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SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

70 NRP Energy Turnaround
National Research Programme

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Accident Risk Assessment for Hydropower and Deep Geothermal Energy Systems

SCCER-SoE Annual Meeting, Lausanne, Switzerland, 03 September 2019

Outline

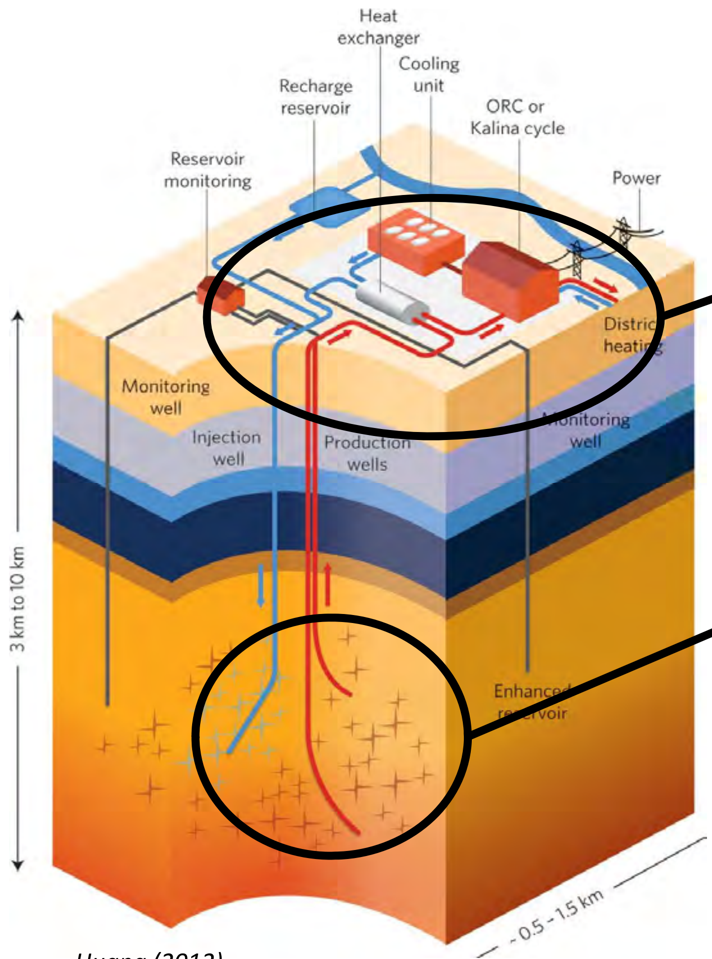
- Risk Assessment for Deep Geothermal Energy (DGE) Systems
  - Risk Associated to DGE
  - PSI's Framework for Comparative Risk Assessment
  - Result
  - DGE in a comparative perspective

- Risk Assessment for Hydropower
  - Description of the NRP70 Project
  - Phase 1: Analysis for historical dam accidents
  - Phase 2: Uncertainty quantification in the modeling of dam-break consequences

- Summary

Risk Assessment for Deep Geothermal Energy (DGE) systems

Risk Associated to Deep Geothermal Energy (DGE)



Huang (2012)

- Induced Seismicity
- DGE is, as all the other technologies, not risk free!
- A … the following p…
  - … out accidents)
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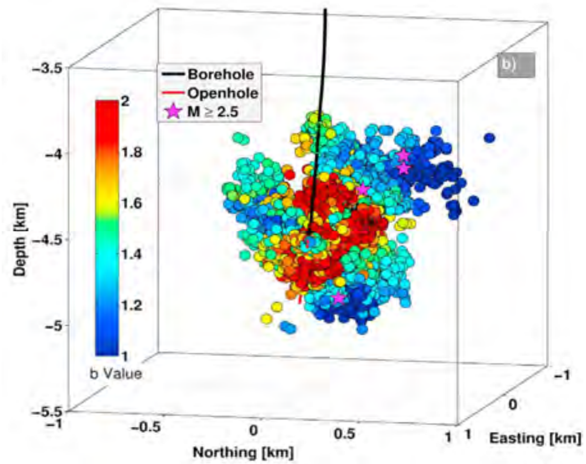
- … the use of

Basel (Switzerland)



Bachmann et al (2012)

Accident Risk for DGE Systems

Phase	Issue	Risk
Drilling	Drilling Muds	Risk related to the use of hazardous substances
Stimulation	Stimulation	Risk related to the use of hazardous substances
Drilling and Operational	Blowout	Risk related to blowout accidents
	Landslides	Risk related to landslide hazard
	Induced Seismicity	Risk related to induced seismicity hazard
Operational	Geofluids	Risk related to the hazardous substances brought to the surface by the circulation of the geofluids
	Cooling system	Risk related to the use of hazardous substances
	Working Fluids	Risk related to the use of hazardous substances

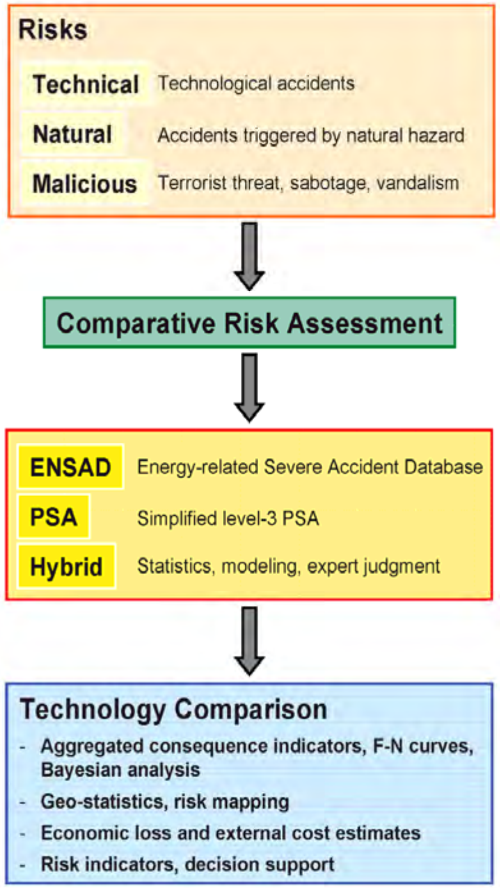
Based on an extensive literature review

Aggregated risk indicators for different consequences (e.g., fatalities, injuries, etc.)

Induced seismicity and landslides risk not treated here

PSI's Comparative Risk Assessment Framework

Framework



- Risk (R) = Frequency (F) * Consequences (C)
- Full energy chain approach because accidents can occur at all stages
- Data normalization to ensure comparison across different energy chains → e.g., GWeyr
- Regional aggregation at different spatial scales (e.g. OECD, EU, non-OECD, etc. or individual countries (if sufficient data available)
- Risk results in terms of aggregated risk indicators, Frequency-Consequence (F-N) curves, advanced statistical methods (e.g., Bayesian Analysis), etc.

Accident Risk for DGE Systems: Data

- Time period: 1990 – 2017
- OECD data only
- No geothermal related accidents are found
- Data for Hazardous Substances (transportation, storage):
  - Caustic Soda (additive for drilling mud)
  - Hydrogen Chloride, Hydrogen Fluoride, Ammonium Persulphate and Boric Acid (matrix acidizing for the stimulation phase)
  - Benzene, Toluene, Methanol, n-Hexane, o-Xylene (ORC cycle working fluids, geothermal type accidents included) and Ammonia (Kalina cycle working fluid, geothermal type accidents included)
- Data for Blowouts:
  - On-shore accidents collected for Natural Gas since it is more likely to be found in Switzerland than Oil
  - Accidents collected for USA and Alberta (Canada)

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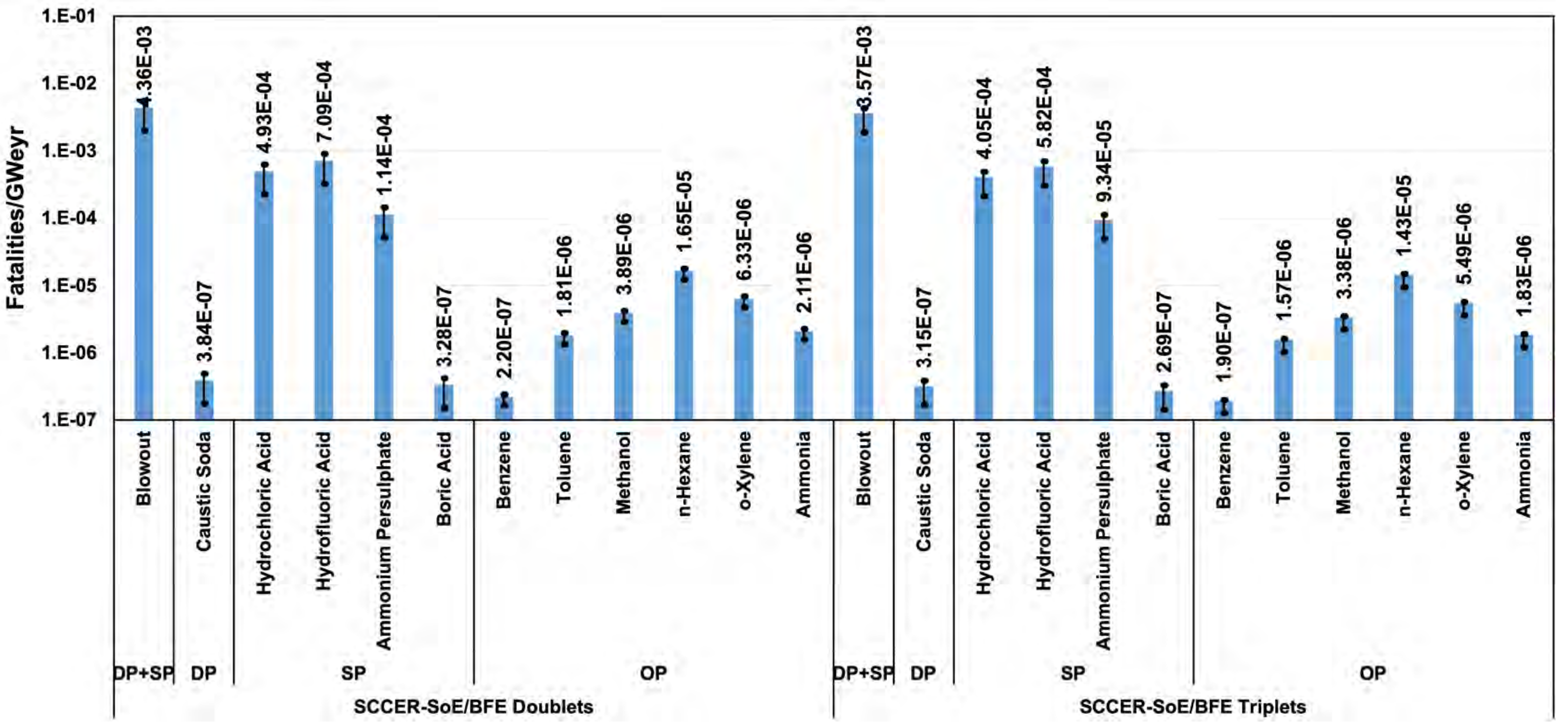
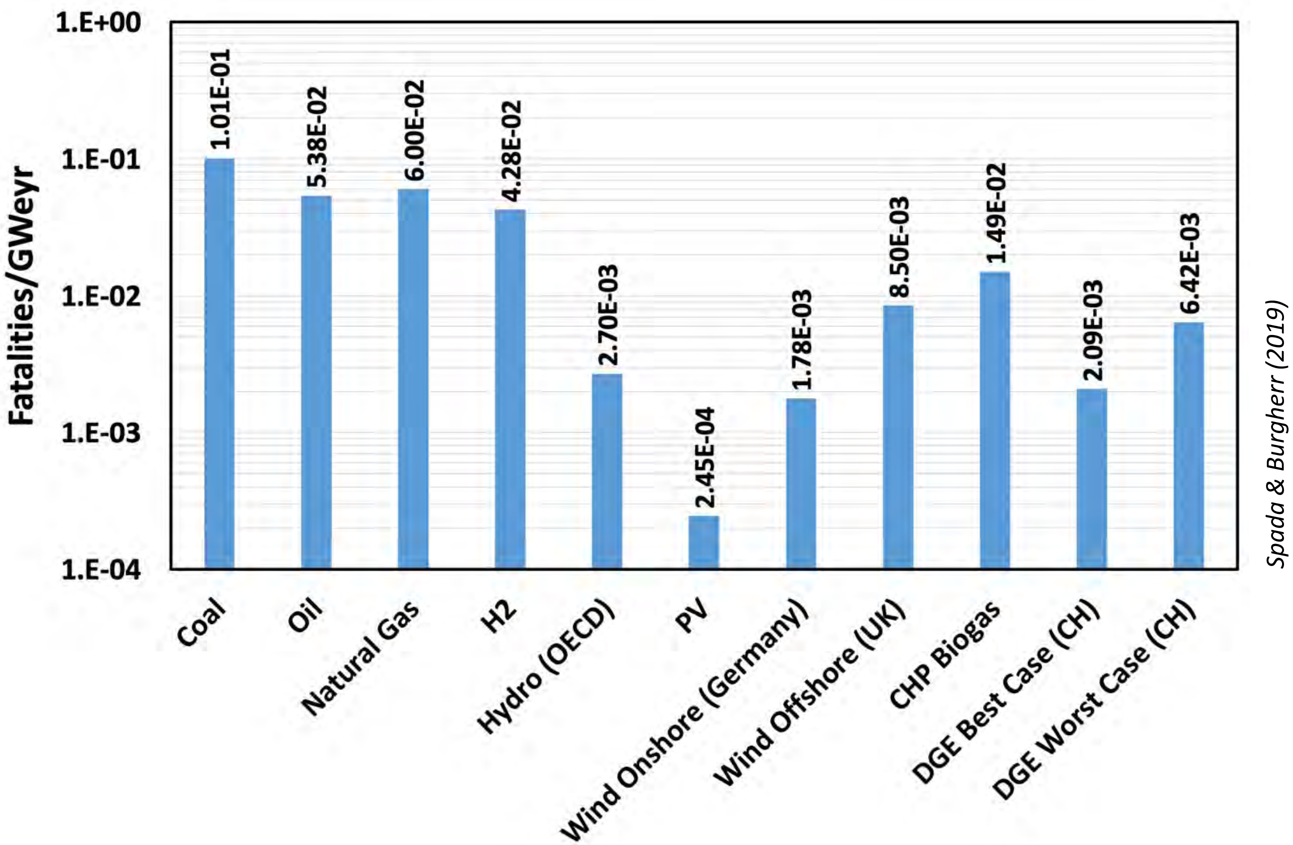
Accident Risk for DGE Systems: Example of Risk Indicator – Fatalities/GWeyr



