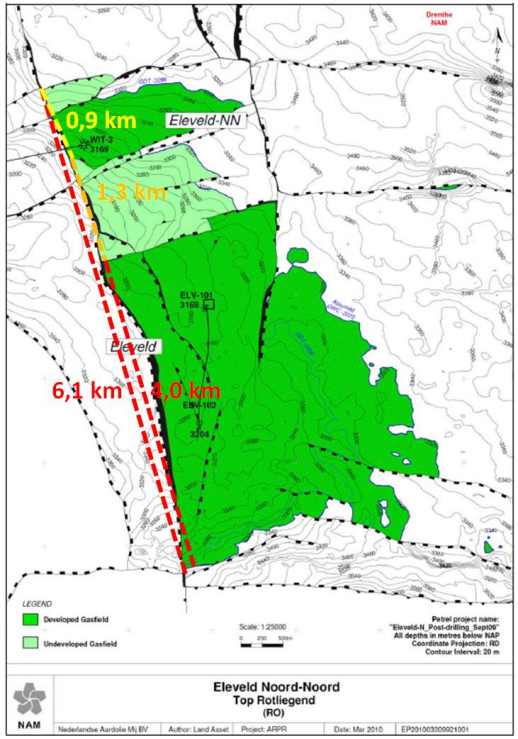
Stein & Wysession, 2006

$$M_L = ({}^{10}\log(M_0) - 9.1)/1.5$$

Example:
Eleveld gas field

Fault length: 6,1 km

Ml=3,6



Based on available compaction energy

$$RM = 2 * G * Vc$$

RM = reservoir moment,
G = shear modulus
Vc = compaction volume

$$M = ({}^{10}log\left(\alpha\frac{RM}{2}\right) - 9.1)/1.5$$

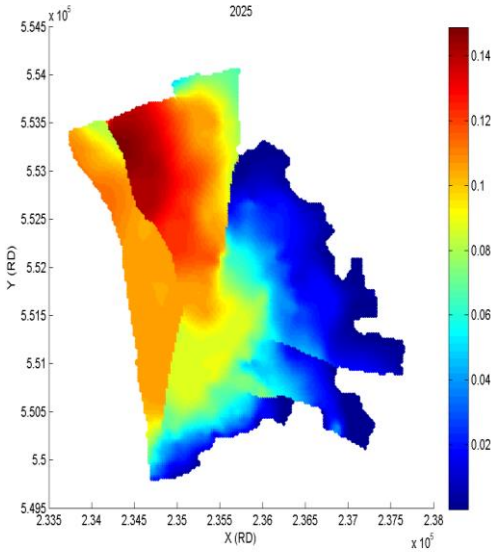
Bourne et al., 2014

α=1%, based on experience in NL

Example:
Eleveld gas field

Compaction in 2025,
<15 cm

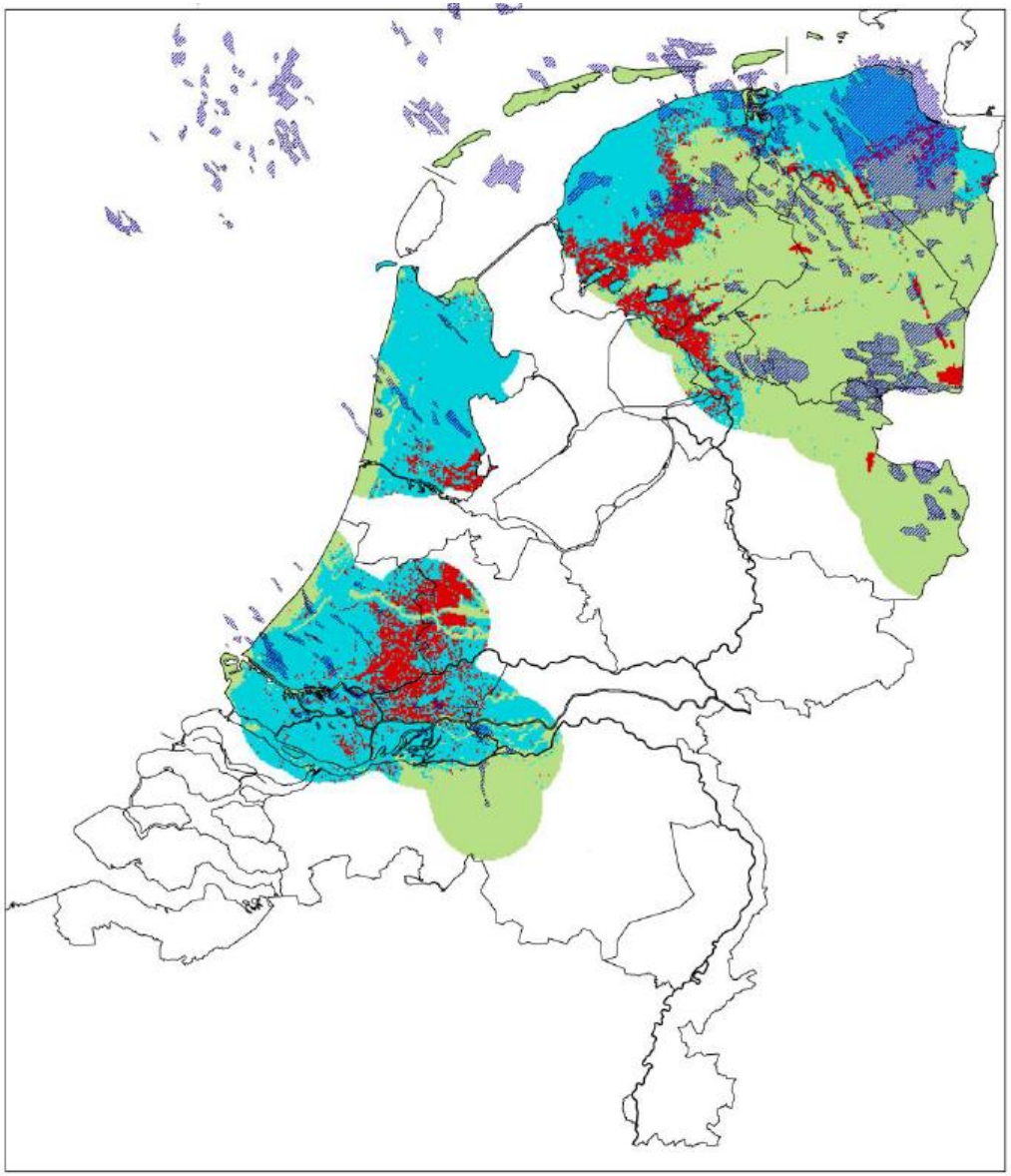
Ml=3,1



SITE RESPONSE

- Sensitive soils (for example peat layers)
- Stiff soils
- Weak soils (for example clay)

Wassing et al., 2012



SUBSURFACE FACTORS

Points	Probability and occurrence of induced events	Magnitude	Location gas field	Site response
5		Both methods M_L >4,5		
