Implications of Earthquakes on the Stability of Tailing Dams

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Introduction

- Increase of insured earthquake damages
- No special regard on the mining industry
- Direct motivation:
  - Baja Mare, River Danube, Romania
  - Wismut GmbH, Uranium Tailings, Germany

- Studies about earthquake exposures and their impact for industries

Ranking of Natural Catastrophes

Year	County, Region	Event	Economic Losses[1]	Insured Losses[1]
2005	USA	Hurricane Kathrina	125,000	60,000
1995	Japan, Kobe	Earthquake	> 100,000	3,000
1994	USA, California	Earthquake	44,000	15,300
1998	China	Floods	30,700	1,000
2004	Japan, Niigata	Earthquake	28,000	450
1992	USA	Hurricane Andrew	26,500	17,000
1996	China	Floods	24,000	445
2004	USA, Caribbean	Hurricane Ivan	23,000	11,500
1993	USA	Floods	21,000	1,270
2004	USA, Caribbean	Hurricane Charley	18,000	8,000

[1] Original losses in Million US$

Munich Re 2005, 2006

Funding and Data Aquisition

- Munich Reinsurance (Munich)
- Federal Institute for Geosciences and Natural Resources (Hannover)
- Deutsche Montan Technologie (DMT) (Essen)
- Foundation Library of the Ruhr (Bochum)
- Institute for Geophysics (Münster)
- Geological-Palaeontological Institute (Münster)