Spada & Burgherr (2019)

- Results for three geothermal plants capacity cases for Switzerland defined in the TA-Swiss project (*Treyer, et al. 2015*) and the updated within SCCER-SoE/BFE phases
- Fatality rates are estimated as the ratio between the aggregated number of fatalities and the unit of energy production weighted by a factor dependent on, for example, number of wells/kg used/etc., for each substance and blowout.
- Injuries Rates and Evacuees Rates have been also estimated (not show here)

DGE in a comparative perspective (EU28)



- DGE indicators estimated as the sum of the worst indicators for each chain stage (DGE Worst Case) and the sum of the best indicators for each chain stage (DGE Best Case)
- DGE Best Case is comparable to Wind Onshore and performs better than most of the other renewables, except PV.
- DGE Worst Case performs better than fossils, H2, CHP Biogas and Wind Offshore, but it results worse than the other renewables.

Risk Assessment for Hydropower

Risk Assessment of hydropower in Switzerland: Uncertainty Quantification in the Modelling of the Dam-Break Consequences

- Author: Anna Kalinina

- This research project is part of the National Research Programme "Energy Turnaround" (NRP 70) of the Swiss National Science Foundation (SNSF). Additionally, this work is supported by the Swiss Competence Center on Energy Research (SCCER) Supply of Electricity (SoE).

Phase 1: Analysis of historical dam accidents

Task 1.1. Establishment of a database for dam accidents worldwide

Task 1.2. Probabilistic analysis of the accident risk posed by dams of different characteristics (e.g., dam types, dam purposes) worldwide

Phase 2: Uncertainty quantification in the modelling of dam-break consequences

Task 2.1. Development of a computational model to assess the consequences of the potential failure of a hydropower dam, with a focus on relevant Swiss conditions

Task 2.2. Systematic quantification of uncertainties and global analysis of sensitivities of parameters within the physically-based model of the dam-break consequences

Phase 1: Analysis of historical dam accidents

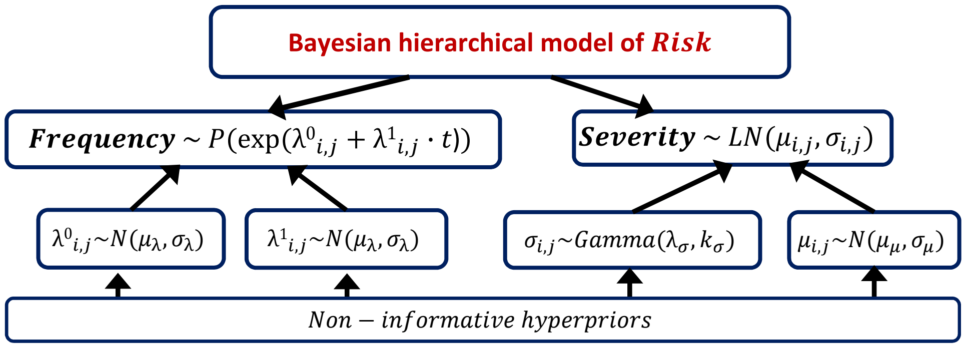
Research goals

- Establishment of a database for dam accidents worldwide
- Probabilistic analysis of the accident risk posed by dams of different characteristics (e.g., dam types, dam purposes) worldwide

Dataset of dam accidents

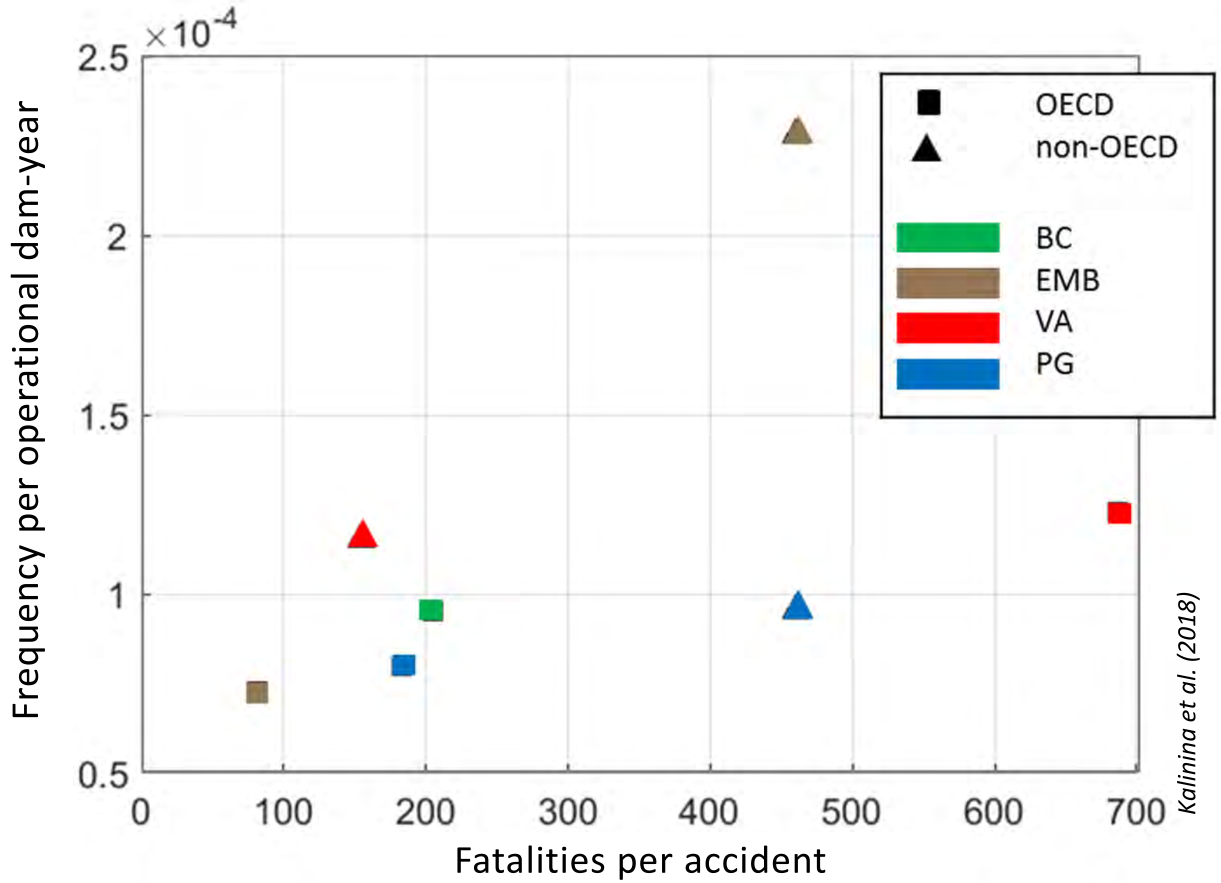
- Review of more than 50 primary information sources
- Dams of all purposes, 1798-2017, worldwide
- 522 new accidents were added to PSI's ENergy-related Severe Accident Database (ENSAD); 569 accidents previously available were reviewed and updated

Method



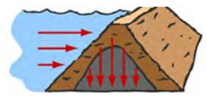
Kalinina et al. (2018)

Phase 1: Accident risk for hydropower dams

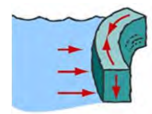


BC – Buttress

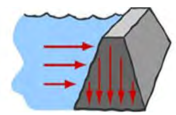
EMB - Embankment



VA - Arch



PG - Gravity



- Embankment and gravity dams have a higher risk in non-OECD than in OECD countries, whereas in OECD arch dams have a higher risk than other dam types
- Accidents due to natural causes have the highest risk in both country groups (not shown in here)
- Dams with height ≥15 m in OECD countries have higher risk than dams with height <15 m (not shown in here)

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Phase 2: Uncertainty quantification in the modelling of dam-break consequences

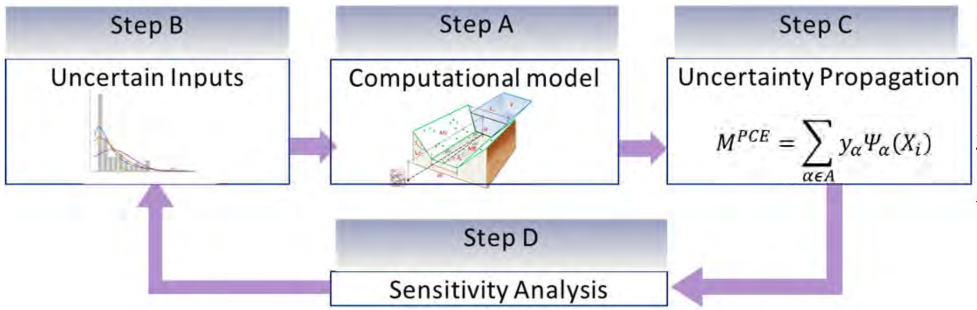
Research goals

- Development of a computational model to assess the consequences of the potential failure of a dam, with a focus on relevant Swiss conditions (i.e., ≥ 100 meters, arch, concrete, hydropower dams in Alpine regions)
- Systematic quantification of uncertainties and global sensitivity analysis for parameters within the physically-based model of the dam-break consequences

Methodology

- Computational model of dam-break consequences

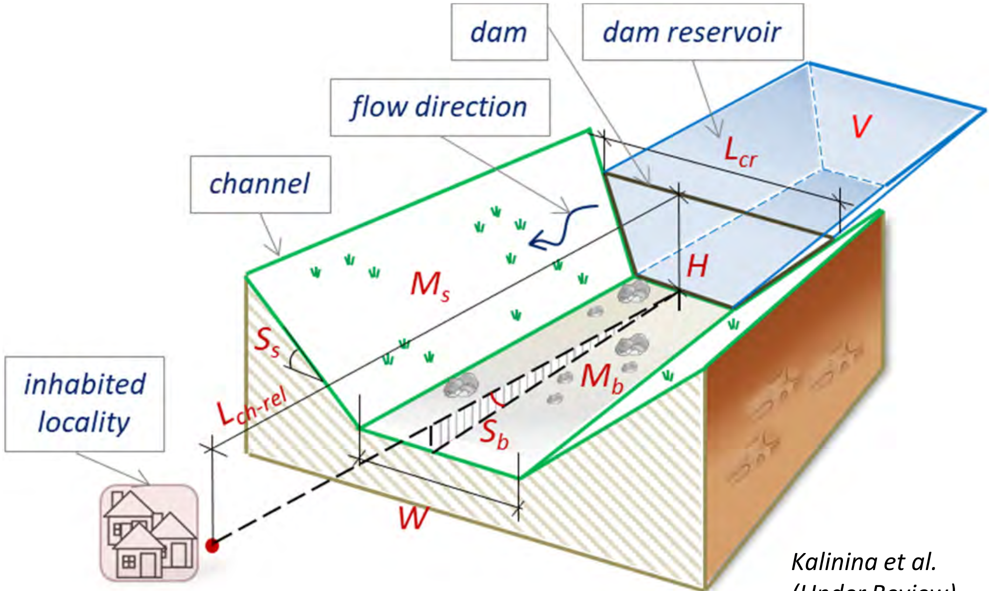
- Metamodelling for Uncertainty Quantification (UQ) and Sensitivity Analysis (SA) purposes



M^{PCE} - Polynomial Chaos Expansion (PCE) model response,
y_α - coefficients,
Ψ_α - multivariate polynomials,
X_i - input vector

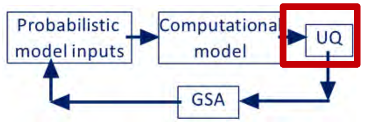
Modified from Sudret (2007)

Block 1: Computational model



Kalinina et al. (Under Review)

- A simplified geometry that rather accurately reflect the population of the representative hydropower dams in Switzerland
- Complete and instantaneous failure of the dam is assumed => the dam-break is treated as a Riemann problem
- A 1D model is then built in the BASEMENT software
- For each parameter in the figure, data on Swiss large hydropower concrete dams and data on slopes and land cover have been collected to define marginal distributions