4	Occurring events, more than 5 $M_L \geq$ 1,5 events per year	1 method M_L > 4,5 and/or both methods 4,1 ≤ M_L ≤ 4,5		
3	Occurring events, less than 5 $M_L \geq$ 1,5 events per year	1 method 4,1 ≤ M_L ≤ 4,5 and/or both methods 3,6 ≤ M_L ≤ 4,0		>60% weak soil ($V_{s,30}$ =< 200m/s) and/or >30% sensitive soil*
2	P=42% or occurring events M_L < 1,5	1 method 3,6 ≤ M_L ≤ 4,0 and/or both methods 3,1 ≤ M_L ≤ 3,5	North of the line Amsterdam - Arnhem	30-60% weak soil ($V_{s,30}$ =< 200m/s) and/or 15-30% sensitive soil*
1	P=19%	1 method 3,1 ≤ M_L ≤ 3,5 and/or both methods 2,6 ≤ M_L ≤ 3,0		10-30% weak soil ($V_{s,30}$ =< 200m/s) and/or 5-15% sensitive soil*
0		1 method 2,6 ≤ M ≤ 3,0 and/or both methods M_L ≤ 2,5	South of the line Amsterdam – Arnhem	<10 % weak soil ($V_{s,30}$ =< 200m/s) and/or < 5% sensitive soil*