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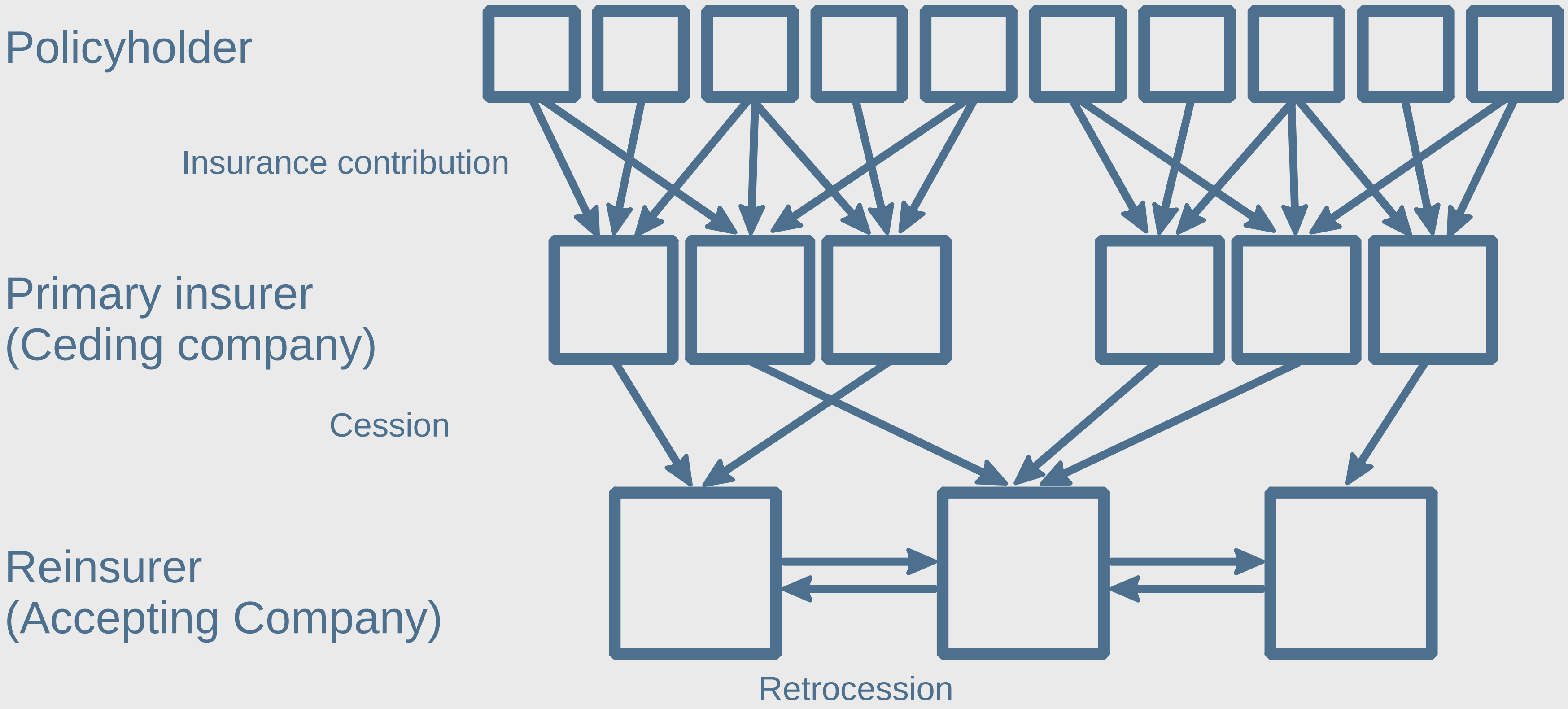
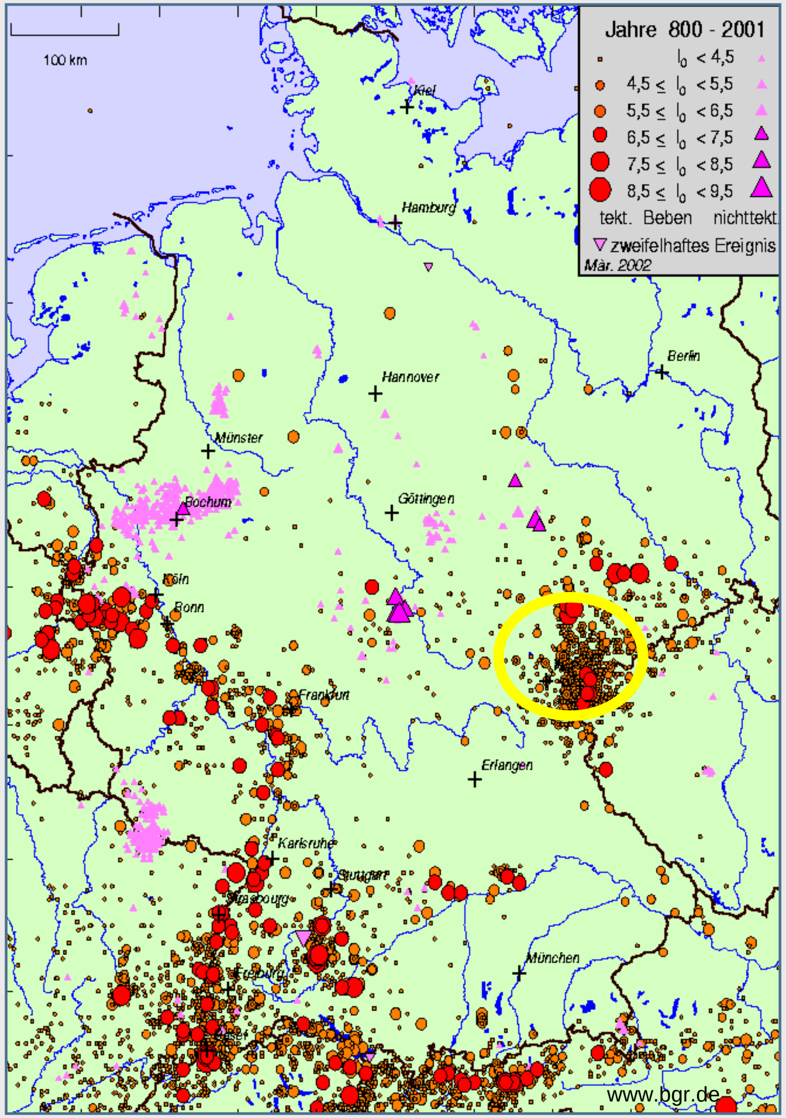
Reinsurance