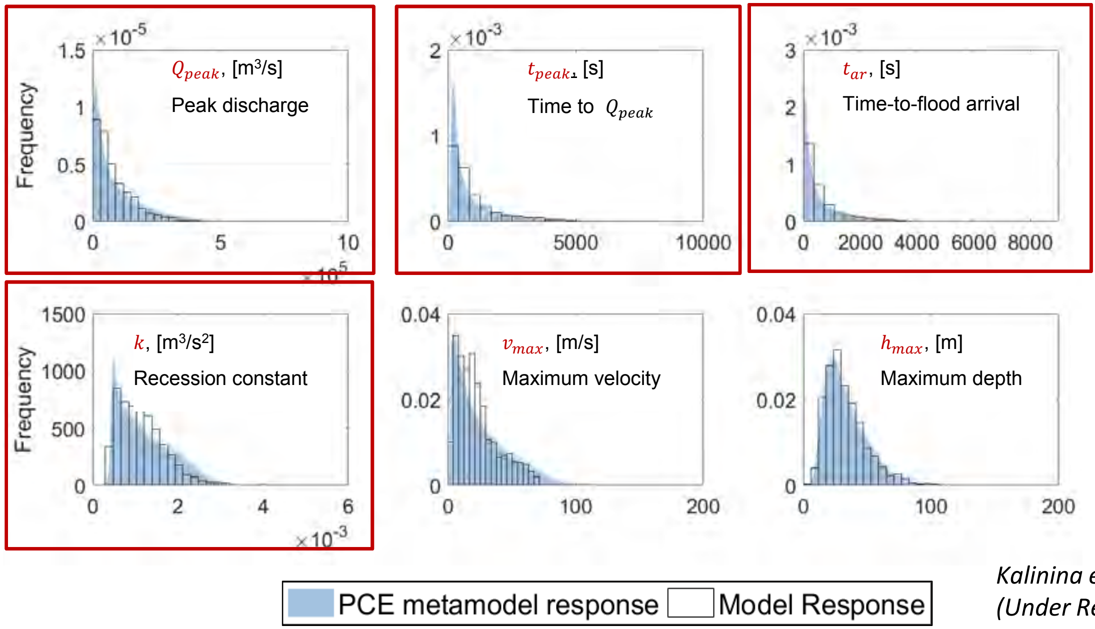
Block 1: Uncertainty propagation

- Individual PCE metamodel was built for each model output with 9 uncertain input parameters of the dam, reservoir, downstream valley and environment

$$M^{PCE} = \sum_{\alpha \epsilon N^M} y_\alpha \Psi_\alpha(H, V, L_{cr}, L_{ch-rel}, W, S_s, S_b, M_s, M_b)$$

- PCEs were built on the experimental design of 2,000 samples and validated using leave-one-out error and mean squared error

- $M_i^{PCE} = \{M_{Q_{peak}}^{PCE}, M_{t_{peak}}^{PCE}, M_{t_{ar}}^{PCE}, M_k^{PCE}, M_{v_{max}}^{PCE}, M_{h_{max}}^{PCE}\}$



Kalinina et al. (Under Review)

- The applied metamodeling approach is in good agreement with the physical model

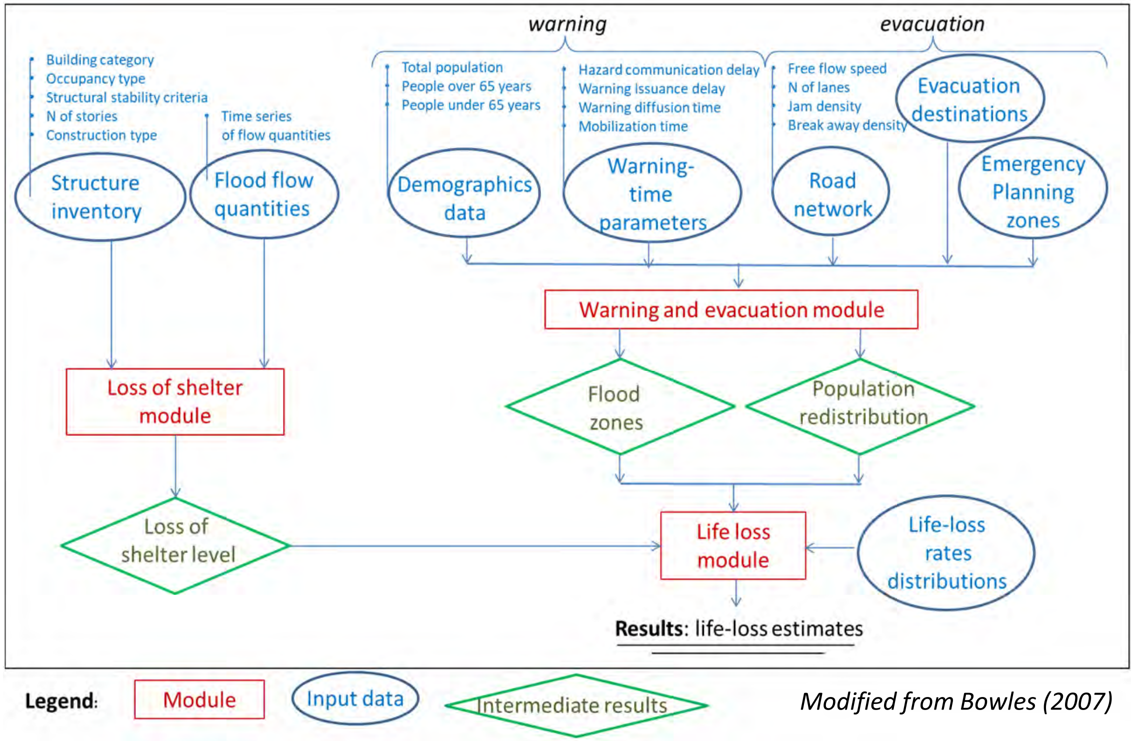
Block 2: Computational model

- mean flood inflow
- 5% flood inflow
- 95% flood inflow

daytime (2 p.m.)

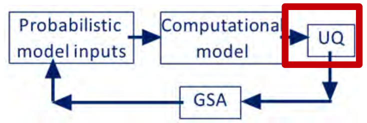
- mean flood inflow
- 5% flood inflow
- 95% flood inflow

night-time (2 a.m.)



Modified from Bowles (2007)

- A hypothetical locality with characteristics representative for the defined population of Swiss dams and their downstream areas
- Simulation of warning and evacuation processes, structural damage, life loss
- 2D urban flood simulation in HEC-RAS, the life-loss model is built in the HEC-LIFESim
- For each parameter, data on demographics, land use, structural inventory, etc. have been collected to define marginal distributions

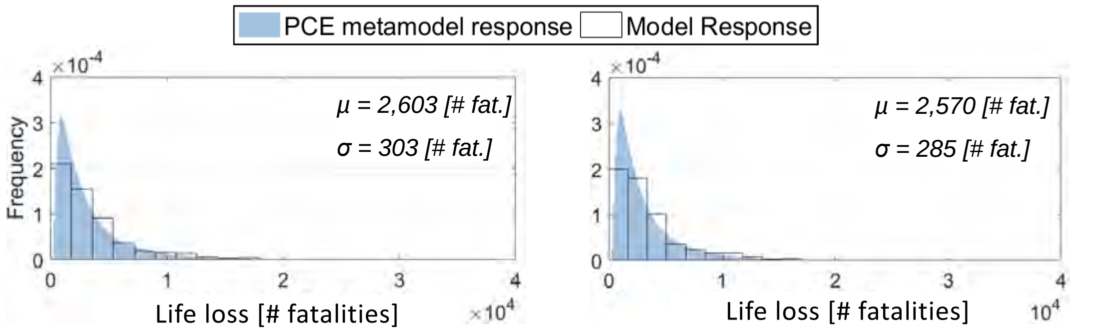


Block 2: Uncertainty propagation

- PCE-metamodel was built for the potential number of life loss using 7 uncertain input parameters of the flood and warning process, and of the inhabited locality:

$$M^{PCE} = \sum_{\alpha \epsilon N^M} y_\alpha \Psi_\alpha (P_{tot}, P_{o65}, H, F_{chance}, F_{compr}, T_{wid}, T_{hcd})$$

- Experimental design (ED) of 550 runs of the original computational model
- Validation was done using both leave-one-out error and mean squared error



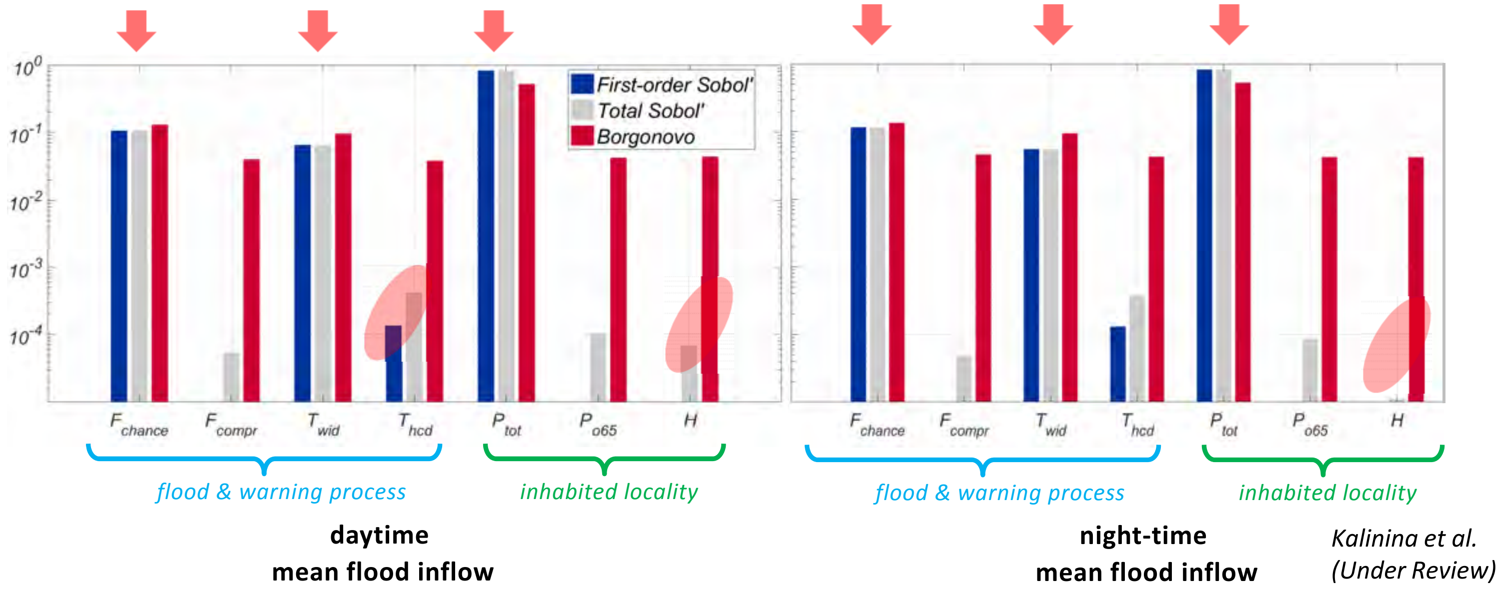
daytime mean flood inflow *Kalinina et al. (Under Review)*

night-time mean flood inflow *Kalinina et al. (Under Review)*

- The applied metamodeling approach is in good agreement with the physical model
- Results for daytime and night-time are similar for the selected hypothetical location

Block 2: Global Sensitivity Analysis

- Global Sensitivity Analysis is performed by calculating 1st order and total Sobol' and Borgonovo sensitivity indices



- Results indicate that the total population, the fatality rate in the chance zone and the warning issuance delay contributed most to the variability of the model output for both day and nighttime.
- Discrepancies between indices are related to the fact that the Borgonovo indices provides a relative ranking with respect to the most important parameter (P_{tot}), while Sobol' provides absolute values.

Summary

1. Accident Risks for DGE are quantified for blowout accidents and accidents related to the use of hazardous substances in drilling, stimulation and operational phases:

   - The accident risk of blowouts is significantly higher than the most accident-prone hazardous substance
   - The drilling phase in deep geothermal systems exhibits the highest risks, followed by the stimulation and the operational phase
   - Deep geothermal system compares favorably to most of the renewables
   - There is a need to finalize the quantitative assessment for the missing potential risks ← **On-Going**

2. Accident risk for hydropower:

   - Up-to-date collection of dam accidents with detailed information on various dam characteristics
   - Bayesian hierarchical model to analyze specific combinations of dams characteristics and explicit assessment of uncertainties
   - Global sensitivity analysis helped to identify the factors that contributed most to the variability of the LL estimates
   - Generic metamodel can be favorable for application in risk analysis and within a policy perspective
   - Proposed framework provides a more generalized risk quantification that can be adapted and applied to other contexts/regions

My thanks go to:

- Anna Kalinina
- Peter Burgherr
- Christopher Robinson
- Stefano Marelli
- David Vetsch
- Bruno Sudrè
- Karin Treyer
- Stefan Hirschberg
- Vinh Dang

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Thank you! Questions?