SUBSURFACE FACTORS

- Probability and occurrence of inducing a seismic event
- Maximum magnitude
- In-situ stress/zechstein salt layer (line Amsterdam-Arnhem)
- Site response

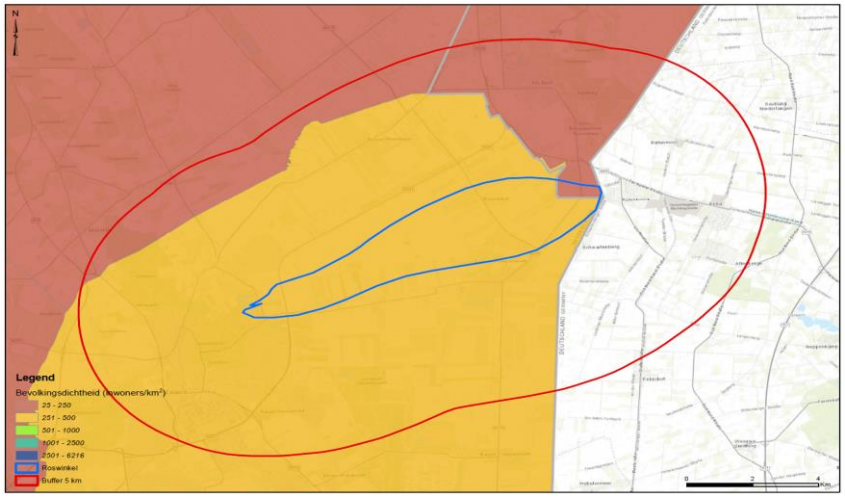
SURFACE FACTORS

- Population density
- Industry
- Special buildings and vital infrastructure
- Dykes