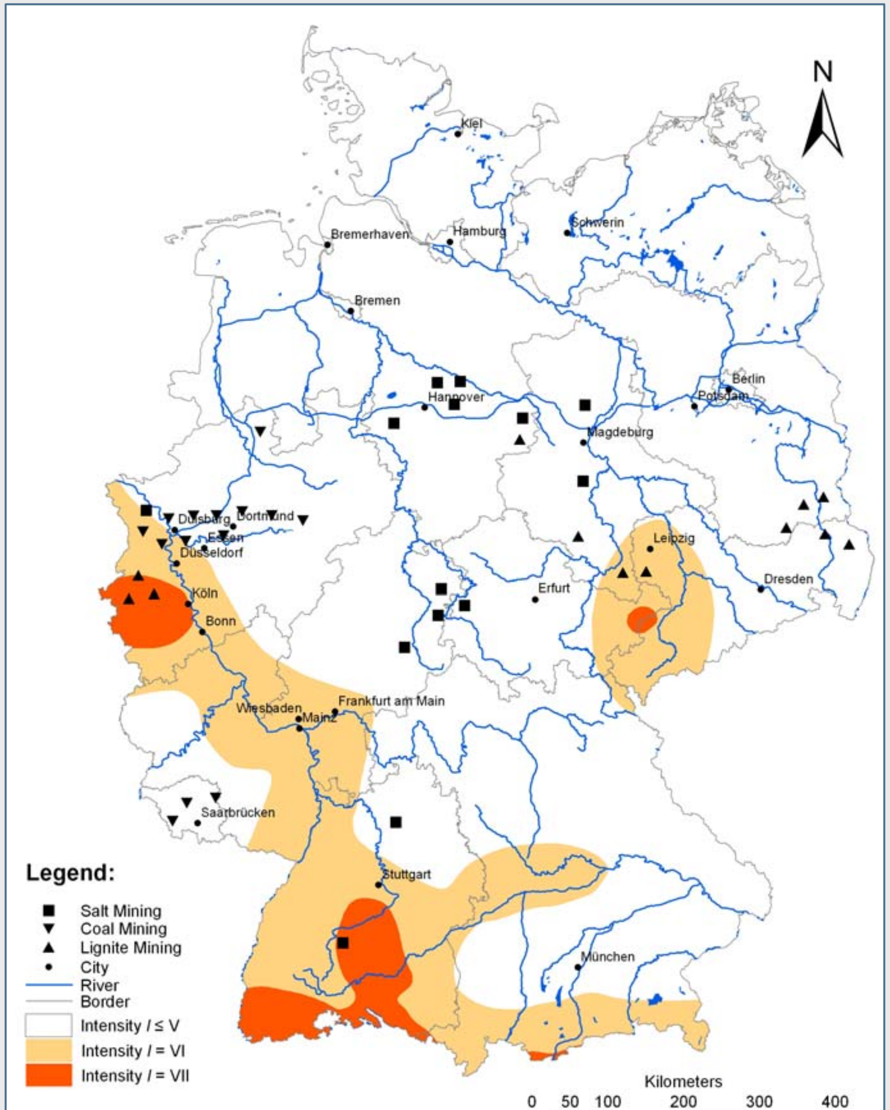


Earthquakes in Germany

- Earthquakes in Germany
  - Regions
  - Noticed intensities
  - Special events
- Mining in Germany
  - Hard coal
  - Brown coal
  - Salt
  - Former uranium



Earthquake Zonation of Germany



after Munich Re 2000

- Magnitude
  - Local magnitude M_L
  - Quantifies the amount of seismic energy released by an earthquake
- Intensity:
  - Quantifies the effects of an earthquake on the earth's surface, humans, objects of nature, and man-made structures
  - Scale of 1 (weak) to 12 (complete destruction)