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Backups

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Possible Working Fluids in Switzerland

Chemical	TDI (mg/kg-day)	GWP (100 yy)	ODP
Ammonia	0.25	0	0
n-Pentane	10	4	0
Tetrafluoroethane/R-134a	10	1430	0
Pentafluoropropane/R-245cb	10	950	0
Propylene	5	1.8	0
Heptafluoropropane/R-227ea	10	3220	0
Hexafluoropropane/R-236fa	10	9810	0
Isobutane/R600	30	3	0
2,2-Dichloro-1,1,1-trifluoroethane/R-123	10	77	0.02
Trichloro-1,1,2-Trifluoro-1,2,2-ethane/R-113	10	6130	1
Propane	10	3.3	0
Difluoroethane-1,1/R-152a	10	124	0
Chloro-2-Tetrafluoro-1,1,1,2-ethane/R-124	10	609	0.022
Isopentane	6	4	0
Ethane	10	5.5	0
n-Butane	8	4	0
Methanol	0.5	2.8	0
n-Hexane	0.2	3	0
Pentane	6	4	0
Benzene	0.01	10	0
Toluene	0.14	2.7	0
o-Xylene	0.03	10	0

- Common working fluids used in Kalina and ORC binary cycles for geothermal systems
- TDI, if not found, is estimated from the ratio NOAEL (No Observed Adverse Effect Level) and an Uncertainty Factor (= 100, for preliminary risk assessment)
- Only Refrigerants with GWP (Global Warming Potential) < 150 (EU Regulation, took effect in 2011), ODP (Ozone Depletion Potential) = 0 and TDI < 1 mg/kg-day are considered in the analysis

Capacity Plants

		SCCER-SoE/BFE/GEOTHERM-2 Doublets			SCCER-SoE/BFE/GEOTHERM-2 Triplets		
Capacity cases		**High**	**Base**	**Low**	**High**	**Base**	**Low**
Net plant power		3.28 Mw_e	1.45 MW_e	1.18 MW_e	5.21 MW_e	2.73 Mw_e	2.27 MW_e
Production in GWeyr (P_{GWeyr})		6.56e-2 Gweyr	2.99e-2 GWeyr	2.36e-2 GWeyr	1.04e-1 GWeyr	5.46e-2 GWeyr	4.54e-2 GWeyr
Well depth (WD)		5 km					
Number of wells (NW)		2			3		
Surface plant life time (LT)		20 years					
Caustic Soda as additive in the drilling mud per Well (CS_{Well})		1 kg/m					
Additives in Hydraulic Stimulation (total average) per Well (HS_{well})		HCl:3.4E7 kg HF:7.1E6 kg; Ammonium Sulphate: 3.1E5 kg; Boric Acid: 1.2E5 kg					
Working Fluids used at the power plant at year 1 (WF_{Year1})	**Ammonia**	1415 kg	863 kg	740 kg	1716 kg	1369 kg	1179 kg
	Benzene	1208 kg	737 kg	632 kg	1465 kg	1169 kg	1007 kg
	Toluene, Methanol, n-Hexane, o-Xylene	1197 kg	730 kg	626 kg	1452 kg	1158 kg	998 kg
Yearly losses of the working fluids (YLWF)		8%					

Accidents

Phase	Hazardous Substance	Accidents/Fatalities	Accidents/Injuries
Drilling	Caustic Soda	13/30	142/1149
Stimulation	Hydrogen Chloride (HCl)	2/4	94/697
	Hydrogen Fluoride (HF)	3/3	26/83
	Ammonium Persulphate	2/2	8/76
	Boric Acid	1/1	10/43
Operational	Benzene	3/4	33/562
	Toluene	16/20	66/679
	Methanol	18/43	15/103
	n-Hexane	11/25	20/205
	o-Xylene	8/24	27/415
	Ammonia	16/20	136/1191

Blowouts	Accidents/Fatalities	Accidents/Injuries
	5/5	11/25

Normalization

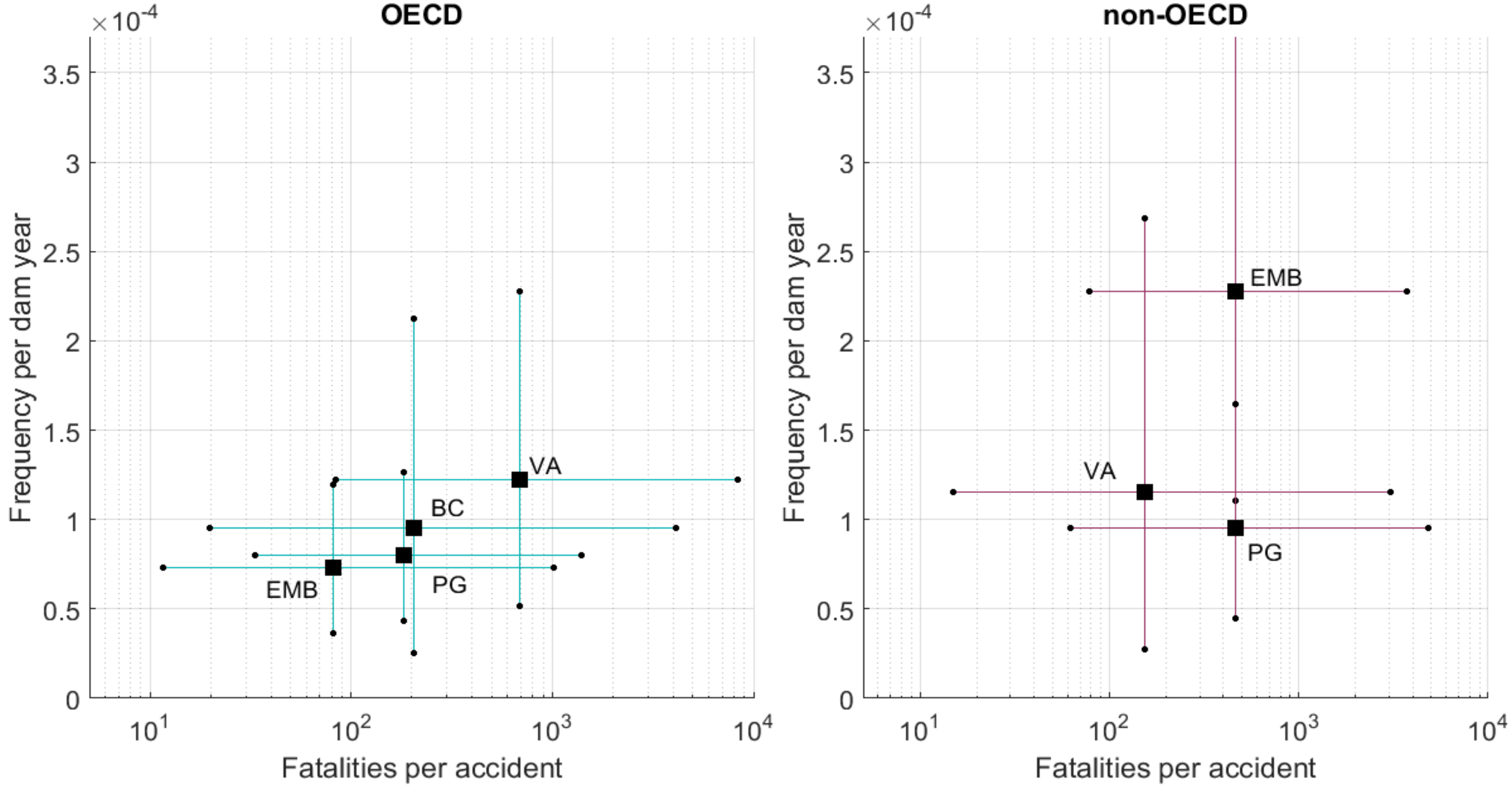
$$NF_{Caustic\ Soda} = \frac{CS_{Well} * WD * NW}{total\ production\ 1990-2017} * \frac{1}{P_{GWeyr}}$$

$$NF_{Stimulation} = \frac{HS_{Well} * NW}{total\ production\ 1990-2017} * \frac{1}{P_{GWeyr}}$$

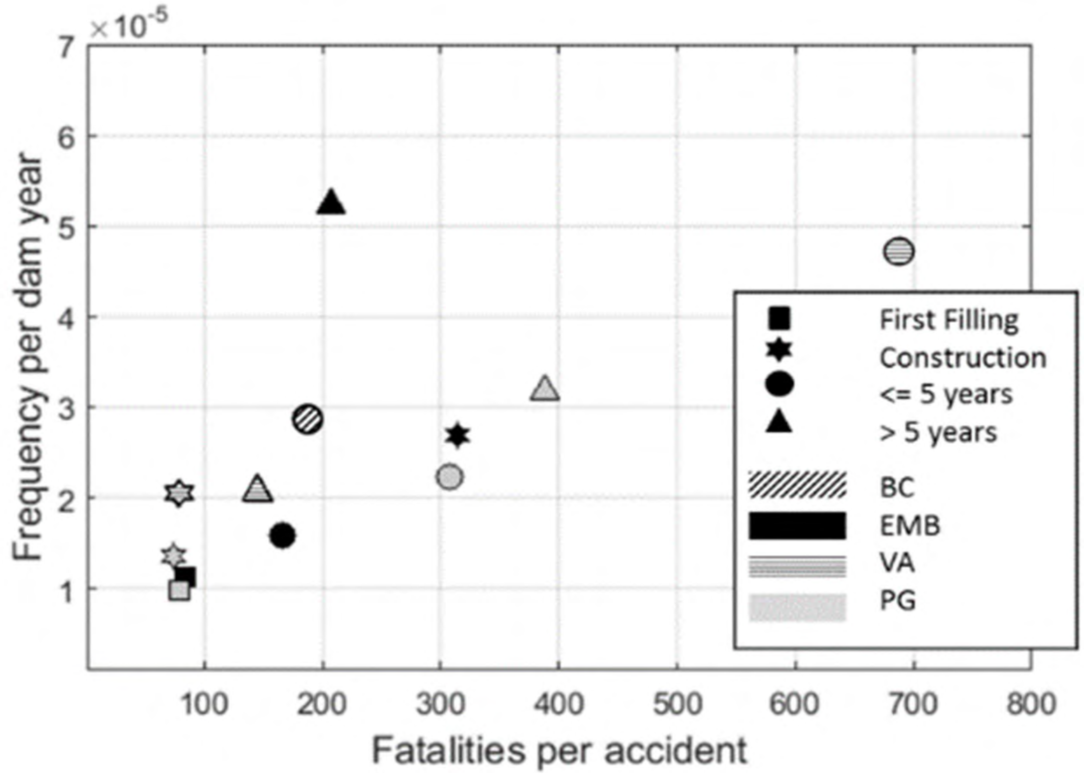
$$NF_{Working\ Fluid} = \frac{WF_{Year1} + (kg\ of\ substance\ refilled * LT)}{total\ production\ 1990-2017} * \frac{1}{P_{GWeyr}}$$

$$\mathrm{NF_{Drill+Stim}} = \frac{\mathrm{NW}}{\text{total number of natural gas drilled wells } 1990-2017} * \frac{1}{\mathrm{P_{GWeyr}}}$$

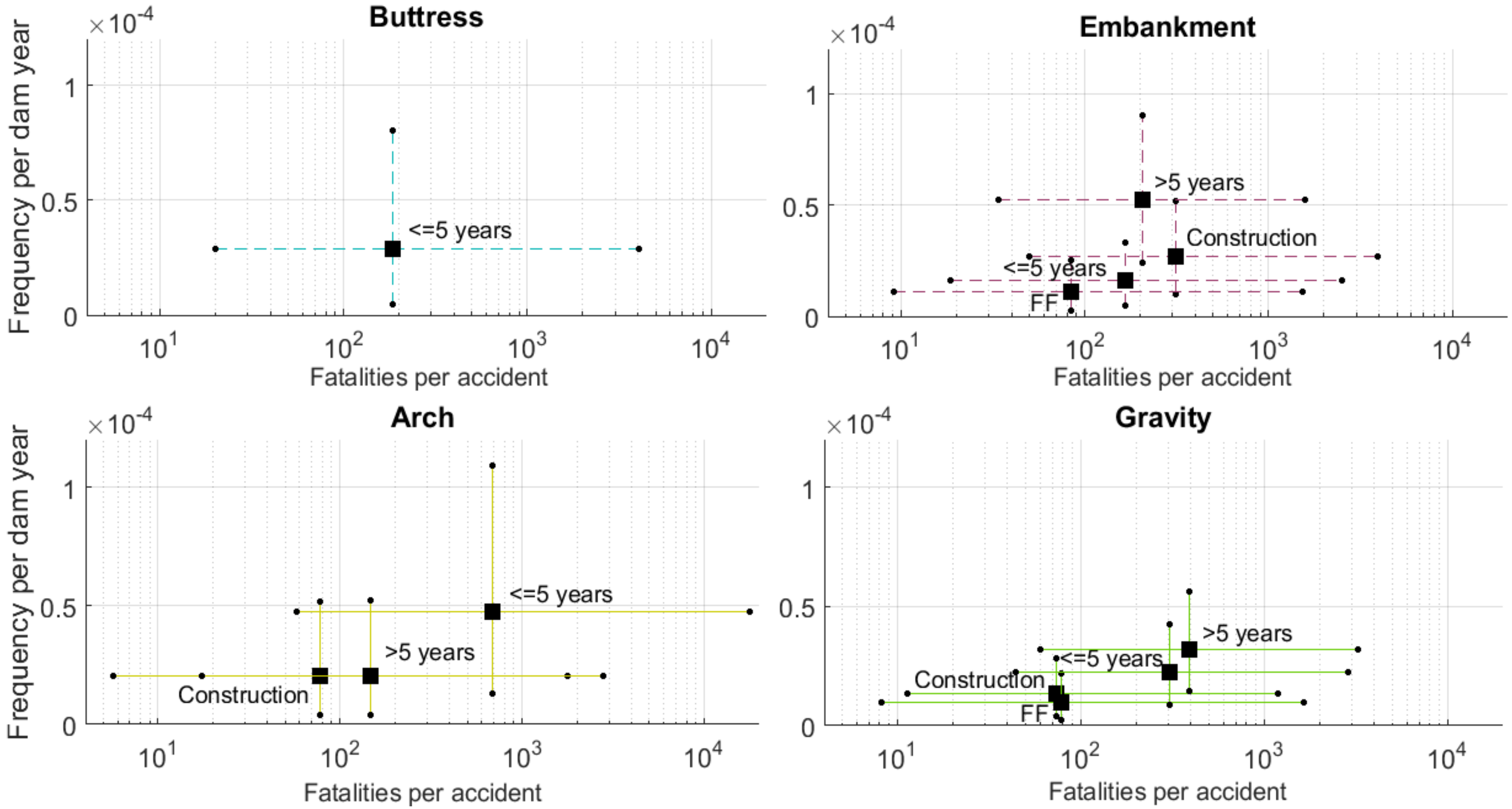
Risk for hydropower dams (1/5)