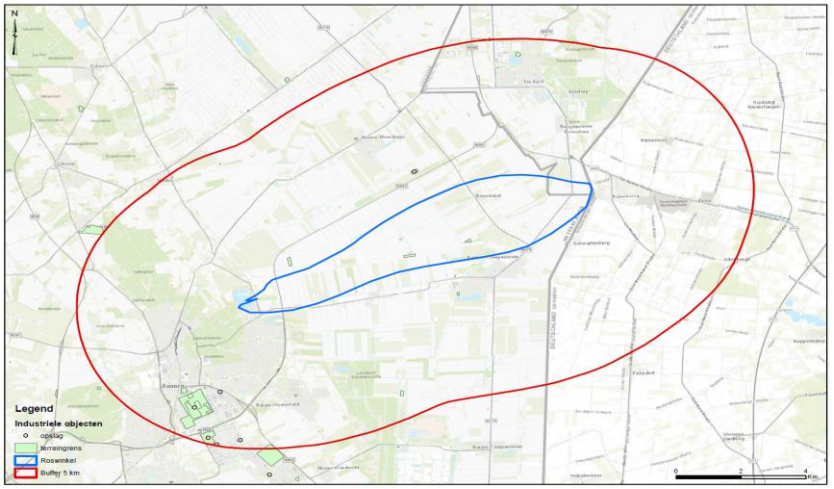
SURFACE FACTORS

TNO innovation for life

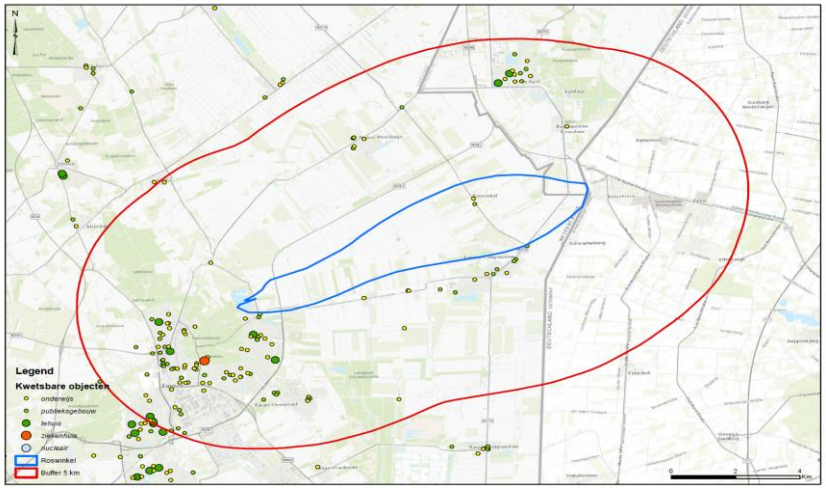
Population density



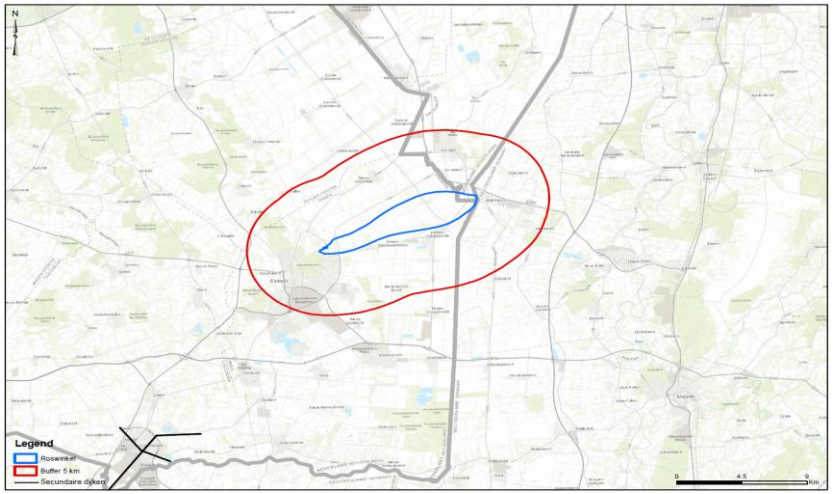
Industry



Special buildings and vital infrastructure



Dykes

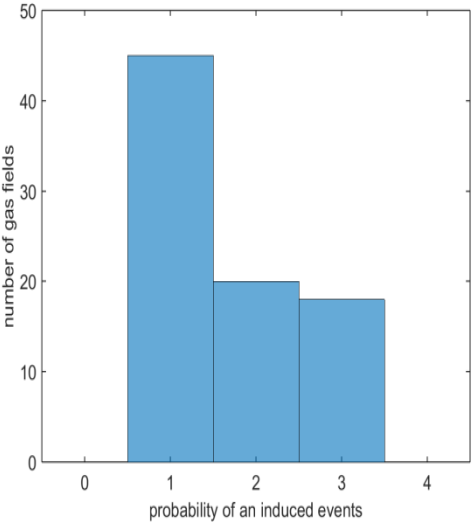


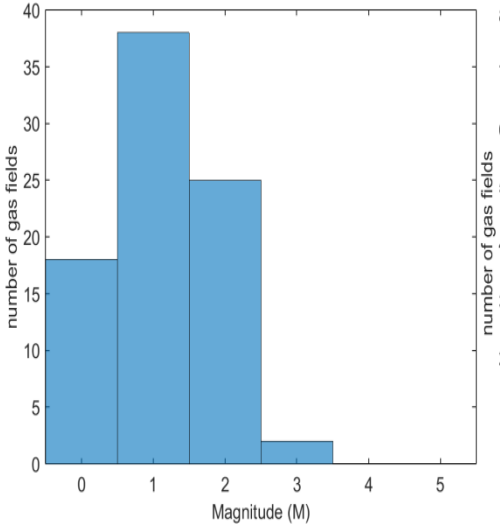
Source: CBS statistics Netherlands, www.risicokaart.nl