Examples of Tailing Damages

Date	Location	Description	Reference
19. July 1985	Stava, South Tyrol, Italy	- Collapse of a dam of a fluorite mine - Mass movement of 180,000 m^3 of mud plus 40,000 m^3 to 50,000 m^3 erosional material - 268 fatalities - Minor environmental contaminations - Cause: wrong angle of the slope - Costs: 15 million US$	STIFTUNG STAVA 19985
25. April 1998	Aznalcollar, Spain	- Collapse of a dam of lead-zinc mine - Semioxidised pyrite plus additional toxic material - Cause: collapse of a separating dam and shearing along a underlying clay horizon - Severe environmental contaminations - Costs: 100 million US$ to 200 million US$	WISE URANIUM PROJECT 2002
30. January 2000	Baia Mare, Rumania	- Collapse of a dam of gold mine - 100.000 m^3 of wastewater including 120 t cyanide and other heavy metals contaminated the rivers up to the Danube - Severe environmental contaminations - Cause: soaking of the dam material and spilling - Costs: 179 million US$	WISE URANIUM PROJECT 2002 BMTF 2000

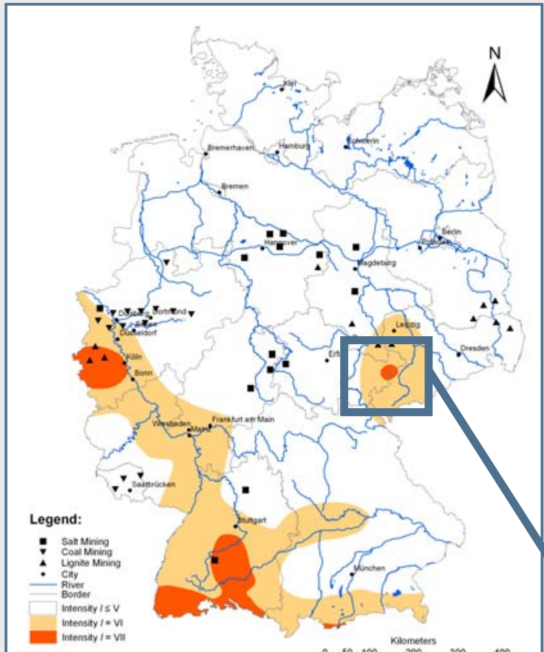
Earthquake Damages on Tailings

Date	Location	Magnitude	Description	Reference
10. January 1928	Chile	8.3 (?)	- Flood wave of 2,800,000 m^3 tailing material - 500 m wide gap in the 61 m high dam - 54 fatalities - Cause: Liquefaction	ICOLD 2001
28. March 1965	El Cobre, Chile	$m_L = 7.1$	- Collapse of two dams of El Cobre copper mine - Two flood waves of 350,000 m^3 (new dam) and of 1,900,000 m^3 (old dam) - Downstream flow of 12 km - The town of El Cobre destroyed - More than 200 fatalities	CASE WESTERN RESERVE UNIVERSITY 2007 NEIC 2007
19. March 1971	Chungar Peru	$m_L = 4.8$	- Landslide causes the break of a tailing dam - Tailing mud destroyed the surface facilities of the mine and ran into the shafts - Only 25 miners survived	SÜDDEUTSCHE ZEITUNG 22. MARCH 1971 NEIC 2007
17. January 1994	Northridge, USA	$m_L = 6.7$	- Collapse of the 24 m high dam of the Tapo Canyon Tailing - 60 m wide breach - Downstream flow of extended hundred meters in an incised canyon - Considerable losses for the owner and a downstream water treatment facility	STEWART ET AL. 1996 NEIC 2007
April 1995	Philippines	$m_b = 6.2$	- Collapse of a dam of the Surigao del Norte gold mine - Several earthquakes damaged the internal structure of the dam - Crest of the dam was a road - Soaking of internal structure of the dam with infiltrating liquids (water) - Collapse with a time lag	BGRM 2000 MR199504A039 NEIC 1995