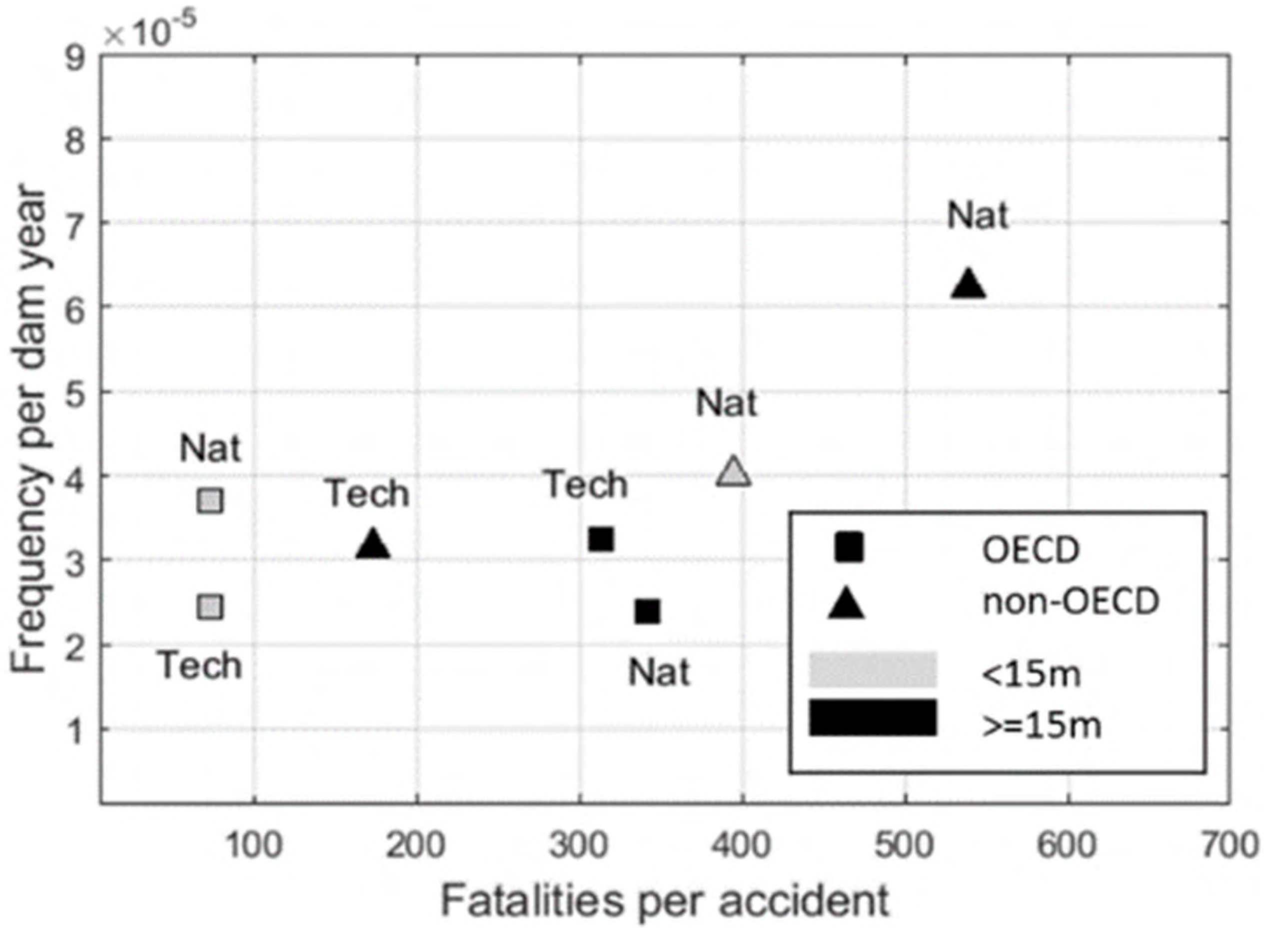
Risk for hydropower dams (2/5)



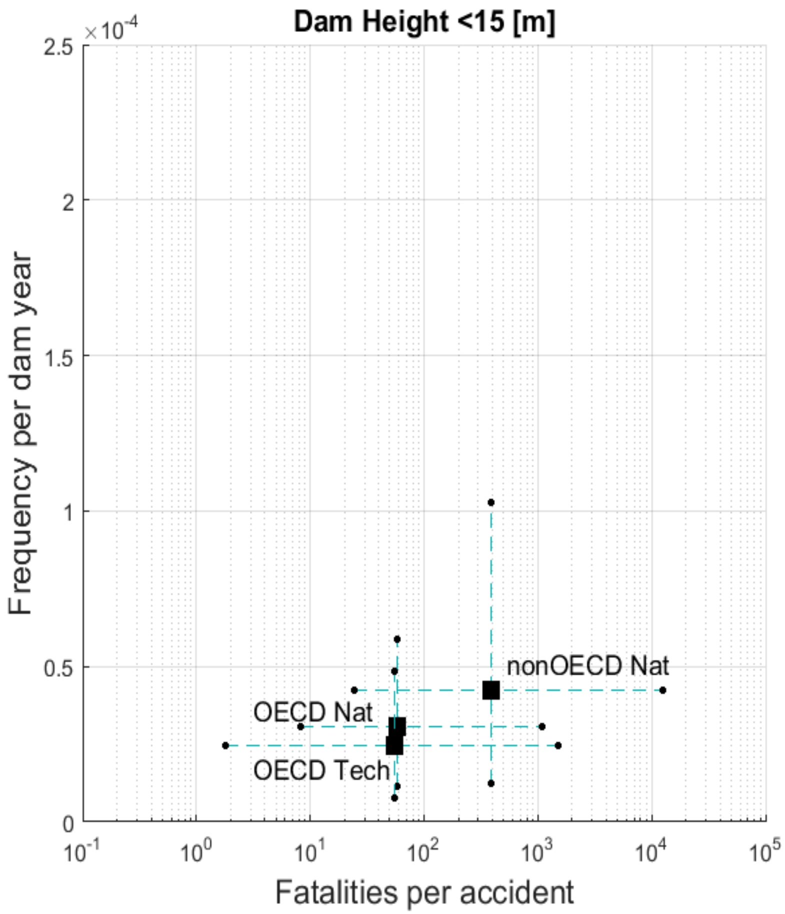
Risk for hydropower dams (3/5)

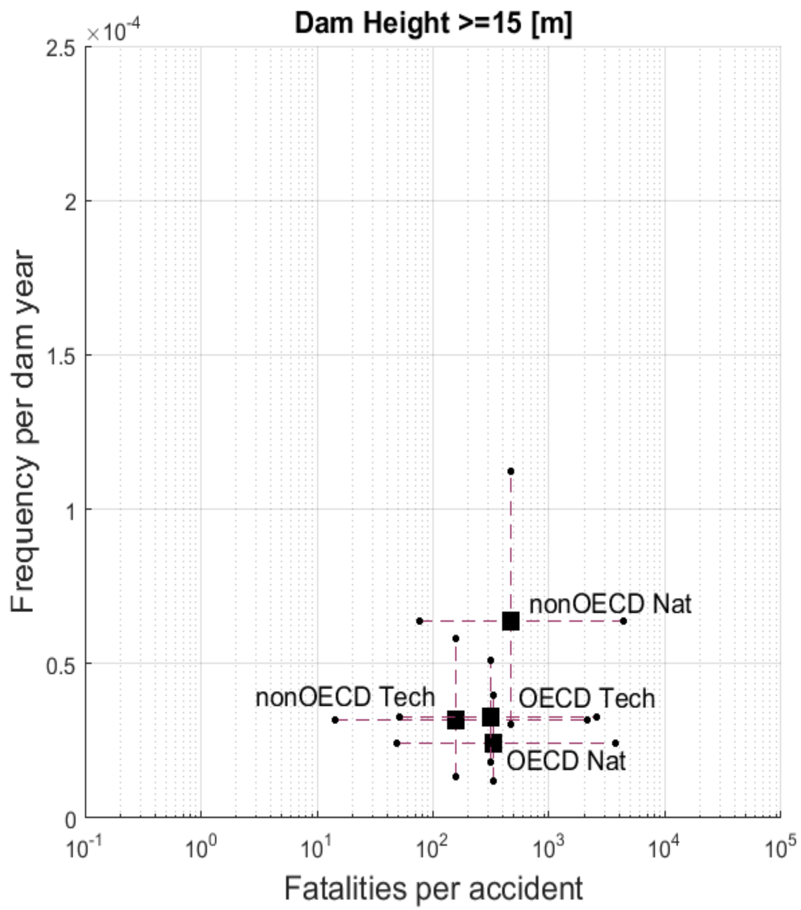


Risk for hydropower dams (4/5)



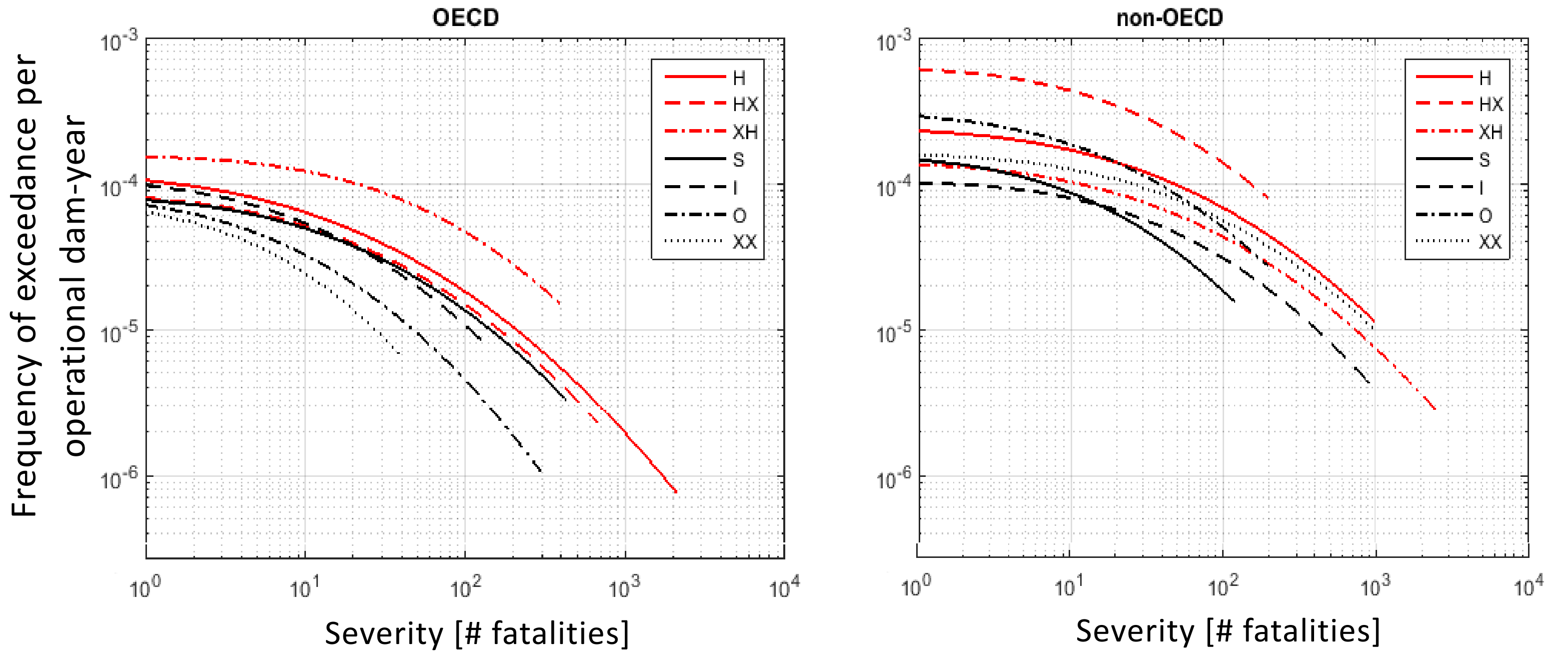
Risk for hydropower dams (5/5)



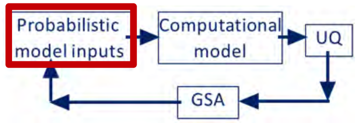


Phase 1: Frequency-consequence curves

Dams with hydropower purpose (*H, HX, XH*) and other dams (*S, I, O, XX*)



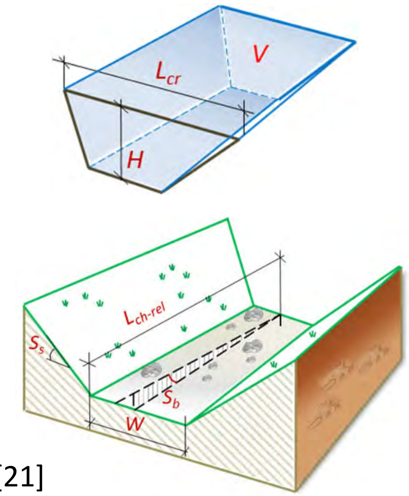
Abbrev-n	Dam purpose
H	Hydropower
HX	Multipurpose - Hydropower as primary function
XH	Multipurpose - Hydropower as secondary function
S	Supply
I	Irrigation
O	Others
XX	Multipurpose - no hydropower function