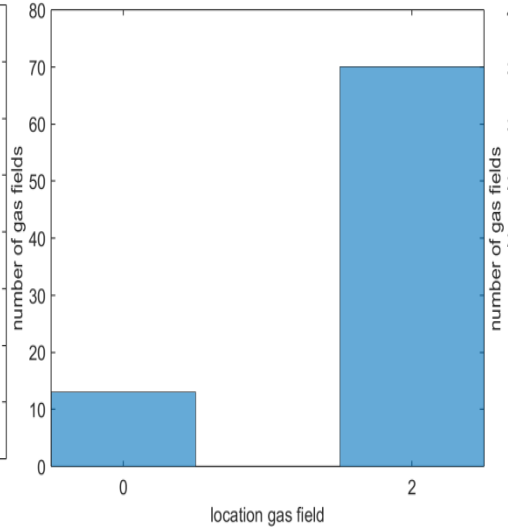
SURFACE FACTORS

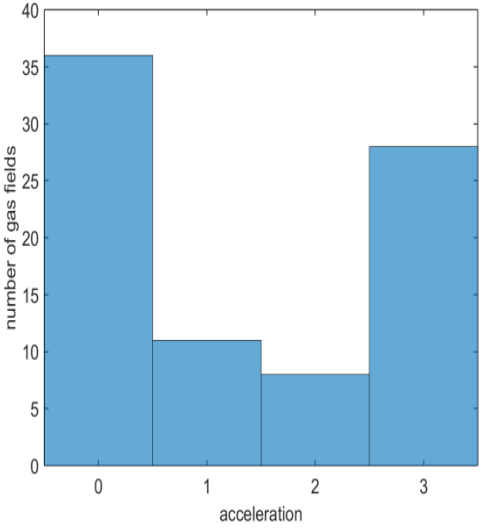
Points	Population density (number of people per km^2)	Industry	Special buildings and vital infrastructure	Dykes
4	> 2500	Multiple directly above the field	Multiple hospitals and/or energy suppliers above the field	Primary dykes above the field
3	1000-2500 and/or 500-1000 including vulnerable flats within 5 km of the gas field	1 above the field and/or multiple within 5 km of the field	1 hospital and/or energy supplier above the field or multiple within 5 km of the field. Multiple schools and/or public buildings above the field	Primary dykes within 5 km of the field and/or secondary dykes above the field
2	500-1000 and/or 250-500 including vulnerable flats within 5 km of the gas field	1 within 5 km of the field	1 school and/or public building above the field or multiple within 5 km of the field	Secondary dykes within 5km of the field
1	250-500 and/or < 250 including vulnerable flats within 5 km of the gas field		1 school and/or public building within 5 km of the field	
0	< 250	None within 5 km of the field	None within 5 km of the field	None within 5 km of the field