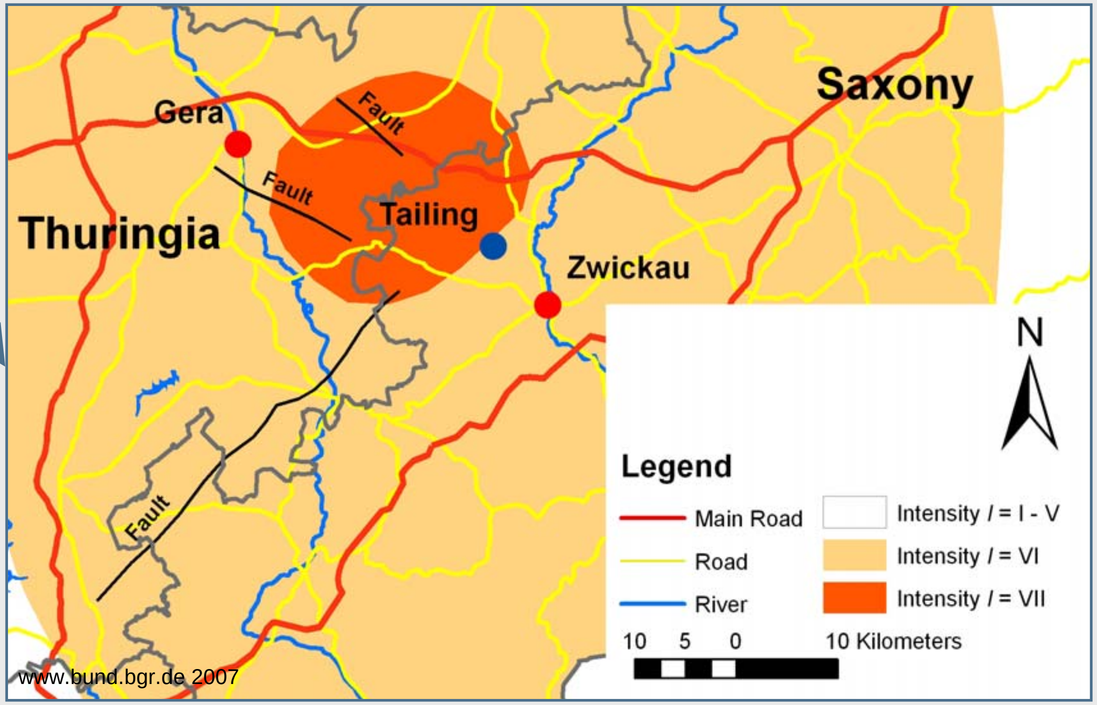
Damage scenarios

- Surface
  - Fractures and breaches
  - Liquefaction
  - Slumping
  - Spilling
- Subsurface
  - Flooding of the mine
  - Destruction of the facilities for the subsurface operations
- Surface loss scenarios depending on the structure of the dam and the tailings
- Linking of loss scenarios between surface und subsurface
- Environmental damages