Probabilistic model inputs

Parameter	Name	Unit
Physical characteristics of the dam and reservoir		
H	Dam height	[m]
V	Reservoir volume	[m^3]
L_{cr}	Length of the dam crest	[m]
Physical characteristics of the channel		
L_{ch-rel}	Relative channel length	[m/m]
W	Channel width	[m]
S_b	Slope of channel bed	[-]
S_s	Slope of channel sides	[-]
Characteristics of the environment		
M_b	Roughness coefficient of channel bed	[s/m$^{1/3}$]
M_s	Roughness coefficient of channel sides	[s/m$^{1/3}$]

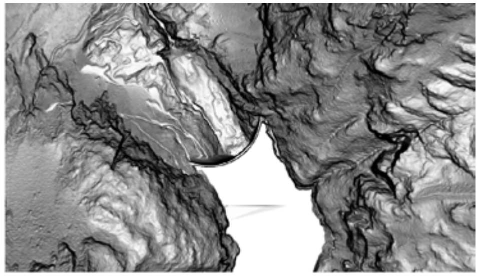
[21]



- **Marginal probability distributions**
  - data on Swiss large hydropower concrete dams and data on slopes and land cover [14, 23]
  - uniform and 2- and 4-parameters beta probability distributions
- **Dependence between parameters**
  - Gaussian copula parametrized by the Spearman rank correlation coefficient

Classification of the dam-downstream topographies (1/3)

- **C**lassification using:



Swiss ALTI 3D (slope)

Swiss TLM 3D (land cover)

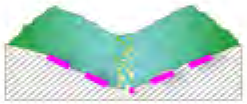
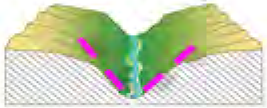
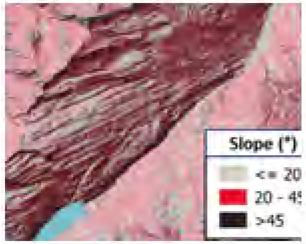
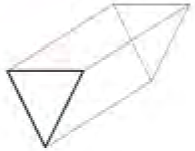
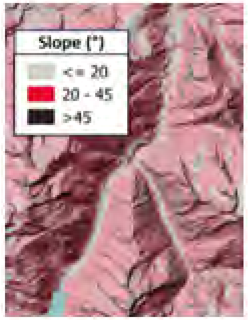
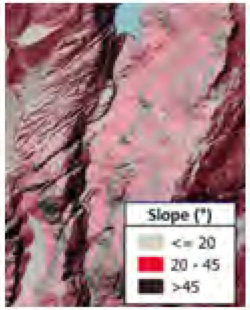
- Only arch dams
- 5 dams were excluded
- 3 classes are identified

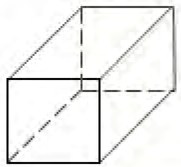
?	Mauvoisin	VA
1	**Luzzone**	**VA**
1	**Contra**	**VA**
downstream area in France	~~Emosson~~	~~VA~~
?	Zeuzier	VA
3	**Curnera**	**VA**
2	**Zervreila**	**VA**
2	**Moiry**	**VA**
?	Gigerwald	VA
very remote area	~~Limmern~~	~~VA~~
2	**Valle di Lei**	**VA**
3	**Punt dal Gall**	**VA**
?	Sambuco	VA
3	**Nalps**	**VA**
Multiple Arch	~~Hongrin Nord~~	~~VA~~
?	Gebidem	VA
2	**Santa Maria**	**VA**
"cascade event" with Oberaar dam	~~Spitallamm~~	~~VA~~
very remote area	~~Cavagnoli~~	~~VA~~

Classification of the dam-downstream topographies (2/3)

N	Name of the dam	Dam height H (m)	Length of the dam crest, L_{cr} (m)	Volume of the dam reservoir, V (10^3m^3)	Name of the locality	Distance to the locality (km)	Distance relative to the dam height (m/m)	Population of the locality (Year reported)	Elevation at the dam site (m.a.s.l.)	Elevation at the locality (m.a.s.l.)
1	Contra	220	380	105,000	Locarno	1.298	5.9	16,122 (2016)	315	282
2	Curnera	153	350	41,100	Sedrun (Tujetsch)	5.809	37.97	1,838 (2008)	1,829	1,422
3	Gebidem	122	327	9,200	Bitsch	4.888	40.07	894 (2015)	1,364	750
4	Gigerwald	147	430	35,600	Vättis	3.807	25.90	410 (-)	1,296	952
5	Hongrin North	125	325	53,200	Albeute, Lessoc	13.421	107.37	761 (-)	1,213	769
6	Limmern	146	375	93,000	ARGE Kraftwerk	4.095	*28.05*	*industrial area*	1,735	812
7	Luzzone	225	600	108,000	Olivone	4.502	20.01	867 (-)	1498	918
8	Mauvoisin	250	520	211,500	Bagnes	13.604	54.42	8,057 (2016)	1,809	1,098
9	Moiry	148	610	78,000	Grimentz	4.04	27.30	475 (2007)	2,130	1,600
10	Nalps	127	480	45,000	Sedrun (Tujetsch)	5.5	43.31	1,838 (2008)	1,830	1,373
11	Sambuco	130	363	63,000	Brontallo (Lavarizza)	13.734	105.65	520 (2000)	1400	583
12	St. Maria	117	560	67,300	Disentis	14.461	123.60	2,058 (2014)	1,835	1,051
13	Zervreila	151	504	100,500	Vals	5.205	34.47	990 (2015)	1,742	1,310
14	Zeuzier	156	256	51,000	Saint-Léonard	11.809	75.70	2,269 (-)	1,685	516
15	Cavagnoli				very remote area, possible cascade events with the Robiei dam, requires different assessment					
16	Emosson				downstream area is partially in France (suitable digital data is not available)					
17	Valle di Lei				downstream area is in Italy (suitable digital data is not available)					
18	Punt dal Gall				digital data on the slope and landcover is not provided					
19	Spitallamm				possible cascade event with the Oberaar dam, requires different assessment					

Classification of the dam-downstream topographies (3/3)

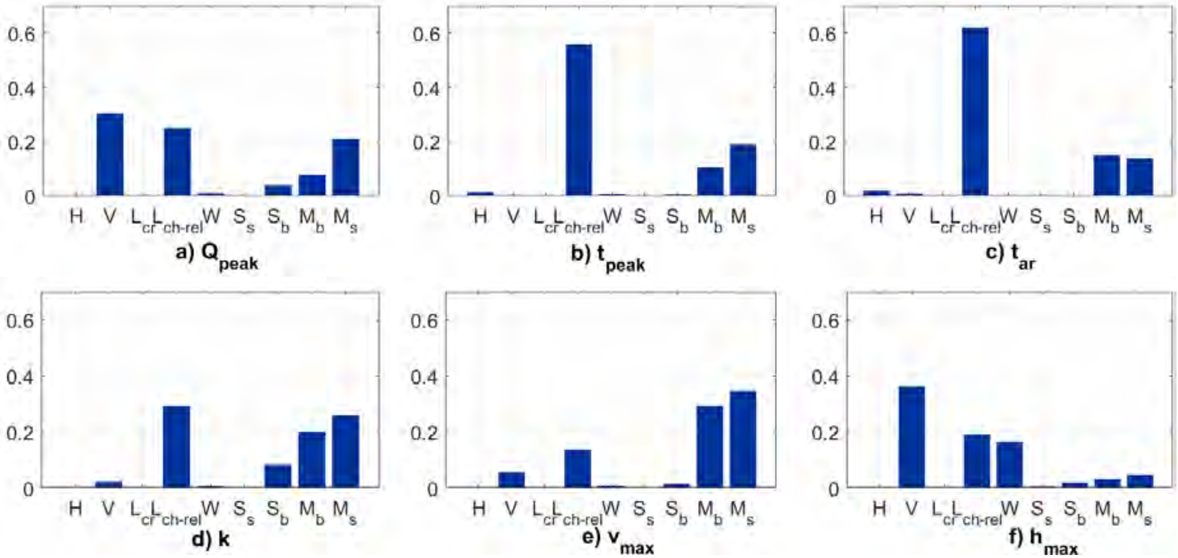
<table>
<tr><th colspan="2">Valley type based on Rosgen (1996) & Rosgen et al. (2013)</th><th colspan="2">Dam-downstream valleys in Switzerland</th><th>Simplified geometry</th></tr>
<tr><td colspan="5">Class 1: Channel with a triangular cross section</td></tr>
<tr><td>Moderately steep, gentle-sloping side-slopes (often in colluvial valleys)
</td><td>Steep, confined, V-notched canyons, rejuvenated side-slopes
</td><td colspan="2">Zevreila dam

</td><td>Channel with a triangular cross section
</td></tr>
<tr><td colspan="5">Class 2: Channel with a trapezoidal cross section</td></tr>
<tr><td>Moderately steep, U-shaped glacial-through valleys
</td><td>Santa Maria dam

</td><td colspan="2">Moiry dam

</td><td>Channel with a trapezoidal cross section
</td></tr>
<tr><td colspan="5">Class 3: Other topographies</td></tr>
<tr><td>Joint-, bedrock-controlled valleys
</td><td colspan="3">Gigerwald dam

</td><td>Channel with a rectangular cross section
</td></tr>
</table>

Phase 1: Global Sensitivity Analysis

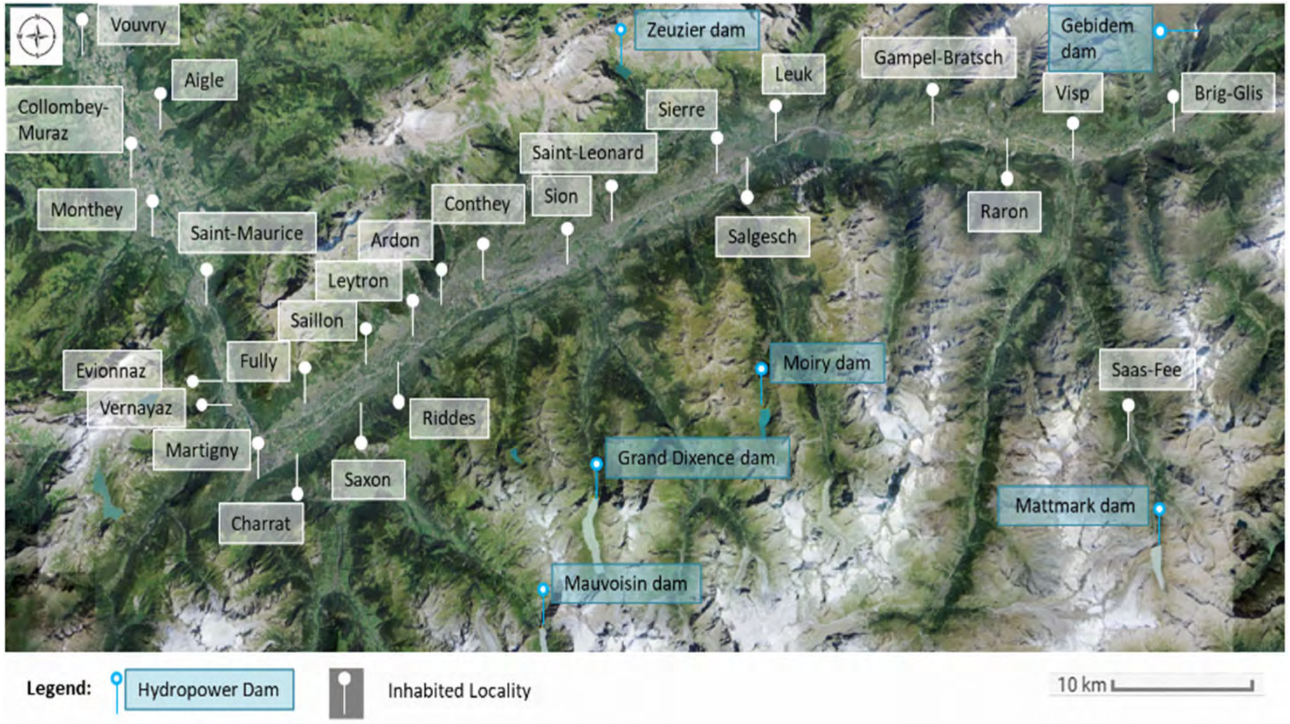
- 1st order **Sobol' sensitivity indices** define individual contribution of each model input *(X_i)* to the total variance *Var(Y)* *(Sobol, 1993)*;
- They can be calculated **directly from the coefficients of the built PCE** *(Sudret, 2008)*:

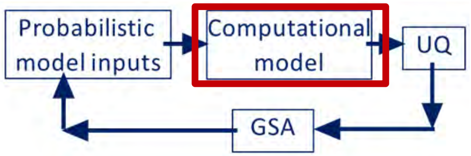
$$S_i = \frac{V_i}{Var(Y)} = \frac{\sum_{\alpha \in A_i} y_\alpha^2}{D}$$



- Reservoir volume, length of the valley, and surface roughness contributed most to the variability of the flood water quantities

The Rhone valley with all major inhabited localities, as well as large dams and dam reservoirs located around the valley (topography image is provided by swisstopo (2019))