INFLUENCE FACTORS SUBSURFACE

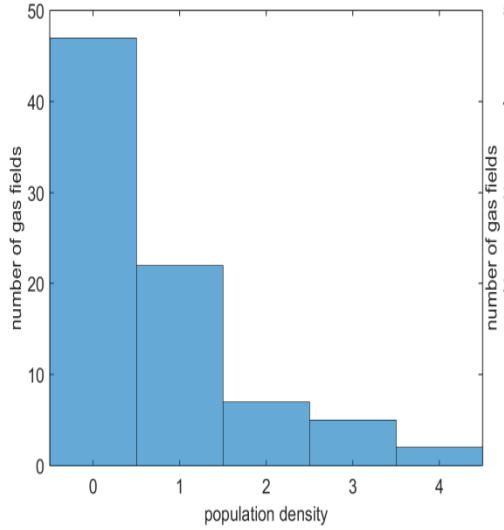


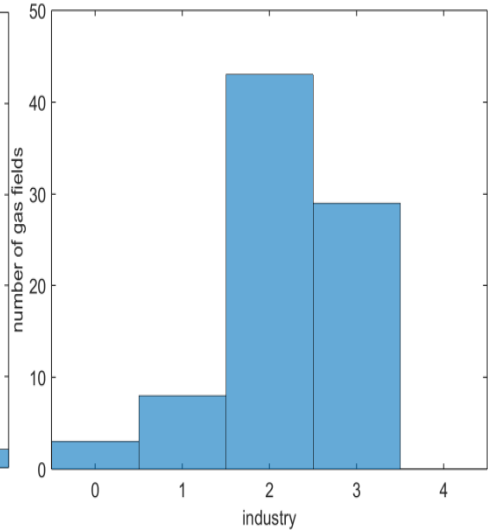


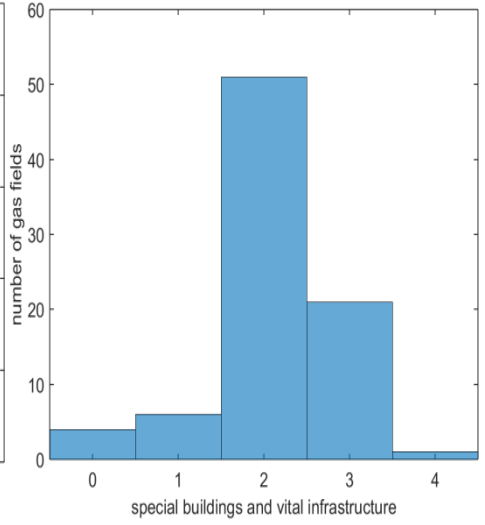


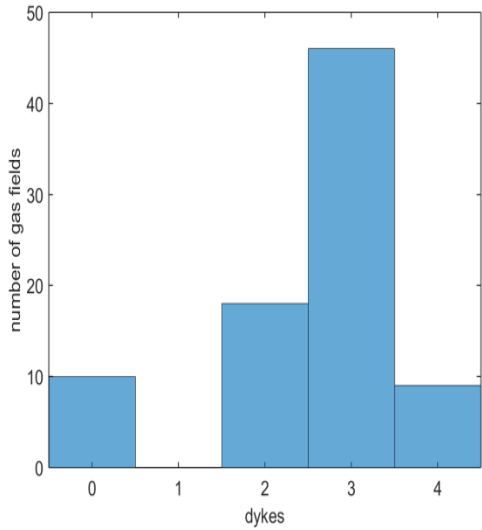


INFLUENCE FACTORS SURFACE

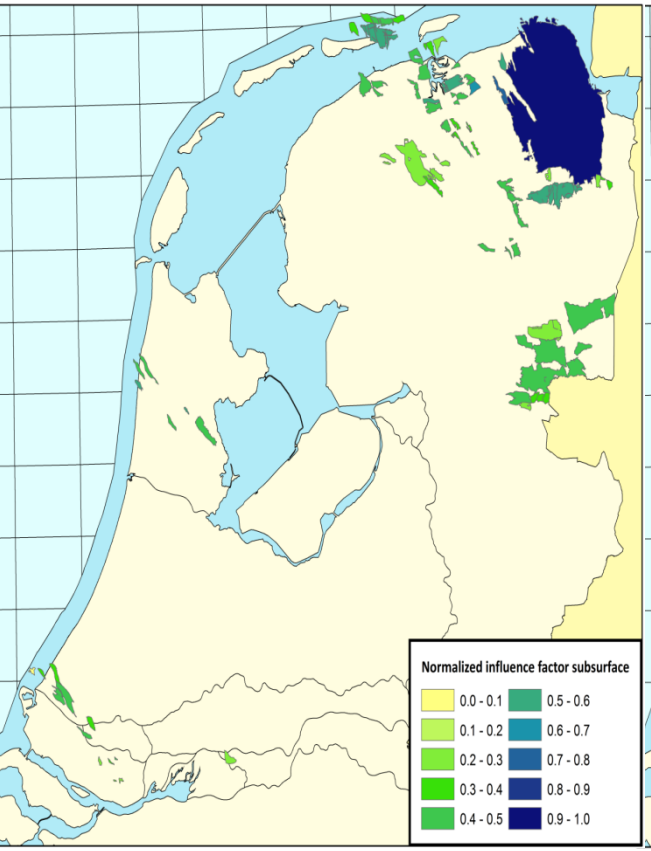