Example Germany

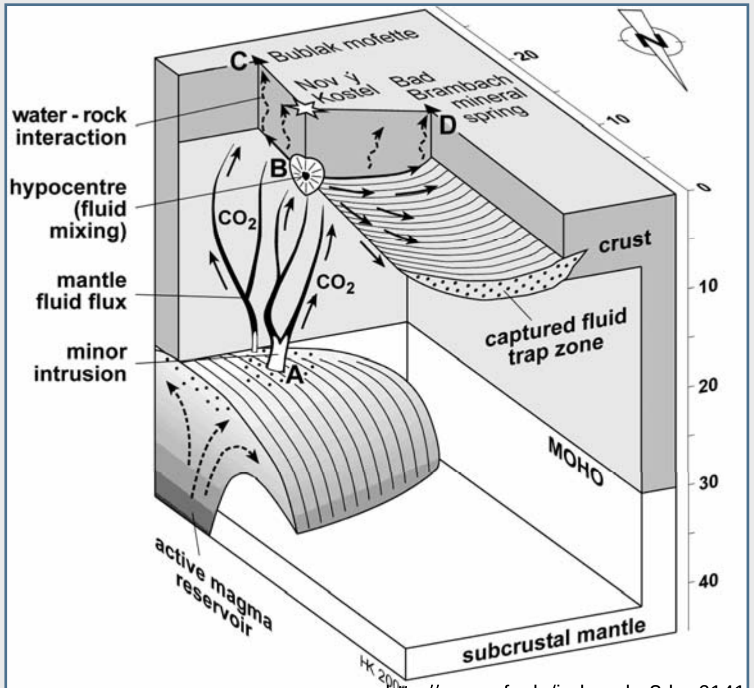


after Munich Re 2000

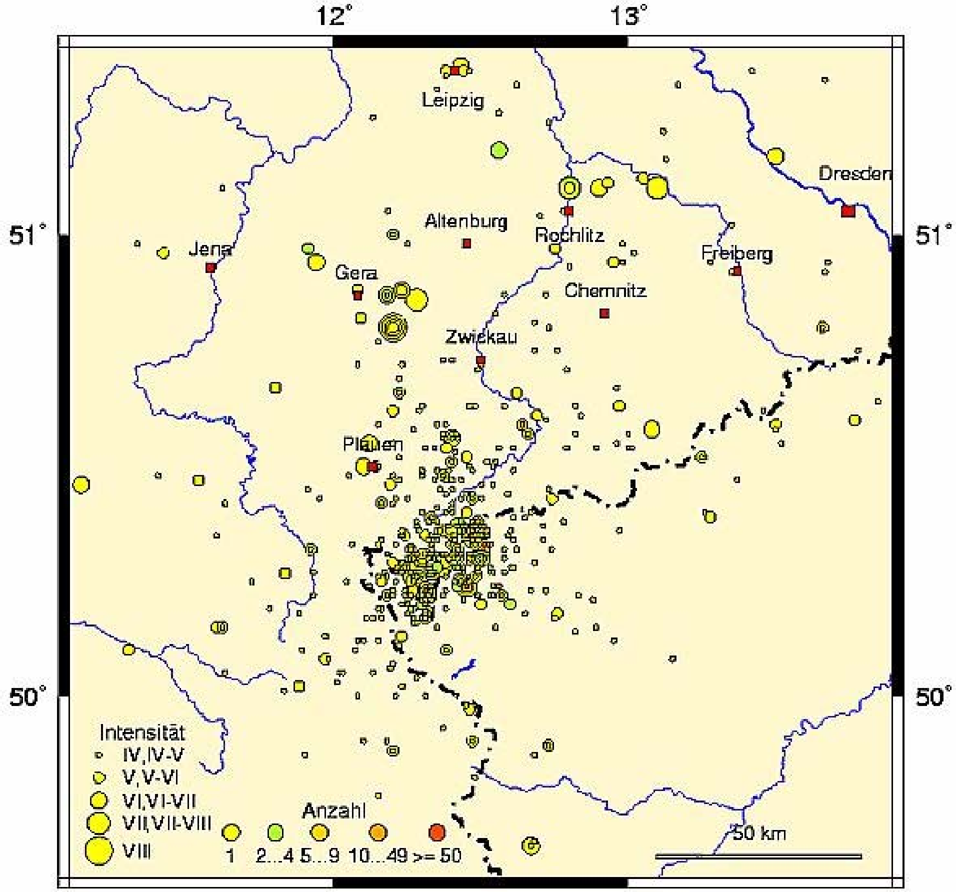


www.bund.bgr.de 2007

Swarm Earthquakes in SE-Germany



http://www.ufz.de/index.php?de=6141



Alle wahrgenommenen Beben mit Intensität >= IV seit 800 (Leydecker, 2001)

http://www.uni-leipzig.de/collm/Vogtland_1.html

Observed highest magnitude in 1986: $m_L = 4.6$

Input Parameters

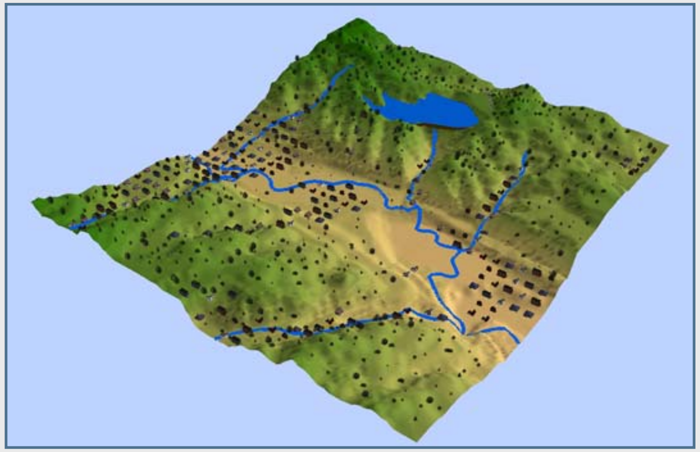
- Earthquake scenarios

	Monitored Earthquakes	Earthquake Scenario 1 (No collapse of the dam)	Earthquake Scenario 2 (No structural damages)
Magnitude M	4.6	5.4	4.3
Intensity I	VI to VII	VIII	VI to VII
Hypocenter h	10 km to 5 km	10 km	5 km