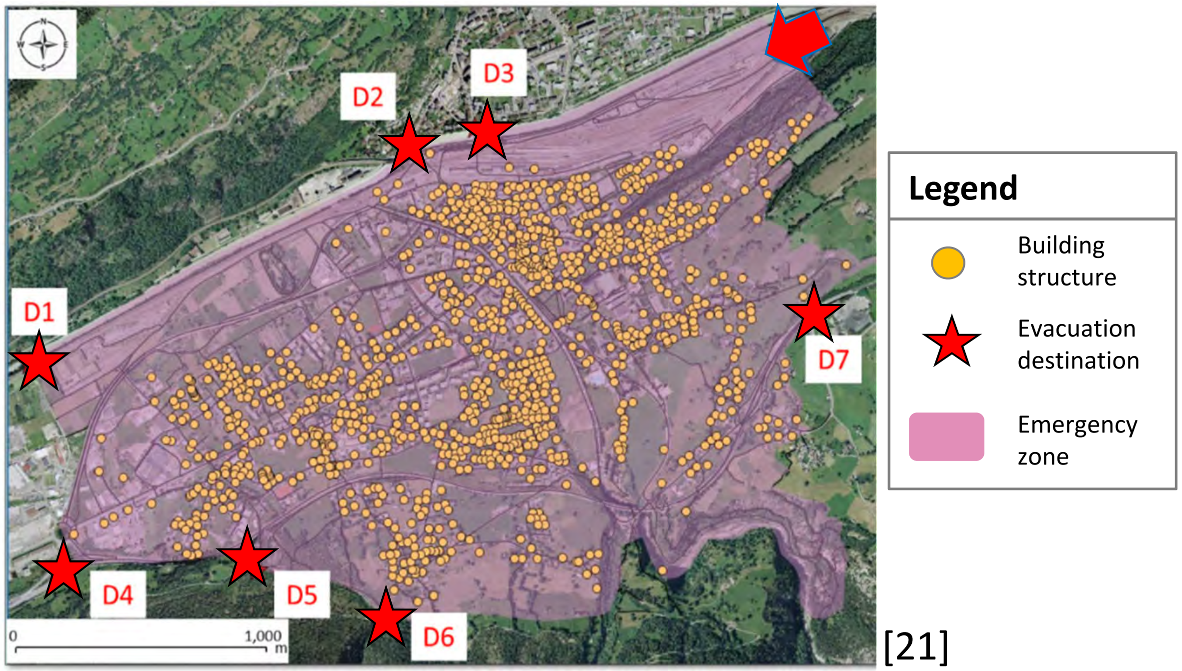
Block 2: Computational model

- mean flood inflow
- 5% flood inflow
- 95% flood inflow

daytime (2 p.m.)

- mean flood inflow
- 5% flood inflow
- 95% flood inflow

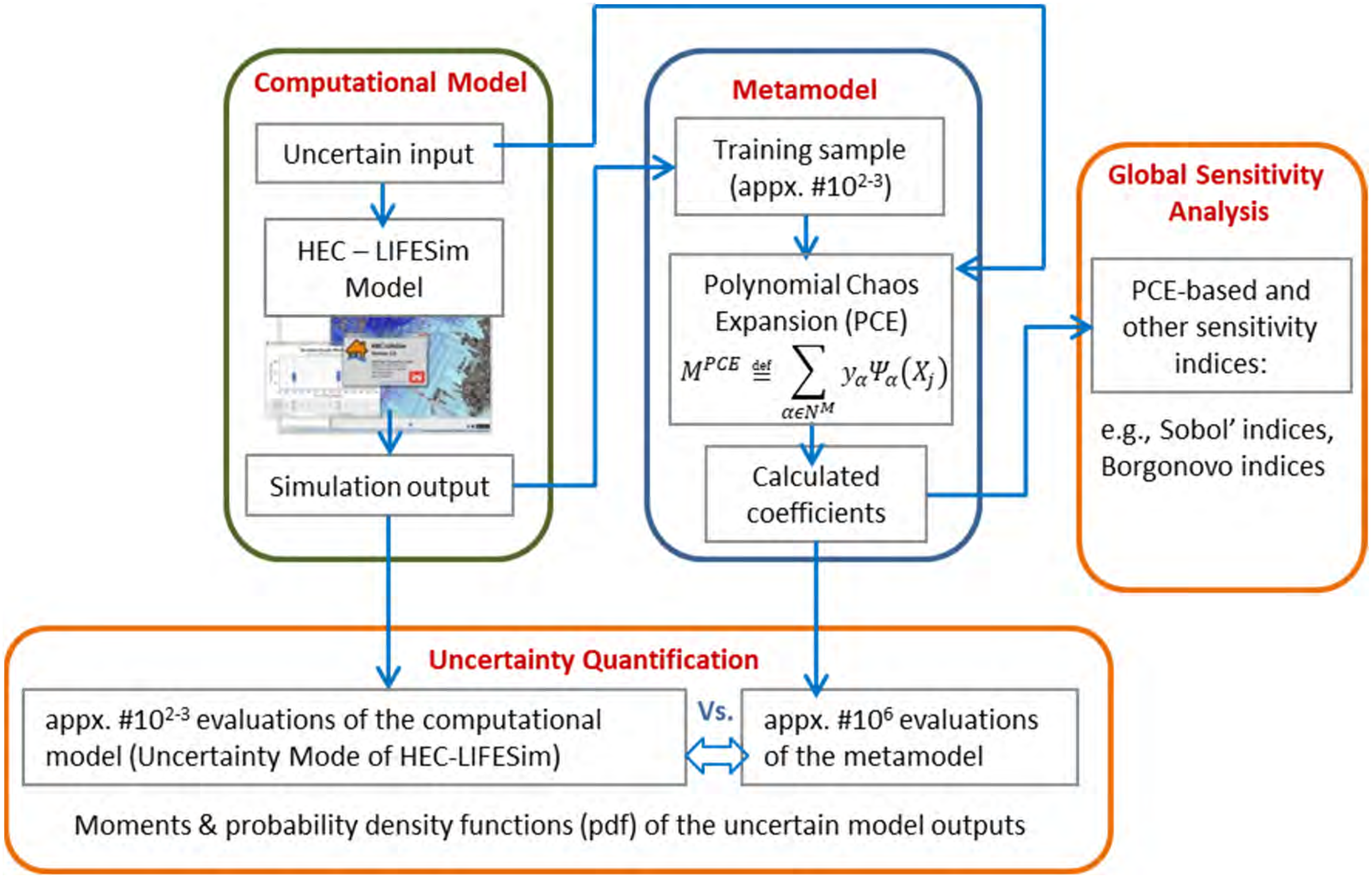
night-time (2 a.m.)



[21]

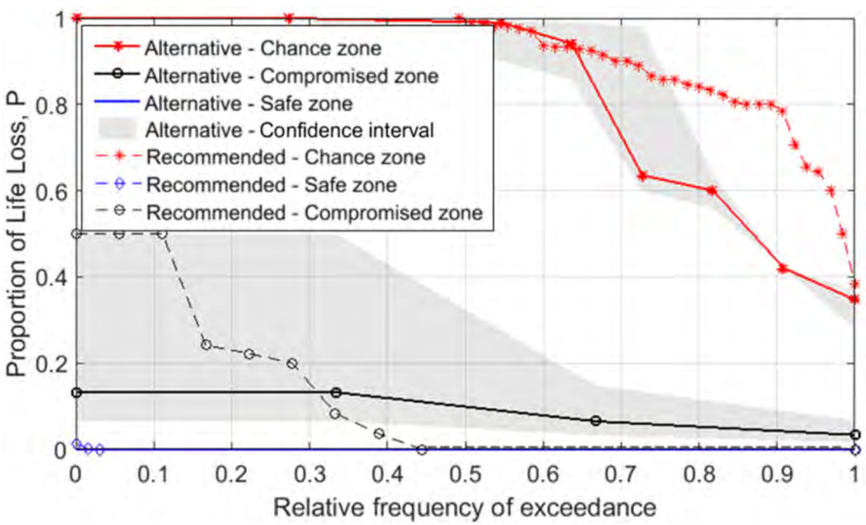
- A hypothetical locality with characteristics representative for the defined population of Swiss dams and their downstream areas
- Simulation of warning and evacuation processes, structural damage, life loss
- 2D urban flood simulation in HEC-RAS, the life-loss model is built in the HEC-LIFESim [24, 25]

Methodology Phase2 Block2

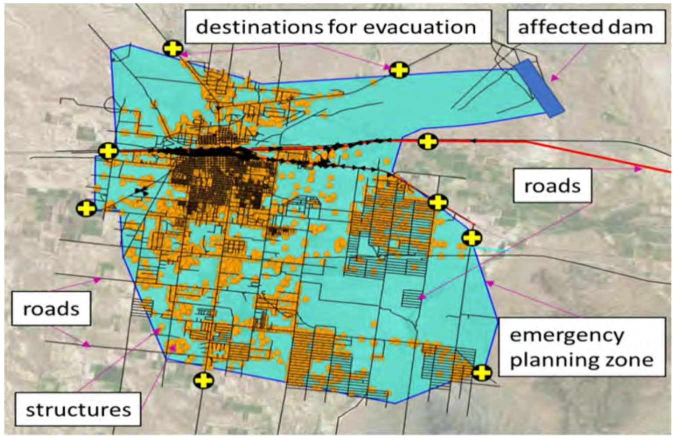


LL-rates distributions for the Swiss case

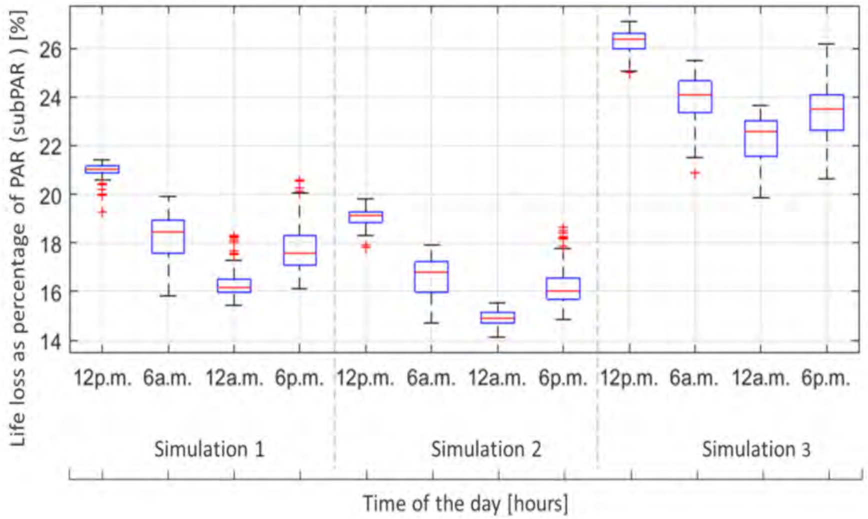
- This example demonstrates **importance** of using **data relevant for the local conditions**, where LL-consequences are being simulated;
- **Historical LL-rates distributions**:
  - LL-rates distributions developed by McClelland and Bowles (2002);
  - Alternative distributions built on dam failure dataset of large concrete and masonry dams in mountain regions of OECD countries
- **Simulation example:** hypothetical city in USA; all input data is relevant for USA, e.g., TRB2000, HAZUS; 2 types of LL-rates were tested



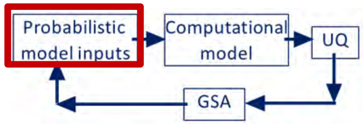
modified from McClelland and Bowles (2002); Kalinina A., et al. (2018)



modified from USACE (2017)



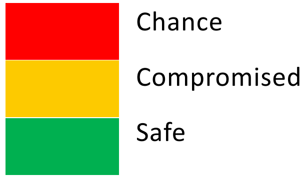
Kalinina A., et al. (2018)



Probabilistic model inputs

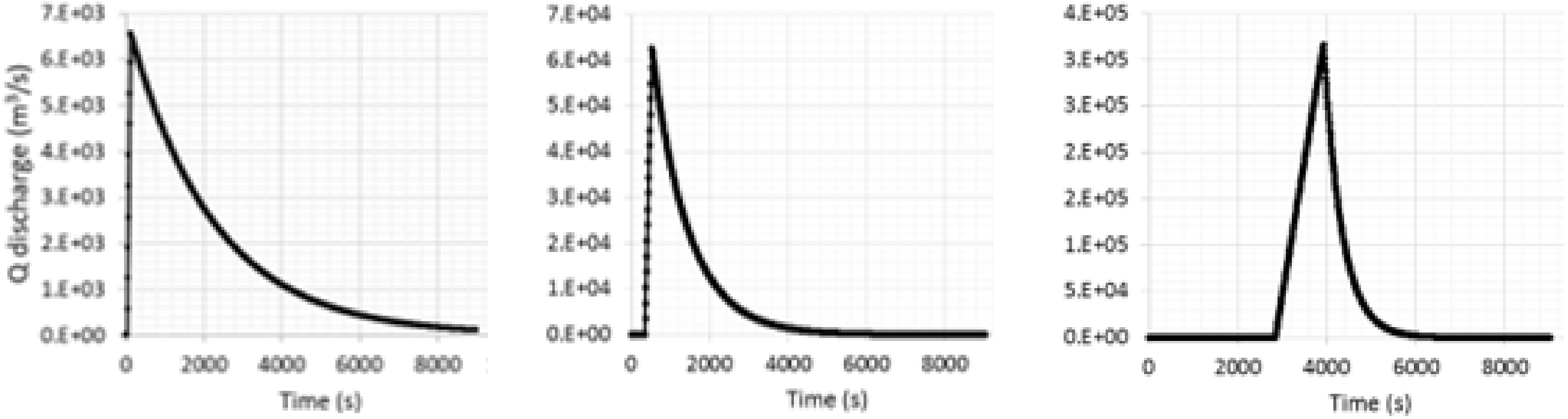
Parameter	Name	Unit
	Inhabited locality	
P_{tot}	Total population	[people]
P_{o65}	Population over 65	[fraction]
H	Building foundation height	[m]
	Flood and Warning process	
F_{chance}	Fatality rate in the chance zone	[fraction]
F_{compr}	Fatality rate in the compromised zone	[fraction]
T_{hcd}	Hazard communication delay	[hour]
T_{wid}	Warning issuance delay	[hour]