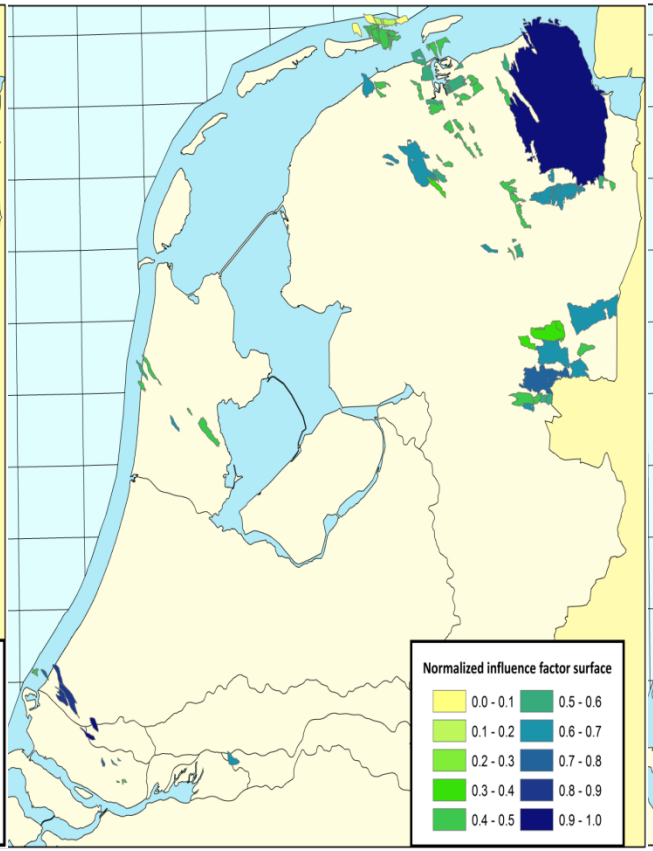


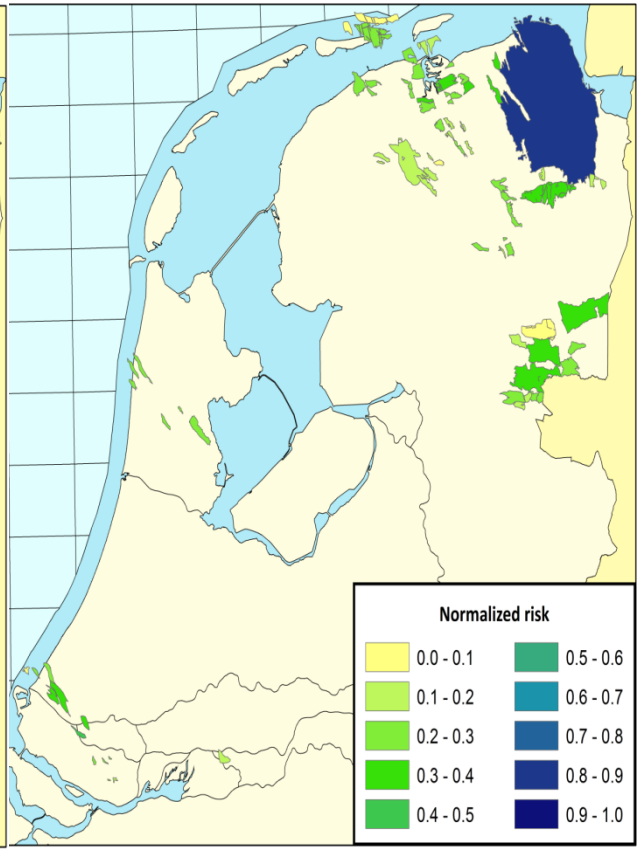




SUBSURFACE SURFACE RISK



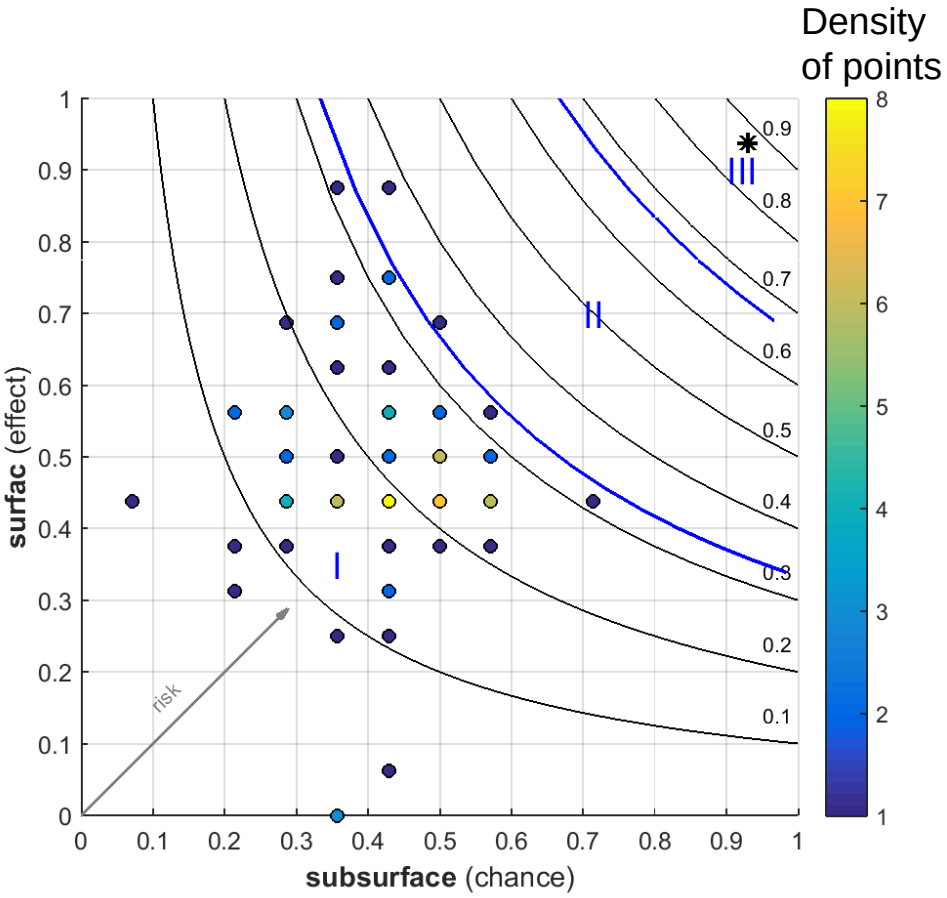




RISK

Guideline for seismic risk (SodM, 2016)

- Categories I, II, III
- Groningen gas field(*) only field in category III => needs quantitative seismic risk assessment
- Category II, a couple of fields => monitoring, seismic risk plan
- Category I, most fields => monitoring

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