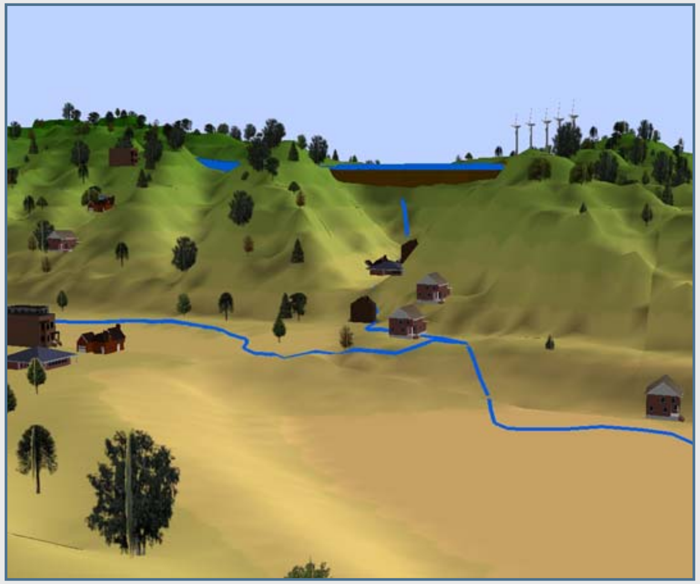
- Volume
  - 40 million m^3 tailing mud
  - 5 million m^3 free water
- Tools
  - NOAA: Simplified Dam Break (SMPDBK)
  - ArcGIS

Collapse of the Tailing Dam

1.

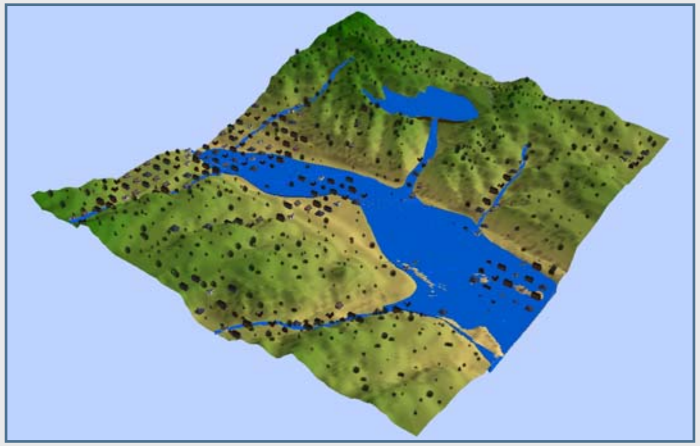


2.