Flood zones [26]:

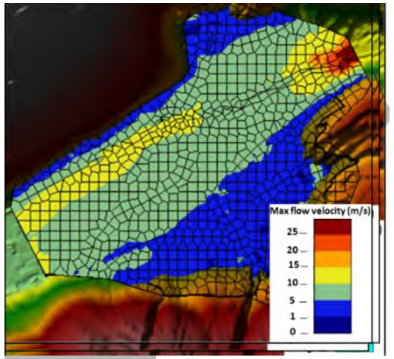


- **Marginal probability distributions**
  - data on demographics, land use, structural inventory, etc. [27-29]
  - uniform, beta, and lognormal probability distribution
- **Dependence between parameters**
  - no dependence is assumed due to different nature of the input parameters and assumptions made

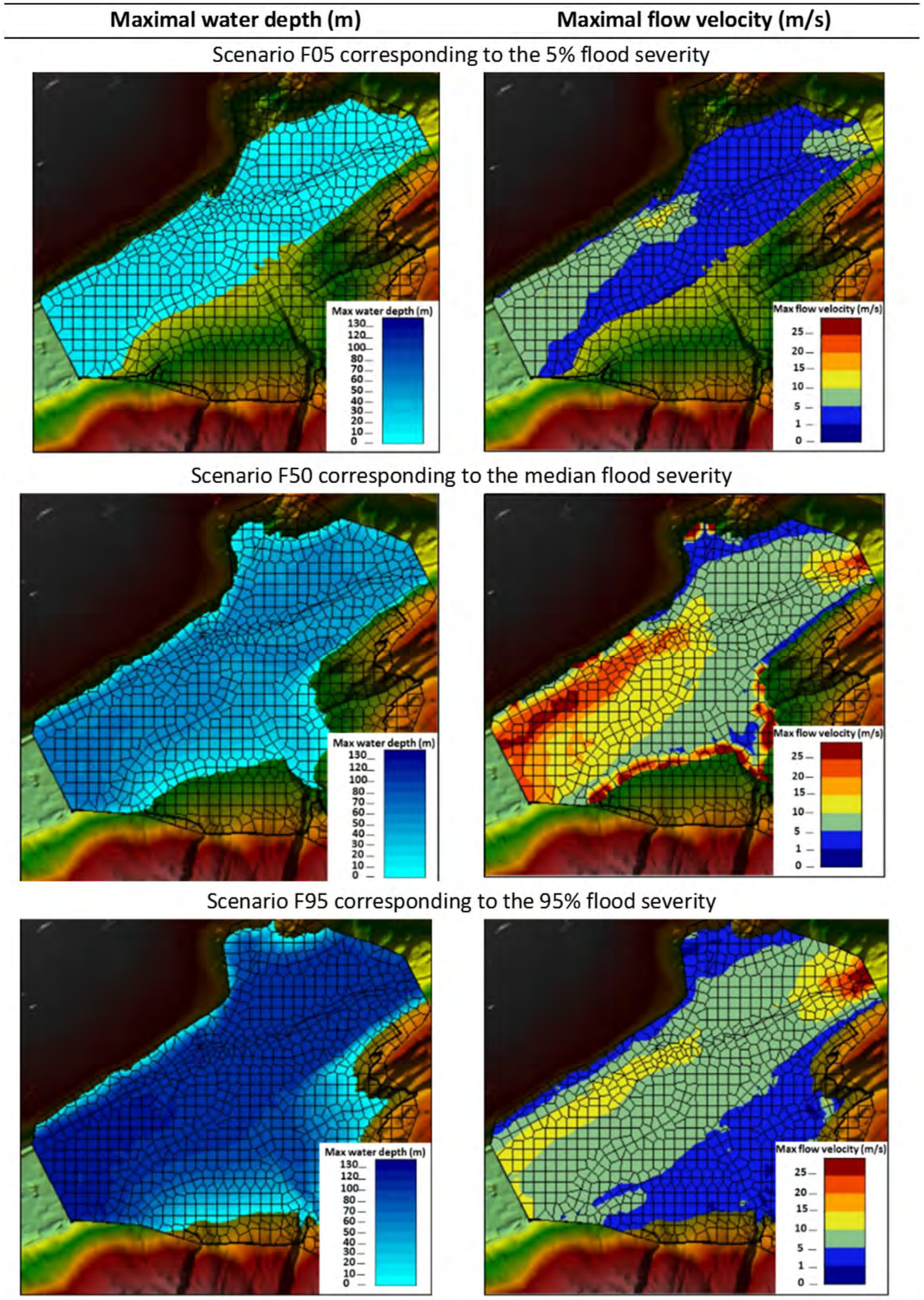
Definition of the 3 scenarios for different flood inflow hydrographs (1/2)



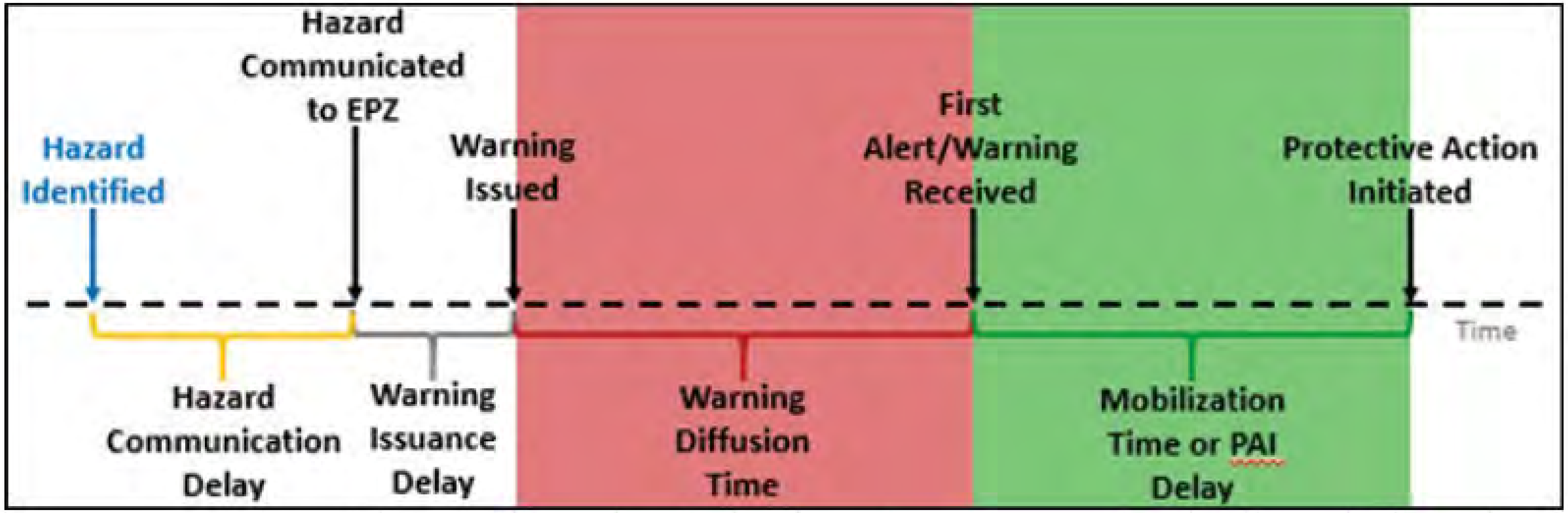
	F05	F50	F95
Peak discharge, Q_{max} (m³/s)	6.57E+03	6.25E+04	3.17E+05
Time-to-peak discharge, t_{max} (s)	129.72	522.05	3.93E+03
Time-to-flood arrival, t_{ar} (s)	31.55	340.10	2.84E+03
Recession constant, k (m³/s²)	4.60E-04	0.0011	0.0024

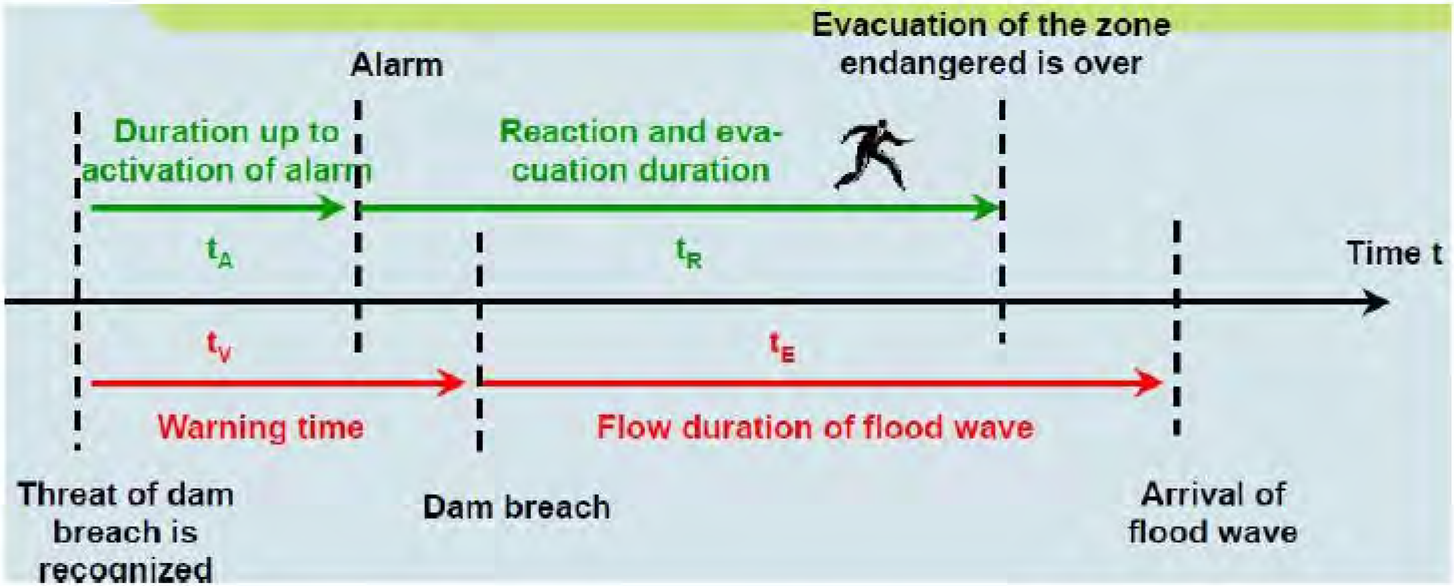


Definition of the 3 scenarios for different flood inflow hydrographs (2/2)



Flood warning and evacuation time in HEC-LIFESim





Criteria for the successful evacuation (Darbre, 2015)

Zusammenfassung

Kantonaler Bevölkerungsschutz

- ✓ Erstellung der Evakuierungspläne;
- ✓ Einbezug des Szenarios eines Talsperrenbruches ins kantonale Krisenmanagement (Einsatz KP/ZS);
- ✓ Planung, Installation und Unterhalt der kantonalen Alarmierungsstrukturen (inkl. Koordination und Regelung der Aufgaben mit den Betreiberinnen);
- ✓ Auslösung des AA (des WA als Redundanz);
- ✓ Krisenbewältigung.

Betreiberin

- ✓ Erstellung und Umsetzung des Notfallreglements (Überflutungskarte, Gefahrenanalyse, Notfallstrategie, Notfallorganisation, Einsatzdossier);
- ✓ (Planung, Installation und Unterhalt der Wasseralarmkomponente des Alarmierungssystems (in Abstimmung mit den Kantonen));
- ✓ Auslösung der Alarmierung (Wasseralarm direkt, Allgemeiner Alarm indirekt);
- ✓ Ergreifen von notwendigen Massnahmen.

BFE

- ✓ Festlegung des Typs des Alarmierungssystems;
- ✓ (Festlegung der Nahzone (Wasseralarm).)

Zuständige Aufsichtsbehörde

- ✓ Prüfung und Genehmigung der Elemente des Notfallreglements;
- ✓ Einsatz im Notfall (inkl. Änderung der Gefahrenstufe bei Bedarf).

BABS (IN)

- ✓ Anforderungen an die technischen Alarmierungssysteme; (auch WA)
- ✓ erlässt Vorschriften über das Verhalten der Bevölkerung bei Alarmierung
- ✓ Genehmigung Konzeption und Überwachung der Installation der Alarmierungssysteme und Abnahme;
- ✓ Verwaltung der zentralen Steuerung der Alarmierungssysteme (national).
- ✓ Beaufsichtigung Vollzug Evak. pläne

NAZ

- ✓ Informieren / Alarmieren der Bundes- und Partnerstellen zum Ereignis gem. Alarmierungskaskade Bund
- ✓ Betrieb Notfallmanagement Bund (GS4+GS5)
- ✓ Unterstützungsleistungen an Kt. auf Anfrage
- ✓ ICARO-Alarmierung auf Ersuchen eines Kantons (Redundanz)

Darbre, SFOE