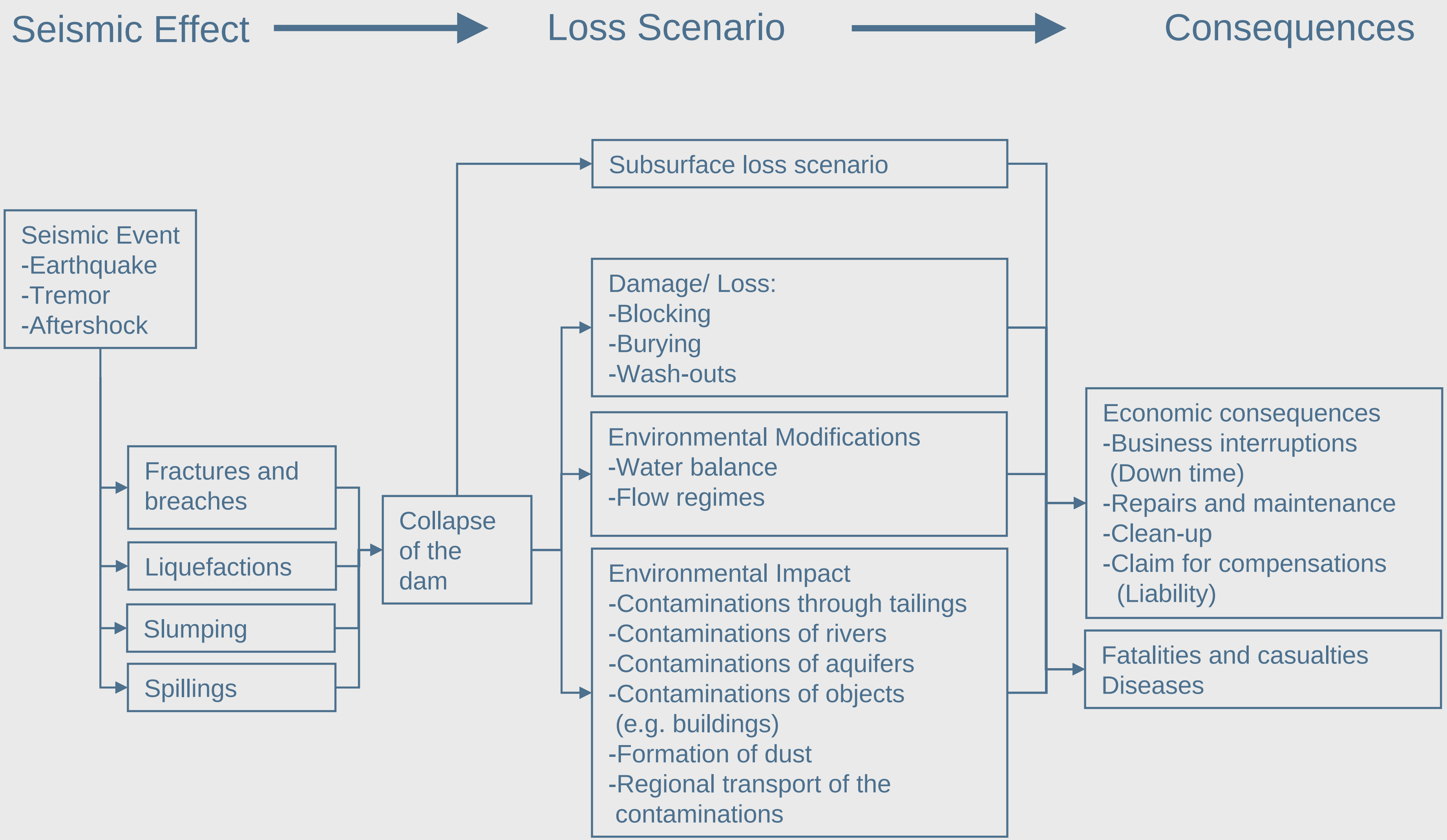


3.

4.



Flow Chart


Seismic Effect
Loss Scenario
Consequences
Seismic Event
-Earthquake
-Tremor
-Aftershock
Fractures and breaches
Liquefactions
Slumping
Spillings
Collapse of the dam
Subsurface loss scenario
Damage/ Loss:
-Blocking
-Burying
-Wash-outs
Environmental Modifications
-Water balance
-Flow regimes
Environmental Impact
-Contaminations through tailings
-Contaminations of rivers
-Contaminations of aquifers
-Contaminations of objects
(e.g. buildings)
-Formation of dust
-Regional transport of the contaminations
Economic consequences
-Business interruptions
(Down time)
-Repairs and maintenance
-Clean-up
-Claim for compensations
(Liability)
Fatalities and casualties
Diseases

Conclusion

- Special exposure of Germany
- Main loss scenarios
  - Fractures and breaches
  - Liquefactions
  - Slumpings
  - Spillings
  - Subsurface loss scenarios
- Severe environmental damages and contaminations (local and regional)
- Economic losses
- High expenses for
  - Business interruptions (Down-time)
  - Repair and maintenance
  - Clean-up
  - Claim for compensations (Liability)